NIST SPECIAL PUBLICATION 1800-13

Mobile Application Single Sign-On

Improving Authentication for Public Safety First Responders

Includes Executive Summary (A); Approach, Architecture, and Security Characteristics (B); and How-To Guides (C)

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May 2019

SECOND DRAFT

This publication is available free of charge from https://www.nccoe.nist.gov/projects/use-cases/mobile-sso

National Institute of Standards and Technology
U.S. Department of Commerce

NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

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**Former employee; all work for this publication was done while at employer.*

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May 2019

U.S. Department of Commerce
Wilbur Ross, Secretary

National Institute of Standards and Technology
Walter Copan, NIST Director and Undersecretary of Commerce for Standards and Technology

NIST SPECIAL PUBLICATION 1800-13A

Mobile Application Single Sign-On

Improving Authentication for Public Safety First Responders

Volume A:
Executive Summary

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NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

Executive Summary

- On-demand access to public safety data is critical to ensuring that public safety and first responders (PSFRs) can protect life and property during an emergency.
- This public safety information, often needing to be accessed via mobile or portable devices, routinely includes sensitive information, such as personally identifiable information, law enforcement sensitive information, and protected health information.
- Because the communications are critical to public safety and may include sensitive information, robust and reliable authentication mechanisms that do not hinder delivery of emergency services are required.
- In collaboration with the National Institute of Standards and Technology (NIST) Public Safety Communications Research laboratory and industry stakeholders, the National Cybersecurity Center of Excellence (NCCoE) at NIST built a laboratory environment to demonstrate standards-based technologies that can enable PSFRs to gain access to public safety information efficiently and securely by using mobile devices.
- The technologies demonstrated are currently available and include (1) single sign-on (SSO) capabilities that reduce the number of credentials that need to be managed by public safety personnel, and reduce the time and effort that individuals spend authenticating themselves; (2) identity federation that can improve the ability to authenticate personnel across public safety organization (PSO) boundaries; and (3) multifactor authentication (MFA) that enables authentication with a high level of assurance.
- This NIST Cybersecurity Practice Guide describes how organizations can implement these technologies to enhance public safety mission capabilities by using standards-based commercially available or open-source products. The technologies described facilitate interoperability among diverse mobile platforms, applications, relying parties, identity providers (IdPs), and public-sector and private-sector participants, regardless of the application development platform used in their construction.

CHALLENGE

Recent natural and man-made disasters and crises have highlighted the importance of efficient and secure access to critical information by PSFRs. For decades, much of this information was broadcast to PSFRs by voice over radio. More recently, many PSOs have transitioned to a hybrid model that includes automated access to much of this information via ruggedized mobile laptops and tablets. Further advances in technology have resulted in increasing reliance on smartphones or similar portable devices for field access to public safety information. The increasing reliance on these devices has driven the use of “native app”-based interfaces to access information, in addition to more traditional browser-based methods.

Many PSOs are in the process of transitioning from traditional land-based mobile communications to high-speed, regional or nationwide wireless broadband networks (e.g., FirstNet). These emerging “5G” systems employ internet protocol-based communications to provide secure and interoperable public safety communications to support initiatives such as Criminal Justice Information Services, Regional Information Sharing Systems, and international justice and public safety services such as those provided by Nlets. This transition will foster critically needed interoperability within and among jurisdictions, but it will create a significant increase in the number of mobile devices that PSOs will need to manage.

Current PSO authentication services may not be sustainable in the face of this growth. There are needs to improve security assurance, limit authentication requirements that are imposed on users (e.g., reduce the number of passwords that are required), improve the usability and efficiency of user account management, and share identities across jurisdictional boundaries. There is no single management or administrative hierarchy spanning the PSFR population. PSFR organizations operate in a variety of environments with different authentication requirements. Standards-based solutions are needed to support technical interoperability and a diverse set of PSO environments.

SOLUTION

To address these challenges, the NCCoE brought together common identity and software application providers to demonstrate how a PSO can implement mobile native and web application SSO, access federated identity sources, and implement MFA. SSO limits the time and effort that PSFR personnel spend authenticating, while MFA provides PSOs with adequate confidence that users who are accessing their information are who they say they are. The architecture supports identity federation that allows PSOs to share identity assertions between applications and across PSO jurisdictions. A combination of all of these capabilities can allow PSFR personnel to authenticate—say, at the beginning of their shift—and leverage that high-assurance authentication to gain cross-jurisdictional access to many other mobile native and web applications while on duty.

The guide provides

- a detailed example solution and capabilities that address risk and security controls
- a demonstration of the approach using commercially available products
- “how to” instructions for implementers and security engineers on integrating and configuring the example solution into their organization’s enterprise in a manner that achieves security goals with minimal impact on operational efficiency and expense

The NCCoE assembled existing technologies that support the following standards:

- Internet Engineering Task Force Request for Comments 8252, *OAuth 2.0 for Native Apps*
- FIDO Universal Second Factor and Universal Authentication Framework
- Security Assertion Markup Language 2.0
- OpenID Connect 1.0

Commercial, standards-based products, such as the ones that we used, are readily available and interoperable with existing information technology (IT) infrastructures. While the NCCoE used a suite of commercial products to address this challenge, this guide does not endorse these particular products, nor does it guarantee compliance with any regulatory initiatives. Your organization’s information security experts should identify the products that will best integrate with your existing tools and IT system infrastructure. Your organization can adopt this solution or one that adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and implementing parts of a solution.

BENEFITS

The NCCoE's practice guide to *Mobile Application Single Sign-On* can help PSOs:

- define requirements for mobile application SSO and MFA implementation
- improve interoperability among mobile platforms, applications, and IdPs, regardless of the application development platform used in their construction
- enhance the efficiency of PSFRs by reducing the number of authentication steps, the time needed to access critical data, and the number of credentials that need to be managed
- support a diverse set of credentials, enabling a PSO to choose an authentication solution that best meets its individual needs

SHARE YOUR FEEDBACK

You can view or download the guide at https://www.nccoe.nist.gov/projects/use-cases/mobile-sso. Help the NCCoE make this guide better by sharing your thoughts with us as you read the guide. If you adopt this solution for your own organization, please share your experience and advice with us. We recognize that technical solutions alone will not fully enable the benefits of our solution, so we encourage organizations to share lessons learned and best practices for transforming the processes associated with implementing this guide.

To provide comments or to learn more by arranging a demonstration of this example implementation, contact the NCCoE at psfr-nccoe@nist.gov.

TECHNOLOGY PARTNERS/COLLABORATORS

Organizations participating in this project submitted their capabilities in response to an open call in the Federal Register for all sources of relevant security capabilities from academia and industry (vendors and integrators). The following respondents with relevant capabilities or product components (identified as "Technology Partners/Collaborators" herein) signed a Cooperative Research and Development Agreement (CRADA) to collaborate with NIST in a consortium to build this example solution.

MOTOROLA SOLUTIONS | Nok Nok LABS | Ping Identity | STRONGKEY | yubico

Certain commercial entities, equipment, products, or materials may be identified by name or company logo or other insignia in order to acknowledge their participation in this collaboration or to describe an experimental procedure or concept adequately. Such identification is not intended to imply special status or relationship with NIST or recommendation or endorsement by NIST or NCCoE; neither is it intended to imply that the entities, equipment, products, or materials are necessarily the best available for the purpose.

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NIST SPECIAL PUBLICATION 1800-13B

Mobile Application Single Sign-On

Improving Authentication for Public Safety First Responders

Volume B:
Approach, Architecture, and Security Characteristics

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National Institute of Standards and Technology Special Publication 1800-13B, Natl. Inst. Stand. Technol. Spec. Publ. 1800-13B, 73 pages (May 2019), CODEN: NSPUE2

FEEDBACK

You can improve this guide by contributing feedback. As you review and adopt this solution for your own organization, we ask you and your colleagues to share your experience and advice with us.

Comments on this publication may be submitted to: psfr-nccoe@nist.gov.

Public comment period: May 29, 2019, through June 28, 2019

All comments are subject to release under the Freedom of Information Act.

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NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

The National Cybersecurity Center of Excellence (NCCoE), a part of the National Institute of Standards and Technology (NIST), is a collaborative hub where industry organizations, government agencies, and academic institutions work together to address businesses' most pressing cybersecurity issues. This public-private partnership enables the creation of practical cybersecurity solutions for specific industries, as well as for broad, cross-sector technology challenges. Through consortia under Cooperative Research and Development Agreements (CRADAs), including technology partners—from Fortune 50 market leaders to smaller companies specializing in information technology security—the NCCoE applies standards and best practices to develop modular, easily adaptable example cybersecurity solutions using commercially available technology. The NCCoE documents these example solutions in the NIST Special Publication 1800 series, which maps capabilities to the NIST Cybersecurity Framework and details the steps needed for another entity to re-create the example solution. The NCCoE was established in 2012 by NIST in partnership with the State of Maryland and Montgomery County, Maryland.

To learn more about the NCCoE, visit https://www.nccoe.nist.gov. To learn more about NIST, visit https://www.nist.gov.

NIST CYBERSECURITY PRACTICE GUIDES

NIST Cybersecurity Practice Guides (Special Publication 1800 series) target specific cybersecurity challenges in the public and private sectors. They are practical, user-friendly guides that facilitate the adoption of standards-based approaches to cybersecurity. They show members of the information security community how to implement example solutions that help them align more easily with relevant standards and best practices and provide users with the materials lists, configuration files, and other information they need to implement a similar approach.

The documents in this series describe example implementations of cybersecurity practices that businesses and other organizations may voluntarily adopt. These documents do not describe regulations or mandatory practices, nor do they carry statutory authority.

ABSTRACT

On-demand access to public safety data is critical to ensuring that public safety and first responder (PSFR) personnel can deliver the proper care and support during an emergency. This requirement necessitates heavy reliance on mobile platforms while in the field, which may be used to access sensitive information, such as personally identifiable information, law enforcement sensitive information, and protected health information. However, complex authentication requirements can hinder the process of providing emergency services, and any delay—even seconds—can become a matter of life or death.

In collaboration with NIST'S Public Safety Communications Research lab and industry stakeholders, the NCCoE aims to help PSFR personnel efficiently and securely gain access to mission data via mobile devices and applications. This practice guide describes a reference design for multifactor authentication (MFA) and mobile single sign-on (MSSO) for native and web applications while improving interoperability among mobile platforms, applications, and identity providers, regardless of the application development platform used in their construction. This NCCoE practice guide details a

collaborative effort between the NCCoE and technology providers to demonstrate a standards-based approach that uses commercially available and open-source products.

This guide discusses potential security risks facing organizations, benefits that may result from implementation of an MFA/MSSO system, and the approach that the NCCoE took in developing a reference architecture and build. This guide includes a discussion of major architecture design considerations, an explanation of the security characteristics achieved by the reference design, and a mapping of the security characteristics to applicable standards and security control families.

For parties interested in adopting all or part of the NCCoE reference architecture, this guide includes a detailed description of the installation, configuration, and integration of all components.

KEYWORDS

access control; authentication; authorization; identity; identity management; identity provider; relying party; single sign-on

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Derek Hanson	Yubico
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Mike Korus	Motorola Solutions
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Pushkar Marathe	StrongKey
Max Smyth	StrongKey
Scott Wong	StrongKey
Akhilesh Sah	Nok Nok Labs
Avinash Umap	Nok Nok Labs

The Technology Partners/Collaborators who participated in this build submitted their capabilities in response to a notice in the Federal Register. Respondents with relevant capabilities or product components were invited to sign a Cooperative Research and Development Agreement (CRADA) with NIST, allowing them to participate in a consortium to build this example solution. We worked with:

Technology Partner/Collaborator	Build Involvement
Ping Identity	Federation Server
Motorola Solutions	Mobile Apps
Yubico	External Authenticators
Nok Nok Labs	Fast Identity Online (FIDO) Universal Authentication Framework Server
StrongKey	FIDO Universal Second Factor Server

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1 Summary

The National Cybersecurity Center of Excellence (NCCoE), with the National Institute of Standards and Technology's (NIST's) Public Safety Communications Research lab, is helping the public safety and first responder (PSFR) community address the challenge of securing sensitive information accessed on mobile applications. The Mobile Application Single Sign-On (SSO) Project is a collaborative effort with industry and the information technology (IT) community, including vendors of cybersecurity solutions.

This project aims to help PSFR personnel efficiently and securely gain access to mission-critical data via mobile devices and applications through mobile SSO, identity federation, and multifactor authentication (MFA) solutions for native and web applications by using standards-based commercially available and open-source products.

The reference design herein

- provides a detailed example solution and capabilities that address risk and security controls
- demonstrates standards-based MFA, identity federation, and mobile SSO for native and web applications
- supports multiple authentication methods, considering unique environmental constraints faced by first responders in emergency medical services, law enforcement, and fire services

1.1 Challenge

On-demand access to public safety data is critical to ensuring that PSFR personnel can protect life and property during an emergency. Mobile platforms offer a significant operational advantage to public safety stakeholders by providing access to mission-critical information and services while deployed in the field, during training and exercises, or when participating in day-to-day business and preparing for emergencies during nonemergency periods. These advantages can be limited if complex authentication requirements hinder PSFR personnel, especially when a delay—even seconds—is a matter of containing or exacerbating an emergency. PSFR communities are challenged with implementing efficient and secure authentication mechanisms to protect access to this sensitive information while meeting the demands of their operational environment.

Many public safety organizations (PSOs) are in the process of transitioning from traditional land-based mobile communications to high-speed, regional or nationwide wireless broadband networks (e.g., First Responder Network Authority [FirstNet]). These emerging 5G systems employ internet protocol-based communications to provide secure and interoperable public safety communications to support initiatives such as Criminal Justice Information Services; Regional Information Sharing Systems; and international justice and public safety services, such as those provided by Nlets. This transition will foster critically needed interoperability within and among jurisdictions but will create a significant increase in the number of mobile Android and iPhone operating system (iOS) devices that PSOs will need to manage.

Current PSO authentication services may not be sustainable in the face of this growth. There are needs to improve security assurance, limit authentication requirements that are imposed on users (e.g., avoid the number of passwords that are required), improve the usability and efficiency of user account management, and share identities across jurisdictional boundaries. There is no single management or administrative hierarchy spanning the PSFR population. PSFR organizations operate in a variety of environments with different authentication requirements. Standards-based solutions are needed to support technical interoperability and this diverse set of PSO environments.

1.1.1 Easing User Authentication Requirements

Many devices that digitally access public safety information employ different software applications to access different information sources. Single-factor authentication processes, usually passwords, are most commonly required to access each of these applications. Users often need different passwords or personal identification numbers (PINs) for each application used to access critical information. Authentication prompts, such as entering complex passwords on a small touchscreen for each application, can hinder PSFRs. There is an operational need for the mobile systems on which they rely to support a single authentication process that can be used to access multiple applications. This is referred to as single sign-on, or SSO.

1.1.2 Improving Authentication Assurance

Single-factor password authentication mechanisms for mobile native and web applications may not provide sufficient protection for control of access to law enforcement-sensitive information, protected health information, and personally identifiable information (PII). Replacement of passwords by multifactor technology (e.g., a PIN plus some physical token or biometric) is widely recognized as necessary for access to sensitive information. Technology for these capabilities exists, but budgetary, contractual, and operational considerations have impeded implementation and use of these technologies. PSOs need a solution that supports differing authenticator requirements across the community (e.g., law enforcement, fire response, emergency medical services) and a "future proof" solution allowing for adoption of evolving technologies that may better support PSFRs in the line of duty.

1.1.3 Federating Identities and User Account Management

PSFRs need access to a variety of applications and databases to support routine activities and emergency situations. These resources may be accessed by portable mobile devices or mobile data terminals in vehicles. It is not uncommon for these resources to reside within neighboring jurisdictions at the federal, state, county, or local level. Even when the information is within the same jurisdiction, it may reside in a third-party vendor's cloud service. This environment results in issuance of many user accounts to each PSFR that are managed and updated by those neighboring jurisdictions or cloud service providers. When a PSFR leaves or changes job functions, the home organization must ensure that accounts are deactivated, avoiding any orphaned accounts managed by third parties. PSOs need a solution that reduces the number of accounts managed and allows user accounts and credentials issued by a PSFR's home organization to access information across jurisdictions and with cloud services. The ability of one organization to accept the identity and credentials from another organization in the form of an identity assertion is called identity federation. Current commercially available standards support this functionality.

1.2 Solution

This NIST Cybersecurity Practice Guide demonstrates how commercially available technologies, standards, and best practices implementing SSO, identity federation, and MFA can meet the needs of public safety first responder communities when accessing services from mobile devices.

In our lab at the NCCoE, we built an environment that simulates common identity providers (IdPs) and software applications found in PSFR infrastructure. In this guide, we show how a PSFR entity can leverage this infrastructure to implement SSO, identity federation, and MFA for native and web applications on mobile platforms. SSO, federation, and MFA capabilities can be implemented independently, but implementing them together would achieve maximum improvement with respect to usability, interoperability, and security.

At its core, the architecture described in Section 4 implements the Internet Engineering Task Force's (IETF's) best current practice (BCP) guidance found in Request for Comments (RFC) 8252, *OAuth 2.0 for Native Apps* [1]. Leveraging technology newly available in modern mobile operating systems (OSes), RFC 8252 defines a specific flow allowing for authentication to mobile native applications without exposing user credentials to the client application. This authentication can be leveraged by additional mobile native and web applications to provide an SSO experience, avoiding the need for the user to manage credentials independently for each application. Using the Fast Identity Online (FIDO) Universal Authentication Framework (UAF) [2] and Universal Second Factor (U2F) [3] protocols, this solution supports MFA on mobile platforms that use a diverse set of authenticators. The use of security assertion markup language (SAML) 2.0 [4] and OpenID Connect (OIDC) 1.0 [5] federation protocols allows PSOs to share identity assertions between applications and across PSO jurisdictions. Using this architecture allows PSFR personnel to authenticate once—say, at the beginning of their shift—and then leverage that single authentication to gain access to many other mobile native and web applications while on duty, reducing the time needed for authentication.

The PSFR community comprises tens of thousands of different organizations across the United States, many of which may operate their own IdPs. Today, most IdPs use SAML 2.0, but OIDC is rapidly gaining market share as an alternative for identity federation. As this build architecture demonstrates, an OAuth authorization server (AS) can integrate with both OIDC and SAML IdPs.

The guide provides:

- a detailed example solution and capabilities that may be implemented independently or in combination to address risk and security controls
- a demonstration of the approach, which uses commercially available products
- how-to instructions for implementers and security engineers on integrating and configuring the example solution into their organization's enterprise in a manner that achieves security goals with minimal impact on operational efficiency and expense

Organizations can adopt this solution or a different one that adheres to these guidelines in whole, or an organization can use this guide as a starting point for tailoring and implementing parts of a solution.

1.3 Benefits

The NCCoE, in collaboration with our stakeholders in the PSFR community, identified the need for a mobile SSO and MFA solution for native and web applications. This NCCoE practice guide, *Mobile Application Single Sign-On*, can help PSOs:

- define requirements for mobile application SSO and MFA implementation
- improve interoperability among mobile platforms, applications, and IdPs, regardless of the application development platform used in their construction
- enhance the efficiency of PSFRs by reducing the number of authentication steps, the time needed to access critical data, and the number of credentials that need to be managed
- support a diverse set of credentials, enabling a PSO to choose an authentication solution that best meets its individual needs
- enable cross-jurisdictional information sharing by identity federation

2 How to Use This Guide

This NIST Cybersecurity Practice Guide demonstrates a standards-based reference design and provides users with the information they need to replicate an MFA and mobile SSO solution for mobile native and web applications. This reference design is modular and can be deployed in whole or in part.

This guide contains three volumes:

- NIST Special Publication (SP) 1800-13A: *Executive Summary*
- NIST SP 1800-13B: *Approach, Architecture, and Security Characteristics*—what we built and why **(you are here)**
- NIST SP 1800-13C: *How-To Guides*—instructions for building the example solution

Depending on your role in your organization, you might use this guide in different ways:

Business decision makers, including chief security and technology officers, will be interested in the *Executive Summary* (NIST SP 1800-13A), which describes the following topics:

- challenges that enterprises face in MFA and mobile SSO for native and web applications
- example solution built at the NCCoE
- benefits of adopting the example solution

Technology or security program managers who are concerned with how to identify, understand, assess, and mitigate risk will be interested in this part of the guide, NIST SP 1800-13B, which describes what we did and why. The following sections will be of particular interest:

- Section 3.5, Risk Assessment, provides a description of the risk analysis we performed.
- Appendix A, Mapping to Cybersecurity Framework Core, maps the security characteristics of this example solution to cybersecurity standards and best practices.

You might share the *Executive Summary,* NIST SP 1800-13A, with your leadership team members to help them understand the importance of adopting a standards-based MFA and mobile SSO solution for native and web applications.

Information Technology (IT) professionals who want to implement an approach like this will find the whole practice guide useful. You can use the how-to portion of the guide, NIST SP 1800-13C, to replicate all or parts of the build created in our lab. The how-to portion of the guide provides specific product installation, configuration, and integration instructions for implementing the example solution. We do not re-create the product manufacturer's documentation, which is generally widely available. Rather, we show how we incorporated the products together in our environment to create an example solution.

This guide assumes that IT professionals have experience implementing security products within the enterprise. While we have used a suite of commercial products to address this challenge, this guide does not endorse these particular products. Your organization can adopt this solution or one that adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and implementing SSO or MFA separately. Your organization's security experts should identify the products that will best integrate with your existing tools and IT system infrastructure. We hope you will seek products that are congruent with applicable standards and best practices. Section 3.7, Technologies, lists the products we used and maps them to the cybersecurity controls provided by this reference solution.

A NIST Cybersecurity Practice Guide does not describe "the" solution, but a possible solution. This is a draft guide. We seek feedback on its contents and welcome your input. Comments, suggestions, and success stories will improve subsequent versions of this guide. Please contribute your thoughts to psfr-nccoe@nist.gov.

2.1 Typographic Conventions

The following table presents typographic conventions used in this volume.

Typeface/Symbol	Meaning	Example
Italics	file names and pathnames, references to documents that are not hyperlinks, new terms, and placeholders	For detailed definitions of terms, see the *NCCoE Glossary*.
Bold	names of menus, options, command buttons, and fields	Choose **File > Edit.**
`Monospace`	command-line input, onscreen computer output, sample code examples, and status codes	`mkdir`
`Monospace Bold`	command-line user input contrasted with computer output	**`service sshd start`**
blue text	link to other parts of the document, a web URL, or an email address	All publications from NIST's NCCoE are available at https://www.nccoe.nist.gov.

3 Approach

In conjunction with the PSFR community, the National Cybersecurity Center of Excellence developed a project description identifying MFA and SSO for mobile native and web applications as a critical need for PSFR organizations. The NCCoE then engaged subject matter experts from industry organizations, technology vendors, and standards bodies to develop an architecture and reference design leveraging new capabilities in modern mobile OSes and best current practices in SSO and MFA.

3.1 Audience

This guide is intended for individuals or entities that are interested in understanding the mobile native and web application SSO and MFA reference designs that the NCCoE has implemented to allow PSFR personnel to securely and efficiently gain access to mission-critical data by using mobile devices. Though the NCCoE developed this reference design with the PSFR community, any party interested in SSO and MFA for native mobile and web applications can leverage the architecture and design principles implemented in this guide.

The overall build architecture addresses three different audiences with somewhat separate concerns:

- IdPs–PSFR organizations that issue and maintain user accounts for their users. Larger PSFR organizations may operate their own IdP infrastructures and may federate by using SAML or OIDC services, while others may seek to use an IdP service provider. IdPs are responsible for identity proofing, account creation, account and attribute management, and credential management.
- Relying parties (RPs)–organizations providing application services to multiple PSFR organizations. RPs may be software as a service (SaaS) providers or PSFR organizations providing shared services consumed by other organizations. The RP operates an OAuth 2.0 AS, which integrates with users' IdPs and issues access tokens to enable mobile applications to make requests to the back-end application servers.
- Application developers–mobile application developers. Today, mobile client applications are typically developed by the same software provider as the back-end RP applications. However, the OAuth framework enables interoperability between RP applications and third-party client applications. In any case, mobile application development is a specialized skill with unique considerations and requirements. Mobile application developers should consider implementing the AppAuth library for IETF RFC 8252 to enable standards-based SSO.

3.2 Scope

The focus of this project is to address the need for secure and efficient mobile native and web application SSO. The NCCoE drafted a use case that identified numerous desired solution characteristics. After an open call in the Federal Register for vendors to help develop a solution, we chose participating technology collaborators on a first-come, first-served basis. We scoped the project to produce the following high-level desired outcomes:

- Provide a standards-based solution architecture that selects an effective and secure approach to implementing mobile SSO, leveraging native capabilities of the mobile OS.
- Ensure that mobile applications do not have access to user credentials.
- Support MFA and multiple authentication protocols.
- Support multiple authenticators, considering unique environmental constraints faced by first responders in emergency medical services, law enforcement, and fire services.
- Support cross-jurisdictional information sharing through identity federation.

To maintain the project's focus on core SSO and MFA requirements, the following subjects are out of scope. These technologies and practices are critical to a successful implementation, but they do not directly affect the core design decisions.

- Identity proofing–The solution creates synthetic digital identities that represent the identities and attributes of public safety personnel to test authentication assertions. This includes the usage of a lab-configured identity repository—not a genuine repository and schema provided by any PSO. This guide will not demonstrate an identity proofing process.
- Access control–This solution supports the creation and federation of attributes but will not discuss or demonstrate access control policies that an RP might implement to govern access to specific resources.
- Credential storage–This solution is agnostic to where credentials are stored on the mobile device. For example, this use case is not affected by storing a certificate in software versus hardware, such as a trusted platform module.
- Enterprise Mobility Management (EMM)–The solution assumes that all applications involved in the SSO experience are allowable via an EMM. This implementation may be supported by using an EMM (for example, to automatically provision required mobile applications to the device), but it does not strictly depend on using an EMM.
- Fallback authentication mechanisms–This solution involves the use of multifactor authenticators, which may consist of physical authentication devices or cryptographic keys stored directly on mobile devices. Situations may arise where a user's authenticator or device has been lost or stolen. This practice guide recommends registering multiple authenticators for each user as a partial mitigation, but in some cases, it may be necessary to either enable users to fall back to single-factor authentication or provide other alternatives. Such fallback mechanisms must be evaluated considering the organization's security and availability requirements.

3.3 Assumptions

Before implementing the capabilities described in this practice guide, organizations should review the assumptions underlying the NCCoE build. These assumptions are detailed in Appendix B. Though not in scope for this effort, implementers should consider whether the same assumptions can be made based on current policy, process, and IT infrastructure. As detailed in Appendix B, applicable and appropriate guidance is provided to assist this process for the following functions:

- identity proofing
- mobile device security
- mobile application security
- EMM

- FIDO enrollment process

3.4 Business Case

Any decision to implement IT systems within an organization must begin with a solid business case. This business case could be an independent initiative or a component of the organization's strategic planning cycle. Individual business units or functional areas typically derive functional or business unit strategies from the overall organization's strategic plan. The business drivers for any IT project must originate in these strategic plans, and the decision to determine if an organization will invest in mobile SSO, identity federation, or MFA by implementing the solution in this practice guide will be based on the organization's decision-making process for initiating new projects.

Important inputs to the business case are the risks to the organization from mobile authentication and identity management, as outlined in Section 3.5. Apart from addressing cybersecurity risks, SSO also improves the user experience and alleviates the overhead associated with maintaining and using passwords for multiple applications. This provides a degree of convenience to all types of users, but reducing the authentication overhead for PSFR users and reducing barriers to getting the information and applications that they need could have a tremendous effect. First responder organizations and application providers also benefit by using interoperable standards that provide easy integration across disparate technology platforms. In addition, the burden of account management is reduced by using a single user account managed by the organization to access multiple applications and services.

3.5 Risk Assessment

NIST SP 800-30 Revision 1 [6], *Guide for Conducting Risk Assessments,* states that risk is "a measure of the extent to which an entity is threatened by a potential circumstance or event, and typically a function of (i) the adverse impacts that would arise if the circumstance or even occurs; and (ii) the likelihood of occurrence." The guide further defines risk assessment as "the process of identifying, estimating, and prioritizing risks to organizational operations (including mission, functions, image, reputation), organizational assets, individuals, other organizations, and the Nation, resulting from the operation of an information system. Part of risk management incorporates threat and vulnerability analyses, and considers mitigations provided by security controls planned or in place."

The NCCoE recommends that any discussion of risk management, particularly at the enterprise level, begins with a comprehensive review of NIST SP 800-37 Revision 2, *Guide for Applying the Risk Management Framework to Federal Information Systems* [7]—material that is available to the public. The risk management framework guidance, as a whole, proved invaluable in giving us a baseline to assess risks, from which we developed the project, the security characteristics of the build, and this guide.

3.5.1 PSFR Risks

As PSFR communities adopt mobile platforms and applications, organizations should consider potential risks that these new devices and ecosystems introduce that may negatively affect PSFR organizations and the ability of PSFR personnel to operate. These are some of the risks:

- The reliance on passwords alone by many PSFR entities effectively expands the scope of a single application/database compromise when users fall back to reusing a small set of easily remembered passwords across multiple applications.
- Complex passwords are harder to remember and input to IT systems. Mobile devices exacerbate this issue with small touchscreens that may not work with gloves or other PSFR equipment, and with three separate keyboards among which the user must switch. In an emergency response, any delay in accessing information may prove critical to containing a situation.
- Social engineering, man-in-the-middle attacks, replay attacks, and phishing all present real threats to password-based authentication systems.
- Deterministic, cryptographic authentication mechanisms have security benefits yet come with the challenge of cryptographic key management. Loss or misuse of cryptographic keys could undermine an authentication system, leading to unauthorized access or data leakage.
- Biometric authentication mechanisms may be optimal for some PSFR personnel, yet organizations need to ensure that PII, such as fingerprint templates, is protected.
- Credentials exposed to mobile applications could be stolen by malicious applications or misused by nonmalicious applications. Previously, it was common for native applications to use embedded user-agents (commonly implemented with web views) for OAuth requests. That approach has many drawbacks, including the host application being able to copy user credentials and cookies, as well as the user needing to authenticate again in each application.

3.5.2 Mobile Ecosystem Threats

Any discussion of risks and vulnerabilities is incomplete without considering the threats that are involved. NIST SP 800-150, *Guide to Cyber Threat Information Sharing* [8], states that a cyber threat is "any circumstance or event with the potential to adversely impact organizational operations (including mission, functions, image, or reputation), organizational assets, individuals, other organizations, or the Nation through an information system via unauthorized access, destruction, disclosure, or modification of information, and/or denial of service."

To simplify this concept, a *threat* is anything that can exploit a *vulnerability* to damage an *asset*. Finding the intersection of these three will yield a *risk*. Understanding the applicable threats to a system is the first step in determining its risks.

However, identifying and delving into mobile threats is not the primary goal of this practice guide. Instead, we rely on prior work from NIST's Mobile Threat Catalogue (MTC), along with its associated

NIST Interagency Report 8144, *Assessing Threats to Mobile Devices & Infrastructure* [9]. Each entry in the MTC contains several pieces of information: an identifier, a category, a high-level description, details on its origin, exploit examples, examples of common vulnerabilities and exposures, possible countermeasures, and academic references. For the purposes of this practice guide, we are primarily interested in threat identifiers, categories, descriptions, and countermeasures.

In broad strokes, the MTC covers 32 threat categories that are grouped into 12 distinct classes, as shown in Table 3-1. Of these categories, three in particular, highlighted in green in the table, are covered by the guidance in this practice guide. If implemented correctly, this guidance will help mitigate those threats.

Table 3-1 Threat Classes and Categories

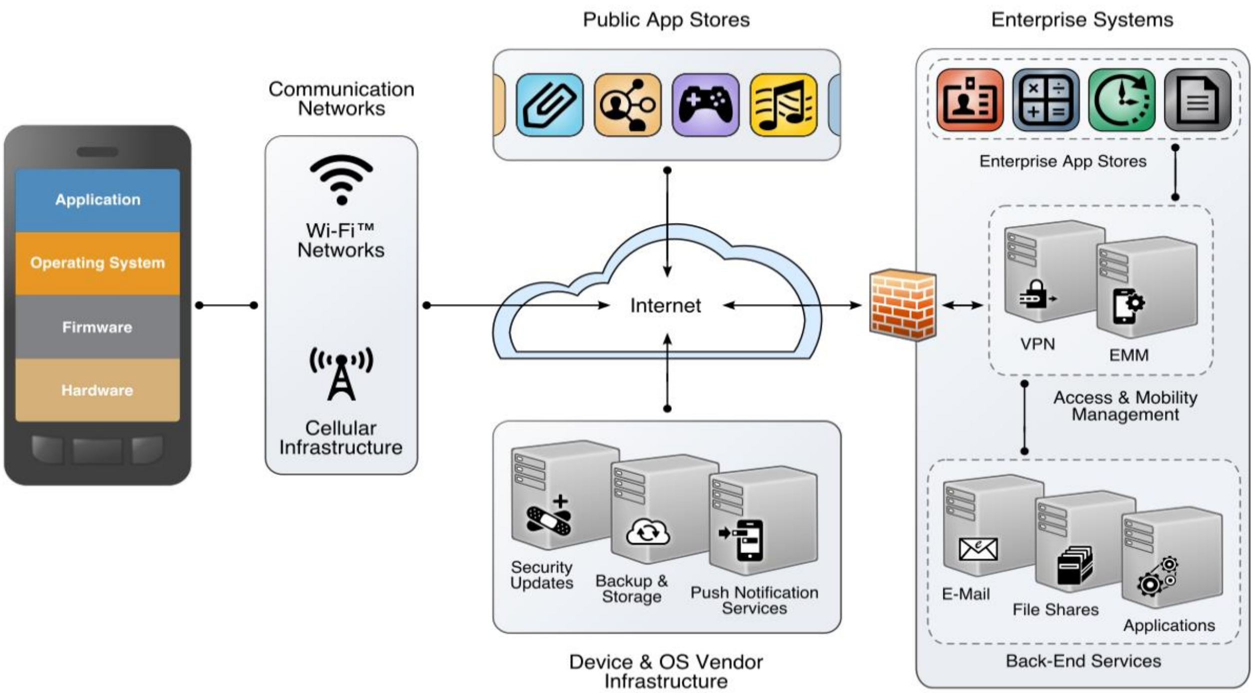
Threat Class	Threat Category	Threat Class	Threat Category
Application	Malicious or Privacy-Invasive Applications	**Local Area Network and Personal Area Network**	Network Threats: Bluetooth
	Vulnerable Applications		Network Threats: Near Field Communication (NFC)
Authentication	Authentication: User or Device to Network		Network Threats: Wi-Fi
	Authentication: User or Device to Remote Service	**Payment**	Application-Based
	Authentication: User to Device		In-Application Purchases
Cellular	Carrier Infrastructure		NFC-Based
	Carrier Interoperability	**Physical Access**	Physical Access
	Cellular Air Interface	**Privacy**	Behavior Tracking
	Consumer-Grade Femtocell	**Supply Chain**	Supply Chain
	SMS/MMS/RCS	**Stack**	Baseband Subsystem
	USSD		Boot Firmware
	VoLTE		Device Drivers

Threat Class	Threat Category
Ecosystem	Mobile Application Store
	Mobile OS & Vendor Infrastructure
EMM	EMM
Global Positioning System (GPS)	GPS

Threat Class	Threat Category
	Isolated Execution Environments
	Mobile Operating System
	SD Card
	USIM/SIM/UICC Security

The other categories, while still important elements of the mobile ecosystem and critical to the health of an overall mobility architecture, are out of scope for this document. The entire mobile ecosystem should be considered when analyzing threats to the architecture; this ecosystem is depicted in Figure 3-1, taken from NIST Interagency Report 8144. Each player in the ecosystem—the mobile device user, the enterprise, the network operator, the application developer, and the original equipment manufacturer (OEM)—can find suggestions to deter other threats by reviewing the MTC and NIST Interagency Report 8144. Many of these share common solutions, such as using EMM software to monitor device health, and installing applications from only authorized sources.

Figure 3-1 The Mobile Ecosystem



3.5.3 Authentication and Federation Threats

The MTC is a useful reference from the perspective of mobile devices, applications, and networks. In the context of mobile SSO, specific threats to authentication and federation systems must also be considered. Table 8-1 in NIST SP 800-63B [10] lists several categories of threats against authenticators:

- theft—stealing a physical authenticator, such as a smart card or U2F device
- duplication—unauthorized copying of an authenticator, such as a password or private key
- eavesdropping—interception of an authenticator secret when in use
- offline cracking—attacks on authenticators that do not require interactive authentication attempts, such as brute-force attacks on passwords used to protect cryptographic keys
- side-channel attack—exposure of an authentication secret through observation of the authenticator's physical characteristics
- phishing or pharming—capturing authenticator output through impersonation of the RP or IdP
- social engineering—using a pretext to convince the user to subvert the authentication process

- online guessing—attempting to guess passwords through repeated online authentication attempts with the RP or IdP
- end point compromise—malicious code on the user's device, which is stealing authenticator secrets, redirecting authentication attempts to unintended RPs, or otherwise subverting the authentication process
- unauthorized binding—binding an attacker-controlled authenticator with the user's account by intercepting the authenticator during provisioning or impersonating the user in the enrollment process

These threats undermine the basic assumption that use of an authenticator in an authentication protocol demonstrates that the user initiating the protocol is the individual referenced by the claimed user identifier. Mitigating these threats is the primary design goal of MFA, and the FIDO specifications address many of these threats.

An additional set of threats concerns federation protocols. Authentication threats affect the process of direct authentication of the user to the RP or IdP, whereas federation threats affect the assurance that the IdP can deliver assertions that are genuine and unaltered, only to the intended RP. Table 8-1 in NIST SP 800-63C [11] lists the following federation threats:

- assertion manufacture or modification—generation of a false assertion or unauthorized modification of a valid assertion
- assertion disclosure—disclosure of sensitive information contained in an assertion to an unauthorized third party
- assertion repudiation by the IdP—IdP denies having authenticated a user after the fact
- assertion repudiation by the subscriber—subscriber denies having authenticated and performed actions on the system
- assertion redirect—subversion of the federation protocol flow to enable an attacker to obtain the assertion or to redirect it to an unintended RP
- assertion reuse—attacker obtains a previously used assertion to establish his own session with the RP
- assertion substitution—attacker substitutes an assertion for a different user in the federation flow, leading to session hijacking or fixation

Federation protocols are complex and require interaction among multiple systems, typically under different management. Implementers should carefully apply best security practices relevant to the federation protocols in use. Most federation protocols can incorporate security measures to address these threats, but this may require specific configuration and enabling optional features.

3.6 Systems Engineering

Some organizations use a systems engineering-based approach to plan and implement their IT projects. Organizations wishing to implement IT systems should develop robust requirements, taking into consideration the operational needs of each system stakeholder. Standards such as International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) ISO/IEC/IEEE 15288:2015, *Systems and software engineering—System life cycle processes* [12]; and NIST SP 800-160, *Systems Security Engineering: Considerations for a Multidisciplinary Approach in the Engineering of Trustworthy Secure Systems* [13] provide guidance for applying security in systems development. With both standards, organizations can choose to adopt only those sections of the standard that are relevant to their development approach, environment, and business context. NIST SP 800-160 recommends a thorough analysis of alternative solution classes accounting for security objectives, considerations, concerns, limitations, and constraints. This advice applies to both new system developments and integration of components into existing systems, the focus of this practice guide. Section 4.1, General Architecture Considerations, may assist organizations with this analysis.

3.7 Technologies

Table 3-2 lists all of the technologies used in this project and provides a mapping among the generic application term, the specific product used, and the NIST Cybersecurity Framework Subcategory that the product provides. For a mapping of Cybersecurity Framework Subcategories to security controls, please refer to Appendix A, Mapping to Cybersecurity Framework Core. Refer to Table A-1 for an explanation of the Cybersecurity Framework Category and Subcategory codes.

Table 3-2 Products and Technologies

Component	Specific Product Used	How the Component Functions in the Build	Applicable Cybersecurity Framework Subcategories
Federation Server	Ping Federate 8.2	OAuth 2.0 AS OIDC provider SAML 2 IdP	PR.AC-3: Remote access is managed.
FIDO U2F Server	StrongKey Crypto Engine (SKCE) 2.0	FIDO U2F server	PR.AC-1: Identities and credentials are managed for authorized devices and users.

Component	Specific Product Used	How the Component Functions in the Build	Applicable Cybersecurity Framework Subcategories
External Authenticator	YubiKey Neo	FIDO U2F token supporting authentication over NFC	PR-AC-1: Identities and credentials are managed for authorized devices and users.
FIDO UAF Server	Nok Nok Labs FIDO UAF Server	UAF authenticator enrollment, authentication, and transaction confirmation	PR.AC-1: Identities and credentials are managed for authorized devices and users.
Mobile Applications (including SaaS back end)	Motorola Solutions Public Safety Experience (PSX) Cockpit, PSX Messenger, and PSX Mapping 5.2; custom demo applications developed by the build team	Provide application programming interfaces (APIs) for mobile client applications to access cloud-hosted services and data; consume OAuth tokens	PR.AC-3: Remote access is managed.
SSO Implementing Best Current Practice	AppAuth Software Development Kit (SDK) for iOS and Android	Library used by mobile applications, providing an IETF RFC 8252-compliant OAuth 2.0 client implementation; implements authorization requests, Proof Key for Code Exchange (PKCE), and token refresh	PR.AC-3: Remote access is managed.

4 Architecture

The NCCoE worked with industry subject matter experts to develop an open, standards-based, commercially available architecture demonstrating three main capabilities:

- SSO to RP applications using OAuth 2.0 implemented in accordance with RFC 8252 (the *OAuth 2.0 for Native Apps* BCP)
- identity federation to RP applications using both SAML 2.0 and OIDC 1.0
- MFA to mobile native and web applications using FIDO UAF and U2F

Though these capabilities are implemented as an integrated solution in this guide, organizational requirements may dictate that only a subset of these capabilities be implemented. The modular approach of this architecture is designed to support such use cases.

Additionally, the authors of this document recognize that PSFR organizations will have diverse IT infrastructures, which may include previously purchased authentication, federation, or SSO capabilities, and legacy technology. For this reason, Section 4.1 and Appendix C outline general considerations that any organization may apply when designing an architecture tailored to organizational needs. Section 4.2 follows with considerations for implementing the architecture specifically developed by the NCCoE for this project.

Organizations are encouraged to read Section 3.2, Section 3.3, Section 3.5, and Appendix B to understand context for this architecture design.

4.1 General Architectural Considerations

The PSFR community is large and diverse, comprising numerous state, local, tribal, and federal organizations with individual missions and jurisdictions. PSFR personnel include police, firefighters, emergency medical technicians, public health officials, and other skilled support personnel. There is no single management or administrative hierarchy spanning the PSFR population. PSFR organizations operate in a variety of environments with different technology requirements and wide variations in IT staffing and budgets.

Cooperation and communication among PSFR organizations at multiple levels is crucial to addressing emergencies that span organizational boundaries. Examples include coordination among multiple services within a city (e.g., fire and police services), among different state law enforcement agencies to address interstate crime, and among federal agencies like the Department of Homeland Security and its state and local counterparts. This coordination is generally achieved through peer-to-peer interaction and agreement or through federation structures, such as the National Identity Exchange Federation. Where interoperability is achieved, it is the result of the cooperation of willing partners rather than adherence to central mandates.

Enabling interoperability across the heterogeneous, decentralized PSFR user base requires a standards-based solution; a proprietary solution might not be uniformly adopted and could not be mandated. The solution must also support identity federation and federated authentication, as user accounts and authenticators are managed by several different organizations. The solution must also accommodate organizations of different sizes, levels of technical capabilities, and budgets. Compatibility with the existing capabilities of fielded identity systems can reduce the barrier to entry for smaller organizations.

Emergency response and other specialized work performed by PSFR personnel often require that they wear personal protective equipment, such as gloves, masks, respirators, and helmets. This equipment renders some authentication methods impractical or unusable. Fingerprint scanners cannot be used with gloves, authentication using a mobile device camera to analyze the user's face or iris may be hampered by masks or goggles, and entering complex passwords on small virtual keyboards is also impractical for gloved users. In addition, PSFR work often involves urgent and hazardous situations requiring the ability to quickly perform mission activities like driving, firefighting, and administering urgent medical aid. Therefore, the solution must support a variety of authenticators in an interoperable way so that individual user groups can select authenticators suited to their operational constraints.

In considering these requirements, the NCCoE implemented a standards-based architecture and reference design. Section 4.1.1 through Section 4.1.3 detail the primary standards used, while Appendix C goes into great depth on architectural consideration when implementing these standards.

4.1.1 SSO with OAuth 2.0, IETF RFC 8252, and AppAuth Open-Source Libraries

SSO enables a user to authenticate once and to subsequently access different applications without having to authenticate again. SSO on mobile devices is complicated by the sandboxed architecture, which makes it difficult to share the session state with back-end systems between individual applications. EMM vendors have provided solutions through proprietary SDKs, but this approach requires integrating the SDK with each individual application and does not scale to a large and diverse population, such as the PSFR user community.

OAuth 2.0 is an IETF standard that has been widely adopted to provide delegated authorization of clients accessing representational state transfer interfaces, including mobile applications. OAuth 2.0, when implemented in accordance with RFC 8252 (the *OAuth 2.0 for Native Apps* BCP), provides a standards-based SSO pattern for mobile applications. The OpenID Foundation's AppAuth libraries [14] can facilitate building mobile applications in full compliance with IETF RFC 8252, but any mobile application that follows RFC 8252's core recommendation of using a shared external user-agent for the OAuth authorization flow will have the benefit of SSO. OAuth considerations and recommendations are detailed in Section C.1 of Appendix C.

4.1.2 Identity Federation

SAML 2.0 [4] and OIDC 1.0 [5] are two standards that enable an application to redirect users to an IdP for authentication and to receive an assertion of the user's identity and other optional attributes. Federation is important in a distributed environment like the PSFR community, where user management occurs in numerous local organizations. Federated authentication relieves users of having to create accounts in each application that they need to access, and it frees application owners from managing user accounts and credentials. OIDC is a more recent protocol, but many organizations have existing SAML deployments. The architecture supports both standards to facilitate adoption without requiring upgrades or modifications to existing SAML IdPs. Federation considerations and recommendations are detailed in Section C.2 of Appendix C.

4.1.3 FIDO and Authenticator Types

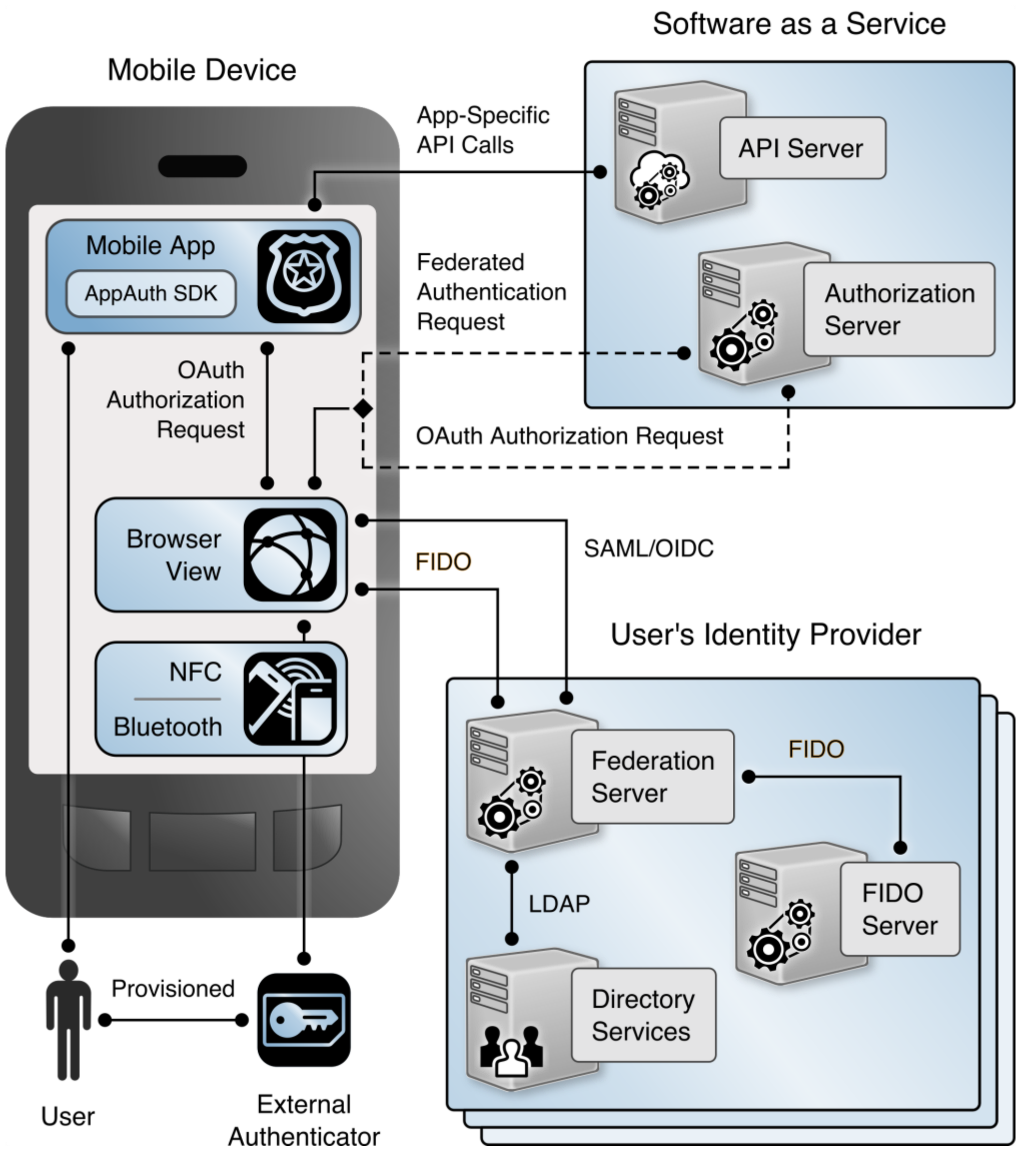
When considering MFA implementations, PSFR organizations should carefully consider organizationally defined authenticator requirements. These requirements are detailed in Section C.3 of Appendix C.

FIDO provides a standard framework within which vendors have produced a wide range of interoperable biometric, hardware, and software authenticators. This will enable PSFR organizations to choose authenticators suitable to their operational constraints. The FIDO Alliance has published specifications for two types of authenticators based on UAF and U2F. These protocols operate agnostic of the FIDO authenticator, allowing PSOs to choose any FIDO-certified authenticator that meets operational requirements and to implement it with this solution. The protocols, FIDO key registration, FIDO authenticator attestation, and FIDO deployment considerations are also detailed in Section C.3 of Appendix C.

4.2 High-Level Architecture

The NCCoE implemented both FIDO UAF and U2F for this project. The high-level architecture varies somewhat between the two implementations. Figure 4-1 depicts the interactions between the key elements of the build architecture with the U2F implementation.

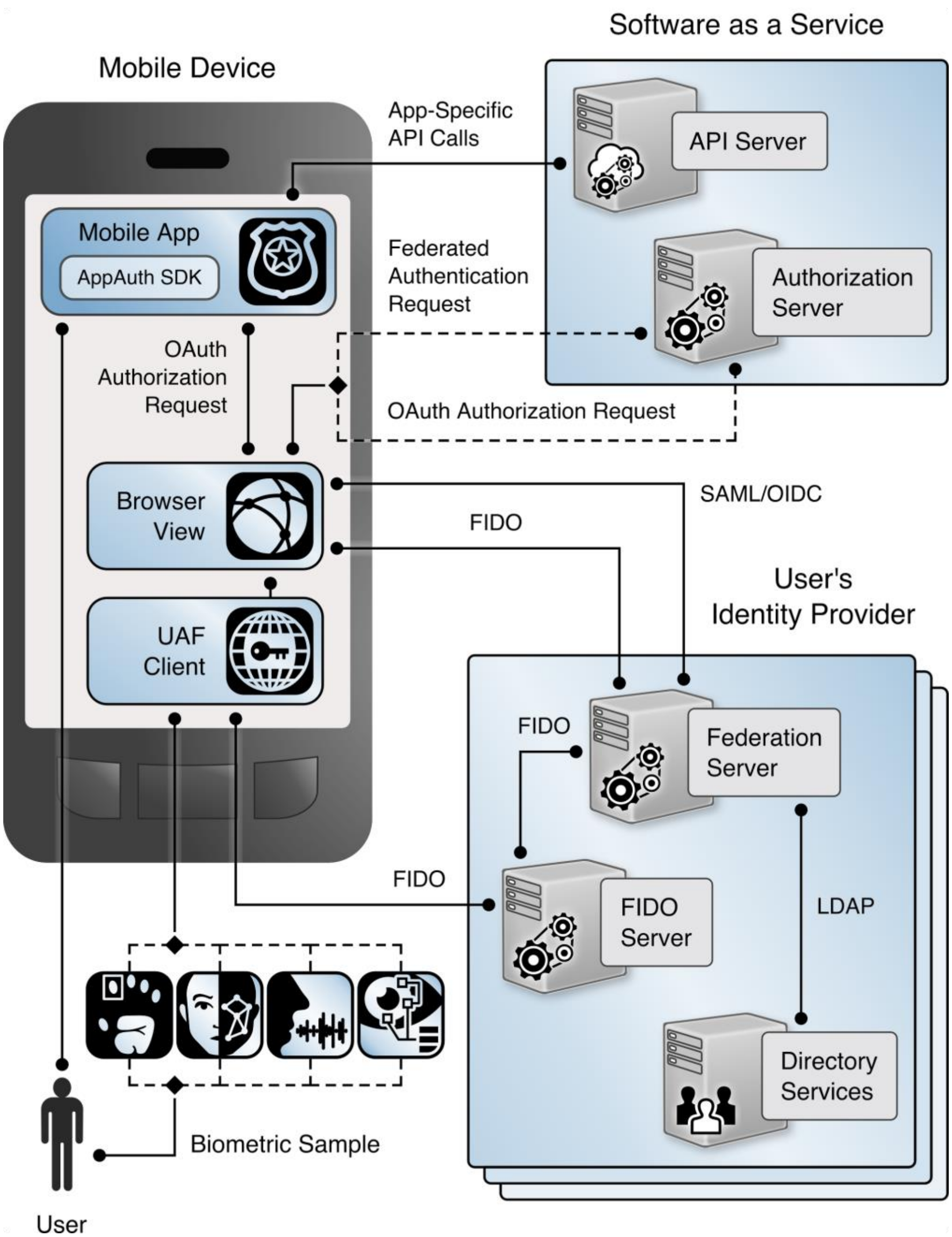
Figure 4-1 High-Level U2F Architecture



On the mobile device, the mobile application includes the OpenID Foundation's AppAuth library, which streamlines implementation of the OAuth client functionality in accordance with the IETF RFC 8252, *OAuth 2.0 for Native Apps*, guidance. AppAuth orchestrates the authorization request flow by using the device's native browser capabilities, including in-application browser tabs on devices that support them. The mobile device also supports the two FIDO authentication schemes, UAF and U2F. UAF typically involves an internal (on-device) authenticator that authenticates the user directly to the device by using biometrics, other hardware capabilities, or a software client. U2F typically involves an external hardware authenticator token, which communicates with the device over NFC or Bluetooth.

Figure 4-2 shows the corresponding architecture view with the FIDO UAF components.

Figure 4-2 High-Level UAF Architecture



The SaaS provider hosts application servers that provide APIs consumed by mobile applications, as well as an OAuth AS. The browser on the mobile device connects to the AS to initiate the OAuth authorization code flow. The AS redirects the browser to the IdP of the user's organization to authenticate the user. Once the user has authenticated, the AS will issue an access token, which is returned to the mobile application through a browser redirect and can be used to authorize requests to the application servers.

The user's IdP includes a federation server that implements SAML or OIDC, directory services containing user accounts and attributes, and a FIDO authentication service that can issue authentication challenges and validate the responses that are returned from FIDO authenticators. The FIDO authentication service may be built into the IdP but is more commonly provided by a separate server.

A SaaS provider may provide multiple applications, which may be protected by the same AS. For example, Motorola Solutions provides both the PSX Mapping and PSX Messaging applications, which are protected by a shared AS. Users may also use services from different SaaS providers, which would have separate ASes. This build architecture can provide SSO between applications hosted by a single SaaS provider as well as across applications provided by multiple SaaS vendors.

Support for these two scenarios differs between the Android and iOS platforms. Today, U2F is not supported on iOS devices, while UAF is supported on both Android and iOS. The build team has only built and tested the U2F implementation on Android devices.

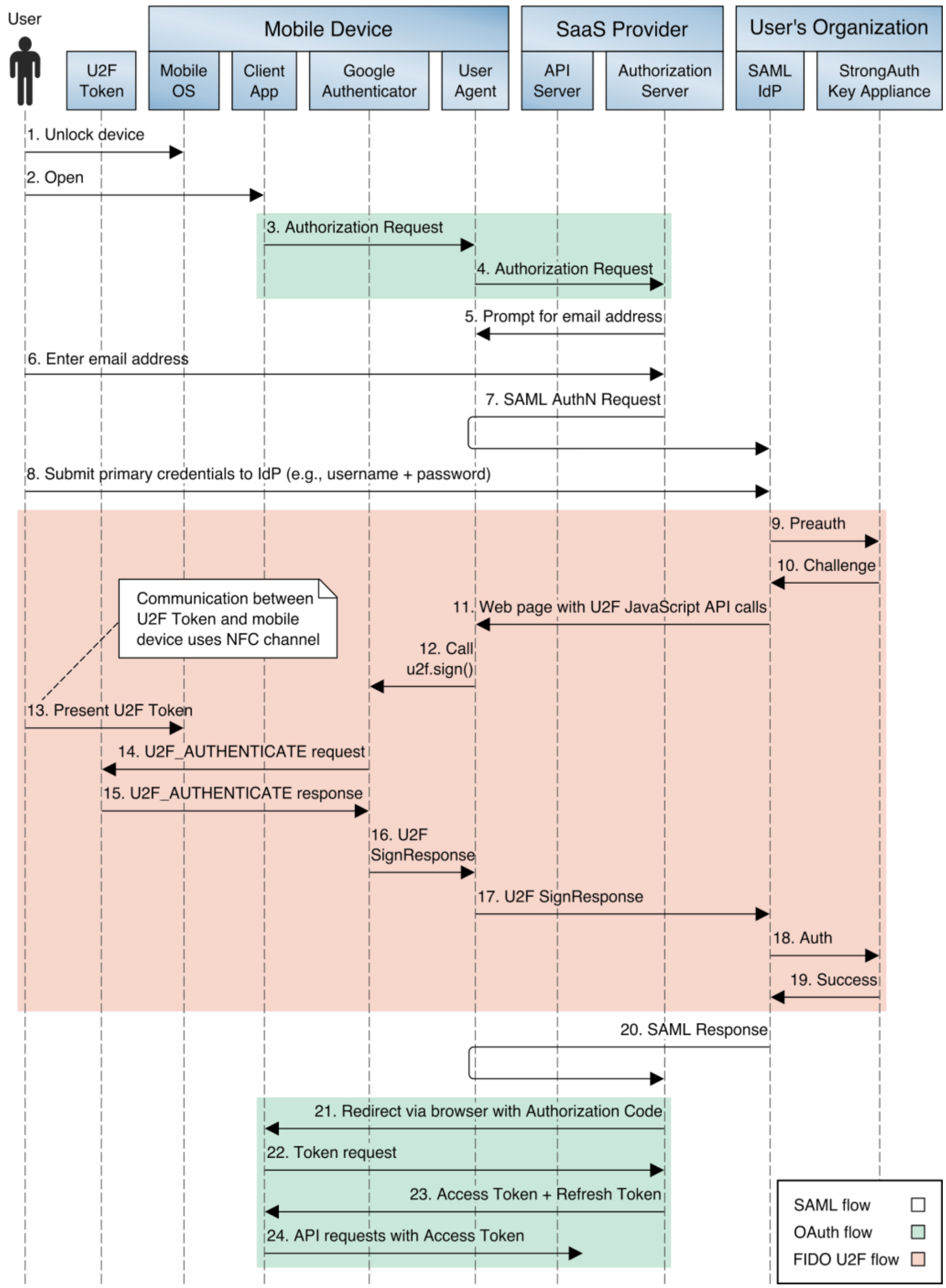
4.3 Detailed Architecture Flow

The mobile SSO lab implementation demonstrates two authentication flows: one in which the user authenticates to a SAML IdP with a YubiKey Neo U2F token and a PIN, and one in which the user authenticates to an OIDC IdP by using UAF with a fingerprint. These pairings of federation and authentication protocols are purely arbitrary; U2F could just as easily be used with OIDC, for example.

4.3.1 SAML and U2F Authentication Flow

The authentication flow using SAML and U2F is depicted in Figure 4-3. As explained in Section 4.2, at the time of publication this implementation is not supported on iOS devices. This figure depicts the message flows among different components on the mobile device or hosted by the SaaS provider or user organization. In the figure, colored backgrounds differentiate the SAML, OAuth, and FIDO U2F protocol flows. Prior to this authentication flow, the user must have registered a FIDO U2F token with the IdP, and the AS and IdP must have exchanged metadata and established an RP trust.

Figure 4-3 SAML and U2F Sequence Diagram



The detailed steps are as follows:

1. The user unlocks the mobile device. Any form of lock-screen authentication can be used; it is not directly tied to the subsequent authentication or authorization.
2. The user opens a mobile application that connects to the SaaS provider's back-end services. The mobile application determines that an OAuth token is needed. This may occur because the application has no access or refresh tokens cached or it has an existing token known to be expired based on token metadata, or it may submit a request to the API server with a cached bearer token and receive an HTTP 401 status code in the response.
3. The mobile application initiates an OAuth authorization request using the authorization code flow by invoking the system browser (or an in-application browser tab) with the uniform resource locator (URL) of the SaaS provider AS's authorization end point.
4. The browser submits the request to the AS over a hypertext transfer protocol secure (https) connection. This begins the OAuth 2 authorization flow.
5. The AS returns a page that prompts for the user's email address.
6. The user submits the email address. The AS uses the domain of the email address for IdP discovery. The user needs to specify the email address only one time; the address is stored in a cookie in the device browser and will be used to automatically determine the user's IdP on subsequent visits to the AS.
7. The AS redirects the device browser to the user's IdP with a SAML authentication request. This begins the SAML authentication flow.
8. The IdP returns a login page. The user submits a username and PIN. The IdP validates these credentials against the directory service. If the credentials are invalid, the IdP redirects back to the login page with an error message and prompts the user to authenticate again. If the credentials are valid, the IdP continues to step 9.
9. The IdP submits a "preauth" API request to the StrongKey SKCE server. The preauth request includes the authenticated username obtained in step 8. This begins the FIDO U2F authentication process.
10. The SKCE responds with a U2F challenge that must be signed by the user's registered key in the U2F token to complete authentication. If the user has multiple keys registered, the SKCE returns a challenge for each key so that the user can authenticate with any registered authenticator.

11. The IdP returns a page to the user's browser that includes Google's JavaScript U2F API and the challenge obtained from the SKCE in step 10. The user taps a button on the page to initiate U2F authentication, which triggers a call to the u2f.sign JavaScript function.

12. The u2f.sign function invokes the Google Authenticator application, passing it the challenge, the appId (typically the domain name of the IdP), and an array of the user's registered key.

13. Google Authenticator prompts the user to hold the U2F token against the NFC radio of the mobile device, which the user does.

14. Google Authenticator connects to the U2F token over the NFC channel and sends an applet selection command to activate the U2F applet on the token. Google Authenticator then submits a U2F_AUTHENTICATE message to the token.

15. Provided that the token has one of the keys registered at the IdP, it signs the challenge and returns the signature in an authentication success response over the NFC channel.

16. Google Authenticator returns the signature to the browser in a SignResponse object.

17. The callback script on the authentication web page returns the SignResponse object to the IdP.

18. The IdP calls the "authenticate" API on the SKCE, passing the SignResponse as a parameter.

19. The SKCE validates the signature of the challenge by using the registered public key and verifies that the appId matches the IdP's and that the response was received within the configured time-out. The API returns a response to the IdP, indicating success or failure and any error messages. This concludes the U2F authentication process; the user has now authenticated to the IdP, which sets a session cookie.

20. The IdP returns a SAML response indicating the authentication success or failure to the AS through a browser redirect. If authentication has succeeded, the response will include the user's identifier and, optionally, additional attribute assertions. This concludes the SAML authentication flow. The user is now authenticated to the AS, which sets a session cookie. Optionally, the AS could prompt the user to approve the authorization request, displaying the scopes of access being requested at this step.

21. The AS sends a redirect to the browser with the authorization code. The target of the redirect is the mobile application's redirect_uri, a link that opens in the mobile application through a mechanism provided by the mobile OS (e.g., custom request scheme or Android AppLink).

22. The mobile application extracts the authorization code from the URL and submits it to the AS's token end point.

23. The AS responds with an access token and, optionally, a refresh token that can be used to obtain an additional access token when the original token expires. This concludes the OAuth authorization flow.

24. The mobile application can now submit API requests to the SaaS provider's back-end services by using the access token in accordance with the bearer token authorization scheme defined in RFC 6750, *The OAuth 2.0 Authorization Framework: Bearer Token Usage* [15].

4.3.2 OpenID Connect and UAF Authentication Flow

The authentication flow involving OIDC and UAF is depicted in Figure 4-4.

Figure 4-4 OIDC and UAF Sequence Diagram

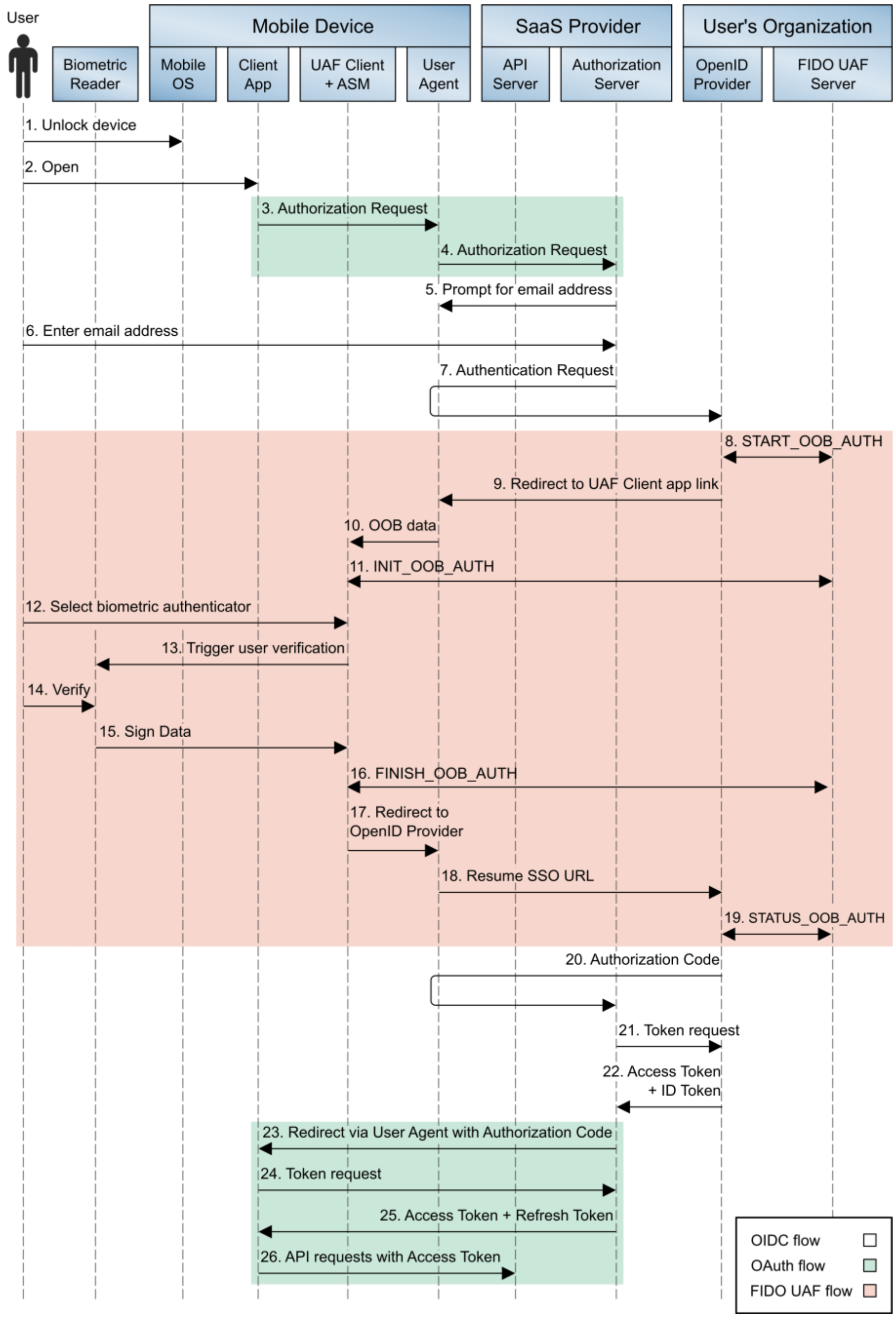


Figure 4-4 uses the same conventions and color coding as the earlier SAML/U2F diagram (Figure 4-3) to depict components on the device, at the SaaS provider, and at the user's organization. Prior to this authentication flow, the user must have registered a FIDO UAF authenticator with the IdP, and the AS must be registered as an OIDC client at the IdP. The detailed steps are listed below. For ease of comparison, steps that are identical to the corresponding step in Figure 4-3 are shown in italics.

1. *The user unlocks the mobile device. Any form of lock-screen authentication can be used; it is not directly tied to the subsequent authentication or authorization.*

2. *The user opens a mobile application that connects to the SaaS provider's back-end services. The mobile application determines that an OAuth token is needed. This may occur because the application has no access or refresh tokens cached or it has an existing token known to be expired based on token metadata, or it may submit a request to the API server with a cached bearer token and receive an HTTP 401 status code in the response.*

3. *The mobile application initiates an OAuth authorization request by using the authorization code flow by invoking the system browser (or an in-application browser tab) with the URL of the SaaS provider AS's authorization end point.*

4. *The in-application browser tab submits the request to the AS over an https connection. This begins the OAuth 2 authorization flow.*

5. *The AS returns a page that prompts for the user's email address.*

6. *The user submits the email address. The AS uses the domain of the email address for IdP discovery. The user needs to specify the email address only one time; the address is stored in a cookie in the device browser and will be used to automatically determine the user's IdP on subsequent visits to the AS.*

7. The AS redirects the device browser to the user's IdP with an OIDC authentication request. This begins the OIDC authentication flow.

8. The IdP submits a START_OOB_AUTH request to the UAF authentication server. The server responds with a data structure containing the necessary information for a UAF client to initiate an Out-of-Band (OOB) authentication, including a transaction identifier linked to the user's session at the IdP.

9. The IdP returns an HTTP redirect to the browser. The redirect target URL is an application link that will pass the OOB data to the Nok Nok Labs Passport application on the device.

10. The Nok Nok Passport application opens and extracts the OOB data from the application link URL.

11. Passport sends an INIT_OOB_AUTH request to the UAF authentication server, including the OOB data and a list of authenticators available on the device that the user has registered for use at the IdP. The server responds with a set of UAF challenges for the registered authenticators.
12. If the user has multiple registered authenticators (e.g., fingerprint and voice authentication), Passport prompts the user to select which authenticator to use.
13. Passport activates the authenticator, which prompts the user to perform the required steps for verification. For example, if the selected authenticator is the Android Fingerprint authenticator, the standard Android fingerprint user interface (UI) overlay will pop over the browser and prompt the user to scan an enrolled fingerprint. The authenticator UI may be presented by Passport (for example, the PIN authenticator), or it may be provided by an OS component such as Apple Touch ID or Face ID.
14. The user completes the biometric scan or other user verification activity. Verification occurs locally on the device; biometrics and secrets are not transmitted to the server.
15. The authenticator signs the UAF challenge by using the private key that was created during initial UAF enrollment with the IdP. The authenticator returns control to the Passport application through an application link with the signed UAF challenge.
16. The Passport application sends a FINISH_OOB_AUTH API request to the UAF authentication server. The server extracts the username and registered public key and validates the signed response. The server can also validate the authenticator's attestation signature and check that the security properties of the authenticator satisfy the IdP's security policy. The server caches the authentication result.
17. The Passport application closes, returning control to the browser, which is redirected to the "resume SSO" URL at the IdP. This URL is defined on the Ping server to enable multistep authentication flows and allow the browser to be redirected back to the IdP after completing required authentication steps with another application.
18. The browser requests the Resume SSO URL at the IdP.
19. The IdP sends a STATUS_OOB_AUTH API request to the UAF authentication server. The UAF server responds with the success/failure status of the out-of-band authentication and any associated error messages. (Note: The IdP begins sending STATUS_OOB_AUTH requests periodically, following step 9 in the flow, and continues to do so until a final status is returned or the transaction times out.) This concludes the UAF authentication process; the user has now authenticated to the IdP, which sets a session cookie.
20. The IdP returns an authorization code to the AS through a browser redirect.

21. The AS submits a token request to the IdP's token end point, authenticating with its credentials and including the authorization code.

22. The IdP responds with an identification (ID) token and an access token. The ID token includes the user's identifier and, optionally, additional attribute assertions. The access token can optionally be used to request additional user claims at the IdP's user information end point. This concludes the OIDC authentication flow. The user is now authenticated to the AS, which sets a session cookie. Optionally, the AS could prompt for the user to approve the authorization request, displaying the scopes of access being requested at this step.

23. *The AS sends a redirect to the browser with the authorization code. The target of the redirect is the mobile application's redirect_uri, a link that opens in the mobile application through a mechanism provided by the mobile OS (e.g., custom request scheme or Android AppLink).*

24. *The mobile application extracts the authorization code from the URL and submits it to the AS's token end point.*

25. *The AS responds with an access token and, optionally, a refresh token that can be used to obtain an additional access token when the original token expires. This concludes the OAuth authorization flow.*

26. *The mobile application can now submit API requests to the SaaS provider's back-end services by using the access token in accordance with the bearer token authorization scheme.*

Both authentication flows end with a single application obtaining an access token to access back-end resources. At this point, traditional OAuth token life-cycle management would begin. Access tokens have an expiration time. Depending on the application's security policy, refresh tokens may be issued along with the access token and used to obtain a new access token when the initial token expires. Refresh tokens and access tokens can continue to be issued in this manner for as long as the security policy allows. When the current access token has expired and no additional refresh tokens are available, the mobile application would submit a new authorization request to the AS.

Apart from obtaining an access token, the user has established sessions with the AS and IdP that can be used for SSO.

Implementation details for this scenario were slightly different on iOS and Android devices. On Android devices, a Chrome Custom Tab was used as the user-agent. On iOS, however, the team encountered issues using the custom tabs implementation in iOS 12 (provided by the ASWebAuthenticationSession API) in conjunction with Passport. At step 17 in the above sequence, where the Passport application should close and control should return to the in-application browser tab, instead a second Safari window opened, and the user was prompted again to authenticate using Passport. The team determined that ASWebAuthenticationSession does not seem to support opening a different application like Passport and then returning to the same ASWebAuthenticationSession instance once the other application closes. This issue was resolved by configuring AppAuth to use Safari instead of ASWebAuthenticationSession.

4.4 Single Sign-On with the OAuth Authorization Flow

When multiple applications invoke a common user-agent to perform the OAuth authorization flow, the user-agent maintains the session state with the AS and IdP. In the build architecture, this can enable SSO in two scenarios.

In the first case, assume that a user has launched a mobile application, has been redirected to an IdP to authenticate, and has completed the OAuth flow to obtain an access token. Later, the user launches a second application that connects to the same AS used by the first application. The application will initiate an authorization request using the same user-agent as the first application. Provided that the user has not logged out at the AS, this request will be sent with the session cookie that was established when the user authenticated in the previous authorization flow. The AS will recognize the user's active session and issue an access token to the second application without requiring the user to authenticate again.

In the second case, again assume that the user has completed an OAuth flow, including authentication to an IdP, while launching the first application. Later, the user launches a second application that connects to an AS that is different from the first application. Again, the second application initiates an authorization request using the same user-agent as the first application. The user has no active session with the second AS, so the user-agent is redirected to the IdP to obtain an authentication assertion. Provided that the user has not logged out at the IdP, the authentication request will include the previously established session cookie, and the user will not be required to authenticate again at the IdP. The IdP will return an assertion to the AS, which will then issue an access token to the second application.

This architecture can also provide SSO across native and web applications. If the web application is an RP to the same SAML or OIDC IdP used in the authentication flow described above, the application will redirect the browser to the IdP and resume the user's existing session without the need to reauthenticate, provided that the browser used to access the web application is the same one used in the authorization flow described above. For example, if a Google Chrome Custom Tab is used in the native-application OAuth flow, then accessing the web application in Chrome will provide a shared cookie store and SSO. If the web application uses the OAuth 2.0 implicit grant, then SSO could follow either of the above workflows, depending on whether the user is already authenticated at the AS used by the application.

When applications use embedded web views instead of the system browser or in-application tabs for the OAuth authorization flow, each individual application's web view has its own cookie store, so there is no continuity of the session state as the user transitions from one application to another, and the user must authenticate each time.

4.5 Application Developer Perspective of the Build

The following paragraphs provide takeaways from an application developer's perspective regarding the experience of the build team, inclusive of FIDO, the AppAuth library, PKCE, and Chrome Custom Tabs.

AppAuth was integrated as described in Section C.1 of Appendix C. From an application developer perspective, the primary emphasis in the build was integrating AppAuth. The authentication technology was basically transparent to the developer. In fact, the native application developers for this project had no visibility to the FIDO U2F or UAF integration. This transparency was achieved through the AppAuth pattern of delegating the authentication process to the in-application browser tab capability of the OS. Other application developer effects are listed below:

- Several pieces of information must be supplied by an application in the OAuth authorization request, such as the scope and the client ID, which an OAuth AS might use to apply appropriate authentication policy. These details are obtained during the OAuth client registration process with the AS.
- The ability to support multiple IdPs without requiring any hard-coding of IdP URLs in the application itself was achieved by using hypertext markup language (HTML) forms hosted by the IdP to collect information from end users (e.g., domain) during login, which was used to perform IdP discovery.

4.6 Identity Provider Perspective of the Build

The IdP is responsible for account and attribute creation and maintenance, as well as credential provisioning, management, and deprovisioning. Some IdP concerns for this architecture are listed below:

- Enrollment/registration of authenticators: IdPs should consider the enrollment process and life-cycle management for MFA. For this NCCoE project, FIDO UAF enrollment was launched by the user via tapping a native enrollment application (Nok Nok Labs' Passport application). During user authentication, the same application (Passport) was invoked programmatically (via AppLink) to perform FIDO authentication. In a production implementation, the IdP would need to put processes in place to enroll, retire, or replace authenticators when needed. A process for responding when authenticators are lost or stolen is particularly important to prevent unauthorized access.
- For UAF, a FIDO UAF client must be installed (e.g., we installed Nok Nok Labs' NNL Passport).
- For U2F, download and install Google Authenticator (or equivalent) because mobile browsers do not support FIDO U2F 1.1 natively (as do some desktop browsers). This situation is evolving with ratification of the World Wide Web Consortium Web Authentication (WebAuthn) standard [16] and mobile browser support for it. For implementations supporting U2F integration in the browser, such as the one described in this practice guide, Google Authenticator is still required

on Android devices. For implementations using WebAuthn, native browser support may eliminate the need for Google Authenticator.

4.7 Token and Session Management

RP application owners have two separate areas of concern when it comes to token and session management. They have authorization tokens to manage on the client side, and the identity tokens/sessions to receive and manage from the IdP side. Each of these functions has its own separate concerns and requirements.

When dealing with the native application's access to RP application data, RP operators need to make sure that appropriate authorization is in place. The architecture in Section 4.2 uses OAuth 2.0 and authorization tokens for this purpose, following the guidance from IETF RFC 8252. Native-application clients present a special challenge, as mentioned earlier, especially when it comes to protecting the authorization code being returned to the client. To mitigate a code interception threat, RFC 8252 requires that both clients and servers use PKCE for public native-application clients. ASes should reject authorization requests from native applications that do not use PKCE. The lifetime of the authorization tokens depends on the use case, but the general recommendation from the OAuth working group is to use short-lived access tokens and long-lived refresh tokens. The reauthentication requirements in NIST SP 800-63B [10] can be used as guidance for maximum refresh token lifetimes at each authenticator assurance level. All security considerations from RFC 8252 apply here as well, such as making sure that attackers cannot easily guess any of the token values or credentials.

The RP may directly authenticate the user, in which case all of the current best practices for web session security and protecting the channel with Transport Layer Security (TLS) apply. However, if there is delegated or federated authentication via a third-party IdP, then the RP must also consider the implications for managing the identity claims received from the IdP, whether it be an ID token from an OIDC provider or a SAML assertion from a SAML IdP. This channel is used for authentication of the user, which means that potential PII may be obtained. Care must be taken to obtain user consent prior to authorization for release and use of this information in accordance with relevant regulations. If OIDC is used for authentication to the RP, then all of the OAuth 2.0 security applies again here. In all cases, all channels between parties must be protected with TLS encryption.

5 Security Characteristic Analysis

The purpose of the security characteristic analysis is to understand the extent to which the project meets its objective of demonstrating MFA and mobile SSO for native and web applications. In addition, it seeks to document the security benefits and drawbacks of the example solution.

5.1 Assumptions and Limitations

This security characteristics analysis is focused on the specific design elements of the build, consisting of MFA, SSO, and federation implementation. It discusses some elements of application development, but only the aspects that directly interact with the SSO implementation. It does not focus on potential underlying vulnerabilities in OSes, application run times, hardware, or general secure coding practices. It is assumed that risks to these foundational components are managed separately (e.g., through asset and patch management). As with any implementation, all layers of the architecture must be appropriately secured, and it is assumed that implementers will adopt standard security and maintenance practices to the elements not specifically addressed here.

This project did not include a comprehensive test of all security components or "red team" penetration testing or adversarial emulation. Cybersecurity is a rapidly evolving field where new threats and vulnerabilities are continually discovered. Therefore, this security guidance cannot be guaranteed to identify every potential weakness of the build architecture. It is assumed that implementers will follow risk management procedures as outlined in the NIST Risk Management Framework.

5.2 Threat Analysis

The following subsections describe how the build architecture addresses the threats discussed in Section 3.5.

5.2.1 Mobile Ecosystem Threat Analysis

In Section 3.5.2, we introduced the MTC, described the 32 categories of mobile threats that it covers, and highlighted the three categories that this practice guide addresses: Vulnerable Applications, Authentication: User or Device to Network, and Authentication: User or Device to Remote Service.

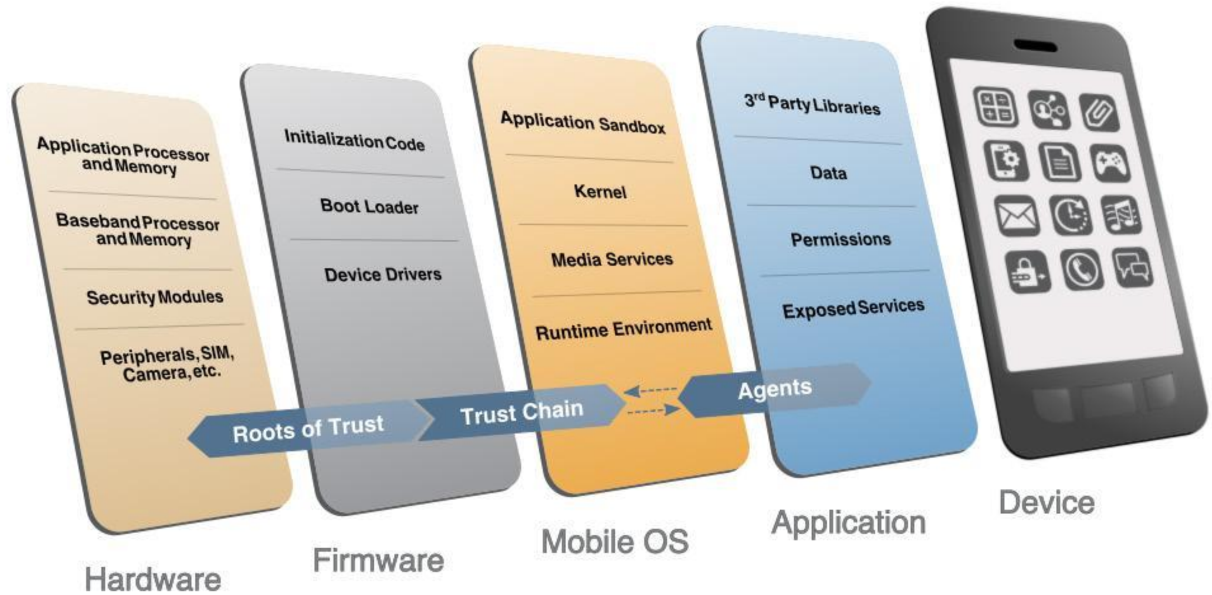
At the time of this writing, these categories encompass 18 entries in the MTC. However, the MTC is a living catalog, which is continually being updated. Instead of addressing each threat, we describe in general how these types of threats are mitigated by the architecture laid out in this practice guide:

- Use encryption for data in transit: The IdP and AS enforce https encryption by default, which the application is required to use during SSO authentication.
- Use newer mobile platforms: Volume C of this guide (NIST SP 1800-13C) calls for using at least Android 5.0 or iOS 8.0 or newer, which mitigates weaknesses of older versions (e.g., applications can access the system log in Android 4.0 and older).
- Use built-in browser features: The AppAuth for Android library utilizes the Chrome Custom Tabs feature, which activates the device's native browser. This allows the application to leverage built-in browser features, such as identifying and avoiding known malicious web pages. AppAuth for iOS supports using the SFSafariViewController and SFAuthenticationSession APIs or the Safari browser.

- Avoid hard-coded secrets: The AppAuth guidance recommends and supports the use of PKCE. This allows developers to avoid using a hard-coded OAuth client secret.
- Avoid logging sensitive data: The AppAuth library, which handles the OAuth 2 flow, does not log any sensitive data.
- Use sound authentication practices: By using SSO, the procedures outlined in this guide allow application developers to rely on the IdP’s implementation of authentication practices, such as minimum length and complexity requirements for passwords, maximum authentication attempts, and periodic reset requirements. In addition, the IdP can introduce new authenticators without any downstream effect to applications.
- Use sound token management practices: Again, this guide allows application developers to rely on the IdP’s implementation of authorization tokens and good management practices, such as replay-resistance mechanisms and token expirations.
- Use two-factor authentication: Both FIDO U2F and UAF, as deployed in this build architecture, provide multifactor cryptographic user authentication. The U2F implementation requires the user to authenticate with a password or PIN and with a single-factor cryptographic token. However, the UAF implementation utilizes a key pair stored in the device’s hardware-backed key store that is unlocked through user verification consisting of a biometric (e.g., fingerprint or voice match) or a password or PIN.
- Protect cryptographic keys: FIDO U2F and UAF authentication leverage public key cryptography. In this architecture, U2F private keys are stored external to the mobile device in a hardware-secure element on a YubiKey Neo. UAF private keys are stored on the mobile device’s hardware-backed key store. These private keys are never sent to external servers.
- Protect biometric templates: When using biometric authentication mechanisms, organizations should consider storage and use of user biometric templates. This architecture relies on the native biometric mechanisms implemented by modern mobile devices and OSes, which verify biometric templates locally and store them in protected storage.

To fully address these threats and threats in other MTC categories, additional measures should be taken by all parties involved in the mobile ecosystem: the mobile device user, the enterprise, the network operator, the application developer, and the OEM. A figure depicting this ecosystem in total is shown in Section 3.5.2. In addition, the mobile platform stack should be understood in great detail to fully assess the threats that may be applicable. An illustration of this stack, taken from NIST Interagency Report 8144 [9], is shown in Figure 5-1.

Figure 5-1 Mobile Device Technology Stack



Several tools, techniques, and best practices are available to mitigate these other threats. EMM software can allow enterprises to manage devices more fully and to gain a better understanding of device health; one example of this is detecting whether a device has been *rooted* or *jailbroken*, which compromises the security architecture of the entire platform. Application security-vetting software (commonly known as app-vetting software) can be utilized to detect vulnerabilities in first-party applications and to discover potentially malicious behavior in third-party applications. Using app-vetting software in conjunction with EMM software prevents the installation of unauthorized applications and reduces the attack surface of the platform. For more guidance on these threats and mitigations, refer to the MTC and NIST Interagency Report 8144 [9].

5.2.2 Authentication and Federation Threat Analysis

Section 3.5.3 discussed threats specific to authentication and federation systems, which are cataloged in NIST SP 800-63-3 [17]. MFA, provided in the build architecture by FIDO U2F and UAF, is designed to mitigate several authentication risks:

- Theft of physical authenticator: Possessing an authenticator, which could be a YubiKey (in the case of U2F) or the mobile device itself (in the case of UAF), does not in itself enable an attacker to impersonate the user to an RP or IdP. Additional knowledge or a biometric factor is needed to authenticate.
- Eavesdropping: Some MFA solutions, including many onetime password (OTP) implementations, are vulnerable to eavesdropping attacks. FIDO implements cryptographic authentication, which does not involve transmission of secrets over the network.

- Social engineering: A typical social engineering exploit involves impersonating a system administrator or other authority figure under some pretext to convince users to disclose their passwords over the phone, but this comprises only a single authentication factor.
- Online guessing: Traditional password authentication schemes may be vulnerable to online guessing attacks, though lockout and throttling policies can reduce the risk. Cryptographic authentication schemes are not vulnerable to online guessing.

FIDO also incorporates protections against phishing and pharming attacks. When a FIDO authenticator is registered with an RP, a new key pair is created and associated with the RP's application ID, which is derived from the domain name in the URL where the registration transaction was initiated. During authentication, the application ID is again derived from the URL of the page that is requesting authentication, and the authenticator will sign the authentication challenge only if a key pair has been registered with the matching application ID. The FIDO facets specification enables sites to define a list of domain names that should be treated as a single application ID to accommodate service providers that span multiple domain names, such as google.com and gmail.com.

The application ID verification effectively prevents the most common type of phishing attack, in which the attacker creates a new domain and tricks users into visiting that domain instead of an intended RP where the user has an account. For example, an attacker might register a domain called "google-accts.com" and send emails with a pretext to get users to visit the site, such as a warning that the user's account will be disabled unless some action is taken. The attacker's site would present a login screen identical to Google's login screen to obtain the user's password (and OTP, if enabled) credentials and to use them to impersonate the user to the real Google services. With FIDO, the authenticator would not have an existing key pair registered under the attacker's domain, so the user would be unable to return a signed FIDO challenge to the attacker's site. If the attacker could convince the user to register the FIDO authenticator with the malicious site and then sign an authentication challenge, the signed FIDO assertion could not be used to authenticate to Google because the RP can also verify the application ID associated with the signed challenge, and it would not be the expected ID.

A more advanced credential theft attack involves an active man in the middle that can intercept the user's requests to the legitimate RP and act as a proxy between the two. To avoid TLS server certificate validation errors, in this case, the attacker must obtain a TLS certificate for the legitimate RP site that is trusted by the user's device. This could be accomplished by exploiting a vulnerability in a commercial certificate authority; it presents a high bar for the attacker but is not unprecedented. Application ID validation is not sufficient to prevent this attacker from obtaining an authentication challenge from the RP, proxying it to the user, and using the signed assertion that it gets back from the user to authenticate to the RP. To prevent this type of attack, the FIDO specifications permit token binding to protect the signed assertion that is returned to the RP by including information in the assertion about the TLS channel over which it is being delivered. If there is a man in the middle (or a proxy of any kind) between the user and the RP, the RP can detect it by examining the token-binding message included in the assertion and comparing it with the TLS channel over which it was received. Token binding is not widely implemented today, but with finalization of the token-binding specification in RFC 8471 [18] and related RFCs, adoption is expected to increase.

Many of the federation threats discussed in Section 3.5.3 can be addressed by signing assertions, ensuring their integrity and authenticity. An encrypted assertion can also provide multiple protections, preventing disclosure of sensitive information contained in the assertion and providing a strong protection against assertion redirection because only the intended RP will have the key required to decrypt the assertion. Most mitigations to federation threats require application of protocol-specific guidance for SAML and OIDC. These considerations are not specific to the mobile SSO use case; application of a security-focused profile of these protocols can mitigate many potential issues.

In addition to RFC 8252, application developers and RP service providers should consult the *OAuth 2.0 Threat Model and Security Considerations* documented in RFC 6819 [19] for best practices for implementing OAuth 2.0. The AppAuth library supports a secure OAuth client implementation by automatically handling details like PKCE. Key protections for OAuth and OIDC include those listed below:

- Requiring https for protocol requests and responses protects access tokens and authorization codes and authenticates the server to the client.
- Using the mobile operating system browser or in-application browser tabs for the authentication flow, in conformance with RFC 8252, protects user credentials from exposure to the mobile client application or the application service provider.
- OAuth tokens are associated with access scopes, which can be used to limit the authorizations granted to any given client application, which somewhat mitigates the potential for misuse of compromised access tokens.
- PKCE, as explained previously, prevents interception of the authorization code by malicious applications on the mobile device.

5.3 Scenarios and Findings

The overall test scenario on Android devices involved launching the Motorola Solutions PSX Cockpit mobile application, authenticating, and then subsequently launching additional PSX applications and validating that the applications could access the back-end APIs and reflected the identity of the authenticated user. To enable testing of the two different authentication scenarios, two separate "user organization" infrastructures were created in the NCCoE lab, and both were registered as IdPs to the test PingFederate instance acting as the PSX AS. A "domain selector" was created in PingFederate to perform IdP discovery based on the domain of the user's email address, enabling the user to trigger authentication at one of the IdPs.

On iOS devices, two demonstration applications—a chat application and a mapping application, with corresponding back-end APIs—were developed to demonstrate SSO. The iOS demo used the same authentication infrastructure in the NCCoE lab as the Android demo. The demo consisted of launching either application and authenticating to the IdP that supported OpenID Connect and FIDO UAF, then launching the additional demo application to demonstrate SSO and access to the back-end APIs with the identity of the authenticated user.

Prior to testing the authentication infrastructure, users had to register U2F and UAF authenticators at the respective IdPs. FIDO authenticator registration requires a process that provides high assurance that the authenticator is in possession of the claimed account holder. In practice, this typically requires a strongly authenticated session or an in-person registration process overseen by an administrator. In the lab, a notional enrollment process was implemented with the understanding that real-world processes would be different and subject to agency security policies. Organizations should refer to NIST SP 800-63B [10] for specific considerations regarding credential enrollment. From a FIDO perspective, however, the registration data used would be the same.

Lab testing showed that the build architecture consistently provided SSO between applications. Two operational findings were uncovered during testing:

- Knowing the location of the NFC radio on the mobile device greatly improves the user experience when authenticating with an NFC token, such as the YubiKey Neo. The team found that NFC radios are in different locations on different devices; on the Nexus 6P, for example, the NFC radio is near the top of the device, near the camera, whereas on the Galaxy S6 Edge, the NFC radio is slightly below the vertical midpoint of the device. After initial experimentation to locate the radio, team members could quickly and reliably make a good NFC connection with the YubiKey by holding it in the correct location. Device manufacturers provide NFC radio location information via device technical specifications.
- Time synchronization between servers is critical. In lab testing, intermittent authentication errors were found to be caused by clock drift between the IdP and the AS. This manifested as the AS reporting JavaScript Object Notation Web Token validation errors when attempting to validate ID tokens received from the IdP. All participants in the federation scheme should synchronize their clocks to a reliable network time protocol (NTP) source, such as the NIST NTP pools [20]. Implementations should allow for a small amount of clock skew—on the order of a few seconds—to account for the unpredictable latency of network traffic.

6 Future Build Considerations

6.1 Single Logout

To ensure that only authorized personnel get access to application resources, users must be logged out from application sessions when access is no longer needed or when a session expires. In an SSO scenario, a user may need to be logged out from one or many applications at a given time. This scenario will demonstrate architectures for tearing down user sessions, clearly communicating to the user which application(s) has (have) active sessions, and ensuring that active sessions are not orphaned.

6.2 Shared Devices

This scenario will focus on a situation where two or more colleagues share a single mobile device to accomplish a mission. The credentials, such as the FIDO UAF and U2F used in this guide, will be included but may need to be registered to multiple devices. This scenario will explore situations in which multiple profiles or no profiles are installed on a device, potentially requiring the user to log out prior to giving the device to another user.

6.3 Step-Up Authentication

A user will access applications by using an acceptable but low assurance authenticator. Upon requesting access to an application that requires higher assurance, the user will be prompted for an additional authentication factor. Determinations on whether to step up may be based on risk-relevant data points collected by the IdP at the time of authentication, referred to as the authentication context.

Appendix A Mapping to Cybersecurity Framework Core

Table A-1 maps informative National Institute of Standards and Technology (NIST) and consensus security references to the Cybersecurity Framework core Subcategories that are addressed by NIST Special Publication (SP) 1800-13. The references do not include protocol specifications that are implemented by the individual products that compose the demonstrated security platforms. While some of the references provide general guidance that informs implementation of referenced Cybersecurity Framework core functions, the NIST SP 1800-13 references provide specific recommendations that should be considered when composing and configuring security platforms and technologies described in this practice guide.

Table A-1 Cybersecurity Framework Categories

Category	Subcategory	Informative References
Asset Management (ID.AM): The data, personnel, devices, systems, and facilities that enable the organization to achieve business purposes are identified and managed consistent with their relative importance to business objectives and the organization's risk strategy.	**ID.AM-1:** Physical devices and systems within the organization are inventoried.	**CCS CSC** 1 **COBIT 5** BAI09.01, BAI09.02 **ISA 62443-2-1:2009** 4.2.3.4 **ISA 62443-3-3:2013** SR 7.8 **ISO/IEC 27001:2013** A.8.1.1, A.8.1.2 **NIST SP 800-53 Rev. 4** CM-8
Access Control (PR.AC): Access to assets and associated facilities is limited to authorized users, processes, or devices, and to authorized activities and transactions.	**PR.AC-1:** Identities and credentials are managed for authorized devices and users.	**CCS CSC** 16 **COBIT 5** DSS05.04, DSS06.03 **ISA 62443-2-1:2009** 4.3.3.5.1 **ISA 62443-3-3:2013** SR 1.1, SR 1.2, SR 1.3, SR 1.4, SR 1.5, SR 1.7, SR 1.8, SR 1.9 **ISO/IEC 27001:2013** A.9.2.1, A.9.2.2, A.9.2.4, A.9.3.1, A.9.4.2, A.9.4.3 **NIST SP 800-53 Rev. 4** AC-2, Information Assurance Family

Category	Subcategory	Informative References
	PR.AC-3: Remote access is managed.	**COBIT 5** APO13.01, DSS01.04, DSS05.03 **ISA 62443-2-1:2009** 4.3.3.6.6 **ISA 62443-3-3:2013** SR 1.13, SR 2.6 **ISO/IEC 27001:2013** A.6.2.2, A.13.1.1, A.13.2.1 **NIST SP 800-53 Rev. 4** AC-17, AC-19, AC-20
	PR.AC-4: Access permissions are managed, incorporating the principles of least privilege and separation of duties.	**CCS CSC** 12, 15 **ISA 62443-2-1:2009** 4.3.3.7.3 **ISA 62443-3-3:2013** SR 2.1 **ISO/IEC 27001:2013** A.6.1.2, A.9.1.2, A.9.2.3, A.9.4.1, A.9.4.4 **NIST SP 800-53 Rev. 4** AC-2, AC-3, AC-5, AC-6, AC-16
Data Security (PR.DS): Information and records (data) are managed consistent with the organization's risk strategy to protect the confidentiality, integrity, and availability of information.	**PR.DS-5:** Protections against data leaks are implemented.	**CCS CSC** 17 **COBIT 5** APO01.06 **ISA 62443-3-3:2013** SR 5.2 **ISO/IEC 27001:2013** A.6.1.2, A.7.1.1, A.7.1.2, A.7.3.1, A.8.2.2, A.8.2.3, A.9.1.1, A.9.1.2, A.9.2.3, A.9.4.1, A.9.4.4, A.9.4.5, A.13.1.3, A.13.2.1, A.13.2.3, A.13.2.4, A.14.1.2, A.14.1.3 **NIST SP 800-53 Rev. 4** AC-4, AC-5, AC-6, PE-19, PS-3, PS-6, SC-7, SC-8, SC-13, SC-31, SI-4

Category	Subcategory	Informative References
Protective Technology (PR.PT): Technical security solutions are managed to ensure the security and resilience of systems and assets, consistent with related policies, procedures, and agreements.	**PR.PT-1:** Audit/log records are determined, documented, implemented, and reviewed in accordance with policy.	**CCS CSC** 14 **COBIT 5** APO11.04 **ISA 62443-2-1:2009** 4.3.3.3.9, 4.3.3.5.8, 4.3.4.4.7, 4.4.2.1, 4.4.2.2, 4.4.2.4 **ISA 62443-3-3:2013** SR 2.8, SR 2.9, SR 2.10, SR 2.11, SR 2.12 **ISO/IEC 27001:2013** A.12.4.1, A.12.4.2, A.12.4.3, A.12.4.4, A.12.7.1 **NIST SP 800-53 Rev. 4** Audit and Accountability Family
	PR.PT-2: Removable media is protected and its use restricted according to policy.	**COBIT 5** DSS05.02, APO13.01 **ISA 62443-3-3:2013** SR 2.3 **ISO/IEC 27001:2013** A.8.2.2, A.8.2.3, A.8.3.1, A.8.3.3, A.11.2.9 **NIST SP 800-53 Rev. 4** MP-2, MP-4, MP-5, MP-7
	PR.PT-3: Access to systems and assets is controlled, incorporating the principle of least functionality.	**COBIT 5** DSS05.02 **ISA 62443-2-1:2009** 4.3.3.5.1, 4.3.3.5.2, 4.3.3.5.3, 4.3.3.5.4, 4.3.3.5.5, 4.3.3.5.6, 4.3.3.5.7, 4.3.3.5.8, 4.3.3.6.1, 4.3.3.6.2, 4.3.3.6.3, 4.3.3.6.4, 4.3.3.6.5, 4.3.3.6.6, 4.3.3.6.7, 4.3.3.6.8, 4.3.3.6.9, 4.3.3.7.1, 4.3.3.7.2, 4.3.3.7.3, 4.3.3.7.4 **ISA 62443-3-3:2013** SR 1.1, SR 1.2, SR 1.3, SR 1.4, SR 1.5, SR 1.6, SR 1.7, SR 1.8, SR 1.9, SR 1.10, SR 1.11, SR 1.12, SR 1.13, SR 2.1, SR 2.2, SR 2.3, SR 2.4, SR 2.5, SR 2.6, SR 2.7 **ISO/IEC 27001:2013** A.9.1.2 **NIST SP 800-53 Rev. 4** AC-3, CM-7

Category	Subcategory	Informative References
	PR.PT-4: Communications and control networks are protected.	**CCS CSC** 7 **COBIT 5** DSS05.02, APO13.01 **ISA 62443-3-3:2013** SR 3.1, SR 3.5, SR 3.8, SR 4.1, SR 4.3, SR 5.1, SR 5.2, SR 5.3, SR 7.1, SR 7.6 **ISO/IEC 27001:2013** A.13.1.1, A.13.2.1 **NIST SP 800-53 Rev. 4** AC-4, AC-17, AC-18, CP-8, SC-7

Appendix B Assumptions Underlying the Build

This project is guided by the following assumptions. Implementers are advised to consider whether the same assumptions can be made based on current policy, process, and information technology (IT) infrastructure. Where applicable, appropriate guidance is provided to assist this process as described in the following subsections.

B.1 Identity Proofing

National Institute of Standards and Technology (NIST) Special Publication (SP) 800-63A, *Enrollment and Identity Proofing* [21], addresses how applicants can prove their identities and become enrolled as valid subjects within an identity system. It provides requirements for processes by which applicants can both proof and enroll at one of three different levels of risk mitigation, in both remote and physically present scenarios. NIST SP 800-63A contains both normative and informative material. An organization should use NIST SP 800-63A to develop and implement an identity proofing plan within its enterprise.

B.2 Mobile Device Security

Mobile devices can add to an organization's productivity by providing employees with access to business resources at any time. Not only has this reshaped how traditional tasks are accomplished but organizations are also devising entirely new ways to work. However, mobile devices may be lost or stolen. A compromised mobile device may allow remote access to sensitive on-premises organizational data or any other data that the user has entrusted to the device. Several methods exist to address these concerns (e.g., using a device lock screen, setting shorter screen time-outs, forcing a device wipe in case of too many failed authentication attempts). It is up to the organization to implement these types of security controls, which can be enforced with Enterprise Mobility Management (EMM) software (see Section B.4).

NIST SP 1800-4, *Mobile Device Security: Cloud and Hybrid Builds* [22], demonstrates how to secure sensitive enterprise data that is accessed by and/or stored on employees' mobile devices. The NIST *Mobile Threat Catalogue* [23] identifies threats to mobile devices and associated mobile infrastructure to support development and implementation of mobile security capabilities, best practices, and security solutions to better protect enterprise IT. We strongly encourage organizations implementing this practice guide in whole or in part to consult these resources when developing and implementing a mobile device security plan for their organizations.

B.3 Mobile Application Security

The security qualities of an entire platform can be compromised if an application exhibits vulnerable or malicious behavior. Application security is paramount in ensuring that the security controls implemented in other architecture components can effectively mitigate threats. The practice of making sure that an application is secure is known as software assurance (SwA). This is defined as “the level of confidence that software is free from vulnerabilities, either intentionally designed into the software or accidentally inserted at any time during its lifecycle, and that the software functions in the intended manner” [24].

In an architecture that largely relies on third-party—usually closed-source—applications to handle daily user functions, good SwA hygiene can be difficult to implement. To address this problem, NIST has released guidance on how to structure and implement an application-vetting process (also known as “app vetting”) [25]. This takes an organization through the following steps:

1. understanding the process for vetting the security of mobile applications
2. planning for implementation of an app-vetting process
3. developing application security requirements
4. understanding types of application vulnerabilities and testing methods used to detect those vulnerabilities
5. determining whether an application is acceptable for deployment on the organization’s mobile devices

Public safety organizations (PSOs) should carefully consider their application-vetting needs. Though major mobile-application stores, such as Apple’s iTunes Store and Google’s Play Store, have vetting mechanisms to find vulnerable and malicious applications, organizations may have needs beyond these proprietary tools. Per NIST SP 800-163, *Vetting the Security of Mobile Applications* [25]:

> App stores may perform app vetting processes to verify compliance with their own requirements. However, because each app store has its own unique, and not always transparent, requirements and vetting processes, it is necessary to consult current agreements and documentation for a particular app store to assess its practices. Organizations should not assume that an app has been fully vetted and conforms to their security requirements simply because it is available through an official app store. Third party assessments that carry a moniker of “approved by” or “certified by” without providing details of which tests are performed, what the findings were, or how apps are scored or rated, do not provide a reliable indication of software assurance. These assessments are also unlikely to take organization specific requirements and recommendations into account, such as federal-specific cryptography requirements.

The First Responder Network Authority (FirstNet) provides an application store specifically geared toward first responder applications. Through the FirstNet Developer Portal [26], application developers can submit mobile applications for evaluation against its published development guidelines. The guidelines include security, scalability, and availability. Compliant applications can be selected for inclusion in the FirstNet App Store. This provides first responder agencies with a repository of applications that have been tested to a known set of standards.

PSOs should avoid the unauthorized "side loading" of mobile applications that are not subject to organizational vetting requirements.

B.4 Enterprise Mobility Management

The rapid evolution of mobile devices has introduced new paradigms for work environments, along with new challenges for enterprise IT to address. EMM solutions, as part of an EMM program, provide a variety of ways to view, organize, secure, and maintain a fleet of mobile devices. EMM solutions can vary greatly in form and function, but in general, they use platform-provided application programming interfaces. Sections 3 and 4 of NIST SP 800-124 [27] describe the two basic approaches of EMM, along with components, capabilities, and their uses. One approach, commonly known as "fully managed," controls the entire device. Another approach, usually used for bring-your-own-device situations, wraps or "containerizes" applications inside a secure sandbox so that they can be managed without affecting the rest of the device.

EMM capabilities can be grouped into four general categories:

1. General policy–centralized technology to enforce security policies of particular interest for mobile device security, such as accessing hardware sensors like global positioning system (GPS), accessing native operating-system (OS) services like a web browser or email client, managing wireless networks, monitoring when policy violations occur, and limiting access to enterprise services if the device is vulnerable or compromised
2. Data communication and storage–automatically encrypting data in transit between the device and the organization (e.g., through a virtual private network); strongly encrypting data at rest on internal and removable media storage; and wiping the device if it is being reissued to another user, has been lost, or has surpassed a certain number of incorrect unlock attempts
3. User and device authentication–requiring a device password/passcode and parameters for password strength, remotely restoring access to a locked device, automatically locking the device after an idle period, and remotely locking the device if needed
4. Applications–restricting which application stores may be used, restricting which applications can be installed, requiring specific application permissions (such as using the camera or GPS), restricting use of OS synchronization services, verifying digital signatures to ensure that applications are unmodified and sourced from trusted entities, and automatically installing/updating/removing applications according to administrative policies

Public safety and first responder (PSFR) organizations will have different requirements for EMM; this document does not prescribe any specific processes or procedures but assumes that they have been established in accordance with agency requirements. However, sections of this document refer to the NIST Mobile Threat Catalogue [23], which does list the use of EMM solutions as mitigations for certain types of threats.

B.5 FIDO Enrollment Process

Fast Identity Online (FIDO) provides a framework for users to register a variety of different multifactor authenticators and use them to authenticate to applications and identity providers. Before an authenticator can be used in an online transaction, it must be associated with the user's identity. This process is described in NIST SP 800-63B [10] as *authenticator binding*. NIST SP 800-63B specifies requirements for binding authenticators to a user's account both during initial enrollment and after enrollment, and recommends that relying parties support binding multiple authenticators to each user's account to enable alternative strong authenticators in case the primary authenticator is lost, stolen, or damaged.

Authenticator binding may be an in-person or remote process, but in both cases, the user's identity and control over the authenticator being bound to the account must be established. This is related to identity proofing, discussed in Section B.1, but requires that credentials be issued in a manner that maintains a tight binding with the user identity that has been established through proofing. PSFR organizations will have different requirements for identity and credential management; this document does not prescribe any specific processes or procedures but assumes that they have been established in accordance with agency requirements.

As an example, in-person authenticator binding could be implemented by having administrators authenticate with their own credentials and authorize the association of an authenticator with an enrolling user's account. Once a user has one enrolled authenticator, it can be used for online enrollment of other authenticators at the same assurance level or lower. Allowing users to enroll strong multifactor authenticators based on authentication with weaker credentials, such as username and password or knowledge-based questions, can undermine the security of the overall authentication scheme and should be avoided.

Appendix C Architectural Considerations for the Mobile Application Single Sign-On Build

This appendix details architectural considerations relating to single sign-on (SSO) with OAuth 2.0; Internet Engineering Task Force (IETF) Request for Comments (RFC) 8252; and AppAuth open-source libraries, federation, and types of multifactor authentication (MFA).

C.1 SSO with OAuth 2.0, IETF RFC 8252, and AppAuth Open-Source Libraries

As stated above, SSO streamlines the user experience by enabling a user to authenticate once and to subsequently access different applications without having to authenticate again. SSO on mobile devices is complicated by the sandboxed architecture, which makes it difficult to share the session state with back-end systems between individual applications. Enterprise Mobility Management (EMM) vendors have provided solutions through proprietary software development kits (SDKs), but this approach requires integrating the SDK with each individual application and does not scale to a large and diverse population, such as the public safety and first responder (PSFR) user community.

OAuth 2.0, when implemented in accordance with RFC 8252 (the *OAuth 2.0 for Native Apps* Best Current Practice), provides a standards-based SSO pattern for mobile applications. The OpenID Foundation's AppAuth libraries [14] can facilitate building mobile applications in full compliance with IETF RFC 8252, but any mobile application that follows RFC 8252's core recommendation of using a shared external user-agent for the OAuth authorization flow will have the benefit of SSO.

To implement SSO with OAuth 2.0, this practice guide recommends that application developers choose one of the following options:

- Implement IETF RFC 8252 themselves. This RFC specifies that OAuth 2.0 authorization requests from native applications should be made only through external user-agents, primarily the user's browser. This specification details the security and usability reasons for why this is the case and how native applications and authorization servers can implement this best practice. RFC 8252 also recommends the use of Proof Key for Code Exchange (PKCE), as detailed in RFC 7636 [28], which protects against authorization code interception attacks.
- Integrate the AppAuth open-source libraries (that implement RFC 8252 and RFC 7636) for mobile SSO. The AppAuth libraries make it easy for application developers to enable standards-based authentication, SSO, and authorization to application programming interfaces. This was the option chosen by the implementers of this build.

When OAuth is implemented in a native application, it operates as a *public client;* this presents security concerns with aspects like client secrets and redirected uniform resource identifiers (URIs). The AppAuth pattern mitigates these concerns and provides several security advantages for developers. The primary benefit of RFC 8252 is that native applications use an external user-agent (e.g., the Chrome for Android web browser) instead of an embedded user-agent (e.g., an Android WebView) for their OAuth authorization requests.

An embedded user-agent is demonstrably less secure and user-friendly than an external user-agent. Embedded user-agents potentially allow the client to log keystrokes, capture user credentials, copy session cookies, and automatically submit forms to bypass user consent. In addition, session information for embedded user-agents is stored on a per-application basis. This does not allow for SSO functionality, which users generally prefer and which this practice guide sets out to implement. Recent versions of Android and iPhone operating system (iOS) both provide implementations of "in-application browser tabs" that retain the security benefits of using an external user-agent while avoiding visible context-switching between the application and the browser; RFC 8252 recommends their use where available. In-application browser tabs are supported in Android 4.1 and higher and in iOS 9 and higher.

AppAuth also requires that public client applications eschew client secrets in favor of PKCE, which is a standard extension to the OAuth 2.0 framework. When using the AppAuth pattern, the following steps are performed:

1. The user opens the client application and initiates a sign-in.
2. The client uses a browser to initiate an authorization request to the authentication server (AS).
3. The user authenticates to the identity provider (IdP).
4. The OpenID Connect (OIDC)/security assertion markup language (SAML) flow takes place, and the user authenticates to the AS.
5. The browser requests an authorization code from the AS.
6. The browser returns the authorization code to the client.
7. The client uses its authorization code to request and obtain an access token.

There is a possible attack vector at the end user's device in this workflow if PKCE is not enabled. During step 6, so that the client application can receive the authorization code, the AS redirects the browser to a URI on which the client application is listening. However, a malicious application could register for this URI and attempt to intercept the code so that it may obtain an access token. PKCE-enabled clients use a dynamically generated random *code verifier* to ensure proof of possession for the authorization code. If the grant is intercepted by a malicious application before being returned to the client, the malicious application will be unable to use the grant without the client's secret verifier.

AppAuth also outlines several other actions to consider, such as three types of redirect URIs, native-application client registration guidance, and reverse domain-name-based schemes. These are supported and/or enforced with secure defaults in the AppAuth libraries. The libraries are open-source and include sample code for implementation. In addition, if Universal Second Factor (U2F) or Universal Authentication Framework (UAF) is desired, that flow is handled entirely by the external user-agent, so client applications do not need to implement any of that functionality.

The AppAuth library takes care of several boilerplate tasks for developers, such as caching access tokens and refresh tokens, checking access-token expiration, and automatically refreshing access tokens. To implement the AppAuth pattern in an Android application by using the provided library, a developer needs to perform the following actions:

- Add the Android AppAuth library as a Gradle dependency.
- Add a redirect URI to the Android manifest.
- Add the Java code to initiate the AppAuth flow and to use the access token afterward.
- Register the application's redirect URI with the AS.

Using the AppAuth library in an iOS application is a similar process:

- Add the AppAuth library by using either Pods or Carthage.
- Configure a custom uniform resource locator (URL) scheme in the info.plist file.
- Update the view controllers and application delegate to initiate the AppAuth flow and to use the access token afterward.
- Register the application's redirect URI with the AS.

To implement the AppAuth pattern *without* using a library, the user will need to follow the general guidance laid out in RFC 8252, review and follow the operating system-specific guidance in the AppAuth documentation [14], and adhere to the requirements of both the OAuth 2.0 framework documented in RFC 6749 [29] and the PKCE.

C.1.1 Attributes and Authorization

Authorization, in the sense of applying a policy to determine the rights and privileges that apply to application requests, is beyond the scope of this practice guide. OAuth 2.0 provides delegation of user authorizations to mobile applications acting on their behalf, but this is distinct from the authorization policy enforced by the application. This guide is agnostic to the specific authorization model (e.g., role-based access control [RBAC], attribute-based access control [ABAC], capability lists) that applications will use, and the SSO mechanism documented here is compatible with virtually any back-end authorization policy.

While applications could potentially manage user roles and privileges internally, federated authentication provides the capability for the IdP to provide user attributes to relying parties (RPs). These attributes might be used to map users to defined application roles or used directly in an ABAC policy (e.g., to restrict access to sworn law enforcement officers). Apart from authorization, attributes may provide identifying information useful for audit functions, contact information, or other user data.

In the build architecture, the AS is an RP to the user's IdP, which is either a SAML IdP or an OIDC provider. SAML IdPs can return attribute elements in the SAML response. OIDC providers can return attributes as claims in the identification (ID) token, or the AS can request them from the user information end point. In both cases, the AS can validate the IdP's signature of the asserted attributes to ensure their validity and integrity. Assertions can also optionally be encrypted, which both protects their confidentiality in transit and enforces audience restrictions because only the intended RP will be able to decrypt them.

Once the AS has received and validated the asserted user attributes, it could use them as issuance criteria to determine whether an access token should be issued for the client to access the requested scopes. In the OAuth 2.0 framework, *scopes* are individual access entitlements that can be granted to a client application. In addition, the attributes could be provided to the protected resource server to enable the application to enforce its own authorization policies. Communications between the AS and protected resource are internal design concerns for the software as a service (SaaS) provider. One method of providing attributes to the protected resource is for the AS to issue the access token as a JavaScript Object Notation (JSON) Web Token (JWT) containing the user's attributes. The protected resource could also obtain attributes by querying the AS's token introspection end point, where they could be provided as part of the token metadata in the introspection response.

C.2 Federation

The preceding section discussed the communication of attributes from the IdP to the AS for use in authorization decisions. In the build architecture, it is assumed that the SaaS provider may be an RP of many IdPs supporting different user organizations. Several first responder organizations have their own IdPs, each managing its own users' attributes. This presents a challenge if the RP needs to use those attributes for authorization. Local variations in attribute names, values, and encodings would make it difficult to apply a uniform authorization policy across the user base. If the SaaS platform enables sharing of sensitive data between organizations, participants would need some assurance that their partners were establishing and managing user accounts and attributes appropriately—promptly removing access for terminated employees and performing appropriate validation before assigning attributes that enable privileged access. Federations attempt to address this issue by creating common profiles and policies governing use and management of attributes and authentication mechanisms, which members are expected to follow. This facilitates interoperability, and members are also typically audited for compliance with the federation's policies and practices, enabling mutual trust in attributes and authentication.

As an example, the National Identity Exchange Federation (NIEF) is a federation serving law enforcement organizations and networks, including the Federal Bureau of Investigation, the Department of Homeland

Security, the Regional Information Sharing System, and the Texas Department of Public Safety. NIEF has established SAML profiles for both web-browser and system-to-system use cases, and a registry of common attributes for users, resources, and other entities. NIEF attributes are grouped into attribute bundles, with some designated as mandatory, meaning that all participating IdPs must provide those attributes, and participating RPs can depend on their presence in the SAML response.

The architecture documented in this build guide is fully compatible with NIEF and other federations, though this would require configuring IdPs and RPs in compliance with the federation's policies. The use of SAML IdPs is fully supported by this architecture, as is the coexistence of SAML IdPs and OIDC providers.

NIST SP 800-63-3 [17] defines Federation Assurance Levels (FALs) and their implementation requirements. FALs are a measure of the assurance that assertions presented to an RP are genuine and unaltered, pertain to the individual presenting them, are not subject to replay at other RPs, and are protected from many additional potential attacks on federated authentication schemes. A high-level summary of the requirements for FALs 1–3 is provided in Table C-1.

Table C-1 FAL Requirements

FAL	Requirement
1	Bearer assertion, signed by IdP
2	Bearer assertion, signed by IdP, and encrypted to RP
3	Holder of key assertion, signed by IdP, and encrypted to RP

IdPs typically sign assertions, and this functionality is broadly supported in available software. For SAML, the IdP's public key is provided in the SAML metadata. For OIDC, the public key can be provided through the discovery end point, if supported; otherwise, the key would be provided to the RP out of band. Encrypting assertions is also relatively trivial and requires providing the RP's public key to the IdP. The build architecture in this guide can support FAL-1 and FAL-2 with relative ease.

The requirement for holder of key assertions makes FAL-3 more difficult to implement. A SAML holder of key profile exists but has never been widely implemented in a web-browser SSO context. The OIDC core specification does not include a mechanism for a holder of key assertions; however, the forthcoming token binding over the hypertext transfer protocol (http) specification [30] and related RFCs may provide a pathway to supporting FAL-3 in an OIDC implementation.

C.3 Authenticator Types

When considering MFA implementations, PSFR organizations should carefully consider organizationally defined authenticator requirements. These requirements may include:

- the sensitivity of data being accessed and the commensurate level of authentication assurance needed
- environmental constraints, such as gloves or masks, that may limit the usability and effectiveness of certain authentication modalities
- costs throughout the authenticator life cycle, such as authenticator binding, loss, theft, unauthorized duplication, expiration, and revocation
- policy and compliance requirements, such as the Health Insurance Portability and Accountability Act (HIPAA) [31], the Criminal Justice Information System Security Policy [32], or other organizationally defined requirements
- support of current information technology infrastructure, including mobile devices, for various authenticator types

The new, third revision of NIST SP 800-63, *Digital Identity Guidelines* [17], is a suite of documents that provide technical requirements and guidance for federal agencies implementing digital identity services, and it may assist PSFR organizations when selecting authenticators. The most significant difference from previous versions of NIST SP 800-63 is the retirement of the previous assurance rating system, known as the Levels of Assurance (LOA), established by Office of Management and Budget Memorandum M-04-04, *E-Authentication Guidance for Federal Agencies*. In the new NIST SP 800-63-3 guidance, digital identity assurance is split into three ordinals as opposed to the single ordinal in LOA. The three ordinals are listed below:

- identity assurance level (IAL)
- authenticator assurance level (AAL)
- FAL

This practice guide is primarily concerned with AALs and how they apply to the reference architecture outlined in Table 3-2.

The strength of an authentication transaction is measured by the AAL. A higher AAL means stronger authentication and requires more resources and capabilities by attackers to subvert the authentication process. We discuss a variety of multifactor implementations in this practice guide. NIST SP 800-63-3 gives us a reference to map the risk reduction of the various implementations recommended in this practice guide.

The AAL is determined by authenticator type and combination, verifier requirements, reauthentication policies, and security control baselines, as defined in NIST SP 800-53, *Security and Privacy Controls for Federal Information Systems and Organizations* [33]. A summary of requirements at each of the levels is provided in Table C-2.

A memorized secret (most commonly implemented as a password) satisfies AAL1, but this alone is not enough to reach the higher levels shown in Table C-2. For AAL2 and AAL3, some form of MFA is required. MFA comes in many forms. The architecture in this practice guide describes two examples. One example is a multifactor software cryptographic authenticator, where a biometric authenticator application is installed on the mobile device—the two factors being possession of the private key and the biometric. The other example is a combination of a memorized secret and a single-factor cryptographic device, which performs cryptographic operations via a direct connection to the user end point.

Reauthentication requirements also become more stringent for higher levels. AAL1 requires reauthentication only every 30 days, but AAL2 and AAL3 require reauthentication every 12 hours. At AAL2, users may reauthenticate by using a single authentication factor, but at AAL3, users must reauthenticate by using both of their authentication factors. At AAL2, 30 minutes of idle time is allowed, but only 15 minutes is allowed at AAL3.

For a full description of the different types of multifactor authenticators and AAL requirements, please refer to NIST SP 800-63B [10].

Table C-2 AAL Summary of Requirements

Requirement	AAL1	AAL2	AAL3
Permitted authenticator types	Memorized Secret; Lookup Secret; Out of Band; Single Factor (SF) Onetime Password (OTP) Device; Multifactor (MF) OTP Device; SF Crypto Software; SF Crypto Device; MF Crypto Software; MF Crypto Device	MF OTP Device; MF Crypto Software; MF Crypto Device; or Memorized Secret plus: ▪ Lookup Secret ▪ Out of Band ▪ SF OTP Device ▪ SF Crypto Software ▪ SF Crypto Device	MF Crypto Device; SF Crypto Device plus Memorized Secret; SF OTP Device plus MF Crypto Device or Software; SF OTP Device plus SF Crypto Software plus Memorized Secret
Federal Information Processing Standard (FIPS) 140-2 verification	Level 1 (government agency verifiers)	Level 1 (government agency authenticators and verifiers)	Level 2 overall (MF authenticators) Level 1 overall (verifiers and SF Crypto Devices) Level 3 physical security (all authenticators)

Requirement	AAL1	AAL2	AAL3
Reauthentication	30 days	12 hours, or after 30 minutes of inactivity; MAY use one authentication factor	12 hours, or after 15 minutes of inactivity; SHALL use both authentication factors
Security controls	NIST SP 800-53 Low Baseline (or equivalent)	NIST SP 800-53 Moderate Baseline (or equivalent)	NIST SP 800-53 High Baseline (or equivalent)
Man-in-the-middle resistance	Required	Required	Required
Verifier-impersonation resistance	Not required	Not required	Required
Verifier-compromise resistance	Not required	Not required	Required
Replay resistance	Not required	Required	Required
Authentication intent	Not required	Recommended	Required
Records retention policy	Required	Required	Required
Privacy controls	Required	Required	Required

The Fast Identity Online (FIDO) Alliance has published specifications for two types of authenticators based on UAF and U2F. These protocols operate agnostic of the FIDO authenticator, allowing PSOs to choose any FIDO-certified authenticator that meets operational requirements and to implement it with this solution. As new FIDO-certified authenticators become available in the marketplace, PSOs may choose to migrate to these new authenticators if they better meet PSFR needs in their variety of duties.

C.3.1 UAF Protocol

The UAF protocol [2] allows users to register their device to the online service by selecting a local authentication mechanism, such as swiping a finger, looking at the camera, speaking into the microphone, or entering a personal identification number (PIN). The UAF protocol allows the service to select which mechanisms are presented to the user. Once registered, the user simply repeats the local authentication action whenever they need to authenticate to the service. The user no longer needs to enter their password when authenticating from that device. UAF also allows experiences that combine multiple authentication mechanisms, such as fingerprint plus PIN. Data used for local user verification, such as biometric templates, passwords, or PINs, is validated locally on the device and is not transmitted to the server. Authentication to the server is performed with a cryptographic key pair, which is unlocked after local user verification.

C.3.2 U2F Protocol

The U2F protocol [3] allows online services to augment the security of their existing password infrastructure by adding a strong second factor to user login, typically an external hardware-backed cryptographic device. The user logs in with a username and password as before and is then prompted to present the external second factor. The service can prompt the user to present a second-factor device at any time that it chooses. The strong second factor allows the service to simplify its passwords (e.g., four-digit PIN) without compromising security. During registration and authentication, the user presents the second factor by simply pressing a button on a universal serial bus device or tapping over near field communication.

The user can use their FIDO U2F device across all online services that support the protocol. On desktop operating systems, the Google Chrome and Opera browsers currently support U2F. U2F is also supported on Android through the Google Authenticator application, which must be installed from the Play Store.

C.3.3 FIDO 2

The FIDO 2 project comprises a set of related standardization efforts undertaken by the FIDO Alliance and the World Wide Web Consortium (W3C). The second iteration of the FIDO standards will support the W3C's Web Authentication standard [16]. As a W3C recommendation, Web Authentication is expected to be widely adopted by web browser developers and to provide out-of-the-box FIDO support without the need to install additional client applications or extensions.

In addition, the proposed FIDO Client-to-Authenticator Protocol (CTAP) standard will support new authenticator functions, including the ability to set a PIN on authenticators such as YubiKeys. By requiring a PIN at authentication time, a CTAP-compliant authenticator can provide MFA in a manner similar to a smart card. This would eliminate the need to pair an external authenticator with an existing knowledge factor such as username/password authentication against an LDAP database, as was used in the U2F implementation of this build.

C.3.4 FIDO Key Registration

From the perspective of an IdP, enabling users to authenticate themselves with FIDO-based credentials requires that users register a cryptographic key with the IdP and associate the registered key with the username or distinguished name known to the IdP. FIDO registration must be repeated for each authenticator that the user chooses to associate with their account. FIDO protocols are different from most authentication protocols in that they permit registering multiple cryptographic keys (from different authenticators) to use with a single account. This is convenient for end users as it provides a natural backup solution to lost, misplaced, or forgotten authenticators—users may use any one of their registered authenticators to access their applications.

The process of a first-time FIDO key registration is fairly simple:

1. A user creates an account for themselves at an application site, or one is created for them as part of a business process.
2. The user registers a FIDO key with the application through one of the following processes:
    a. as part of the account self-creation process
    b. upon receiving an email with an invitation to register
    c. as part of a registration process, after an authentication process within an organization application
    d. A FIDO authenticator with a temporary, preregistered key is provided so that the user can strongly authenticate to register a new key with the application, at which point the temporary key is deleted permanently. Authenticators with preregistered keys may be combined with shared secrets given/sent to the user out of band to verify their identity before enabling them to register a new FIDO key with the organization's application.
    e. as part of a custom process local to the IdP

Policy at the organization dictates what might be considered most appropriate for a registration process.

C.3.5 FIDO Authenticator Attestation

To meet AAL requirements, RPs may need to restrict the types of FIDO authenticators that can be registered and used to authenticate. They may also require assurances that the authenticators in use are not counterfeit or vulnerable to known attacks. The FIDO specifications include mechanisms that enable the RP to validate the identity and security properties of authenticators, which are provided in a standard metadata format.

Each FIDO authenticator has an attestation key pair and certificate. To maintain FIDO's privacy guarantees, these attestation keys are not unique for each device but are typically assigned on a manufacturing batch basis. During authenticator registration, the RP can check the validity of the attestation certificate and validate the signed registration data to verify that the authenticator possesses the private attestation key.

For software authenticators, which cannot provide protection of a private attestation key, the UAF protocol allows for surrogate basic attestation. In this mode, the key pair generated to authenticate the user to the RP is used to sign the registration data object, including the attestation data. This is analogous to the use of self-signed certificates for https in that it does not actually provide cryptographic proof of the security properties of the authenticator. A potential concern is that the RP could not distinguish between a genuine software authenticator and a malicious look-alike authenticator that could provide registered credentials to an attacker. In an enterprise setting, this concern could be mitigated by delivering the valid authenticator application using EMM or another controlled distribution mechanism.

Authenticator metadata would be most important in scenarios where an RP accepts multiple authenticators with different assurance levels and applies authorization policies based on the security properties of the authenticators (e.g., whether they provide FIPS 140-2-validated key storage [34]). In practice, most existing enterprise implementations use a single type of authenticator.

C.3.6 FIDO Deployment Considerations

To support any of the FIDO standards for authentication, some integration needs to happen on the server side. Depending on how the federated architecture is set up—whether with OIDC or SAML—this integration may look different. In general, there are two servers where a FIDO server can be integrated: the AS (also known as the RP) and the IdP.

FIDO Integration at the IdP

Primary authentication already happens at the IdP, so logic follows that FIDO authentication (e.g., U2F, UAF) would as well. This is the most common and well-understood model for using a FIDO authentication server and, consequently, there is solid guidance for setting up such an architecture. The IdP already has detailed knowledge of the user and directly interacts with the user (e.g., during registration), so it is not difficult to insert the FIDO server into the registration and authentication flows. In addition, this gives PSOs the most control over the security controls that are used to authenticate their users. However, there are a few downsides to this approach:

- The PSO must now budget, host, manage, and/or pay for the cost of the FIDO server.
- The only authentication of the user at the AS is the bearer assertion from the IdP, so an assertion intercepted by an attacker could be used to impersonate the legitimate user at the AS.

FIDO Integration at the AS

Another option is to integrate FIDO authentication at the AS. One benefit of this is that PSOs will not be responsible for the expenses of maintaining a FIDO server. In addition, an attacker who intercepted a valid user's SAML assertion or ID token could not easily impersonate the user because of the requirement to authenticate to the AS as well. This approach assumes that some mechanism is in place for tightly binding the FIDO authenticator with the user's identity, which is a nontrivial task. In addition, this approach has several downsides:

- Splitting authentication into a two-stage process that spans the IdP and AS is a less well understood model for authentication, which may lead to subtle issues.
- The AS does not have detailed knowledge of—or direct action with—users, so enrollment is more difficult.
- Users would have to register their FIDO authenticators at every AS that is federated to their IdP, which adds complexity and frustration to the process.
- PSOs would lose the ability to enforce which kinds of FIDO token(s) their users utilize.

1564 # Appendix D Acronyms

AAL	Authenticator Assurance Level
ABAC	Attribute-Based Access Control
API	Application Programming Interface
AS	Authorization Server
BCP	Best Current Practice
CRADA	Cooperative Research and Development Agreement
CTAP	Client-to-Authenticator Protocol
EMM	Enterprise Mobility Management
FAL	Federation Assurance Level
FIDO	Fast Identity Online
FIPS	Federal Information Processing Standard
FirstNet	First Responder Network Authority
GPS	Global Positioning System
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
ID	Identification
IdP	Identity Provider
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
iOS	iPhone Operating System
ISO	International Organization for Standardization
IT	Information Technology
LOA	Level of Assurance
MF	Multifactor
MFA	Multifactor Authentication
MSSO	Mobile Single Sign-On
MTC	Mobile Threat Catalogue
NCCoE	National Cybersecurity Center of Excellence
NFC	Near Field Communication
NIEF	National Identity Exchange Federation
NIST	National Institute of Standards and Technology
NTP	Network Time Protocol
OEM	Original Equipment Manufacturer
OIDC	OpenID Connect
OOB	Out of Band
OS	Operating System
OTP	Onetime Password
PII	Personally Identifiable Information
PIN	Personal Identification Number

PKCE	Proof Key for Code Exchange
PSFR	Public Safety and First Responder
PSO	Public Safety Organization
PSX	Public Safety Experience
RFC	Request for Comments
RP	Relying Party
SaaS	Software as a Service
SAML	Security Assertion Markup Language
SDK	Software Development Kit
SF	Single Factor
SKCE	StrongKey Crypto Engine
SP	Special Publication
SSO	Single Sign-On
SwA	Software Assurance
TLS	Transport Layer Security
U2F	Universal Second Factor
UAF	Universal Authentication Framework
UI	User Interface
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
W3C	World Wide Web Consortium

1565 # Appendix E References

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NIST SPECIAL PUBLICATION 1800-13C

Mobile Application Single Sign-On

Improving Authentication for Public Safety First Responders

Volume C:
How-To Guides

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The documents in this series describe example implementations of cybersecurity practices that businesses and other organizations may voluntarily adopt. These documents do not describe regulations or mandatory practices, nor do they carry statutory authority.

ABSTRACT

On-demand access to public safety data is critical to ensuring that public safety and first responder (PSFR) personnel can deliver the proper care and support during an emergency. This requirement necessitates heavy reliance on mobile platforms while in the field, which may be used to access sensitive information, such as personally identifiable information (PII), law enforcement sensitive (LES) information, or protected health information (PHI). However, complex authentication requirements can hinder the process of providing emergency services, and any delay—even seconds—can become a matter of life or death.

In collaboration with NIST's Public Safety Communications Research lab (PSCR) and industry stakeholders, the NCCoE aims to help PSFR personnel to efficiently and securely gain access to mission data via mobile devices and applications. This practice guide describes a reference design for multifactor authentication (MFA) and mobile single sign-on (MSSO) for native and web applications, while improving interoperability between mobile platforms, applications, and identity providers, irrespective of the application development platform used in their construction. This NCCoE practice guide details a collaborative effort between the NCCoE and technology providers to demonstrate a standards-based approach using commercially available and open-source products.

This guide discusses potential security risks facing organizations, benefits that may result from the implementation of an MFA/MSSO system, and the approach that the NCCoE took in developing a reference architecture and build. This guide includes a discussion of major architecture design considerations, an explanation of the security characteristics achieved by the reference design, and a mapping of the security characteristics to applicable standards and security control families.

For parties interested in adopting all or part of the NCCoE reference architecture, this guide includes a detailed description of the installation, configuration, and integration of all components.

KEYWORDS

access control; authentication; authorization; identity; identity management; identity provider; relying party; single sign-on

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The Technology Partners/Collaborators who participated in this build submitted their capabilities in response to a notice in the Federal Register. Respondents with relevant capabilities or product components were invited to sign a Cooperative Research and Development Agreement (CRADA) with NIST, allowing them to participate in a consortium to build this example solution. We worked with:

Technology Partner/Collaborator	Build Involvement
Ping Identity	Federation Server

Technology Partner/Collaborator	Build Involvement
Motorola Solutions	Mobile Applications
Yubico	External Authenticators
Nok Nok Labs	Fast Identity Online (FIDO) Universal Authentication Framework (UAF) Server
StrongKey	FIDO Universal Second Factor (U2F) Server

Contents

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1 Introduction

The following guide demonstrates a standards-based example solution for efficiently and securely gaining access to mission-critical data via mobile devices and applications. This guide demonstrates multifactor authentication (MFA) and mobile single sign-on (MSSO) solutions for native and web applications using standards-based commercially available and open-source products. We cover all of the products that we employed in our solution set. We do not re-create the product manufacturer's documentation. Instead, we provide pointers to where this documentation is available from the manufacturers. This guide shows how we incorporated the products together in our environment as a reference implementation of the proposed build architecture for doing MSSO.

Note: This is not a comprehensive tutorial. There are many possible service and security configurations for these products that are out of scope for this reference solution set.

1.1 Practice Guide Structure

This National Institute of Standards and Technology (NIST) Cybersecurity Practice Guide demonstrates a standards-based example solution and provides users with the information they need to replicate this approach to implementing our MSSO build. The example solution is modular and can be deployed in whole or in part.

This guide contains three volumes:

- NIST SP 1800-13A: *Executive Summary*
- NIST SP 1800-13B: *Approach, Architecture, and Security Characteristics*–what we built and why
- NIST SP 1800-13C: *How-To Guides*–instructions for building the example solution **(you are here)**

See Section 2 in Volume B of this guide for a more detailed overview of the different volumes and sections, and the audiences that may be interested in each.

1.2 Build Overview

The National Cybersecurity Center of Excellence (NCCoE) worked with its build team partners to create a lab demonstration environment that includes all of the architectural components and functionality described in Section 4 of Volume B of this build guide. This includes mobile devices with sample applications, hardware and software-based authenticators to demonstrate the Fast Identity Online (FIDO) standards for MFA, and the authentication server and authorization server (AS) components required to demonstrate the AppAuth authorization flows (detailed in Internet Engineering Task Force [IETF] Request for Comments [RFC] 8252 [1]) with federated authentication to a Security Assertion Markup Language (SAML) Identity Provider (IdP) and an OpenID Connect (OIDC) provider. The complete build includes several systems deployed in the NCCoE lab by StrongKey, Yubico, and Ping Identity as well as cloud-hosted resources made available by Motorola Solutions and by Nok Nok Labs.

This section of the build guide documents the build process and specific configurations that were used in the lab.

1.2.1 Usage Scenarios

The build architecture supports three usage scenarios. The scenarios all demonstrate single sign-on (SSO) among Motorola Solutions Public Safety Experience (PSX) applications and custom-built Apple iPhone operating system (iOS) demo applications using the AppAuth pattern but differ in the details of the authentication process. The three authentication mechanisms are as follows:

- The OAuth AS directly authenticates the user with FIDO Universal Authentication Framework (UAF); user accounts are managed directly by the service provider.
- The OAuth AS redirects the user to a SAML IdP, which authenticates the user with a password and FIDO Universal Second Factor (U2F).
- The OAuth AS redirects the user to an OIDC IdP, which authenticates the user with FIDO UAF.

In all three scenarios, once the authentication flow is completed, the user can launch multiple mobile applications without additional authentication, demonstrating SSO. These three scenarios were chosen to reflect different real-world implementation options that public safety and first responder (PSFR) organizations might choose. Larger PSFR organizations may host (or obtain from a service provider) their own IdPs, enabling them to locally manage user accounts, group memberships, and other user attributes, and to provide them to multiple Relying Parties (RPs) through federation. SAML is currently the most commonly used federation protocol, but OIDC might be preferred for new implementations. As demonstrated in this build, RPs can support both protocols more or less interchangeably. For smaller organizations, a service provider might also act in the role of “identity provider of last resort,” maintaining user accounts and attributes on behalf of organizations.

1.2.2 Architectural Overview

Figure 1-1 shows the lab build architecture.

Figure 1-1 Lab Build Architecture

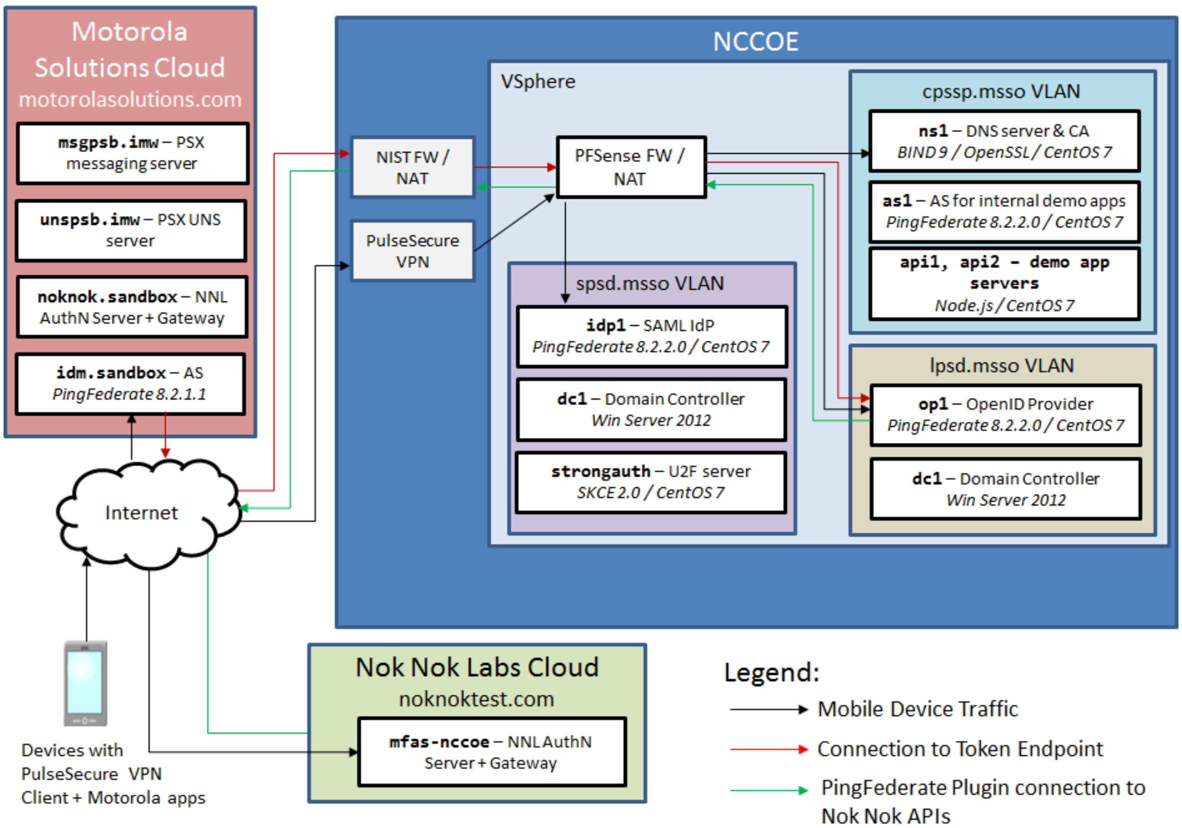


Figure 1-1 depicts the four environments that interact in the usage scenarios:

- Motorola Solutions cloud–a cloud-hosted environment providing the back-end application servers for the Motorola Solutions PSX Mapping and Messaging applications, as well as an OAuth AS that the application servers use to authorize requests from mobile devices
- Nok Nok Labs cloud–a cloud-hosted server running both the Nok Nok Authentication Server (NNAS) and the Nok Nok Labs Gateway
- NCCoE–the NCCoE lab, including several servers hosted in a vSphere environment running the IdPs and directory services that would correspond to PSFR organizations' infrastructure to support federated authentication to a service provider, like Motorola Solutions. An additional AS and some demonstration application back ends are also hosted in the NCCoE lab for internal testing.

- mobile devices connected to public cellular networks with the required client software to authenticate to, and access, Motorola Solutions back-end applications and the NCCoE lab systems

The names of the virtual local area networks (VLANs) in the NCCoE lab are meant to depict different organizations participating in an MSSO scheme:

- SPSD–State Public Safety Department, a PSFR organization with a SAML IdP
- LPSD–Local Public Safety Department, a PSFR organization with an OIDC IdP
- CPSSP–Central Public Safety Service Provider, a software as a service (SaaS) provider serving the PSFR organizations, analogous to Motorola Solutions

The fictitious *.msso* top-level domain is simply a reference to the MSSO project. The demonstration applications hosted in the CPSSP VLAN were used to initially test and validate the federation setups in the user organization and were later expanded to support the iOS demonstration build.

The arrows in Figure 1-1 depict traffic flows between the three different environments to illustrate the networking requirements for cross-organizational MSSO flows. This diagram does not depict traffic flows within environments (e.g., between the IdPs and the Domain Controllers providing directory services). The depicted traffic flows are described below:

- Mobile device traffic–The PSX client applications on the device connect to the publicly routable PSX application servers in the Motorola Solutions cloud. The mobile browser also connects to the Motorola Solutions AS and, in the federated authentication scenarios, the browser is redirected to the IdPs in the NCCoE lab. The mobile devices use the Pulse Secure Virtual Private Network (VPN) client to access internal lab services through Network Address Translation (NAT) addresses established on the pfSense firewall. This enables the use of the internal lab domain name system (DNS) server to resolve the host names under the *.msso* top-level domain, which is not actually registered in a public DNS. To support UAF authentication at the lab-hosted OIDC IdP, the Nok Nok Passport application on the devices also connects to the publicly routable NNAS instance hosted in the Nok Nok Labs cloud environment.
- Connection to Token Endpoint–The usage scenario where the Motorola Solutions AS redirects the user to the OIDC IdP in the lab requires the AS to initiate an inbound connection to the IdP's Token Endpoint. To enable this, the PingFederate run-time port, 9031, is exposed via NAT through the NIST firewall. Note that no inbound connection is required in the SAML IdP integration, as the SAML web browser SSO does not require direct back-channel communication between the AS and the IdP. SAML authentication requests and responses are transmitted through browser redirects.
- PingFederate plug-in connection to Nok Nok Application Programming Interfaces (APIs)–To support UAF authentication, the OIDC IdP includes a PingFederate adapter developed by Nok Nok Labs that needs to connect to the APIs on the NNAS.

In a typical production deployment, the NNAS would not be directly exposed to the internet; instead, mobile client interactions with the Authentication Server APIs would traverse a reverse proxy server. Nok Nok Labs provided a cloud instance of its software as a matter of expedience in completing the lab build.

Additionally, the use of a VPN client on mobile devices is optional. Many organizations directly expose their IdPs to the public internet, though some organizations prefer to keep those services internal and use a VPN to access them. Organizations can decide this based on their risk tolerance, but this build architecture can function with or without a VPN client on the mobile devices.

1.2.3 General Infrastructure Requirements

Some general infrastructure elements must be in place to support the components of this build guide. These are assumed to exist in the environment prior to the installation of the architecture components in this guide. The details of how these services are implemented are not directly relevant to the build.

- DNS–All server names are expected to be resolvable in a DNS. This is especially important for FIDO functionality, as the application identification (App ID) associated with cryptographic keys is derived from the host name used in application uniform resource locators (URLs).
- Network Time Protocol (NTP)–Time synchronization among servers is important. A clock difference of five minutes or more is sufficient to cause JavaScript Object Notation (JSON) Web Token (JWT) validation, for example, to fail. All servers should be configured to synchronize time with a reliable NTP source.
- Certificate Authority (CA)–Hypertext Transfer Protocol Secure (https) connections should be used throughout the architecture. Transport Layer Security (TLS) certificates are required for all servers in the build. If an in-house CA is used to issue certificates, the root and any intermediate certificates must be provisioned to the trust stores in client mobile devices and servers.

1.3 Typographic Conventions

The following table presents typographic conventions used in this volume.

Typeface/ Symbol	Meaning	Example
Italics	file names and path names, references to documents that are not hyperlinks, new terms, and placeholders	For detailed definitions of terms, see the *NCCoE Glossary.*

Typeface/ Symbol	Meaning	Example
Bold	names of menus, options, command buttons, and fields	Choose **File > Edit.**
`Monospace`	command-line input, onscreen computer output, sample code examples, and status codes	`mkdir`
`Monospace Bold`	command-line user input contrasted with computer output	**`service sshd start`**
blue text	link to other parts of the document, a web URL, or an email address	All publications from NIST's NCCoE are available at https://www.nccoe.nist.gov.

2 How to Install and Configure the Mobile Device

This section covers all of the different aspects of installing and configuring the mobile device. There are several prerequisites and different components that need to work in tandem for the entire SSO architecture to work.

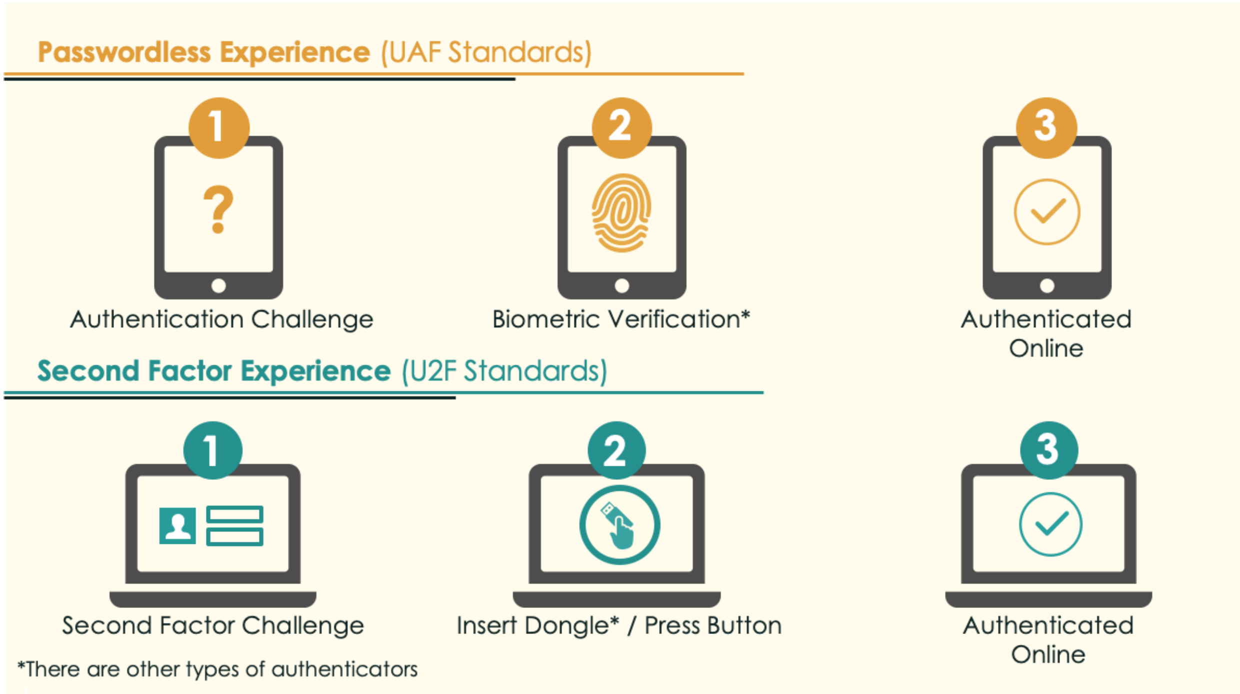
2.1 Platform and System Requirements

This section covers requirements for mobile devices—both hardware and software—for the SSO and FIDO authentication components of the architecture to work properly. The two dominant mobile platforms are Google's Android and Apple's iOS. The NCCoE reference architecture incorporates both iOS and Android devices and applications.

First, for SSO support, the NCCoE reference architecture follows the guidance of the *OAuth 2.0 for Native Apps* Best Current Practice (BCP) [1]. That guidance, also known as *AppAuth*, requires that developers use an *external user-agent* (e.g., Google's Chrome for Android web browser) instead of an *embedded user-agent* (e.g., an Android WebView) for their OAuth authorization requests. Because of this, the mobile platform must support the use of external user-agents.

Second, for FIDO support, this architecture optionally includes two different types of authenticators: UAF and U2F. The *FIDO Specifications Overview* presentation [2] explains the difference, as shown in Figure 2-1.

Figure 2-1 Comparison of UAF and U2F Standards



The following subsections address mobile device requirements to support SSO and FIDO authentication.

2.1.1 Supporting SSO on Android Devices

While it is not strictly required, the BCP recommends that the device provide an external user-agent that supports "in-application browser tabs," which Google describes as the *Android Custom Tab* feature. The following excerpt is from the AppAuth Android-specific guidance in Appendix B.2 of RFC 8252:

> *Apps can initiate an authorization request in the browser without the user leaving the app, through the Android Custom Tab feature which implements the in-app browser tab pattern. The user's default browser can be used to handle requests when no browser supports Custom Tabs.*
>
> *Android browser vendors should support the Custom Tabs protocol (by providing an implementation of the "CustomTabsService" class), to provide the in-app browser tab user experience optimization to their users. Chrome is one such browser that implements Custom Tabs.*

Any device manufacturer can support Custom Tabs in its Android browser. However, Google implemented this in its Chrome for Android web browser in September 2015 [3]. Because Chrome is not part of the operating system (OS) itself but is downloaded from the Google Play Store, recent versions of Chrome can be used on older versions of Android. In fact, the Chrome Developer website's page on

Chrome Custom Tabs [4] states that it can be used on Android Jelly Bean (4.1), which was released in 2012, and up.

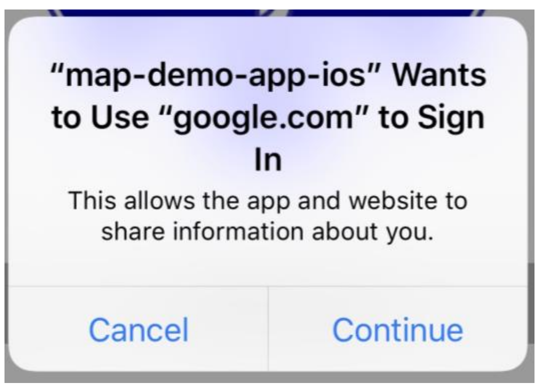
To demonstrate SSO, the NCCoE reference architecture utilizes the Motorola Solutions PSX App Suite, which requires Android Lollipop (5.0) or newer.

2.1.2 Supporting SSO on iOS Devices

Apple's Safari browser is the default external user-agent provided on iOS devices, and iOS has also supported in-application browser tabs with the SFSafariViewController API [5] since iOS 9. Like Chrome Custom Tabs, SFSafariViewController provides the functionality of the OS browser without exiting from the mobile application.

Apple made changes to its in-application browser tab implementation in iOS 11 [6] that impacted SSO functionality. SFSafariViewController instances created by different applications are now effectively sandboxed from each other, with no shared cookie store between them. As described in Section 4.4 of Volume B of this practice guide, the AppAuth pattern depends on shared cookie storage to provide SSO between applications. Apple introduced a new API called SFAuthenticationSession to provide an in-application browser tab implementation specifically for authentication with SSO capabilities with access to the shared Safari cookie store. iOS also prompts for the user's consent when SFAuthenticationSession is used. An example of the consent prompt is shown in Figure 2-2.

Figure 2-2 SFAuthenticationSession Consent Prompt



In iOS 12, Apple replaced the SFAuthenticationSession API with ASWebAuthenticationSession [7], which performs the same functions as SFAuthenticationSession and presents an identical consent prompt. In lab testing, the build team frequently encountered issues with SFAuthenticationSession where cookies created in an SFAuthenticationSession spawned by one application were not available in an SFAuthenticationSession spawned by another application. When this issue occurred, users would be prompted to authenticate in each application that was launched and SSO did not function properly. The team has not encountered these issues with ASWebAuthenticationSession, and the SSO capabilities of in-application browser tabs are much improved in iOS 12.

By default, the AppAuth library for iOS [8] automatically selects an appropriate user-agent based on the version of iOS installed on the mobile device as shown in Table 2-1.

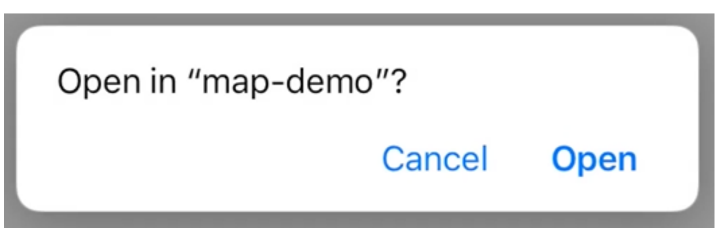
Table 2-1 AppAuth User-Agent by iOS Version

iOS Version	User-Agent
12 and higher	ASWebAuthenticationSession
11	SFAuthenticationSession
9 or 10	SFSafariViewController
8 and lower	Safari

The build team encountered issues with the FIDO UAF login flow demonstrated in this practice guide and the iOS in-application browser tab APIs (SFAuthenticationSession and ASWebAuthenticationSession). In the demo scenario, the login flow begins in the browser, which then launches the Passport application for user verification and FIDO authentication, and then control is returned to the browser to complete the authentication flow and return the user to the application. With ASWebAuthenticationSession, the authentication flow begins successfully in an in-application browser tab, and the user is redirected to the Passport application to authenticate, but control is not properly returned to the in-application browser tab when the Passport application closes. See Section 4.3.2 of Volume B of this practice guide for additional details about this issue. The build team speculates that this issue would generally apply to any login flow that entails launching an external application and then returning control to an in-application browser tab.

This issue was resolved by overriding the default user-agent selection in the AppAuth library. AppAuth provides the OIDExternalUserAgentIOSCustomBrowser interface to enable an application to specify the user-agent that should be used for the login flow. The iOS demo applications were configured to use the Safari browser instead of an in-application browser tab, which enabled the UAF login flow to succeed. The user experience with Safari is very similar to that with ASWebAuthenticationSession. The animation shown when transitioning to the web session is slightly different, and the consent dialogue shown in Figure 2-2 is not shown. After authentication is completed, however, a different dialogue is displayed, prompting the user to open the mobile application as shown in Figure 2-3.

Figure 2-3 Safari Transition Prompt



2.1.3 Supporting FIDO U2F on Android Devices

The device will need the following components for FIDO U2F:

- a web browser compatible with FIDO U2F
- a FIDO U2F client application capable of handling the challenge
- Near Field Communication (NFC) hardware support

Chrome for Android [9] is a U2F-compatible browser. Google has added U2F functionality to the Google Play Services component of Android [10], so devices running Android 5 and later can natively support U2F authentication over NFC, Universal Serial Bus (USB), and Bluetooth Low Energy (BLE) with an over-the-air update to Play Services. To support U2F in the browser, the Google Authenticator application [11] (available on Android Gingerbread [2.3.3] and up) must also be installed.

2.1.4 Supporting FIDO U2F on iOS Devices

At the time of writing, the U2F login flow demonstrated in this practice guide cannot be implemented on iOS devices. Apple's Core NFC APIs do not expose required functionality to implement U2F over NFC. Yubico has published an API enabling the YubiKey Neo to be used for authentication over NFC with an iOS device, but this implementation uses the onetime password authentication mechanism of the YubiKey, not the U2F protocol [12]. BLE U2F authenticators can be paired and used with iOS devices, but their use has been limited. The Google Smart Lock application, which protects Google accounts with U2F authentication on iOS devices, is the only notable U2F implementation on iOS of which the build team is aware.

Yubico has announced development of an authenticator with a Lightning adapter, specifically targeting iOS and Mac devices; and a corresponding mobile software development kit (SDK) for iOS that could enable U2F authentication in native iOS applications [13]. To enable the AppAuth login flow used in this practice guide, a U2F-capable browser is also needed. If Apple adds W3C Web Authentication support to the Safari browser, it may support U2F authentication over Lightning and BLE in the future. Apple has already added experimental support to the Safari Technology Preview release for Mac OS [14].

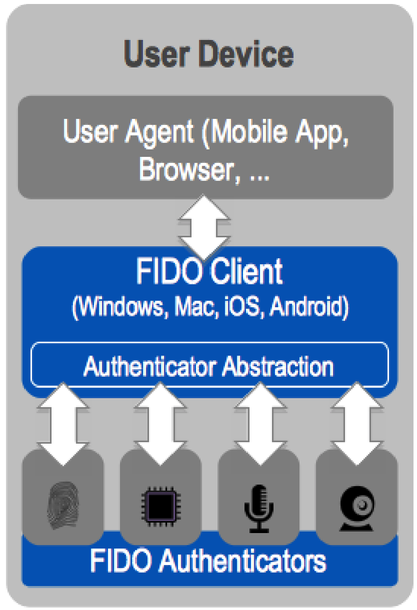
2.1.5 Supporting FIDO UAF

Supporting FIDO UAF is fairly similar on Android and iOS devices. The device will need the following components for FIDO UAF:

- a web browser
- a FIDO UAF client application capable of handling the challenge
- a FIDO UAF authenticator

These components are pictured in Figure 2-4, which is from the *FIDO UAF Architectural Overview* [15].

Figure 2-4 FIDO UAF Architectural Overview



While the overview refers to the last two components (client and authenticator) as separate components, these components can—and often do—come packaged in a single application. The NCCoE reference architecture utilizes the Nok Nok Passport application for Android [16] and iOS [17] to provide these two components. In addition to the applications, the device will need to provide some hardware component to support the FIDO UAF authenticator. For example, for biometric-based FIDO UAF authenticators, a camera would be needed to support face or iris scanning, a microphone would be needed to support voice prints, and a fingerprint sensor would be needed to support fingerprint biometrics. Of course, if a personal identification number (PIN) authenticator is used, a specific hardware sensor is not required. Beyond the actual input method of the FIDO UAF factor, additional (optional) hardware considerations for a UAF authenticator include secure key storage for registered FIDO key pairs, storage of biometric templates, and execution of matching functions (e.g., within dedicated hardware or on processor trusted execution environments).

2.2 How to Install and Configure the Mobile Applications

This section covers the installation and configuration of the mobile applications needed for various components of the reference architecture: SSO, FIDO U2F, and FIDO UAF.

2.2.1 How to Install and Configure SSO-Enabled Applications

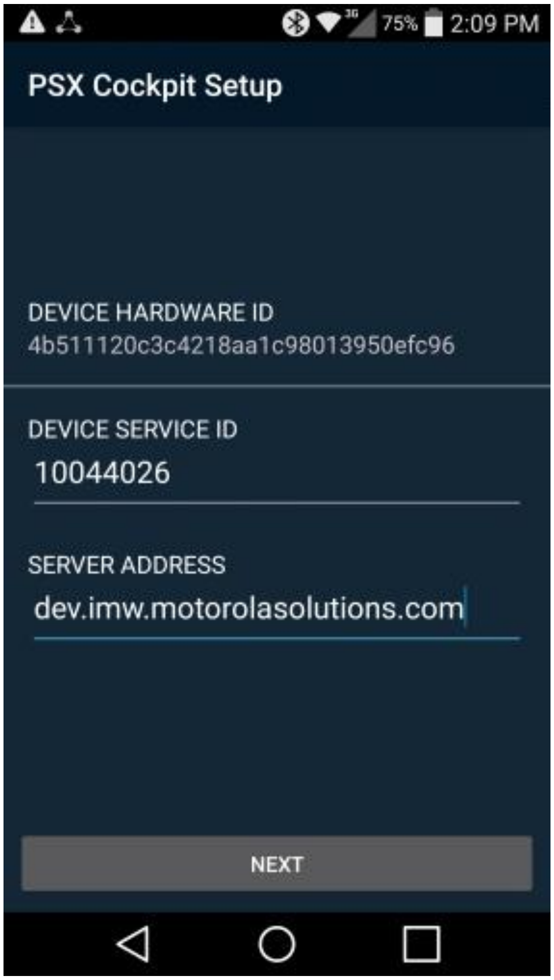
For SSO-enabled applications, there is no universal set of installation and configuration procedures; these will vary depending on the design choices of the application manufacturer. For the Android demo, the NCCoE reference architecture uses the *Motorola Solutions PSX App Suite* [18] Version 5.4. This set of mobile applications provides several capabilities for the public safety community. Our setup consisted of three applications: *PSX Messenger* for text, photo, and video communication; *PSX Mapping* for shared location awareness; and *PSX Cockpit* to centralize authentication and identity information across the other applications. These applications cannot be obtained from a public venue (e.g., the Google Play Store); rather, the binaries must be obtained from Motorola Solutions and installed via other means, such as a Mobile Device Management (MDM) solution or private application store.

For the iOS demo, the team built two iOS demonstration applications—a mapping application called map-demo and a chat application called chat-demo. These applications were built by using Apple's XCode integrated development environment and installed on lab devices using developer certificates.

2.2.1.1 Configuring the PSX Cockpit Application

1. Open the Cockpit application. Your screen should look like Figure 2-5.

Figure 2-5 PSX Cockpit Setup



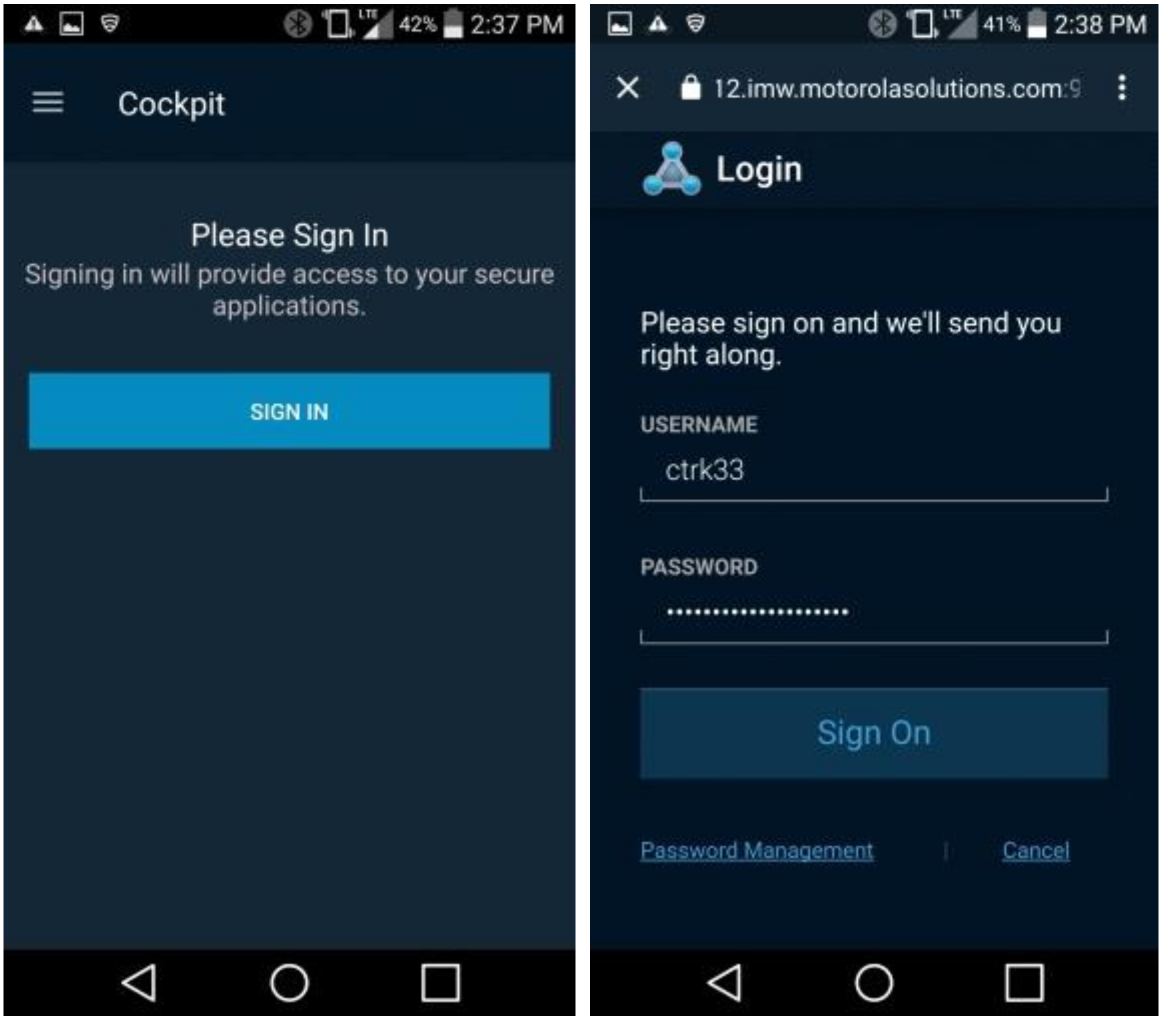
2. For **DEVICE SERVICE ID,** select a Device Service ID in the range given to you by your administrator. Note that these details will be provided by Motorola Solutions if you are using their service offering, or by your administrator if you are hosting the PSX application servers in your own environment. Each device should be configured with a unique Device Service ID corresponding to the username from the username range. For example, the NCCoE lab used a Device Service ID of 22400 to correspond to a username of 2400.

3. For **SERVER ADDRESS,** use the Server Address given to you by your administrator. For example, the NCCoE lab used a Server Address of uns5455.imw.motorolasolutions.com.

4. If a **Use SUPL APN** checkbox appears, leave it unchecked.

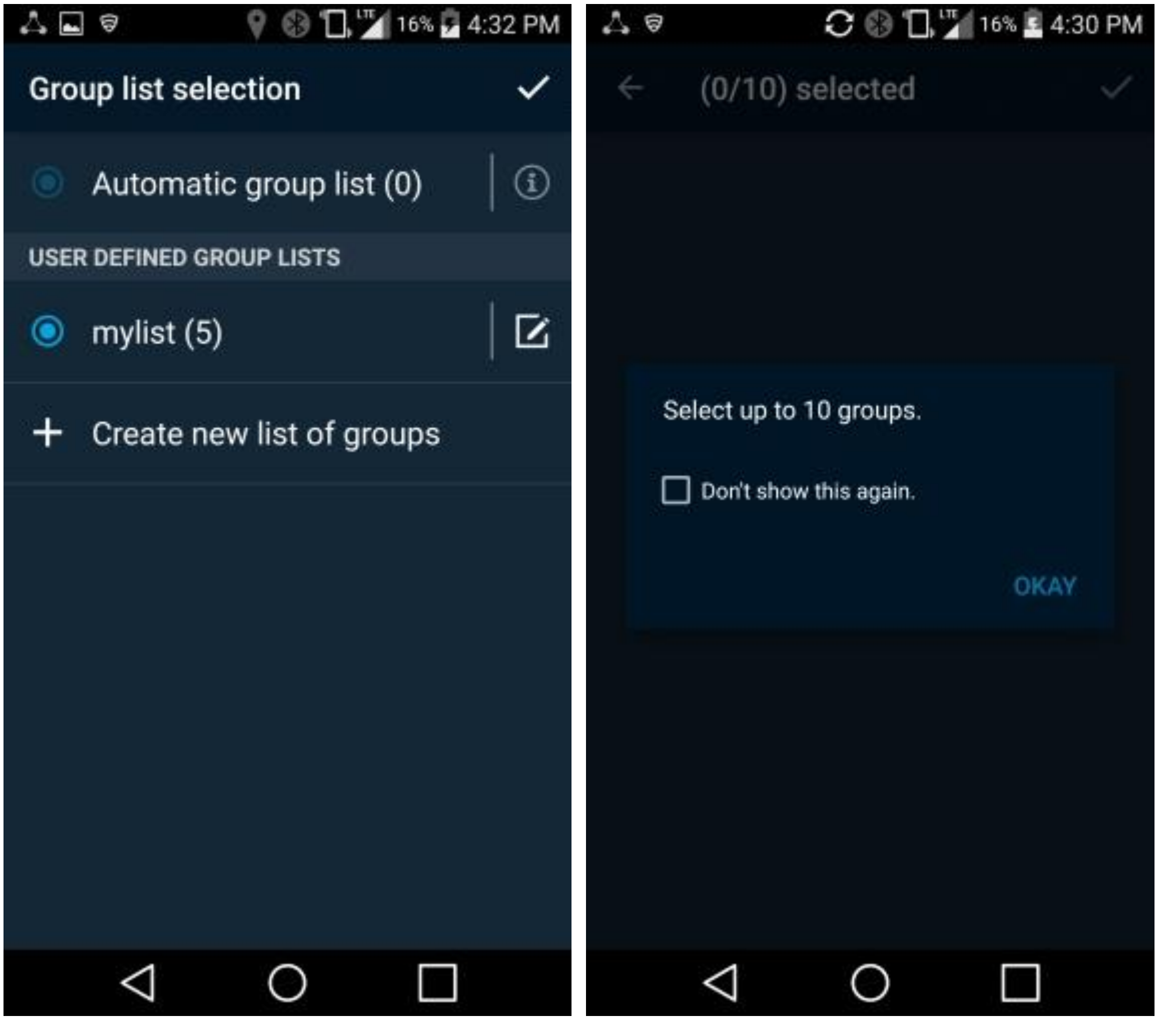
5. Tap **NEXT.** Your screen should look like Figure 2-6.

Figure 2-6 PSX Cockpit Setup, Continued



6. Tap **SIGN IN.**
7. Log in with the authentication procedure determined by the AS and IdP policies. Note that if UAF is used, a FIDO UAF authenticator must be enrolled before this step can be completed. See Section 2.2.3 for details on FIDO UAF enrollment. After you log in, your screen should look like Figure 2-7.

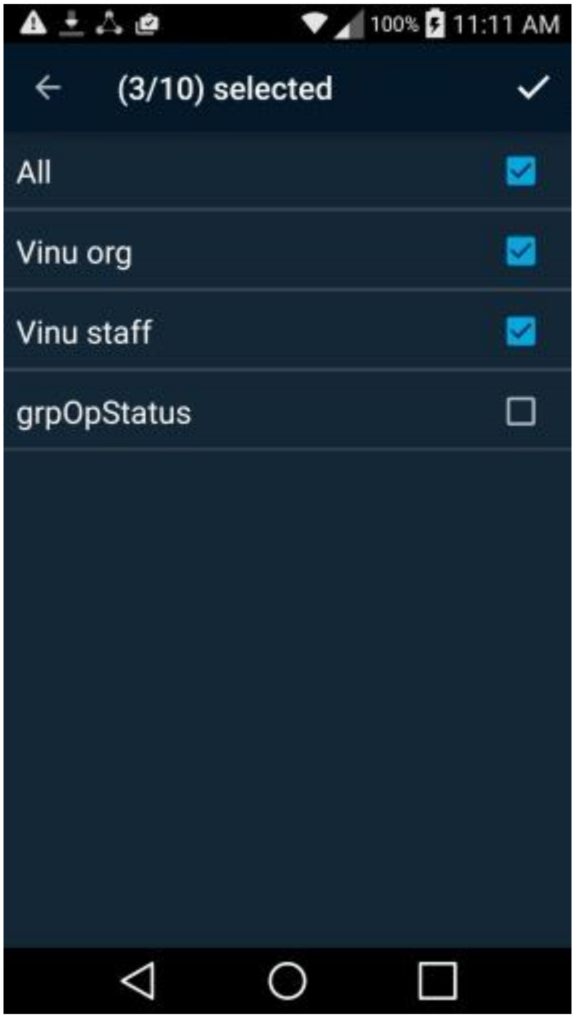
Figure 2-7 PSX Cockpit Group List Selection



8. Tap **Create new list of groups.** This is used to select which organizationally defined groups of users you can receive data updates for in the other PSX applications.

9. Tap **OKAY.** Your screen should look like Figure 2-8.

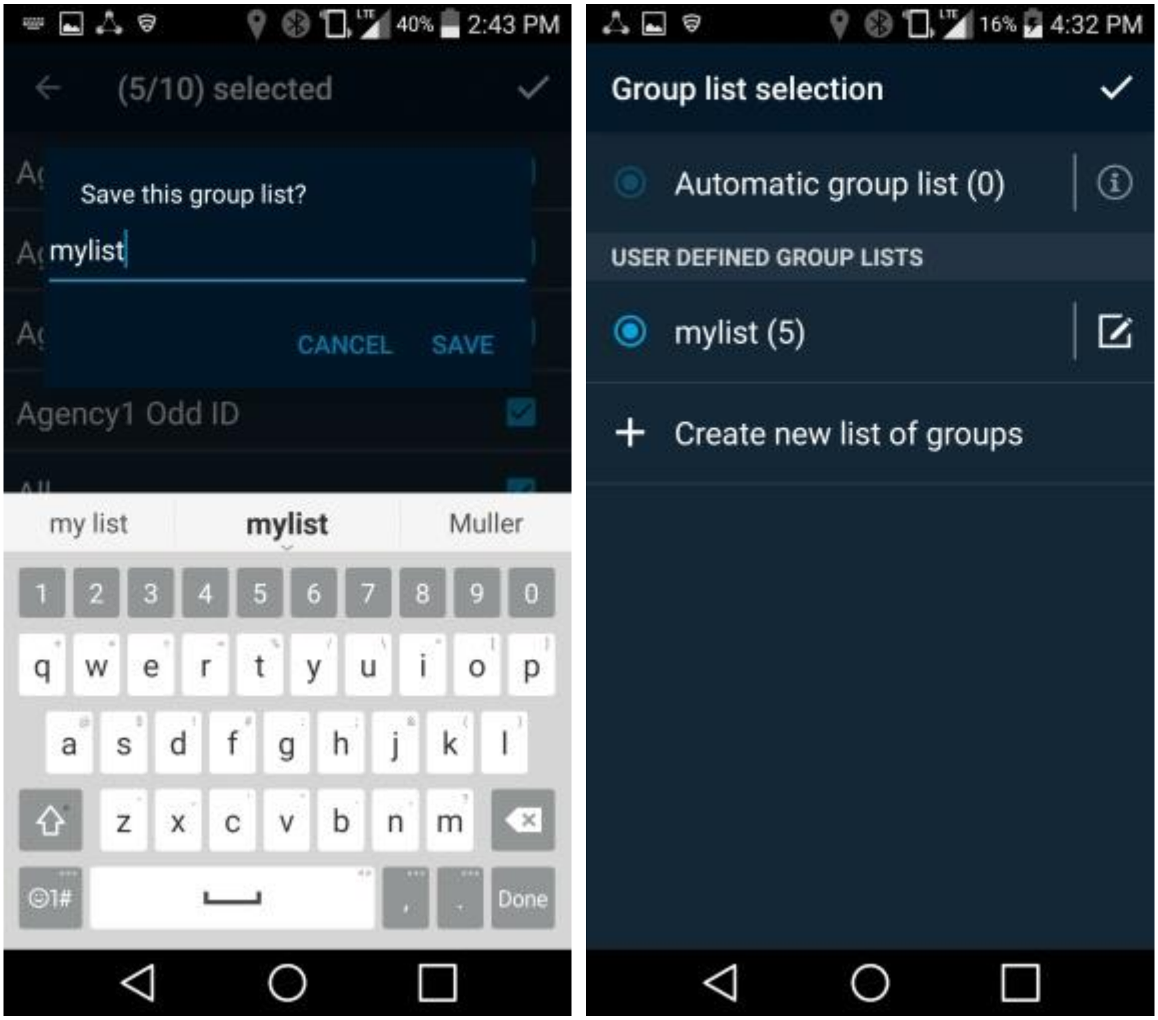
489 **Figure 2-8 PSX Cockpit Groups**

490 

491 10. Check the checkboxes for the groups that you wish to use. Note that it may take a short time for
492 the groups to appear.

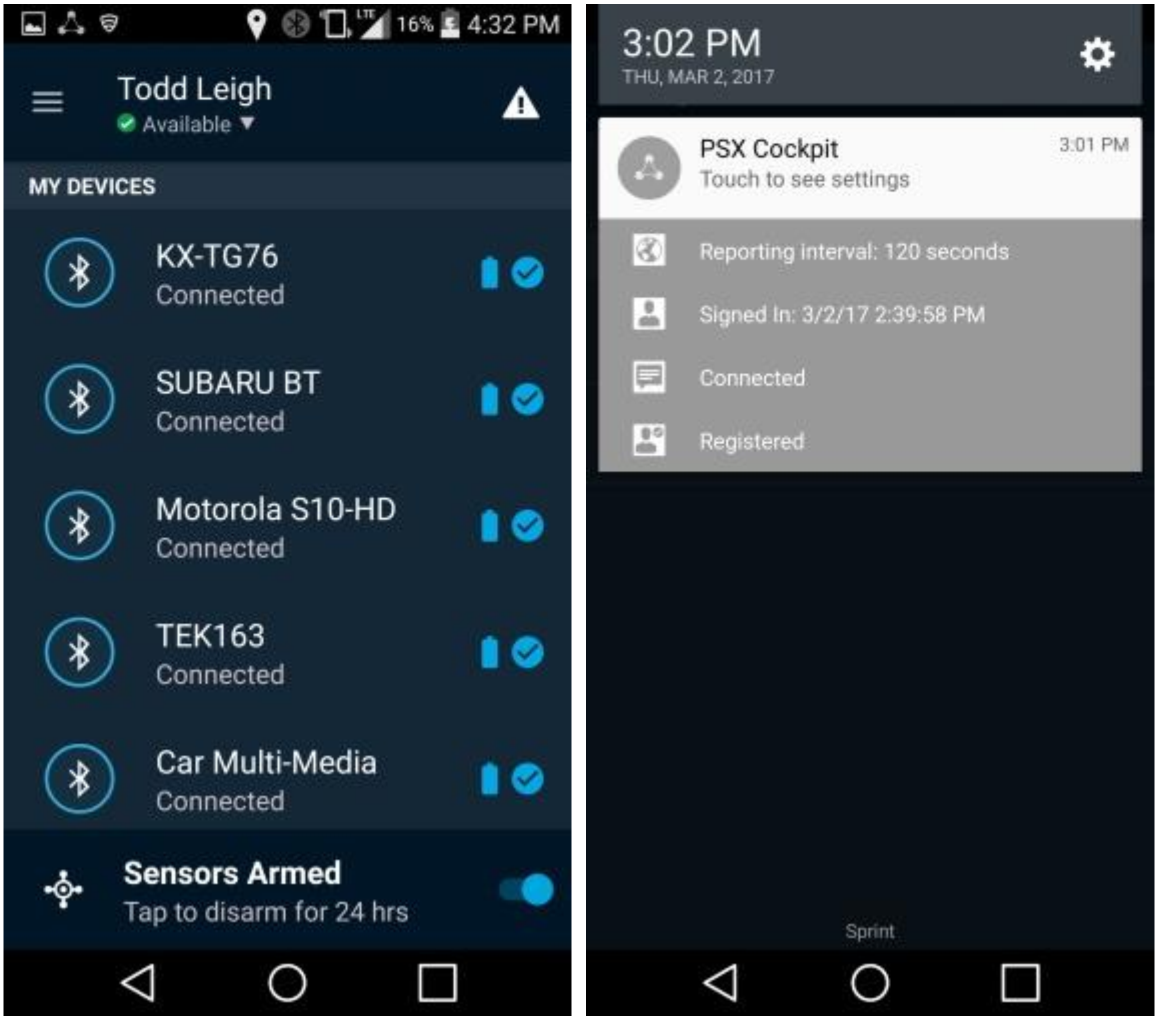
493 11. Tap on the upper-right check mark. Your screen should look like Figure 2-9.

Figure 2-9 PSX Cockpit Group List Setup Complete



12. Enter a group list name (e.g., “mylist”), and tap **SAVE.**
13. Tap the upper-right check mark to select the list. Your screen should look like Figure 2-10.

Figure 2-10 PSX Cockpit User Interface



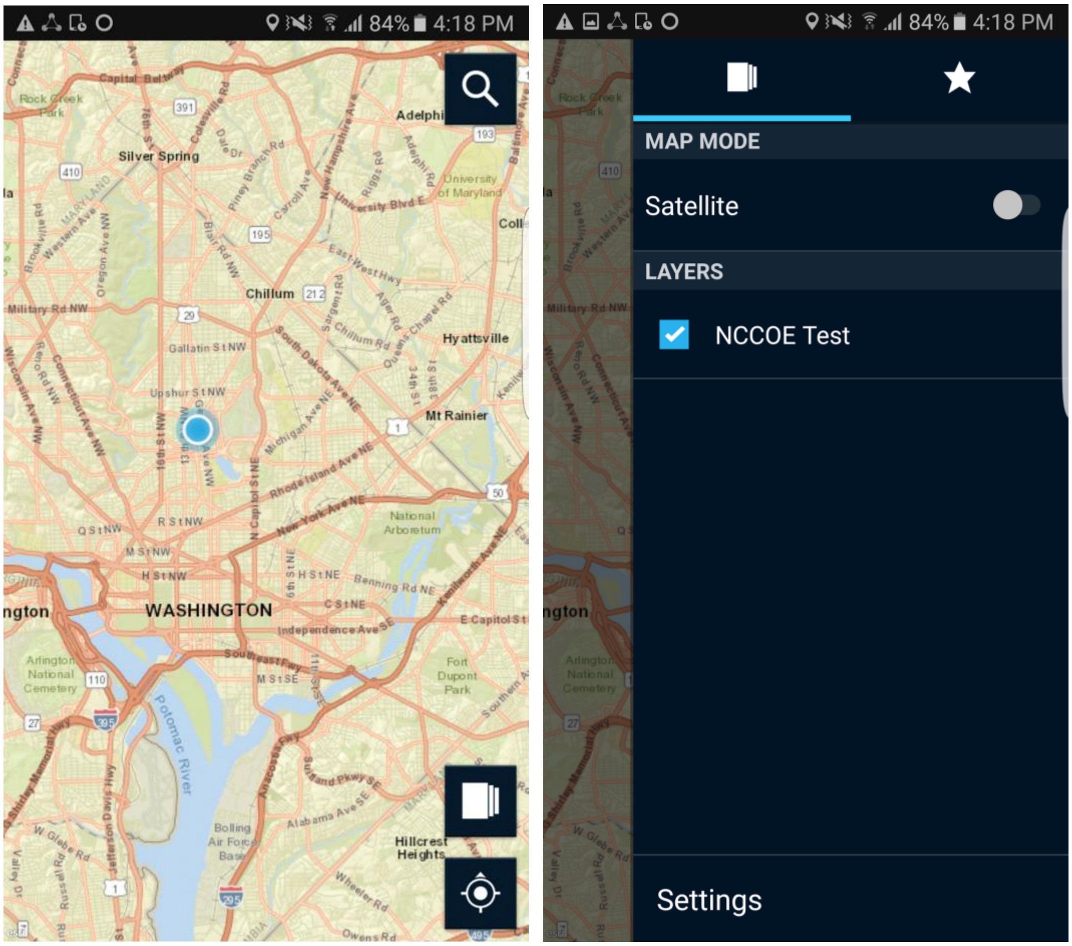
14. On the Cockpit screen, you can trigger an emergency (triangle icon in the upper right). Set your status (drop-down menu under your name); or reselect roles and groups, see configuration, and sign off (hamburger menu to the left of your name, and then tap **username**).

15. If you pull down your notifications, you should see icons and text indicating Reporting interval: 120 seconds, Signed In: <date> <time>, Connected, and Registered.

2.2.1.2 Configuring the PSX Mapping Application

1. Open the Mapping application. You should see the screen shown in Figure 2-11.

Figure 2-11 PSX Mapping User Interface



2. Select the Layers icon in the lower-right corner. Group names should appear under **Layers.**
3. Select a group. Your screen should look like Figure 2-12.

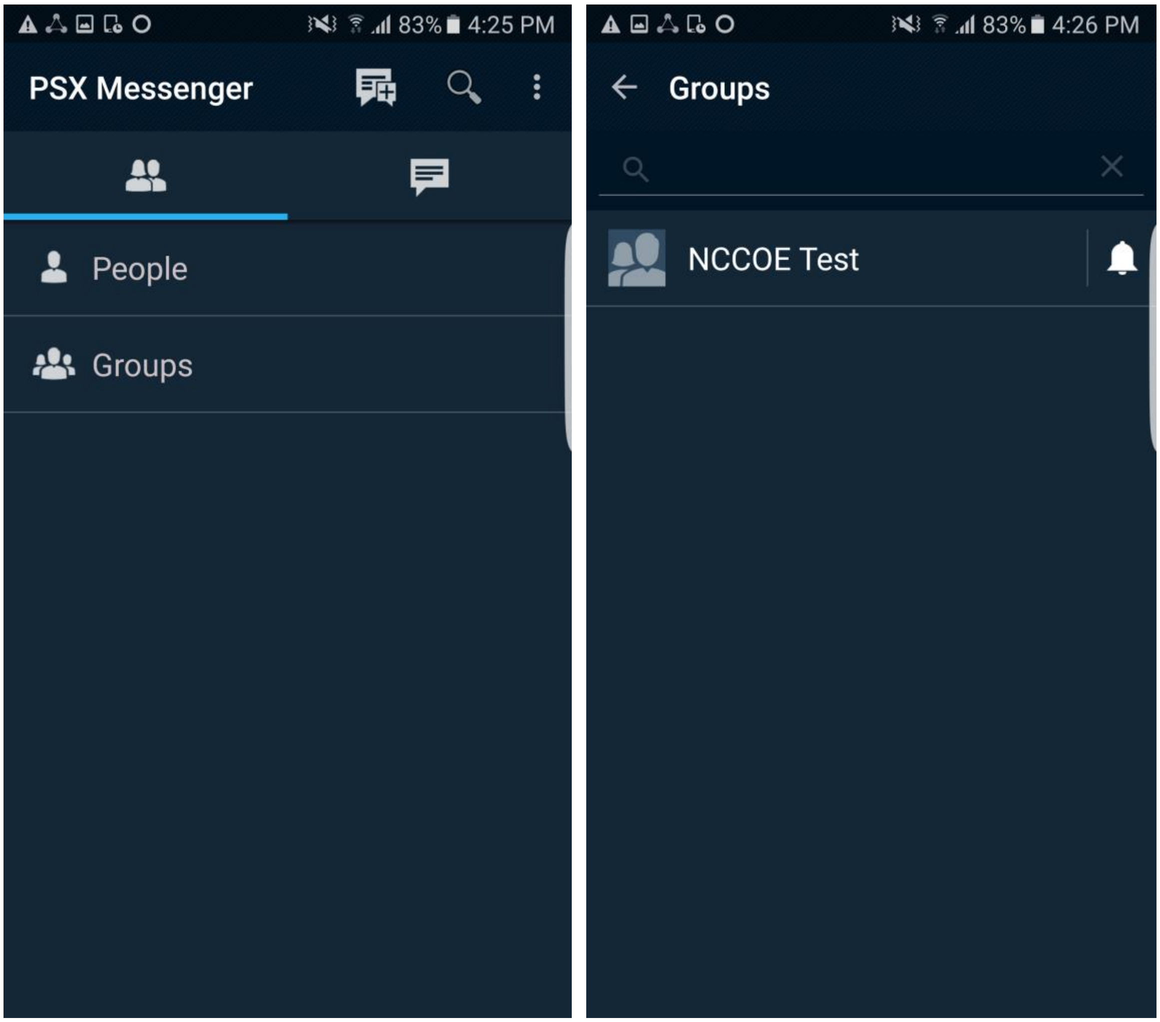
Figure 2-12 PSX Mapping Group Member Information

4. The locations of the devices that are members of that group should appear as dots on the map.
5. Select a device. A pop-up will show the user of the device, and icons for phoning and messaging that user.
6. Selecting the Messenger icon for the selected user will take you to the Messenger application, where you can send a message to the user.

2.2.1.3 Configuring the PSX Messenger Application

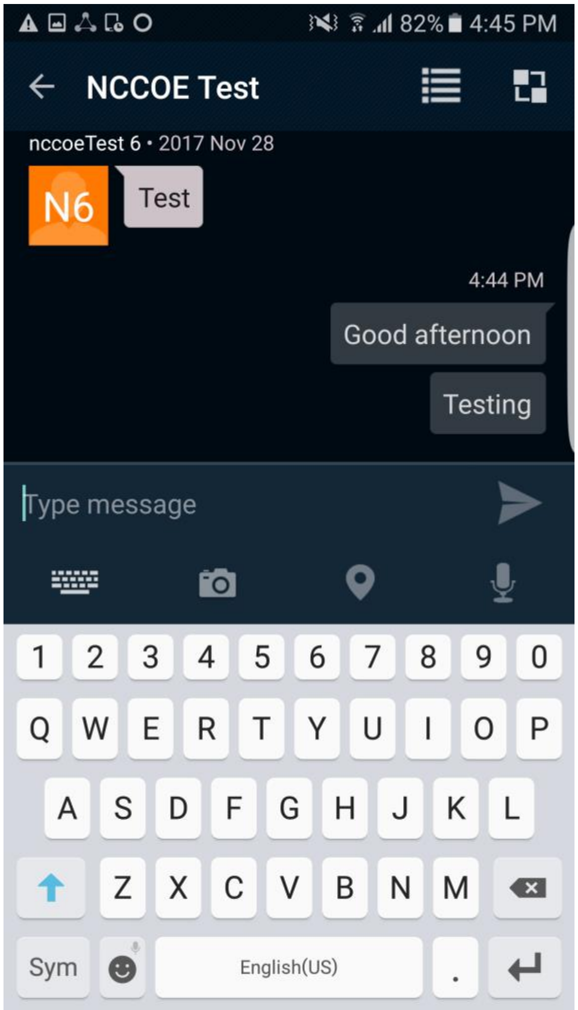
1. Open the Messenger application. Your screen should look like Figure 2-13.

Figure 2-13 PSX Messenger User Interface



2. Your screen should show **People** and **Groups.** Select one of them.
3. A list of people or groups to which you can send a message should appear. Select one of them. Your screen should look like Figure 2-14.

Figure 2-14 PSX Messenger Messages



4. You are now viewing the messaging window. You can type text for a message and attach a picture, video, voice recording, or map.
5. Tap the Send icon. The message should appear on your screen.
6. Tap the Pivot icon in the upper-right corner of the message window. Select Locate, and you will be taken to the Mapping application with the location of the people or group you selected.

2.2.2 How to Install and Configure a FIDO U2F Authenticator

This section covers the installation and usage of a FIDO U2F authenticator on an Android mobile device. As explained in Section 2.1.4, the U2F login flow is not supported on iOS devices. The NCCoE reference architecture utilizes the Google Authenticator application on the mobile device, and a Yubico YubiKey NEO as a hardware token. The application provides an interface between the Chrome browser and the U2F capabilities built into Play Services and is available on Google's Play Store [11].

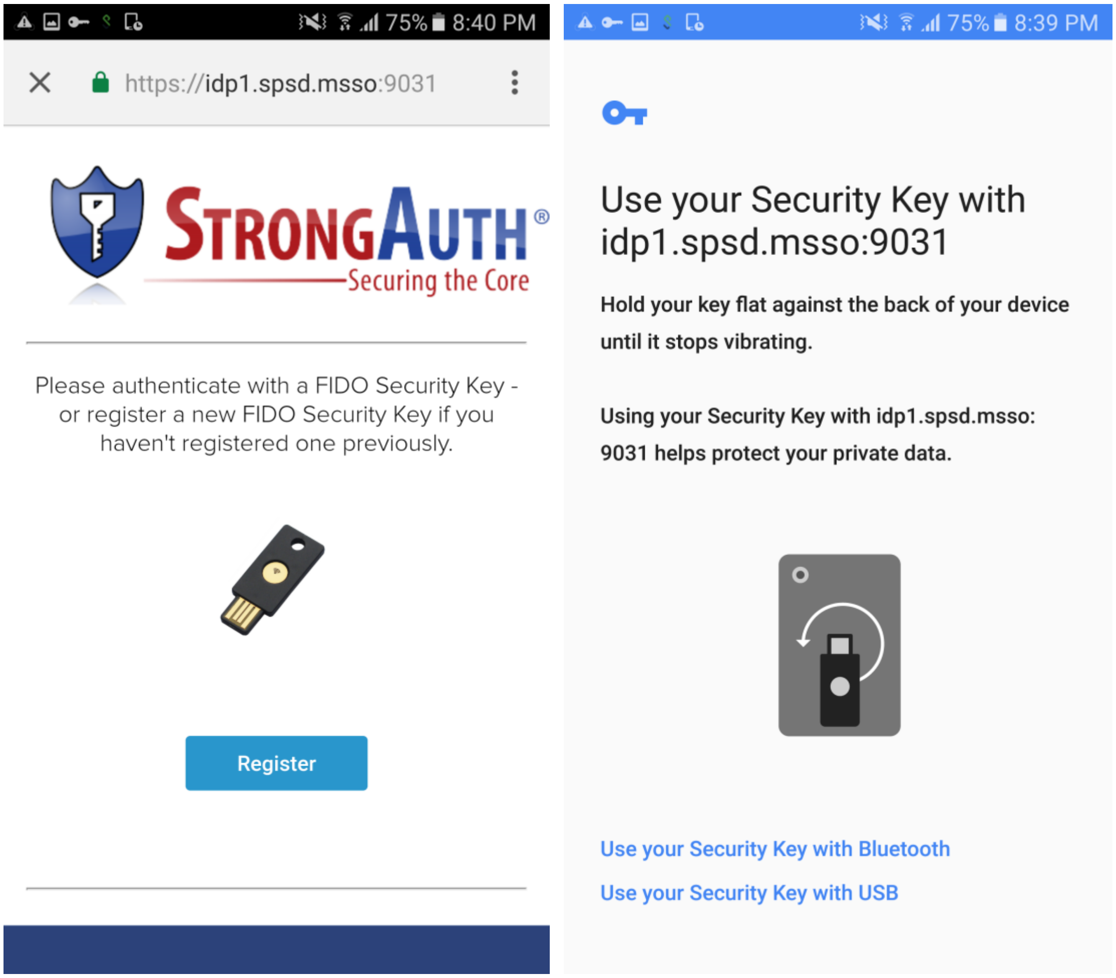
2.2.2.1 Installing Google Authenticator

1. On your Android device, open the Play Store application.
2. Search for Google Authenticator, and install the application. There is no configuration needed until you are ready to register a FIDO U2F token with a StrongKey server.

2.2.2.2 Registering the Token

In the architecture that is laid out in this practice guide, there is no out-of-band process to register the user's U2F token. This takes place the first time the user tries to log in with whatever SSO-enabled application they are using. For instance, when using the PSX Cockpit application, once the user tries to sign into an IdP that has U2F enabled and has successfully authenticated with a username and password, they will be presented with the screen shown in Figure 2-15.

Figure 2-15 FIDO U2F Registration



Because the user has never registered a U2F token, that is the only option the user sees.

1. Click **Register,** and the web page will activate the Google Authenticator application, which asks you to use a U2F token to continue (Figure 2-15 above).

2. Hold the U2F token to your device, and then the token will be registered to your account and you will be redirected to the U2F login screen again.

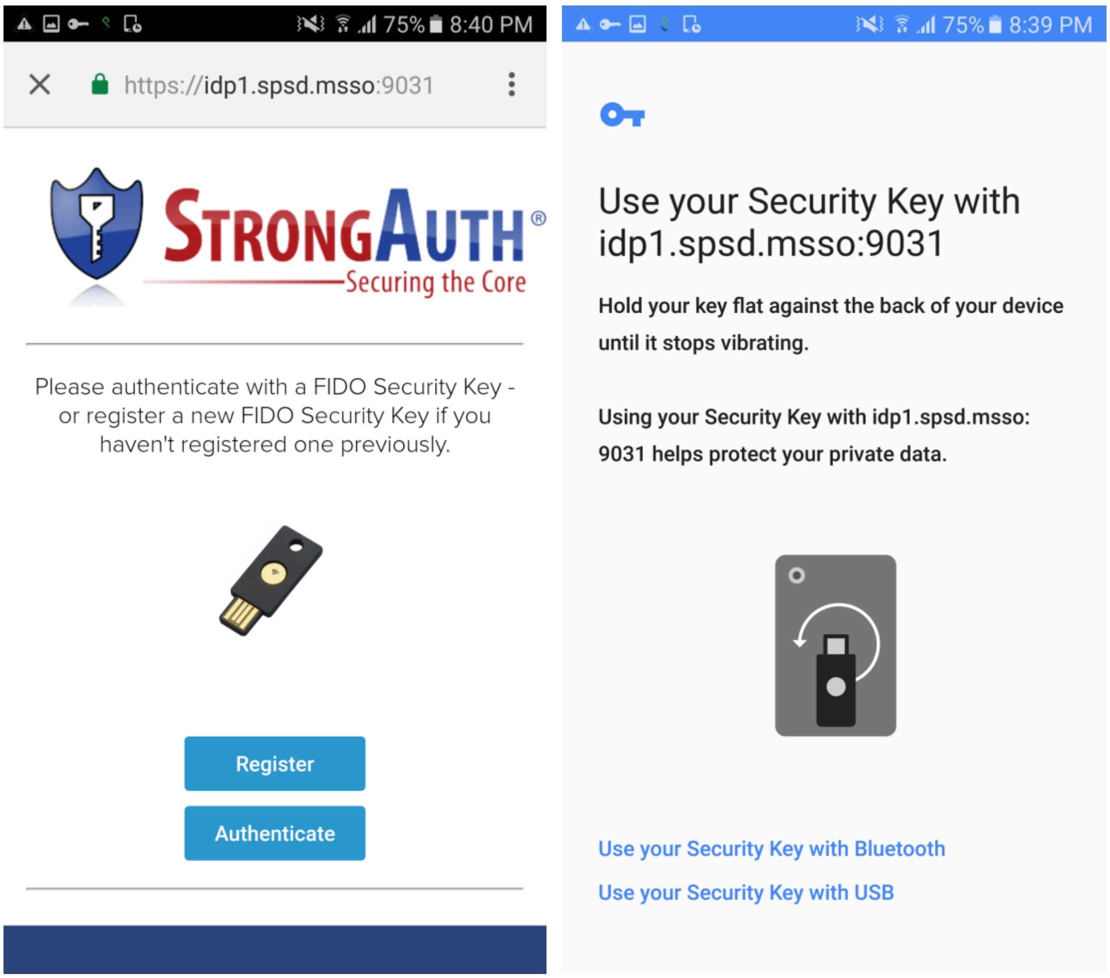
2.2.2.3 Authenticating with the Token

Now, because the system has a U2F token on file for the user, the user has the option to authenticate.

1. Click **Authenticate** (Figure 2-16), and the Google Authenticator application will be activated once more.

2. Hold the U2F token to your device, and then the authentication will be successful and the SSO flow will continue.

Figure 2-16 FIDO U2F Authentication



2.2.3 How to Install and Configure a FIDO UAF Client

This section covers the installation and usage of a FIDO UAF client on the mobile device. Any FIDO UAF client can be used, but the NCCoE reference architecture utilizes the Nok Nok Passport application (hereafter referred to as "Passport"). The Passport application functions as the client-side UAF application and is available on Google's Play Store [16] and Apple's App Store [17]. The following excerpt is from the Play Store page:

> *Passport from Nok Nok Labs is an authentication app that supports the Universal Authentication Framework (UAF) protocol from the FIDO Alliance (www.fidoalliance.org).*

Passport allows you to use out-of-band authentication to authenticate to selected websites on a laptop or desktop computer. You can use the fingerprint sensor on FIDO UAF-enabled devices (such as the Samsung Galaxy S® 6, Fujitsu Arrows NX, or Sharp Aquos Zeta) or enter a simple PIN on non-FIDO enabled devices. You can enroll your Android device by using Passport to scan a QR code displayed by the website, then touch the fingerprint sensor or enter a PIN. Once enrolled, you can authenticate using a similar method. Alternatively, the website can send a push notification to your Android device and trigger the authentication.

This solution lets you use your Android device to better protect your online account, without requiring passwords or additional hardware tokens.

In our reference architecture, we use a Quick Response (QR) code to enroll the device onto Nok Nok Labs' test server.

2.2.3.1 Installing Passport on Android

1. On your Android device, open the Play Store application.
2. Search for Nok Nok Passport, and install the application. There is no configuration needed until you are ready to enroll the device with a Nok Nok Labs server.

Normally, the user will never need to open the Passport application during authentication; it will automatically be invoked by the SSO-enabled application (e.g., PSX Cockpit). Instead of entering a username and password into a Chrome Custom Tab, the user will be presented with the Passport screen to use the user's UAF credential.

2.2.3.2 Installing Passport on iOS

1. On your iOS device, open the App Store application.
2. Search for Nok Nok Passport, and install the application. There is no configuration needed until you are ready to enroll the device with a Nok Nok Labs server.

As with the Android application, the Passport application for iOS is invoked automatically during login with a UAF-enabled server.

2.2.3.3 Enrolling the Device

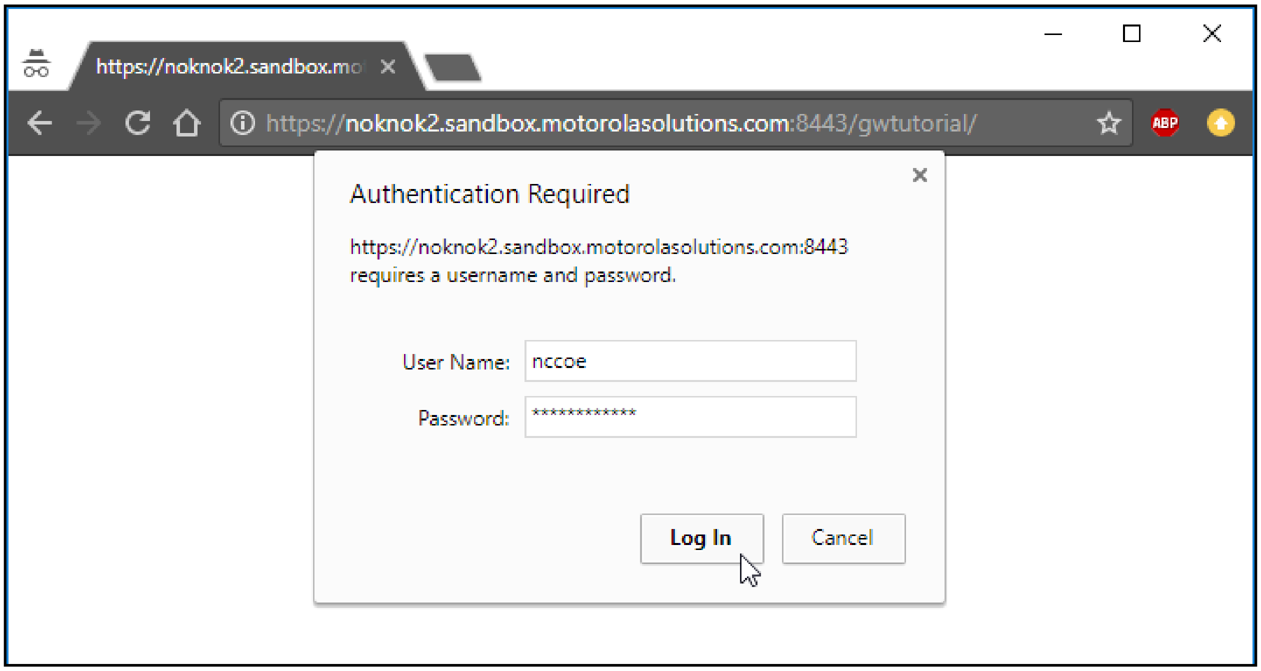
This section details the steps to enroll a device to an NNAS. First, you need a device that has Passport installed. Second, you need to use another computer (preferably a desktop or laptop) to interact with your NNAS web interface.

Note: Users are not authenticated during registration. We are using the "tutorial" application provided with the NNAS. This sample implementation does not meet the FIDO requirement of authentication prior *to registration. The production version of the NNAS may require additional steps and may have a different interface.*

Screenshots that demonstrate the enrollment process are shown in Figure 2-17 through Figure 2-24.

1. First, use your computer to navigate to the NNAS web interface. You will be prompted for a username and password; enter your administrator credentials and click **Log In** (Figure 2-17).

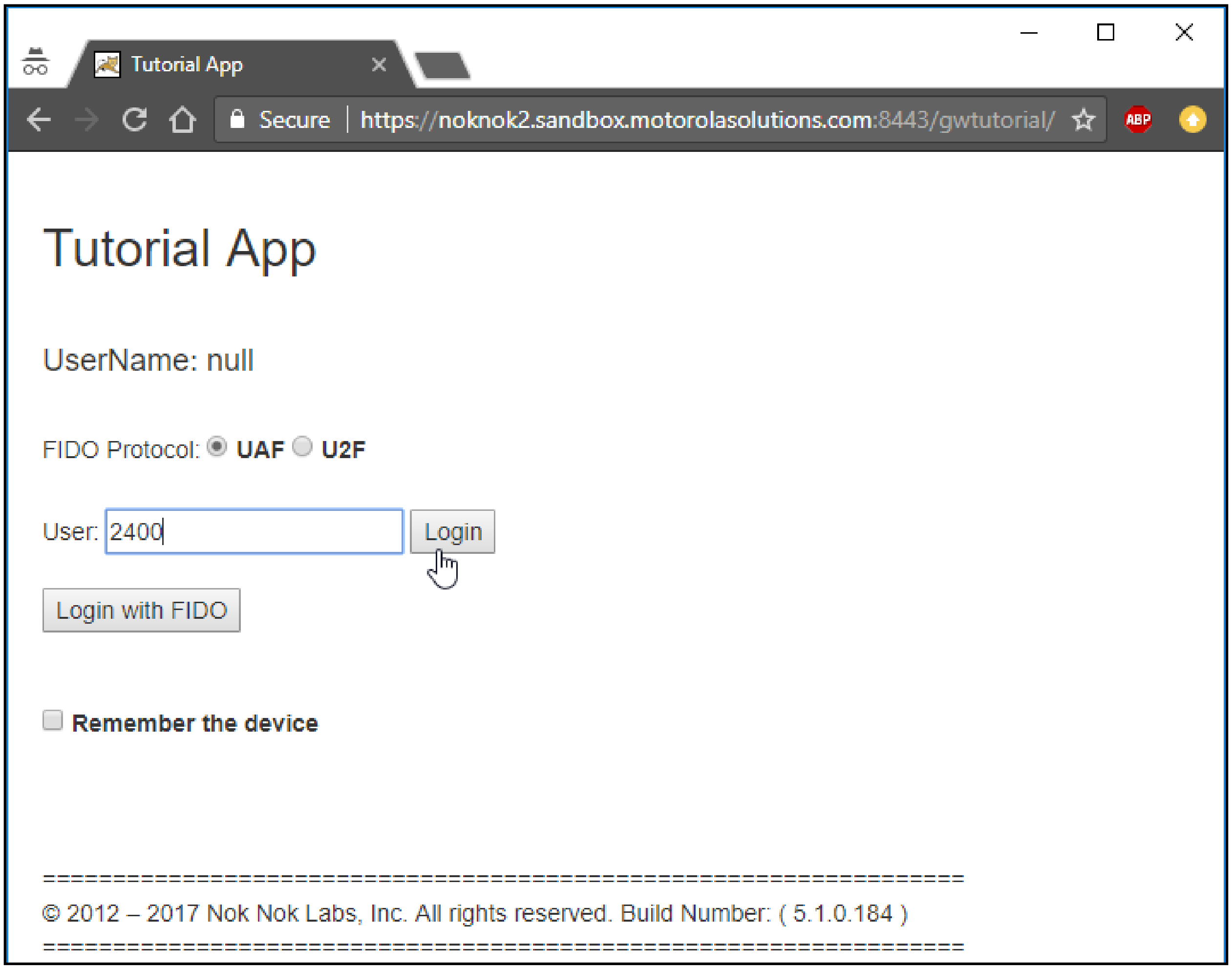
Figure 2-17 Nok Nok Labs Tutorial Application Authentication



2. Once you have logged in to the NNAS as an administrator, you need to identify which user you want to manage. Enter the username and click **Login** (Figure 2-18).

   Note: As stated above, this is the tutorial application, so it prompts for only a username, not a password. A production environment would require user authentication.

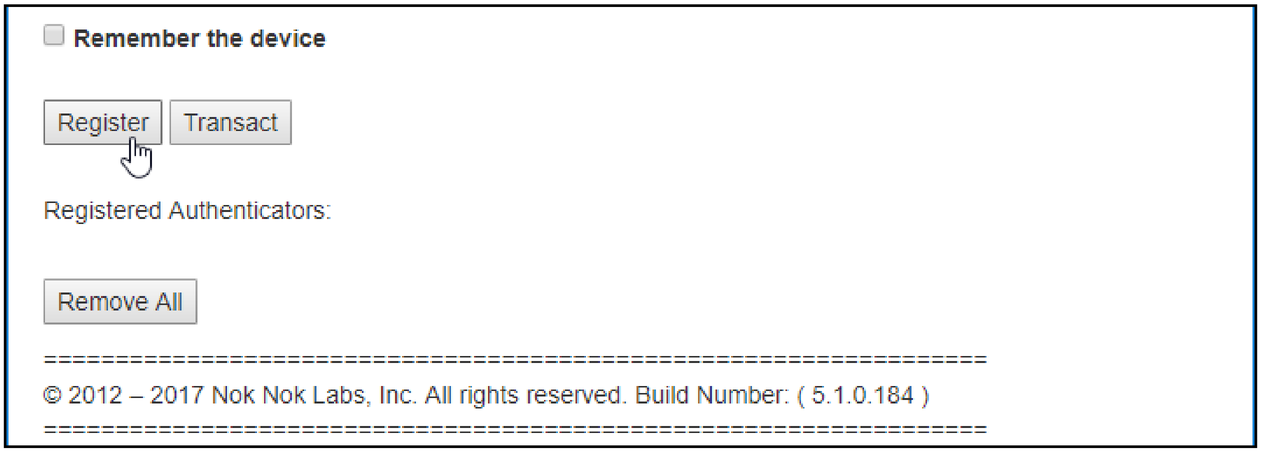
613 **Figure 2-18 Nok Nok Labs Tutorial Application Login**



614

615 3. Once you have selected the user, you will need to start the FIDO UAF registration process. To
616 begin, click **Register** (Figure 2-19).

Figure 2-19 FIDO UAF Registration Interface



4. You will see a window with a QR code and a countdown (Figure 2-20). You have three minutes to finish the registration process with your device.
    a. Once the QR image appears, launch the Passport application on the phone. The Passport application activates the device camera to enable capturing the QR code by centering the code in the square frame in the middle of the screen (Figure 2-21Figure 2-21).
    b. Once the QR code is scanned, the application prompts the user to select the type of verification (fingerprint, PIN, etc.) to use (Figure 2-21). The selections may vary based on the authenticator modules installed on the device. Figure 2-21 shows the Passport application on an Android device. Figure 2-22 shows the same flow on an iOS device. On iOS devices that support Face ID, such as the iPhone X, Face ID is available as a user verification option.

Figure 2-20 FIDO UAF Registration QR Code

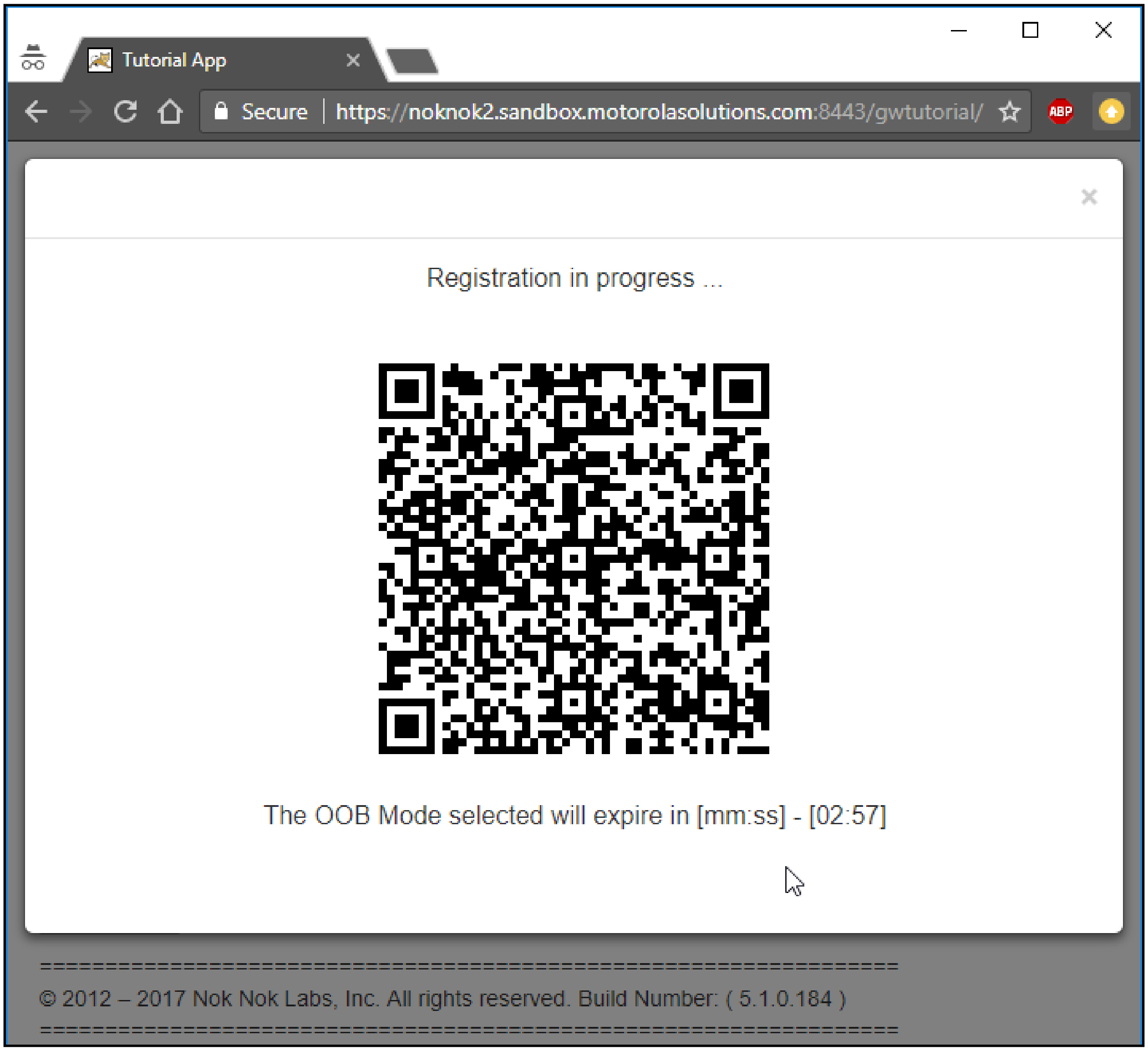


Figure 2-21 FIDO UAF Registration Device Flow, Android Device

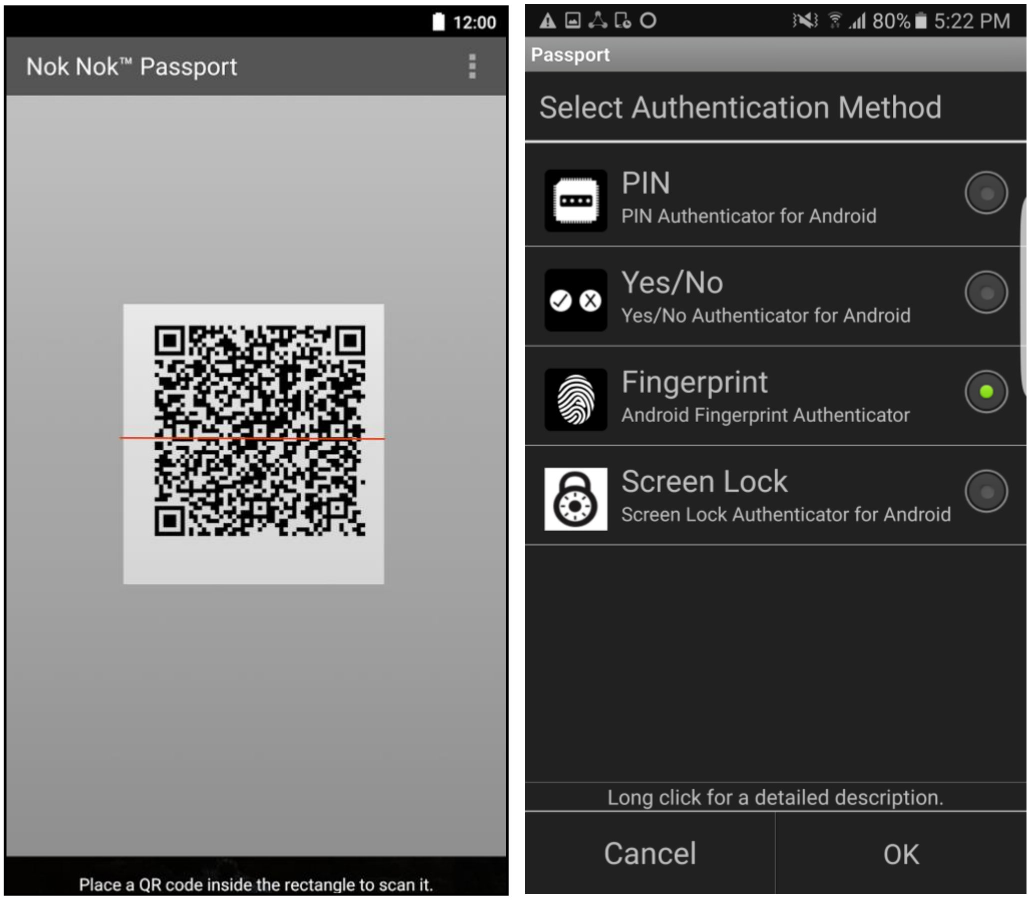
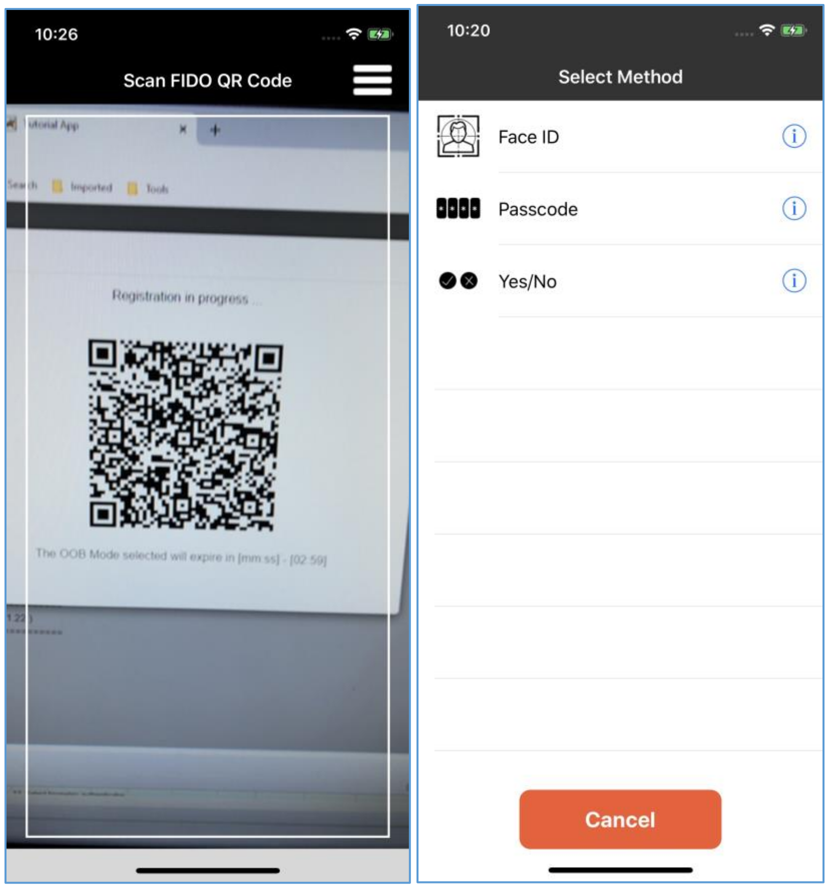
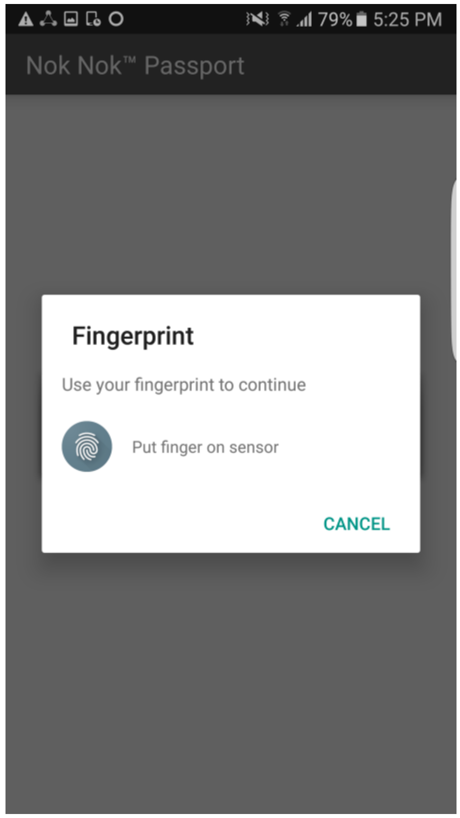


Figure 2-22 FIDO UAF Registration Device Flow, iPhone X



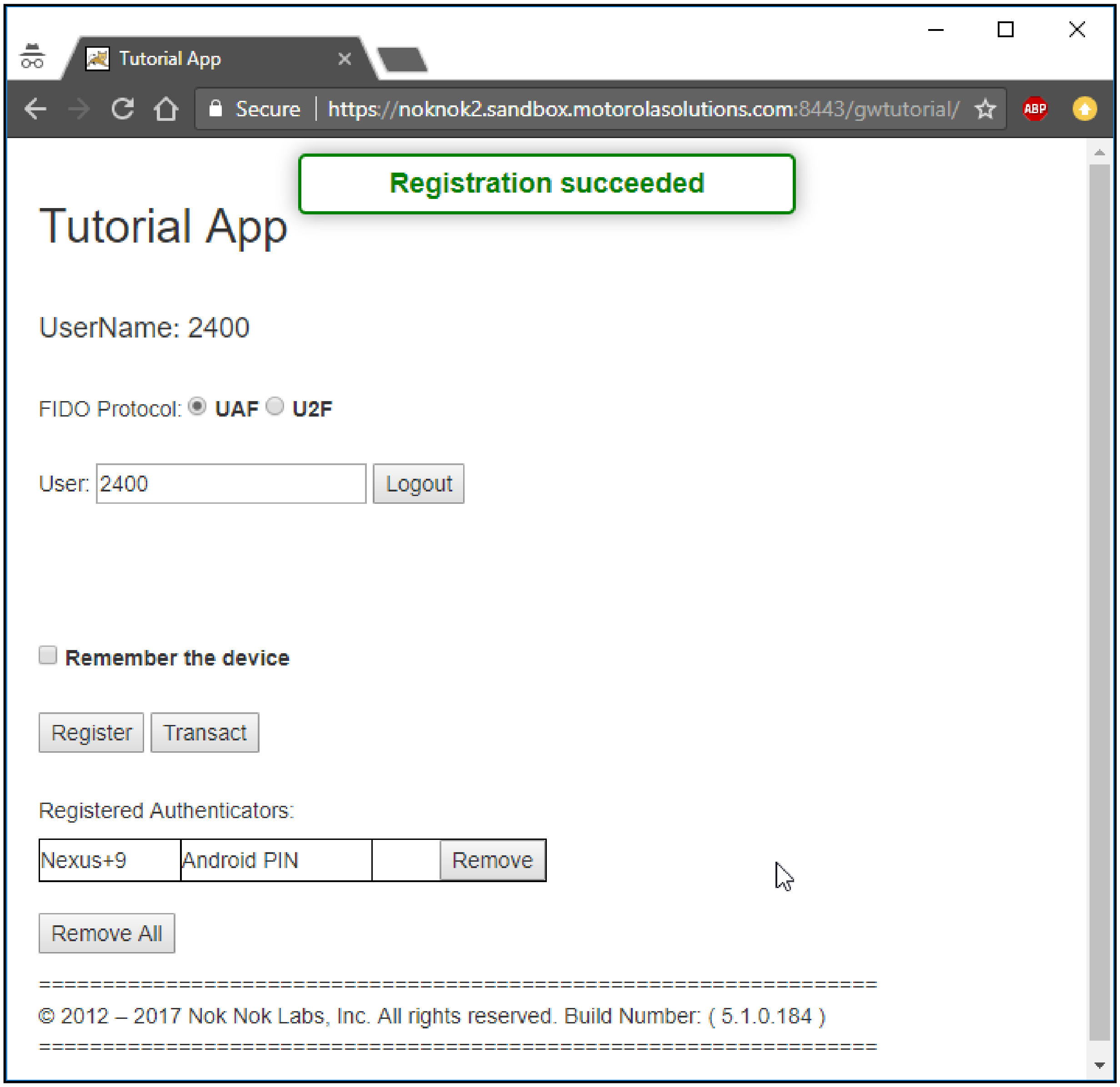
5. The user is then prompted to perform user verification with the selected method. In the example shown in Figure 2-23, a fingerprint authenticator is registered. The user is prompted for a fingerprint scan to complete registration. The fingerprint authenticator uses a fingerprint previously registered in the Android screen-lock settings. If a PIN authenticator were registered, the user would be prompted to set a PIN instead.

Figure 2-23 FIDO UAF Fingerprint Authenticator, Android Device



6. If user verification is successful, then a new UAF key pair is generated, the public key is sent to the server, and registration is completed (Figure 2-24).

Figure 2-24 FIDO UAF Registration Success



2.3 How Application Developers Must Integrate AppAuth for SSO

Application developers can easily integrate AppAuth to add SSO capabilities to their applications. The first step to doing this is reading through the documentation on GitHub for AppAuth for Android [19] or iOS [8]. After doing so, an application developer can begin the integration of AppAuth. The degree of this integration can vary—for instance, you may choose to utilize user attributes to personalize the user's application experience. The following sections describe AppAuth integration for Android and iOS applications.

For either platform, the mobile application must be registered with the OAuth AS and given a client ID as described in Section 3.3. The client ID will be needed when building the mobile application.

2.3.1 AppAuth Integration for Android

In this example, we use Android Studio 3.0, Android Software Development Kit 25, and Gradle 2.14.1.

2.3.1.1 Adding the Library Dependency

1. Edit your application's *build.gradle* file, and add this line to its dependencies (note that the AppAuth library will most likely be updated in the future, so you should use the most recent version for your dependency, not necessarily the one in this document):

```
================================================================================
dependencies {
...
   compile 'net.openid:appauth:0.7.0'
}
================================================================================
```

2.3.1.2 Adding Activities to the Manifest

1. First, you need to identify your AS's host name, OAuth redirect path, and what scheme was set when you registered your application. The scheme here is contrived, but it is common practice to use reverse DNS style names; you should choose whatever aligns with your organization's common practices. Another alternative to custom schemes is to use App Links.
2. Edit your *AndroidManifest.xml* file, and add these lines:

```
================================================================================
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
   xmlns:tools="http://schemas.android.com/tools"
   package="com.example.app">
...
      <activity
         android:name="net.openid.appauth.RedirectUriReceiverActivity"
         tools:node="replace">
         <intent-filter>
```

```
                <action android:name="android.intent.action.VIEW" />
                <category android:name="android.intent.category.DEFAULT" />
                <category android:name="android.intent.category.BROWSABLE" />
                <data
                    android:host="as.example.com"
                    android:path="/oauth2redirect"
                    android:scheme="myappscheme" />
            </intent-filter>
        </activity>
        <activity android:name=".activity.AuthResultHandlerActivity" />
        <activity android:name=".activity.AuthCanceledHandlerActivity" />
    </application>
</manifest>
================================================================================
```

2.3.1.3 Creating Activities to Handle Authorization Responses

1. Create a utility class for reusable code (**Utility**), and create activities to handle successful authorizations (**AuthResultHandlerActivity**) and canceled authorizations (**AuthCanceledHandlerActivity**):

```
================================================================================
public class Utility {
    public static AuthorizationService getAuthorizationService(Context context) {
        AppAuthConfiguration appAuthConfig = new AppAuthConfiguration.Builder()
                .setBrowserMatcher(new BrowserWhitelist(
                        VersionedBrowserMatcher.CHROME_CUSTOM_TAB,
                        VersionedBrowserMatcher.SAMSUNG_CUSTOM_TAB))
                // the browser matcher above allows you to choose which in-app browser
                // tab providers will be supported by your app in its OAuth2 flow
                .setConnectionBuilder(new ConnectionBuilder() {
                    @NonNull
```

```
                public HttpURLConnection openConnection(@NonNull Uri uri)
                        throws IOException {
                    URL url = new URL(uri.toString());
                    HttpURLConnection connection =
                            (HttpURLConnection) url.openConnection();
                    if (connection instanceof HttpsURLConnection) {
                        // optional: use your own trust manager to set a custom
                        // SSLSocketFactory on the HttpsURLConnection
                    }
                    return connection;
                }
            }).build();

        return new AuthorizationService(context, appAuthConfig);
    }

    public static AuthState restoreAuthState(Context context) {
        // we use SharedPreferences to store a String version of the JSON
        // Auth State, and here we retrieve it to convert it back to a POJO
        SharedPreferences sharedPreferences =
                PreferenceManager.getDefaultSharedPreferences(context);
        String jsonString = sharedPreferences.getString("AUTHSTATE", null);
        if (!TextUtils.isEmpty(jsonString)) {
            try {
                return AuthState.jsonDeserialize(jsonString);
            } catch (JSONException jsonException) {
                // handle this appropriately
            }
        }
        return null;
```

```
        }
    }
    ===============================================================================
    public class AuthResultHandlerActivity extends Activity {

        private static final String TAG = AuthResultHandlerActivity.class.getName();

        private AuthState mAuthState;
        private AuthorizationService mAuthService;

        @Override
        protected void onCreate(Bundle savedInstanceState) {
            super.onCreate(savedInstanceState);

            AuthorizationResponse res =
    AuthorizationResponse.fromIntent(getIntent());
            AuthorizationException ex =
    AuthorizationException.fromIntent(getIntent());
            mAuthState = new AuthState(res, ex);
            mAuthService = Utility.getAuthorizationService(this);

            if (res != null) {
                Log.d(TAG, "Received AuthorizationResponse");
                performTokenRequest(res.createTokenExchangeRequest());
            } else {
                Log.d(TAG, "Authorization failed: " + ex);
            }
        }

        @Override
        protected void onDestroy() {
```

```
        super.onDestroy();
        mAuthService.dispose();
    }

    private void performTokenRequest(TokenRequest request) {
        TokenResponseCallback callback = new TokenResponseCallback() {
            @Override
            public void onTokenRequestCompleted(
                    TokenResponse tokenResponse,
                    AuthorizationException authException) {
                receivedTokenResponse(tokenResponse, authException);
            }
        };
        mAuthService.performTokenRequest(request, callback);
    }

    private void receivedTokenResponse(TokenResponse tokenResponse,
                                       AuthorizationException authException) {
        Log.d(TAG, "Token request complete");
        if (tokenResponse != null) {
            mAuthState.update(tokenResponse, authException);

            // persist auth state to SharedPreferences
            PreferenceManager.getDefaultSharedPreferences(this)
                    .edit()
                    .putString("AUTHSTATE", mAuthState.jsonSerializeString())
                    .commit();

            String accessToken = mAuthState.getAccessToken();
            if (accessToken != null) {
```

```
                // optional: pull claims out of JWT (name, etc.)
            }
        } else {
            Log.d(TAG, "  ", authException);
        }
    }
}
================================================================================
public class AuthCanceledHandlerActivity extends Activity {

    private static final String TAG =
AuthCanceledHandlerActivity.class.getName();

    @Override
    protected void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);

        Log.d(TAG, "OpenID Connect authorization flow canceled");

        // go back to MainActivity
        finish();
    }
}
================================================================================
```

2.3.1.4 Executing the OAuth 2 Authorization Flow

1. In whatever activity you are using to initiate authentication, add the necessary code to use the AppAuth SDK to execute the OAuth 2 authorization flow:

```
================================================================================
...

// some method, usually a "login" button, activates the OAuth2 flow
```

```
String OAUTH_AUTH_ENDPOINT =
"https://as.example.com:9031/as/authorization.oauth2";
String OAUTH_TOKEN_ENDPOINT = "https://as.example.com:9031/as/token.oauth2";
String OAUTH_REDIRECT_URI = "myappscheme://app.example.com/oauth2redirect";
String OAUTH_CLIENT_ID = "myapp";
String OAUTH_PKCE_CHALLENGE_METHOD = "S256"; // options are "S256" and "plain"

// CREATE THE SERVICE CONFIGURATION
AuthorizationServiceConfiguration config = new
AuthorizationServiceConfiguration(
       Uri.parse(OAUTH_AUTH_ENDPOINT), // auth endpoint
       Uri.parse(OAUTH_TOKEN_ENDPOINT), // token endpoint
       null // registration endpoint
);

// OPTIONAL: Add any additional parameters to the authorization request
HashMap<String, String> additionalParams = new HashMap<>();
additionalParams.put("acr_values", "urn:acr:form");

// BUILD THE AUTHORIZATION REQUEST
AuthorizationRequest.Builder builder = new AuthorizationRequest.Builder(
       config,
       OAUTH_CLIENT_ID,
       ResponseTypeValues.CODE,
       Uri.parse(OAUTH_REDIRECT_URI))
       .setScopes("profile") // scope is optional, set whatever is needed by
your app
       .setAdditionalParameters(additionalParams);

// SET UP PKCE CODE VERIFIER
String codeVerifier = CodeVerifierUtil.generateRandomCodeVerifier();
String codeVerifierChallenge =
CodeVerifierUtil.deriveCodeVerifierChallenge(codeVerifier);
builder.setCodeVerifier(codeVerifier, codeVerifierChallenge,

       OAUTH_PKCE_CHALLENGE_METHOD);

AuthorizationRequest request = builder.build();

// PERFORM THE AUTHORIZATION REQUEST
// this pauses and leaves the current activity
Intent postAuthIntent = new Intent(this, AuthResultHandlerActivity.class);
Intent authCanceledIntent = new Intent(this,
AuthCanceledHandlerActivity.class);
mAuthService.performAuthorizationRequest(
       request,
       PendingIntent.getActivity(this, request.hashCode(), postAuthIntent, 0),
       PendingIntent.getActivity(this, request.hashCode(), authCanceledIntent,
0));

...
```

```
// when the activity resumes, check if the OAuth2 flow was successful

@Override
protected void onResume() {
    super.onResume();

    AuthState authState = Utility.restoreAuthState(this);
    if (authState != null) {
        // we are authorized!
        // proceed to the next activity that requires an access token
    }
}

...
================================================================================
```

2.3.1.5 Fetching and Using the Access Token

1. After you have proceeded from the prior activity, you can fetch your access token. If some time has passed since you obtained the access token, you may need to use your refresh token to get a new access token. AppAuth handles both cases the same way. Implement the following code wherever you need to use the access token:

```
================================================================================
...


// assuming we have an instance of a Context as mContext...
// ensure we have a fresh access token to perform any future actions
final AuthorizationService authService =
Utility.getAuthorizationService(mContext);
AuthState authState = Utility.restoreAuthState(mContext);
authState.performActionWithFreshTokens(authService, new
AuthState.AuthStateAction() {
    @Override
    public void execute(String accessToken, String idToken,
            AuthorizationException ex) {
        JWT jwt = null;
        if (ex != null) {
            // negotiation for fresh tokens failed, check ex for more details
        } else {
            // we can now use accessToken to access remote services
            // this is typically done by including the token in an HTTP header,
            // or in a handshake transaction if another transport protocol is
used
```

```
            }
            authService.dispose();
        }
    });

    ...
    ================================================================================
```

2.3.2 AppAuth Integration for iOS

The iOS demo applications were built with XCode 10.1 for iOS deployment target 11.0. using the Swift programming language.

2.3.2.1 Adding the Library Dependency

The AppAuth library can be added to an XCode project by using either the CocoaPods or Carthage dependency manager. The CocoaPods method automatically uses the official released version of the library. To use a particular code branch or to get recent updates not available in the release version, Carthage must be used. The official release should be suitable for the majority of applications.

To add the AppAuth library by using CocoaPods:

1. Create a Podfile in the root directory of the project. The following is a sample Podfile from the maps-demo application that adds AppAuth and two other libraries.

```
================================================================================
source 'https://github.com/CocoaPods/Specs.git'
target 'map-demo-app-ios' do
    pod 'GoogleMaps'
    pod 'GooglePlaces'
    pod 'AppAuth'
end
================================================================================
```

2. Open a terminal and navigate to the root directory of the project and run the command:

   `pod install`

3. In XCode, close any open projects. Click File–Open, navigate to the root of the project, and open the file <project-name>.xcworkspace.

To add the AppAuth library by using Carthage:

1. Create a Cartfile with the following contents in the root directory of the project:

```
================================================================================
github "openid/AppAuth-iOS" "master"
================================================================================
```

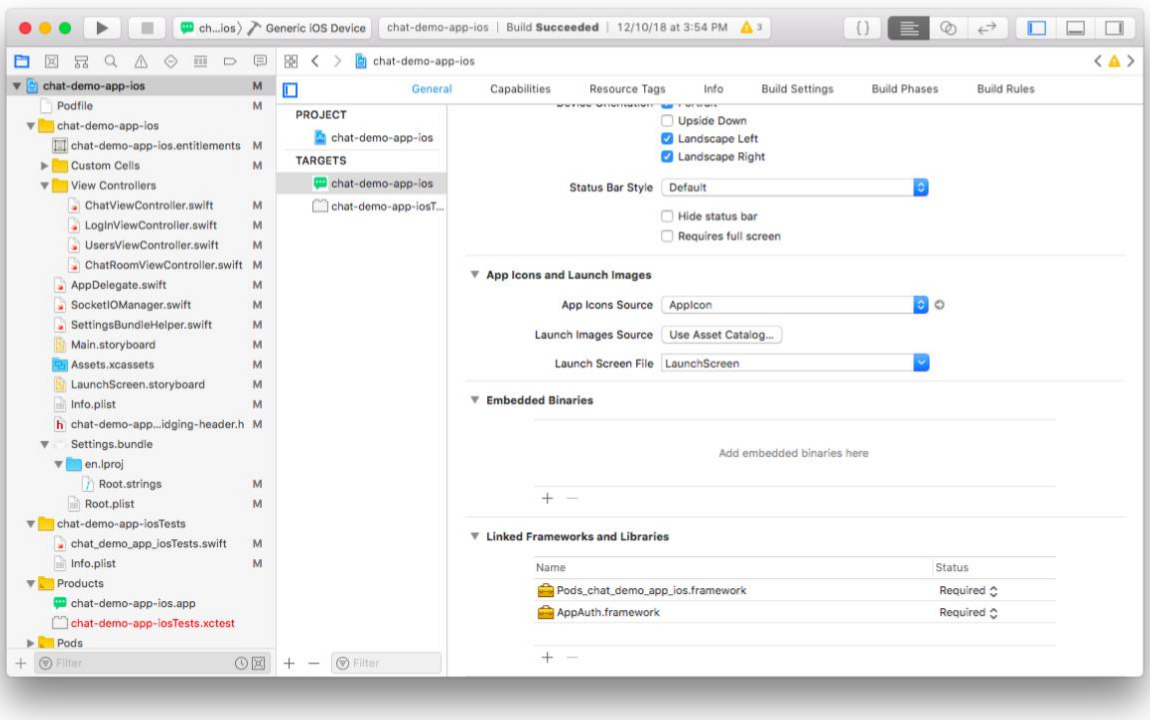
2. Open a terminal and navigate to the root directory of the project and run the command:

   `carthage bootstrap`

3. In XCode, click on the project in the project navigator and select the General tab. Under Linked Frameworks and Libraries, click the plus icon to add a framework.

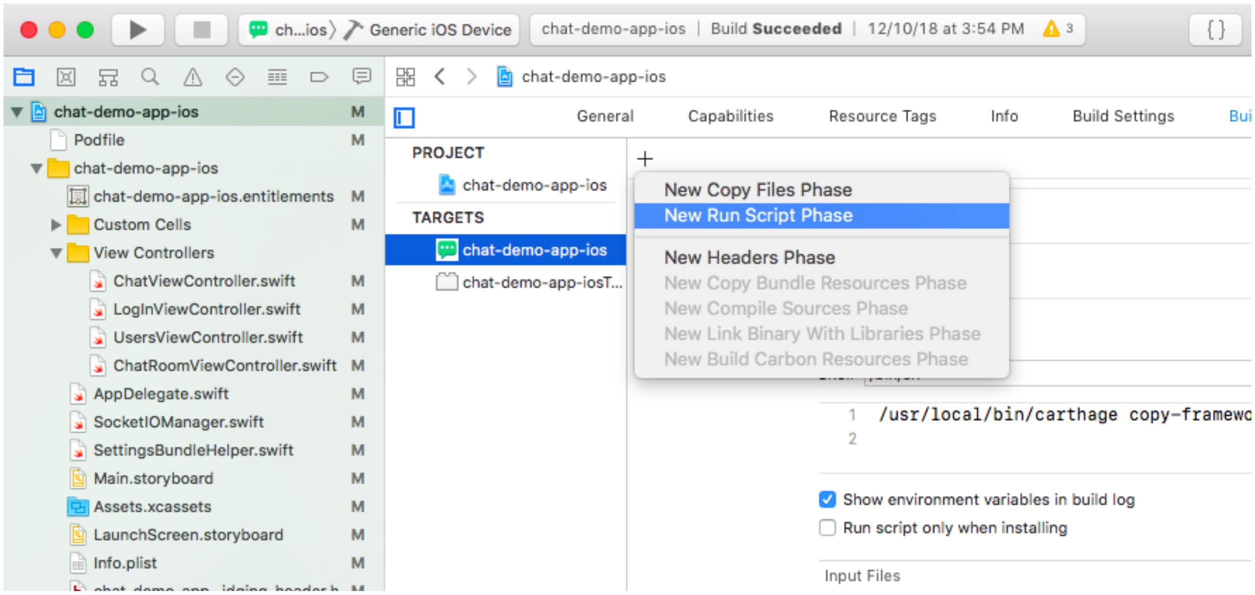
4. Click Add Other…. A file selection dialogue should open and display the root folder of the project. Navigate to the Carthage/Build/iOS subfolder, select AppAuth.framework, and click Open. The Frameworks and Libraries interface is shown in Figure 2-25.

Figure 2-25 Linked Frameworks and Libraries



5. On the Build Phases tab, click the plus icon in the top left corner of the editor and select New Run Script Phase as shown in Figure 2-26.

Figure 2-26 Creating a New Run Script Phase



6. Add the following command to the Run Script:

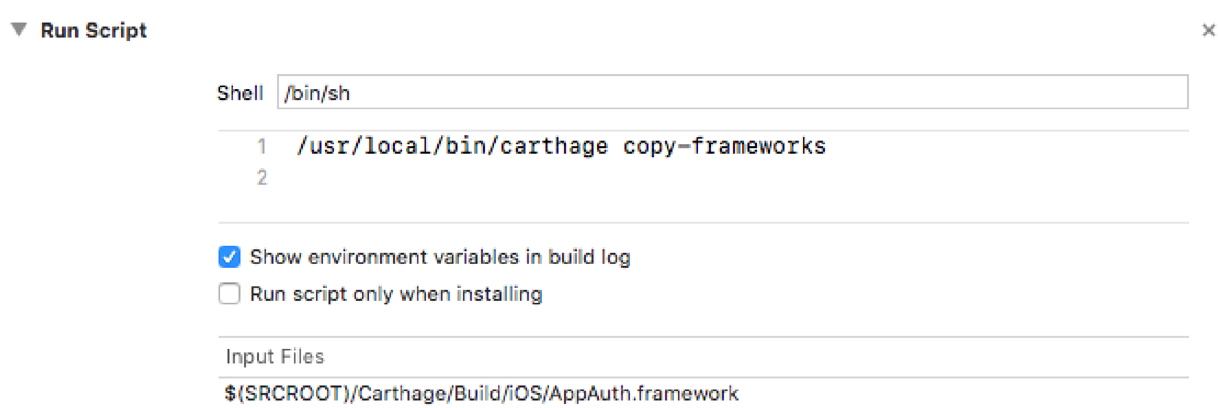
   `/usr/local/bin/carthage copy-frameworks`

7. Click the plus icon under Input Files and add the following entry:

   `$(SRCROOT)/Carthage/Build/iOS/AppAuth.framework`

   Figure 2-27 shows a completed Run Script.

Figure 2-27 Carthage Run Script



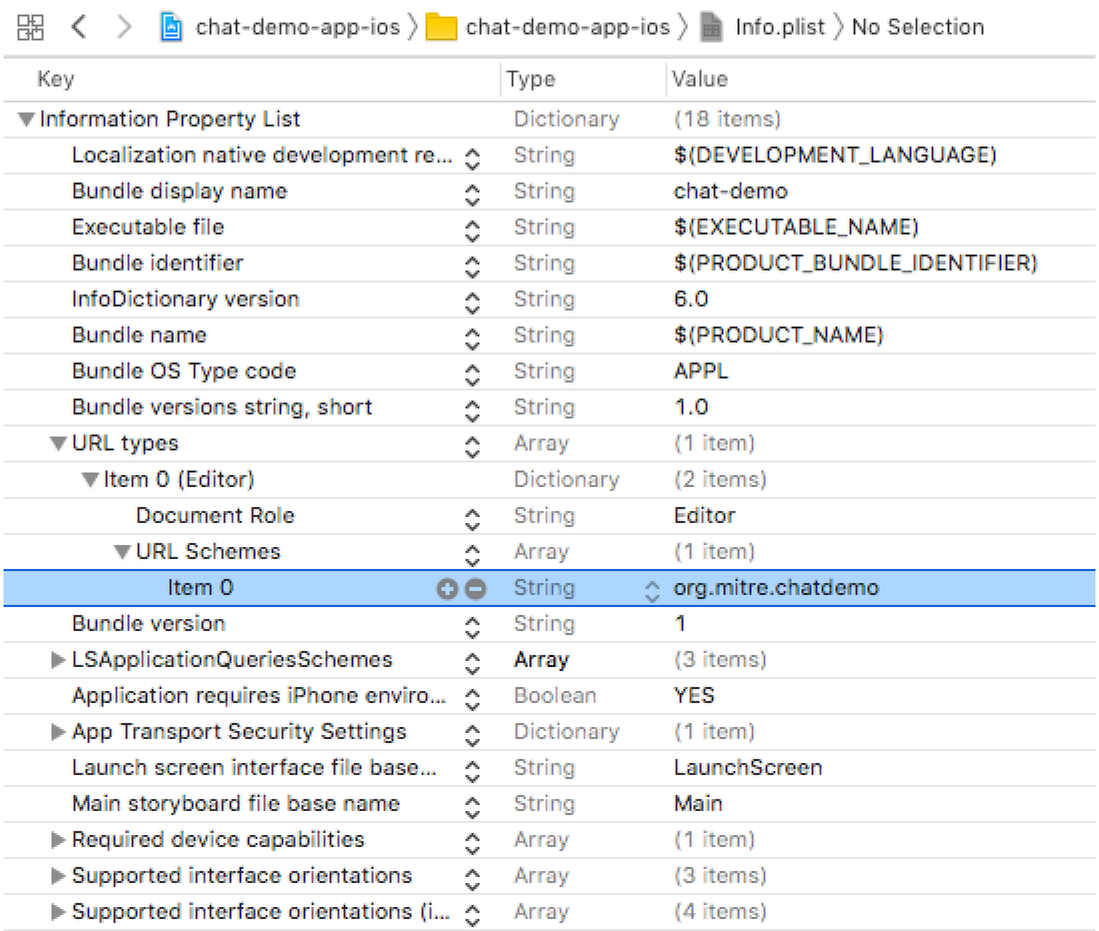
Once either of the above procedures is completed, you should be able to import AppAuth into your project without compiler errors.

2.3.2.2 Registering a Custom URL Scheme

To enable the AS to send a redirect through the browser back to your mobile application, you must either register a custom URL scheme or use Universal Links. This example shows the use of a custom URL scheme. This scheme must be included in the redirect_uri registered with the AS; see Section 3.3 for details on OAuth client registration. To configure the custom URL scheme:

1. In the XCode Project Navigator, select the Info.plist file.
2. Select "URL Types" and click the Plus icon to add a type.
3. Under the created item, click on the selector icon and choose "URL Schemes."
4. Edit the item value to match the URL scheme. Figure 2-28 shows a custom URL scheme of "org.mitre.chatdemo."

Figure 2-28 Custom URL Scheme



2.3.2.3 Handling Authorization Responses

Add the following lines to AppDelegate.swift to handle authorization responses submitted to your application's redirect_uri:

```
==============================================================================
var currentAuthorizationFlow:OIDAuthorizationFlowSession?
func application(_ app: UIApplication, open url: URL, options:
[UIApplicationOpenURLOptionsKey : Any] = [:]) -> Bool {
       if let authorizationFlow = self.currentAuthorizationFlow,
       authorizationFlow.resumeAuthorizationFlow(with: url) {
              self.currentAuthorizationFlow = nil
              return true
       }
       return false
}
```

```
===============================================================================
```

2.3.2.4 Executing the OAuth 2 Authorization Flow

In the View Controller that handles authentication events, add the necessary code to use AppAuth to submit authorization requests to the AS. The configuration parameters for the AS, such as the URLs for the authorization and token endpoints, can be automatically discovered if the AS supports OpenID Connect Discovery; otherwise these parameters must be provided either in settings or in the code. In this example, they are specified in the code. This example also demonstrates how to specify the user-agent for the authorization flow; in this case, Safari will be used.

```
===============================================================================
class LogInViewController: UIViewController, OIDAuthStateChangeDelegate,
OIDAuthStateErrorDelegate {
   let kAppAuthExampleAuthStateKey = authState";

   ...

   func authenticateUsingLab() {
      var configuration: OIDServiceConfiguration =
OIDServiceConfiguration(authorizationEndpoint: URL(string:
"https://as1.cpssp.msso:9031/as/authorization.oauth2")!, tokenEndpoint: URL(string:
"https://as1.cpssp.msso:9031/as/token.oauth2")!)

      guard let redirectURI = URL(string:
"org.mitre.chatdemo:/msso.nccoe.nist/oauth2redirect") else {
         print("Error creating URL for :
org.mitre.chatdemo:/msso.nccoe.nist/oauth2redirect")
         return
      }

      guard let appDelegate = UIApplication.shared.delegate as? AppDelegate else {
         print("Error accessing AppDelegate")
         return
      }

      // builds authentication request
      let request = OIDAuthorizationRequest(configuration: configuration,
                                            clientId: "chatdemo",
                                            clientSecret: nil,
                                            scopes: ["testScope"],
                                            redirectURL: redirectURI,
                                            responseType: OIDResponseTypeCode,
                                            additionalParameters: nil)

      print("Initiating authorization request with scope: \(request.scope ??
"DEFAULT_SCOPE")")

      doAuthWithAutoCodeExchange(configuration: configuration, request: request,
appDelegate: appDelegate)
```

```
    }

    func doAuthWithAutoCodeExchange(configuration: OIDServiceConfiguration, request: 
OIDAuthorizationRequest, appDelegate: AppDelegate) {

        let coordinator: OIDAuthorizationUICoordinatorCustomBrowser = 
OIDAuthorizationUICoordinatorCustomBrowser.customBrowserSafari()

        appDelegate.currentAuthorizationFlow = OIDAuthState.authState(byPresenting: 
request, uiCoordinator: coordinator) { authState, error in
            if let authState = authState {
                self.assignAuthState(authState: authState)
                self.segueToChat()
            } else {
                print("Authorization error: \(error?.localizedDescription ?? 
"DEFAULT_ERROR")")
                self.assignAuthState(authState: nil)
            }
        }
    func saveState(){
        // for production usage consider using the OS Keychain instead
        if authState != nil{
            let archivedAuthState = NSKeyedArchiver.archivedData(withRootObject: 
authState!)
            UserDefaults.standard.set(archivedAuthState, forKey: 
kAppAuthExampleAuthStateKey)
        }
        else{
            UserDefaults.standard.set(nil, forKey: kAppAuthExampleAuthStateKey)
        }
        UserDefaults.standard.synchronize()
    }

    func loadState(){
        // loads OIDAuthState from NSUSerDefaults
        guard let archivedAuthState = UserDefaults.standard.object(forKey: 
kAppAuthExampleAuthStateKey) as? NSData else{
            return
        }
        guard let authState = NSKeyedUnarchiver.unarchiveObject(with: archivedAuthState 
as Data) as? OIDAuthState else{
            return
        }
        assignAuthState(authState: authState)
    }

    func assignAuthState(authState:OIDAuthState?){
        if (self.authState == authState) {
            return;
        }
        self.authState = authState
        self.authState?.stateChangeDelegate = self
```

```
            self.saveState()
        }

        func didChange(_ state: OIDAuthState) {
            authState = state
            authState?.stateChangeDelegate = self
            self.saveState()
        }

        func authState(_ state: OIDAuthState, didEncounterAuthorizationError error: Error)
    {
            print("Received authorization error: \(error)")
        }
    }
    ================================================================================
```

2.3.2.5 Fetching and Using the Access Token

The access token can be retrieved from the authState object. If the access token has expired, the application may need to use a refresh token to obtain a new access token or initiate a new authorization request if it does not have an active refresh token. Access tokens are typically used in accordance with RFC 6750 [20], most commonly in the Authorization header of a Hypertext Transfer Protocol (HTTP) request to an API server. The following example shows a simple usage of an access token to call an API:

```
================================================================================
public func requestChatRooms() {
    let urlString = "\(protocolIdentifier)://\(ipAddress):\(port)/getChatRooms"
    print("URLString \(urlString)")
    guard let url = URL(string: urlString) else { return }
    let token: String? = self.authState?.lastTokenResponse?.accessToken
    var request = URLRequest(url: url)
    request.httpMethod = "GET"
    request.setValue("Bearer \(token)", forHTTPHeaderField: "Authorization")
    URLSession.shared.dataTask(with: request) { (data, response, error) in
        if error != nil {
            print(error!.localizedDescription)
        }
        else {
            guard let data = data else { return }
            let json = try? JSONSerialization.jsonObject(with: data, options: [])

            if let array = json as? [Any] {
                if let firstObject = array.first {
                    if let dictionary = firstObject as? [String: String] {
                        self.chatRooms = dictionary
                        self.loadRooms()
                    }
                }
            }
        }
    }.resume()
```

```
}
================================================================================
```

AppAuth also provides a convenience function, performActionWithFreshTokens, which will automatically handle token refresh if the current access token has expired.

3 How to Install and Configure the OAuth 2 AS

3.1 Platform and System Requirements

Ping Identity is used as the AS for this build. The AS issues access tokens to the client after successfully authenticating the resource owner and obtaining authorization as specified in RFC 6749, The OAuth Authorization Framework [21].

The requirements for Ping Identity can be categorized into three groups: software, hardware, and network.

3.1.1 Software Requirements

The software requirements are as follows:

- OS: Microsoft Windows Server, Oracle Enterprise Linux, Oracle Solaris, Red Hat Enterprise, SUSE Linux Enterprise
- Virtual systems: VMware, Xen, Windows Hyper-V
- Java environment: Oracle Java Standard Edition
- Data integration: Ping Directory, Microsoft Active Directory (AD), Oracle Directory Server, Microsoft Structured Query Language (SQL) Server, Oracle Database, Oracle MySQL 5.7, PostgreSQL

3.1.2 Hardware Requirements

The minimum hardware requirements are as follows:

- Intel Pentium 4, 1.8-gigahertz (GHz) processor
- 1 gigabyte (GB) of Random Access Memory (RAM)
- 1 GB of available hard drive space

A detailed discussion on this topic and additional information can be found at https://documentation.pingidentity.com/pingfederate/pf82/index.shtml#gettingStartedGuide/concept/systemRequirements.html.

3.1.3 Network Requirements

Ping Identity identifies several ports to be open for different purposes. These purposes can include communication with the administrative console, runtime engine, cluster engine, and Kerberos engine.

A detailed discussion on each port can be found at https://documentation.pingidentity.com/pingfederate/pf84/index.shtml#gettingStartedGuide/pf_t_installPingFederateRedHatEnterpriseLinux.html.

In this implementation, we needed ports to be opened to communicate with the administrative console and the runtime engine.

For this experimentation, we have used the configuration identified in the following subsections.

3.1.3.1 Software Configuration

The software configuration is as follows:

- OS: CentOS Linux Release 7.3.1611 (Core)
- Virtual systems: Vmware ESXI 6.5
- Java environment: OpenJDK Version 1.8.0_131
- Data integration: AD

3.1.3.2 Hardware Configuration

The hardware configuration is as follows:

- Processor: Intel(R) Xeon(R) central processing unit (CPU) E5-2420 0 at 1.90 GHz
- Memory: 2 GB
- Hard drive: 25 GB

3.1.3.3 Network Configuration

The network configuration is as follows:

- 9031: This port allows access to the runtime engine; this port must be accessible to client devices and federation partners.
- 9999: This port allows the traffic to the administrative console; only PingFederate administrators need access.

3.2 How to Install the OAuth 2 AS

Before the installation of Ping Identity AS, the prerequisites identified in the following subsections need to be fulfilled.

3.2.1 Java Installation

Java 8 can be installed in several ways on CentOS 7 using *yum*. Yum is a package manager on the CentOS 7 platform that automates software processes, such as installation, upgrade, and removal, in a consistent way.

1. Download the Java Development Kit (JDK) in the appropriate format for your environment, from Oracle's website; for CentOS, the Red Hat Package Manager (RPM) download can be used: http://www.oracle.com/technetwork/java/javase/downloads/jdk8-downloads-2133151.html.

2. As root, install the RPM by using the following command, substituting the actual version of the downloaded file:

   ```
   rpm -ivh jdk-8u151-linux-x64.rpm
   ```

3. Alternatively, the JDK can be downloaded in *.tar.gz* format and unzipped in the appropriate location (i.e., */usr/share* on CentOS 7).

3.2.2 Java Post Installation

The `alternatives` command maintains symbolic links determining default commands. This command can be used to select the default Java command. This is helpful even in cases where there are multiple installations of Java on the system.

1. Use the following command to select the default Java command:

   ```
   alternatives --config java
   ```

   There are three programs that provide "java."

   ```
     Selection    Command
   -----------------------------------------------
      1         /usr/java/jre1.8.0_111/bin/java
   *+ 2         java-1.8.0-openjdk.x86_64 (/usr/lib/jvm/java-1.8.0-openjdk-
   1.8.0.131-3.b12.el7_3.x86_64/jre/bin/java)
      3         /usr/java/jdk1.8.0_131/jre/bin/java
   Enter to keep the current selection[+], or type selection number:
   ```

   This presents the user with a configuration menu for choosing a Java instance. Once a selection is made, the link becomes the default command system wide.

2. To make Java available to all users, the JAVA_HOME environment variable was set by using the following command:

```
echo export JAVA_HOME="/usr/java/latest" > /etc/profile.d/javaenv.sh
```

3. For cryptographic functions, download the *Java Cryptography Extension (JCE) Unlimited Strength Jurisdiction Policy Files 8* from http://www.oracle.com/technetwork/java/javase/downloads/jce8-download-2133166.html.

4. Decompress and extract the downloaded file. The installation procedure is described in the Readme document. In the lab, *local_policy.jar* was extracted to the default location, *<java-home>/lib/security.Network Configuration*.

5. Check if the firewall is running or not by using the command below. If it is up, it will return a status that shows it is running:

```
firewall-cmd --state
```

   a. If it is not running, activate the firewall by using the following command:

   ```
   sudo systemctl start firewalld.service
   ```

6. Check if the required ports, 9031 and 9999, are open by using the following command:

```
firewall-cmd --list-ports
```

   a. This command will return the following values:

   ```
   6031/tcp 9999/udp 9031/tcp 6031/udp 9998/udp 9031/udp 9999/tcp 9998/tcp
   8080/tcp
   ```

   From the returned ports, we can determine which ports and protocols are open.

   b. In case the required ports are not open, issue the command below. It should return `success`.

   ```
   firewall-cmd --zone=public --permanent --add-port=9031/tcp
   success
   ```

7. Reload the firewall by using the following command to make the rule change take effect:

```
firewall-cmd --reload
Success
```

   a. Now, when the open ports are listed, the required ports should show up:

   ```
   firewall-cmd --zone=public --list-ports
   6031/tcp 9999/udp 9031/tcp 6031/udp 9998/udp 9031/udp 9999/tcp 9998/tcp
   8080/tcp 5000/tcp
   ```

3.2.3 PingFederate Installation

Ping installation documentation is available at https://docs.pingidentity.com/bundle/pf_sm_installPingFederate_pf82/page/pf_t_installPingFederateRedHatEnterpriseLinux.html?#.

Some important points are listed below:

- Obtain a Ping Identity license. It can be acquired from https://www.pingidentity.com/en/account/sign-on.html.
- For this experiment, installation was done using the zip file. Installation was done at */usr/share*.
- The license was updated.
- The PingFederate service can be configured as a service that automatically starts at system boot. PingFederate provides instructions for doing this on different OSs. In the lab, the Linux instructions at the link provided below were used. Note that, while the instructions were written for an *init.d*-based system, these instructions will also work on a systemd-based system.

  https://docs.pingidentity.com/bundle/pf_sm_installPingFederate_pf82/page/pf_t_installPingFederateServiceLinuxManually.html?#

The following configuration procedures are completed in the PingFederate administrative console, which is available at *https://<ping-server-hostname>:9999/pingfederate/app.*

3.2.4 Certificate Installation

During installation, PingFederate generates a self-signed TLS certificate, which is not trusted by desktop or mobile device browsers. A certificate should be obtained from a trusted internal or external CA and should be installed on the PingFederate server. The private key and signed certificate can be uploaded and activated for use on the run-time server port and the admin port by navigating to **Server Settings** in the console and clicking on **SSL Server Certificates**.

In addition, most server roles described in this guide will require the creation of a signing certificate. This is required for a SAML or OIDC IdP, and for an OAuth AS if access tokens will be issued as JWTs. To create or import a signing certificate, under **Server Configuration–Certificate Management,** click **Signing & Decryption Keys & Certificates.** A self-signed certificate can be created, or a trusted certificate can be obtained and uploaded there.

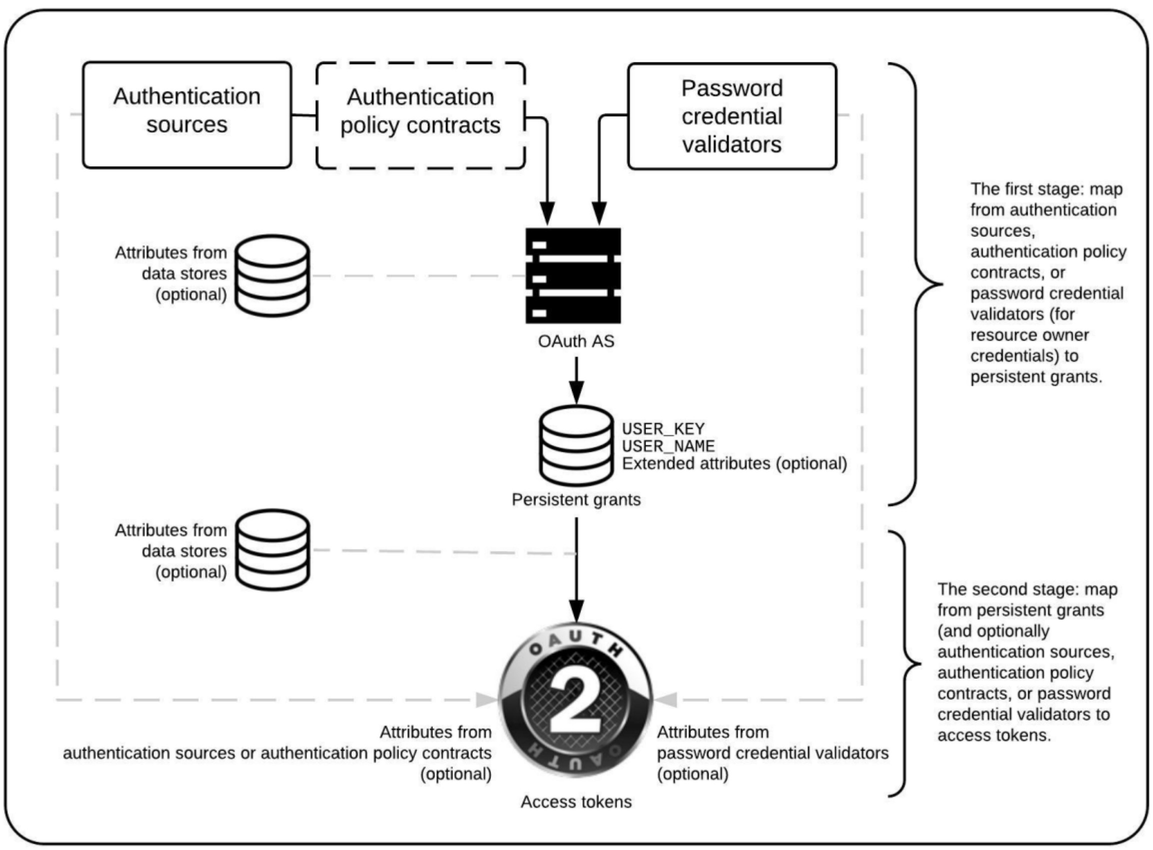
3.3 How to Configure the OAuth 2 AS

Configuration of a Ping OAuth 2 AS is described at https://documentation.pingidentity.com/pingfederate/pf82/index.shtml#concept_usingOauthMenuSelections.html.

This guide documents the configuration for an AS serving the role of the *idm.sandbox* server hosted in the Motorola Solutions cloud instance, as depicted in Figure 1-1. This AS is configured to support the three usage scenarios—local user authentication at the AS, redirection to a SAML IdP, and redirection to an OIDC IdP—and to initiate the correct login flow based on an IdP discovery mechanism.

An understanding of the PingFederate OAuth implementation helps provide context for the configurations documented in this guide. PingFederate supports several different authentication flows and mechanisms, but there is a common framework for how user attributes are mapped into OAuth tokens. This framework is depicted in Figure 3-1, which is taken from PingFederate's documentation at https://documentation.pingidentity.com/pingfederate/pf83/index.shtml#concept_mappingOauthAttributes.html.

Figure 3-1 Access Token Attribute Mapping Framework



The overall OAuth processing flow at the AS is as follows:

1. The AS receives an OAuth authorization request from an unauthenticated user.

2. The AS authenticates the user through the configured authentication adapters, IdP connections, and/or authentication policies.
3. Information from adapters or policy contracts, optionally combined with user information retrieved from data stores such as Lightweight Directory Access Protocol (LDAP), are used to build a persistent grant context. The two mandatory attributes in the persistent grant context are listed below:
   - **USER_KEY**–This is a globally unique user identifier. For ASs that interact with multiple IdPs, this name should be resistant to naming collisions across user organizations (e.g., email address or distinguished name).
   - **USER_NAME**–If the user is prompted to authorize the request, this name will be displayed on the page, so a user-friendly name, such as [givenName lastName], could be used here; the name does not need to be unique.
4. If authorization prompts are enabled, the user is prompted to approve the authorization request; for this lab build, these prompts were disabled on the assumption that fast access to applications is a high priority for the PSFR community.
5. If the request is authorized, a second mapping process takes place to populate the access token with information from the persistent grant and, optionally, from adapters, policy contracts, or data stores.

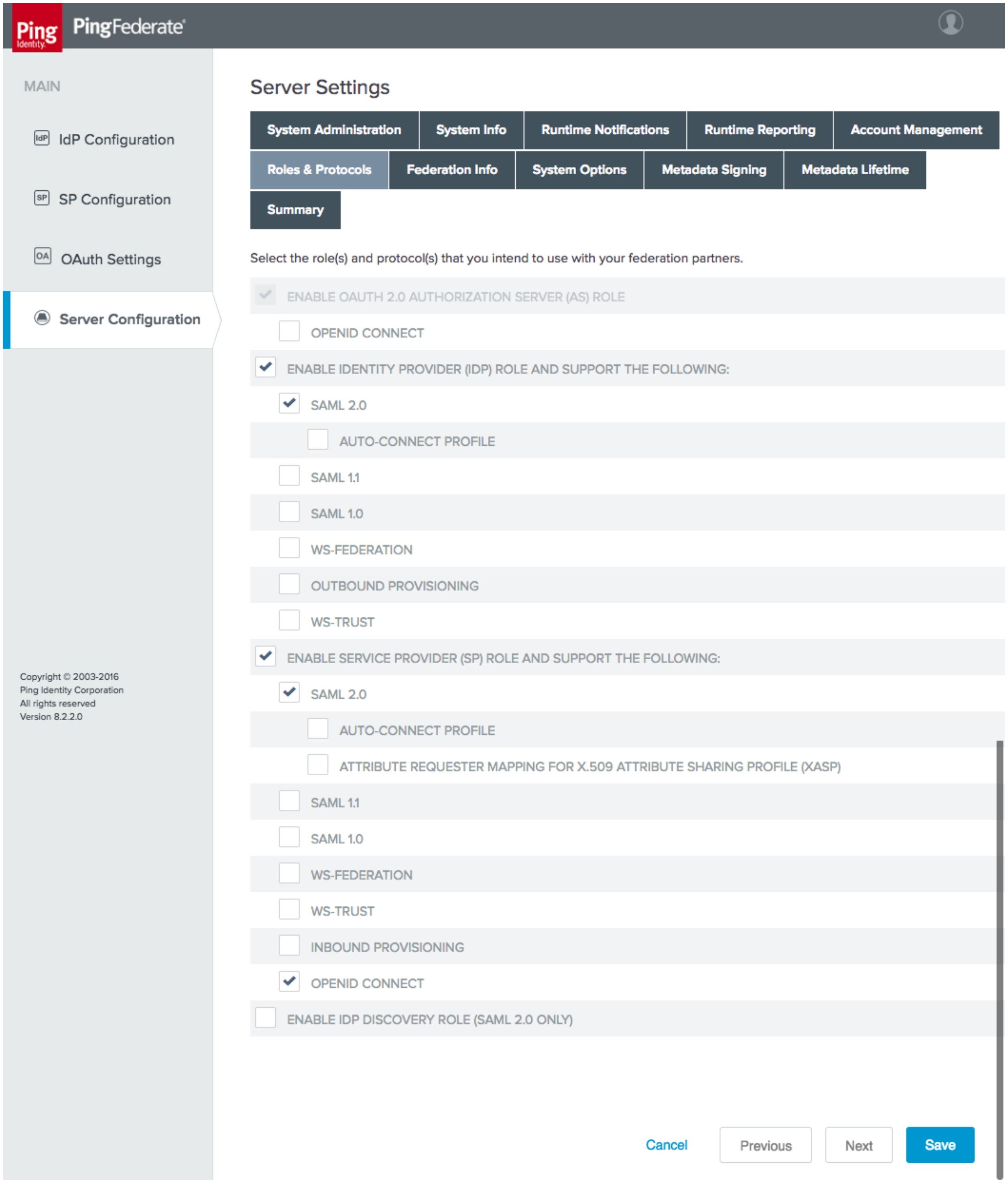
Note that persistent grant attributes are stored and can be retrieved and reused when the client uses a refresh token to obtain a new access token, whereas attributes that are looked up in the second stage would be looked up again during the token refresh request. Storing attributes in the persistent grant can therefore reduce the need for repeated directory queries; however, it may be preferable to always query some attributes that are subject to change (like account status) again when a new access token is requested. In addition, it is important to note that storing persistent grant attributes requires a supported relational database or LDAP data store.

The following steps go through the configuration of the AS.

1. Enable the PingFederate installation to work as an AS. This can be done in the following steps:
   a. Under **Main**, click the **Server Configuration** section tab, and then click **Server Settings.**
   b. In **Server Settings,** click the **Roles & Protocols** tab. The Roles & Protocols screen will appear as shown in Figure 3-2.
      i. Click **ENABLE OAUTH 2.0 AUTHORIZATION SERVER (AS) ROLE.**
      ii. Click **ENABLE IDENTITY PROVIDER (IDP) ROLE AND SUPPORT THE FOLLOWING,** and then under it, click **SAML 2.0.** Although this server does not act as a SAML IdP, it is necessary to enable the IdP role and at least one protocol to configure the local user authentication use case.

iii. Click **ENABLE SERVICE PROVIDER (SP) ROLE AND SUPPORT THE FOLLOWING,** and then under it, click **SAML 2.0** and **OPENID CONNECT;** this enables integration with both types of IdPs.

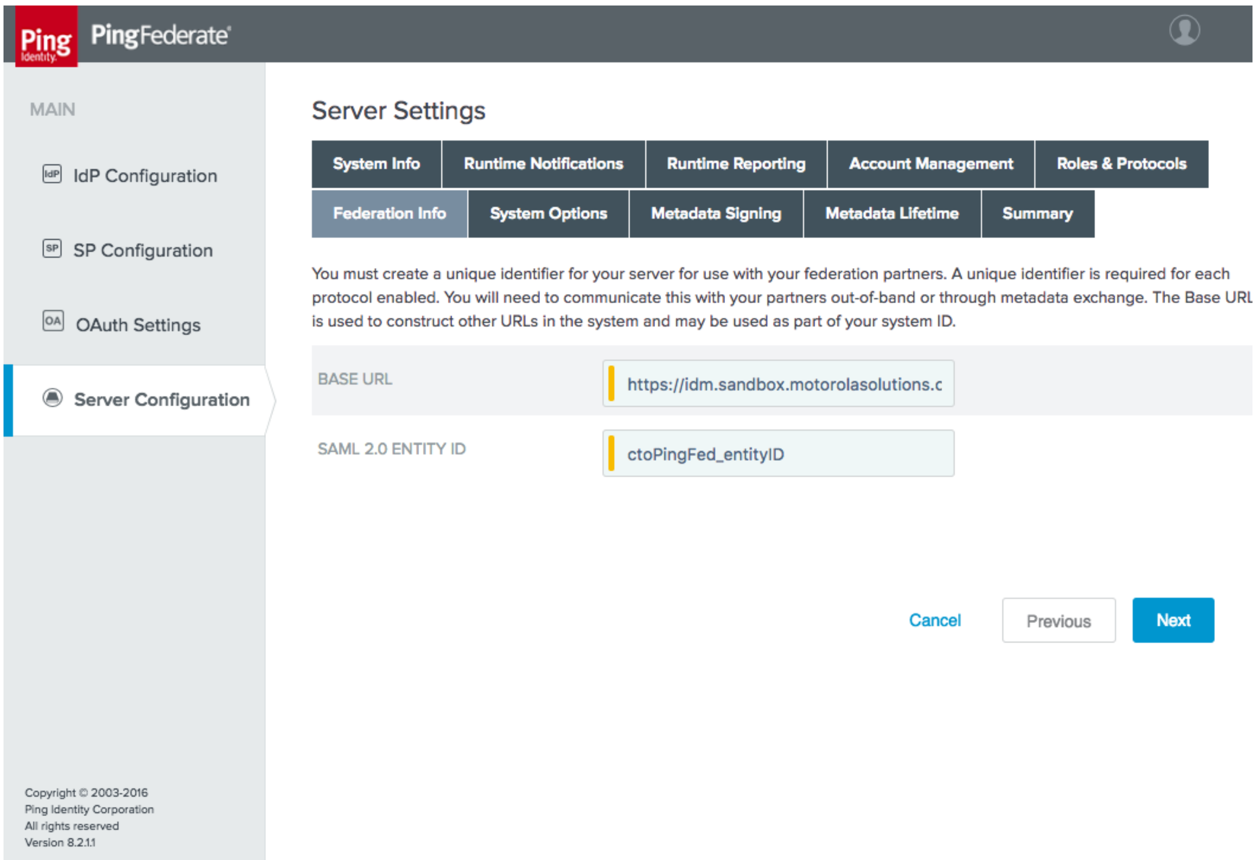
1359 **Figure 3-2 Server Roles for AS**



1360

c. Also under **Server Settings**, on the **Federation Info** tab, enter the **BASE URL** and **SAML 2.0 ENTITY ID** (Figure 3-3). The **BASE URL** should use a public DNS name that is resolvable by any federation partners. The **SAML 2.0 ENTITY ID** is simply an identifier string that must be unique among federation partners; it is recommended to be a Uniform Resource Identifier (URI), per the SAML 2.0 Core specification [22].

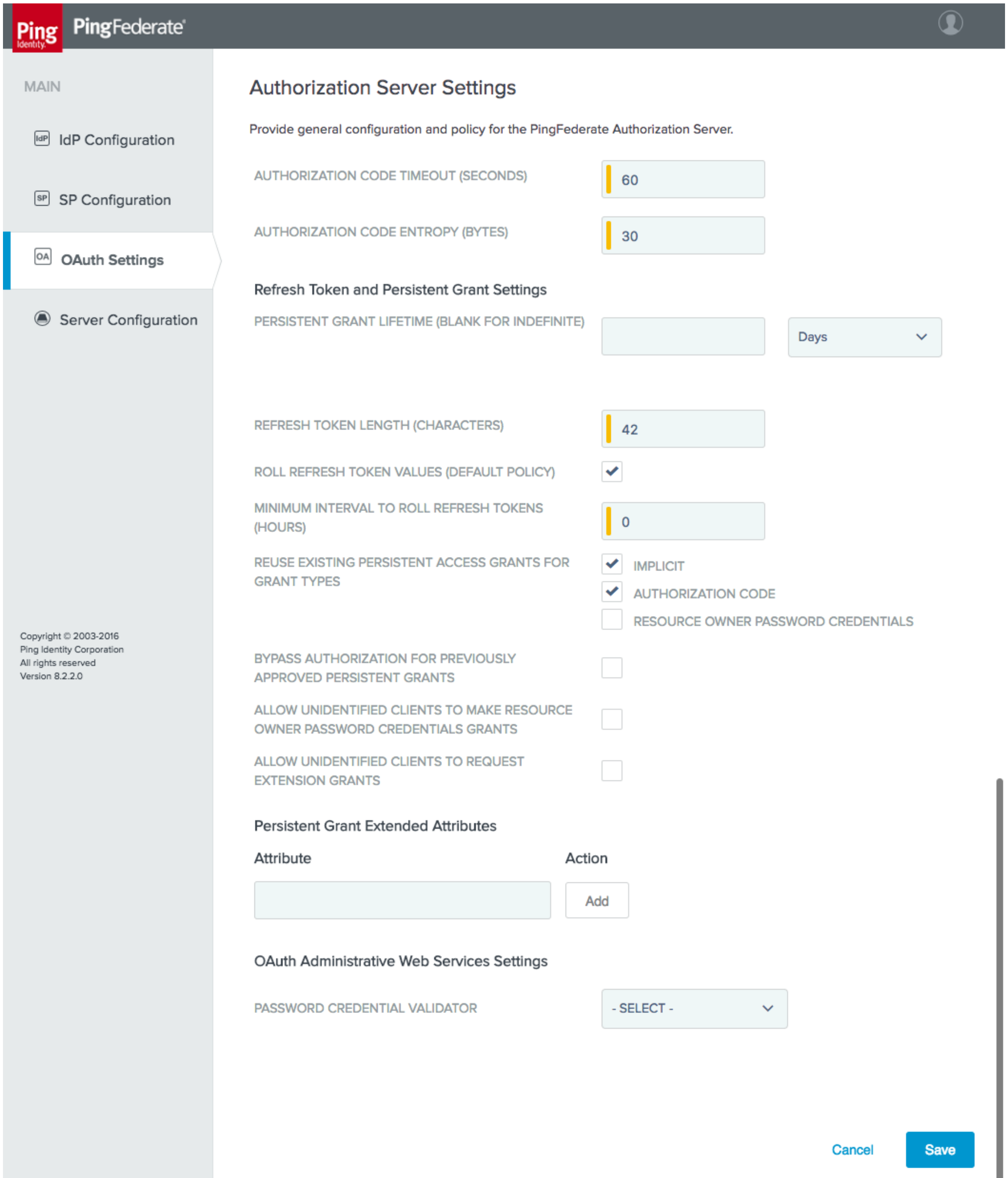
Figure 3-3 Federation Info



2. The next step is to configure the OAuth AS. Click the **OAuth Settings** section tab under **Main**.

   a. Click **Authorization Server Settings** under the **Authorization Server** header. This displays the **Authorization Server Settings** (Figure 3-4).

Figure 3-4 AS Settings

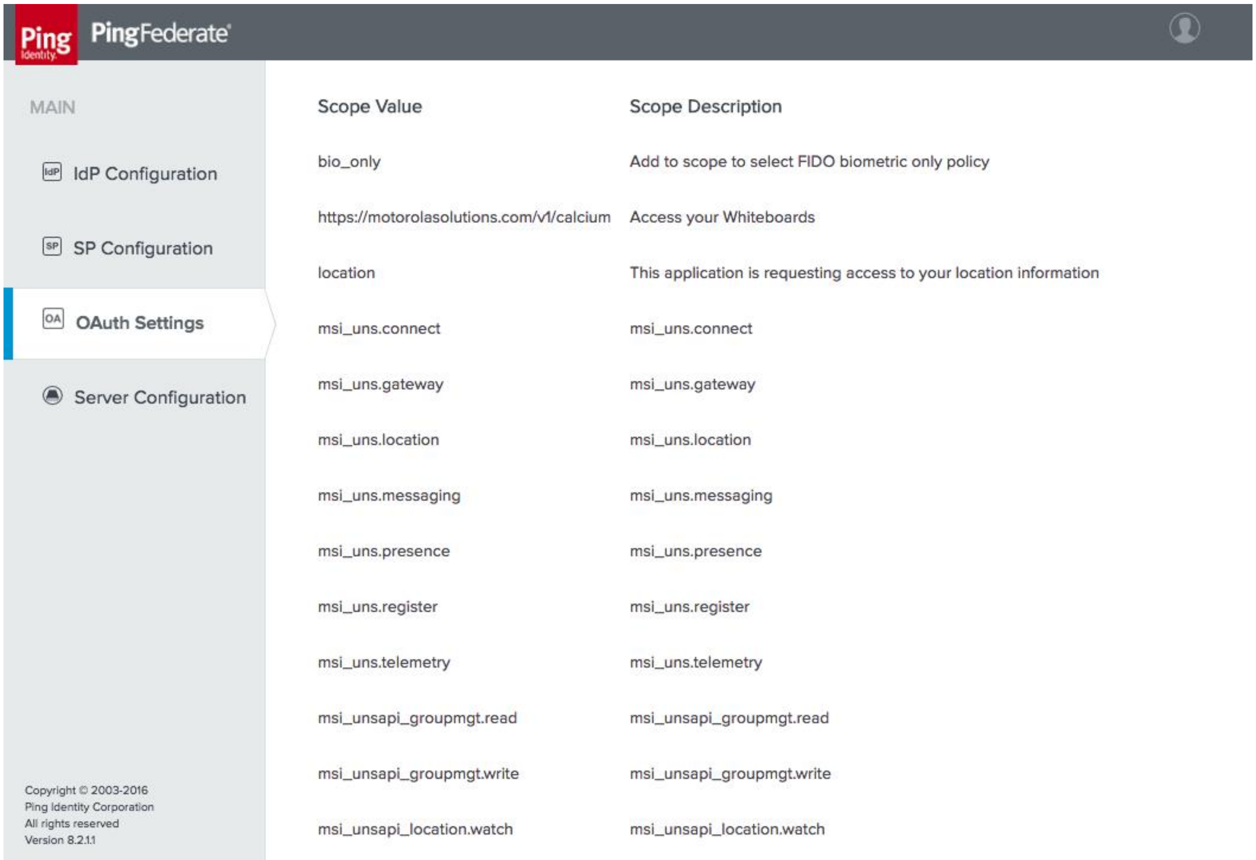


The default settings are suitable for the lab build architecture; organizations may wish to customize these default settings in accordance with organizational security policy or usage requirements. Some notes on individual settings are provided below:

- **AUTHORIZATION CODE TIMEOUT (SECONDS)**: Once an authorization code has been returned to a client, it must be exchanged for an access token within this interval. This reduces the risk of an unauthorized client obtaining an access token through brute-force guessing or intercepting a valid client's code. *Proof Key for Code Exchange (PKCE)* [23], as implemented by the AppAuth library, is another useful mechanism to protect the authorization code.
- **AUTHORIZATION CODE ENTROPY (BYTES)**: length of the authorization code returned by the AS to the client, in bytes
- **REFRESH TOKEN LENGTH (CHARACTERS)**: length of the refresh token, in characters
- **ROLL REFRESH TOKEN VALUES (DEFAULT POLICY)**: When selected, the OAuth AS generates a new refresh token value when a new access token is obtained.
- **MINIMUM INTERVAL TO ROLL REFRESH TOKENS (HOURS)**: the minimum number of hours that must pass before a new refresh token value can be issued
- **REUSE EXISTING PERSISTENT ACCESS GRANTS FOR GRANT TYPES**:
    - **IMPLICIT**: Consent from the user is requested only for the first OAuth resource request associated with the grant.
    - **AUTHORIZATION CODE**: Same as above if the **BYPASS AUTHORIZATION FOR PREVIOUSLY APPROVED PERSISTENT GRANTS** is selected; this can be used to prompt the user for authorization only once to avoid repeated prompts for the same client.
- **PASSWORD CREDENTIAL VALIDATOR**: Required for HTTP Basic authentication if the OAuth Representational State Transfer Web Service is used for managing client applications; this functionality was not used for this build.

3. Next, configure scopes, as required, for the application. Click the **OAuth Settings** section tab, and then click **Scope Management**. The specific scope values will be determined by the client application developer. Generally speaking, scopes refer to different authorizations that can be requested by the client and granted by the user. Access tokens are associated with the scopes for which they are authorized, which can limit the authorities granted to clients. Figure 3-5 shows several scopes that were added to the AS for this lab build that have specific meanings in the PSX applications suite.

Figure 3-5 Scopes



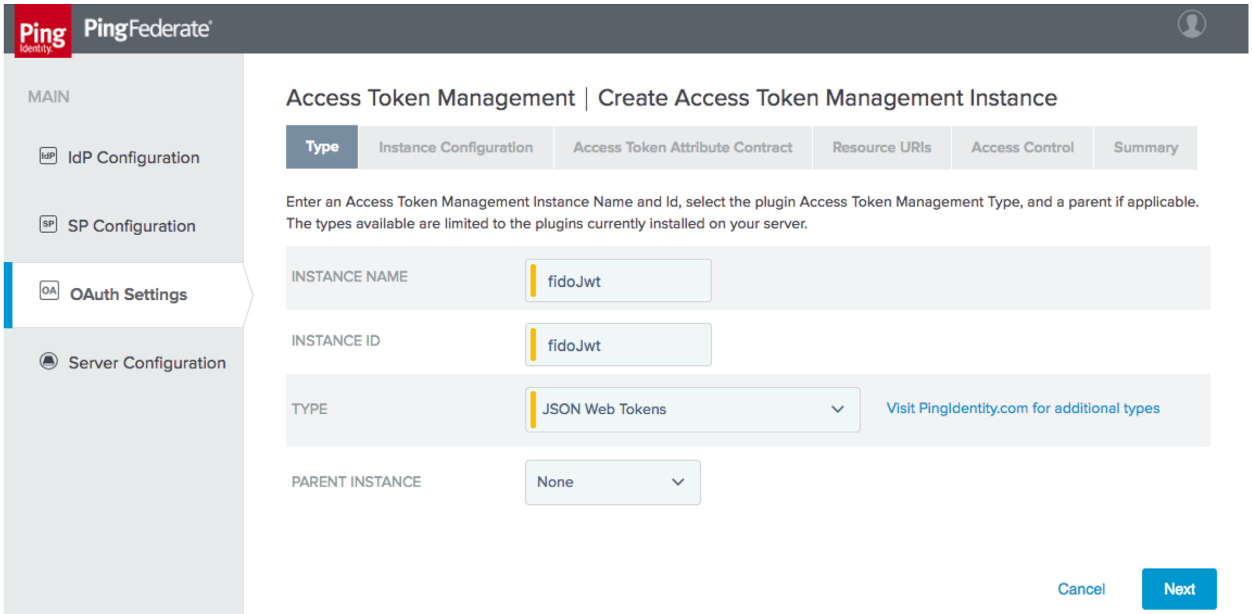
4. Define an Access Token Management Profile. This profile determines whether access tokens are issued as simple reference token strings or as JWTs. For this lab build, JWTs were used. JWTs are signed and optionally encrypted, so resource servers can validate them locally and they can contain user attributes and other information. Reference tokens are also a viable option, but resource servers must contact the AS's introspection endpoint to determine whether they are valid and must obtain the granted scopes and any other information associated with them. The Access Token Management Profile also defines any additional attributes that will be associated with the token.

    a. Create an Access Token Manager by following these steps:

        i. Click the **OAuth Settings** section tab, click **Access Token Management**, and then click **Create New Instance**.

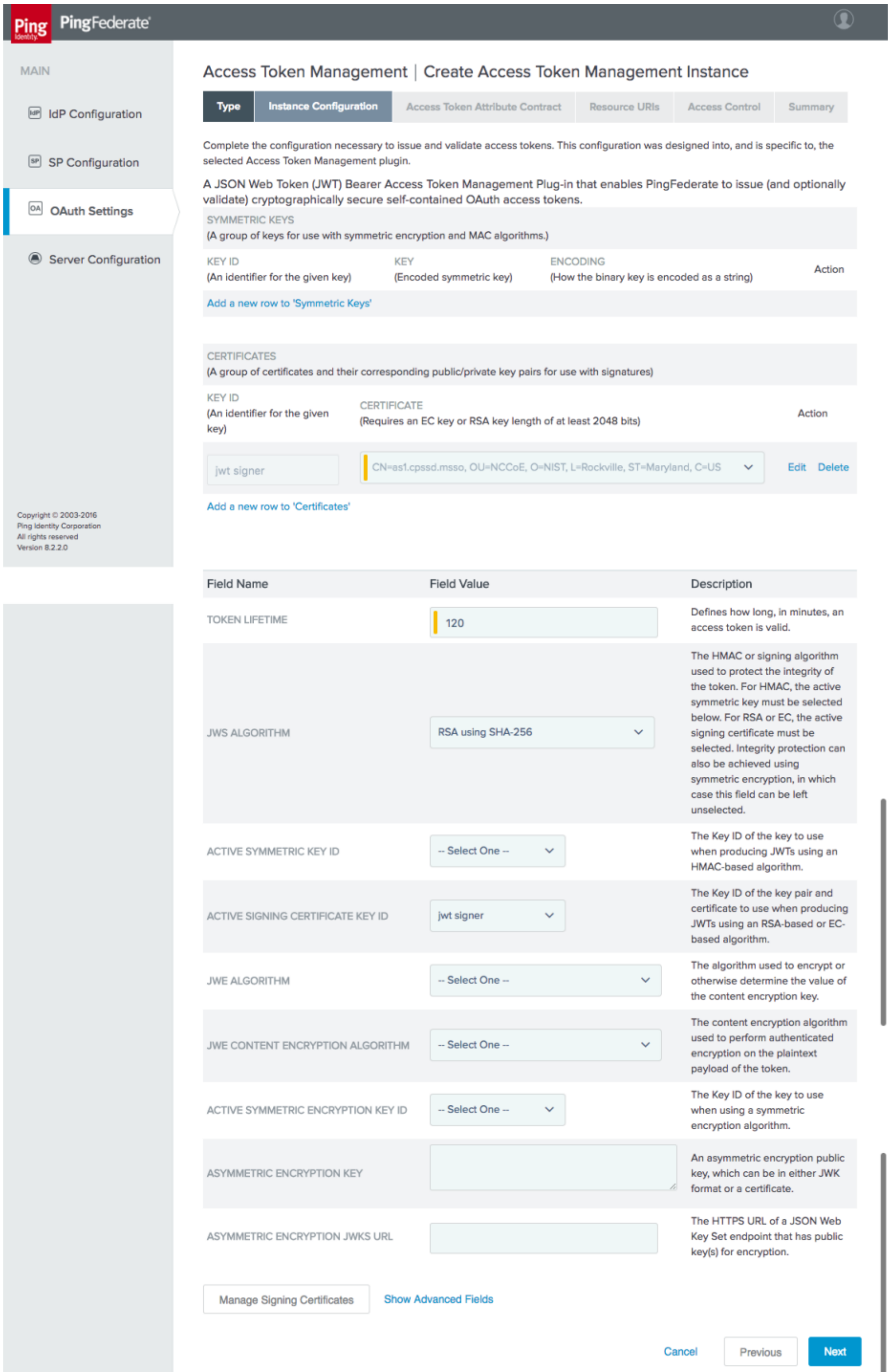
        ii. On the **Type** tab, give the instance a meaningful name and ID, and select the token type (Figure 3-6).

Figure 3-6 Access Token Management Instance



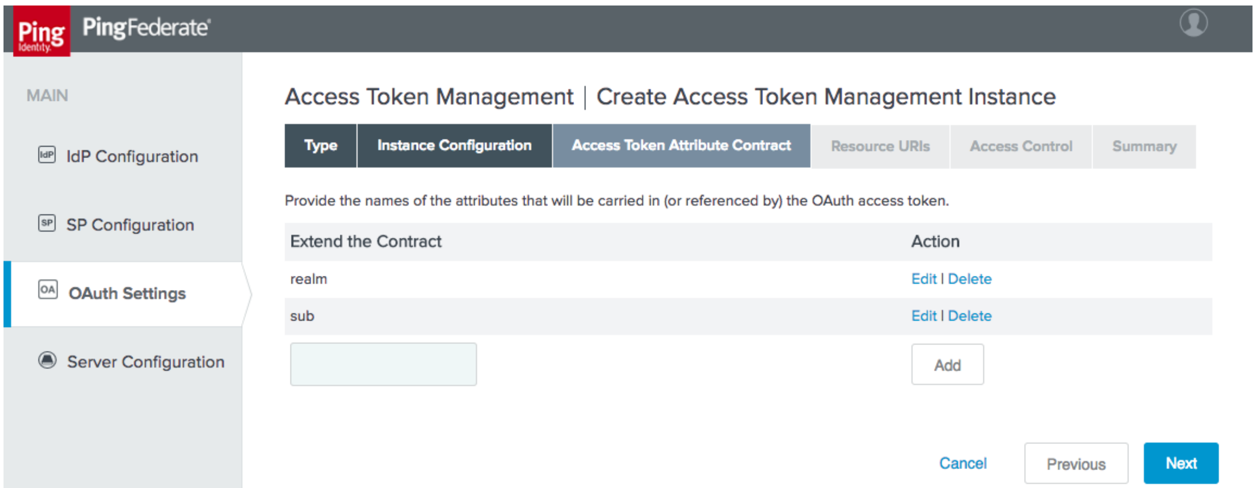
5. On the next tab, **Instance Configuration**, select a symmetric key or certificate to use for JWT signing (Figure 3-7). In this instance, a signing certificate was created as described in Section 3.2.4. Tokens can also optionally be encrypted using JSON Web Encryption (JWE) [24]; in this case, the client developer would provide a certificate in order to receive encrypted messages. JWE was not used in the lab build.

Figure 3-7 Access Token Manager Instance Configuration



6. On the **Access Token Attribute Contract** tab, add the two values **realm** and **sub** to the attribute contract (Figure 3-8).

Figure 3-8 Access Token Manager Attribute Contract



7. The **Resource URIs** and **Access Control** tabs were not used for this build. Click **Save** to complete the Access Token Manager.

8. Next, one or more OAuth clients need to be registered with the AS. In the Motorola Solutions use case, the PSX Cockpit application is registered as a client. OAuth Client registration is described for PingFederate at: https://documentation.pingidentity.com/pingfederate/pf82/index.shtml#concept_configuringClient.html.

   To create a new client, click the **OAuth Settings** section tab, click **Clients**, and then click **Create New**. Clients are displayed on the rightmost side of the screen in the **OAuth Settings** window. Once **Create New** is clicked, the screen shown in Figure 3-9 and Figure 3-10 will appear. Due to the vertical size of the pages of this document, the screenshot is divided into two parts for legibility.

Figure 3-9 OAuth Client Registration, Part 1

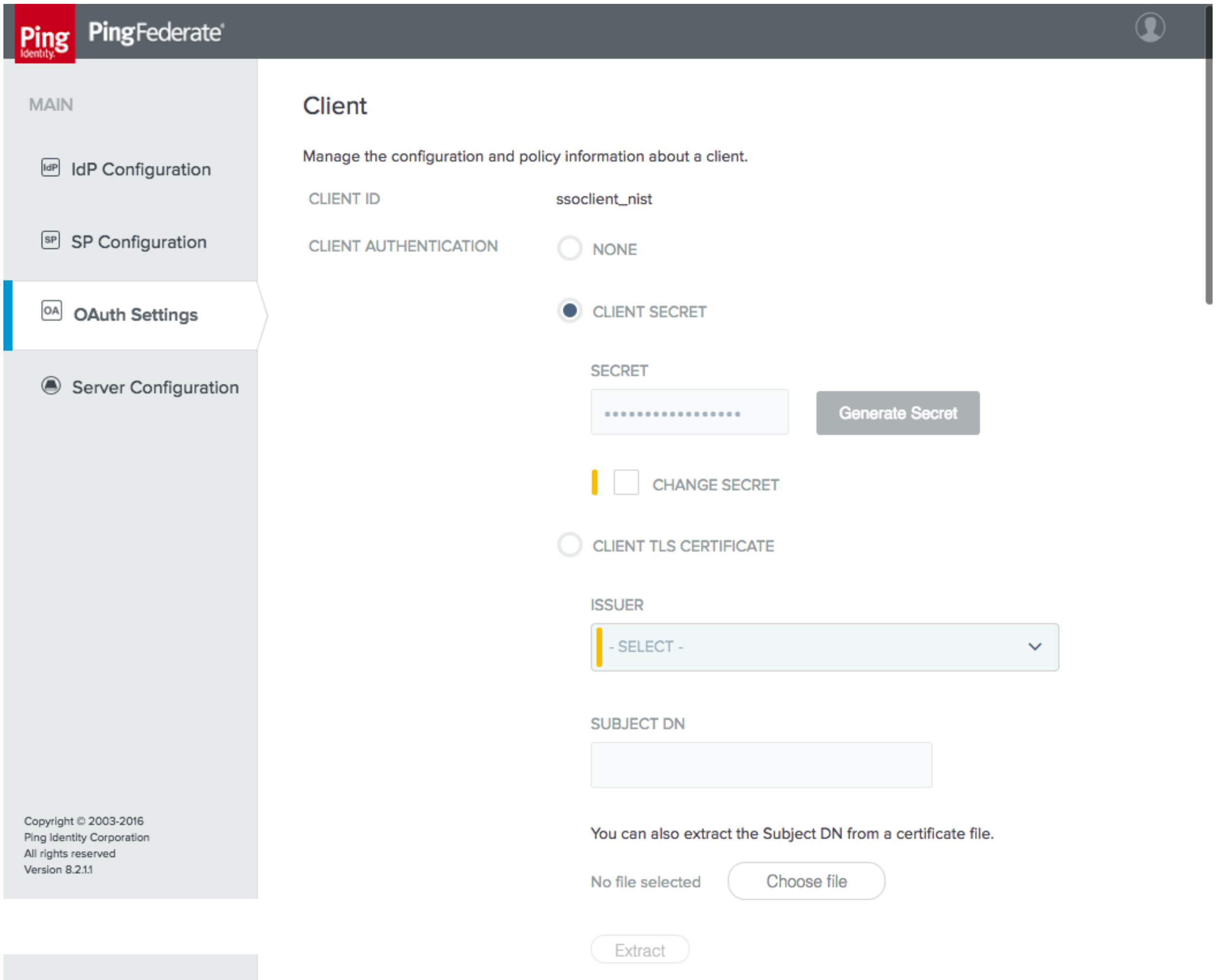
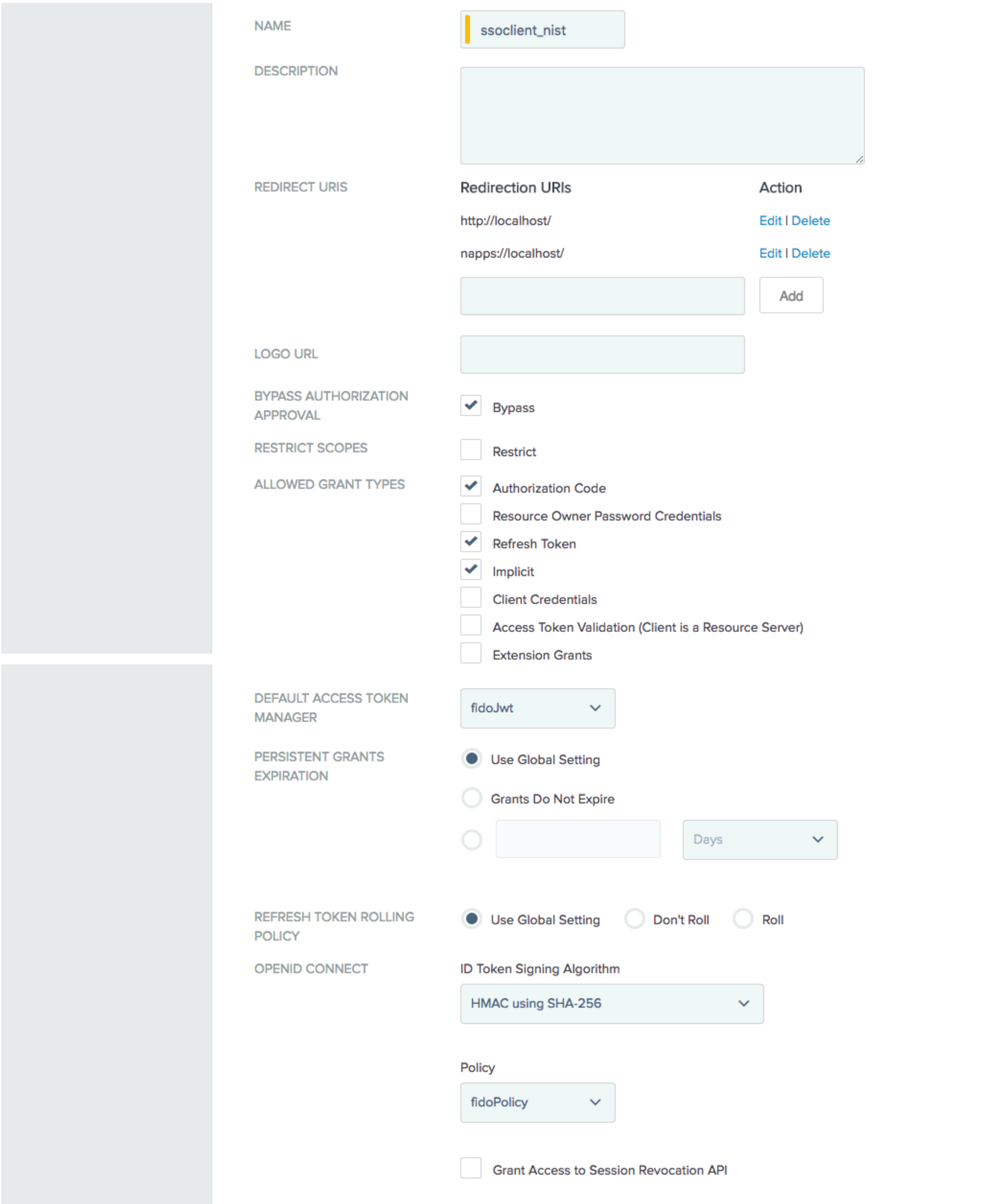


Figure 3-10 OAuth Client Registration, Part 2



The following are notes on the parameters on this screen:

- **CLIENT ID**: This is a required parameter. This is the unique identifier accompanied with each request that is presented to the AS's token and authorization endpoints. For this lab build, Motorola Solutions assigned a client ID of "ssoclient_nist" for the instances of their applications on the test devices.
- **CLIENT AUTHENTICATION**: May be set to **NONE**, **CLIENT SECRET** (for HTTP basic authentication), or **CLIENT TLS CERTIFICATE**. For native mobile application clients, there is no way to protect a client secret or private key and provide it to all instances of the application with any guarantee of confidentiality, as a user might be able to reverse-engineer the application to obtain any secrets delivered with it, or to debug the application to capture any secrets delivered at run-time. Therefore, a value of **NONE** is acceptable for native mobile applications, when mitigated with the use of PKCE. For web clients, servers are capable of protecting secrets; therefore, some form of client authentication should be required.
- **REDIRECT URIS**: Redirect URIs are the URIs to which the OAuth AS may redirect the resource owner's user-agent after authorization is obtained. A redirect URI is used with the **Authorization Code** and **Implicit** grant types. This value is typically provided by the application developer to the AS administrator.
- **ALLOWED GRANT TYPES**: These are the allowed grant types for the client. For this lab build, the **Authorization Code** grant type was used exclusively.
- **DEFAULT ACCESS TOKEN MANAGER**: This is the Access Token Manager profile to be used for this client.
- **PERSISTENT GRANTS EXPIRATION**: This setting offers the option to override the global AS persistent grants settings for this client.
- **REFRESH TOKEN ROLLING POLICY**: This setting offers the option to override the global AS token rolling policy settings for this client.

Once these values are set, click **Save** to store the client.

This completes the required configuration for the AS's interactions with OAuth clients. The following section outlines the steps to set up the AS to authenticate users.

3.4 How to Configure the OAuth 2 AS for Authentication

In this section, the AS is configured to authenticate users locally or through federation with a SAML or OIDC IdP. These settings depend on the selection of roles and protocols, as shown in Figure 3-2, therefore, ensure that has been completed before proceeding.

3.4.1 How to Configure Direct Authentication

The AS was configured to authenticate users with FIDO UAF authentication. This depends on the NNAS, Nok Nok Labs Gateway, and Nok Nok Labs UAF Plugin for PingFederate. See Section 5 for the installation and configuration instructions for those components. This section assumes that those components have already been installed and configured.

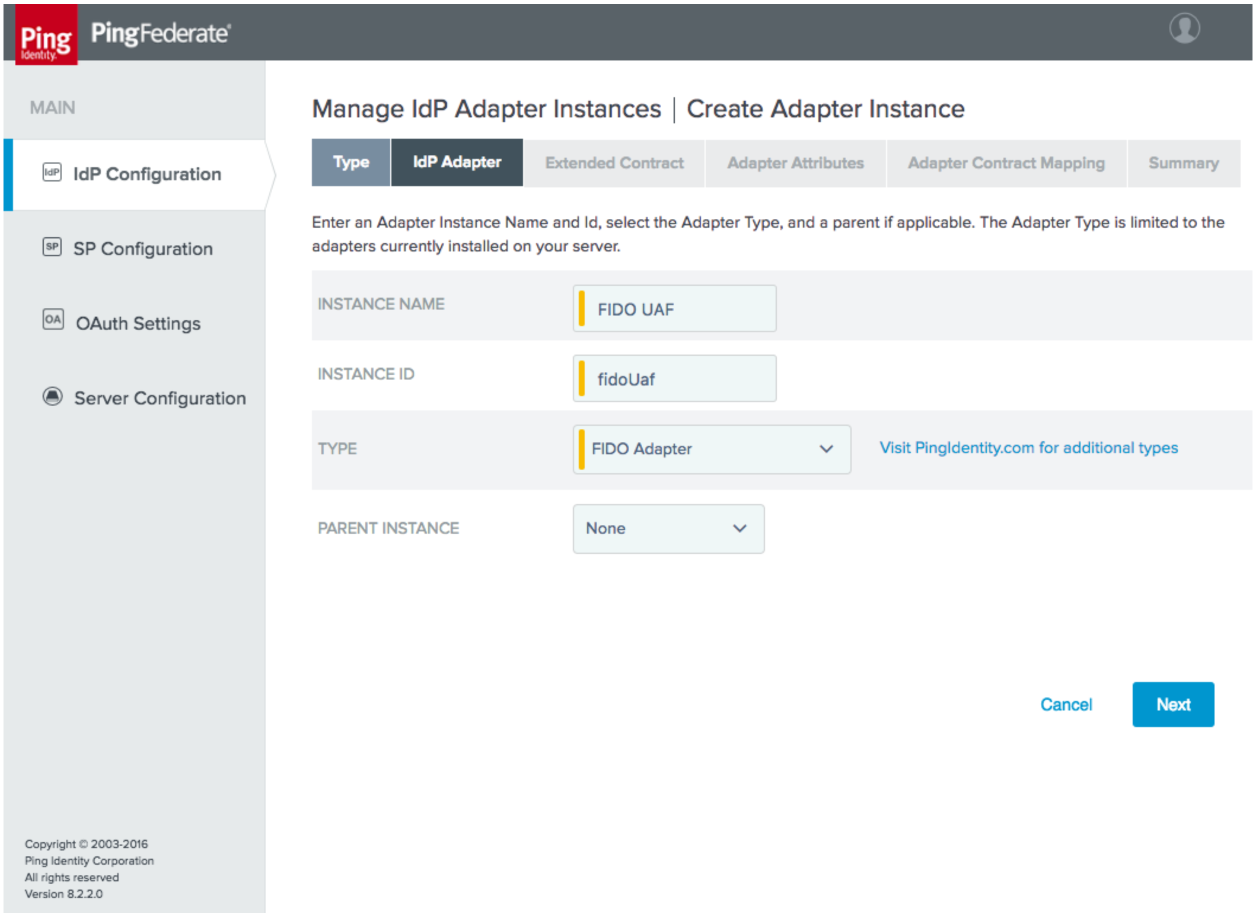
3.4.1.1 Configure Adapter Instance

1. First, an instance of the FIDO UAF adapter must be configured. Click the **IdP Configuration** section tab, and then click **Adapters** under **Application Integration**.

2. Click **Create New Instance** to create an IdP adapter instance. This will bring up the new tabbed screen shown in Figure 3-11.

    a. On the **Type** tab, the **INSTANCE NAME** and **INSTANCE ID** are internal identifiers and can be set to any meaningful values. The **TYPE** selection, “FIDO Adapter,” will not appear until the Nok Nok Labs UAF plugin has been successfully installed on the PingFederate server as described in Section 5.

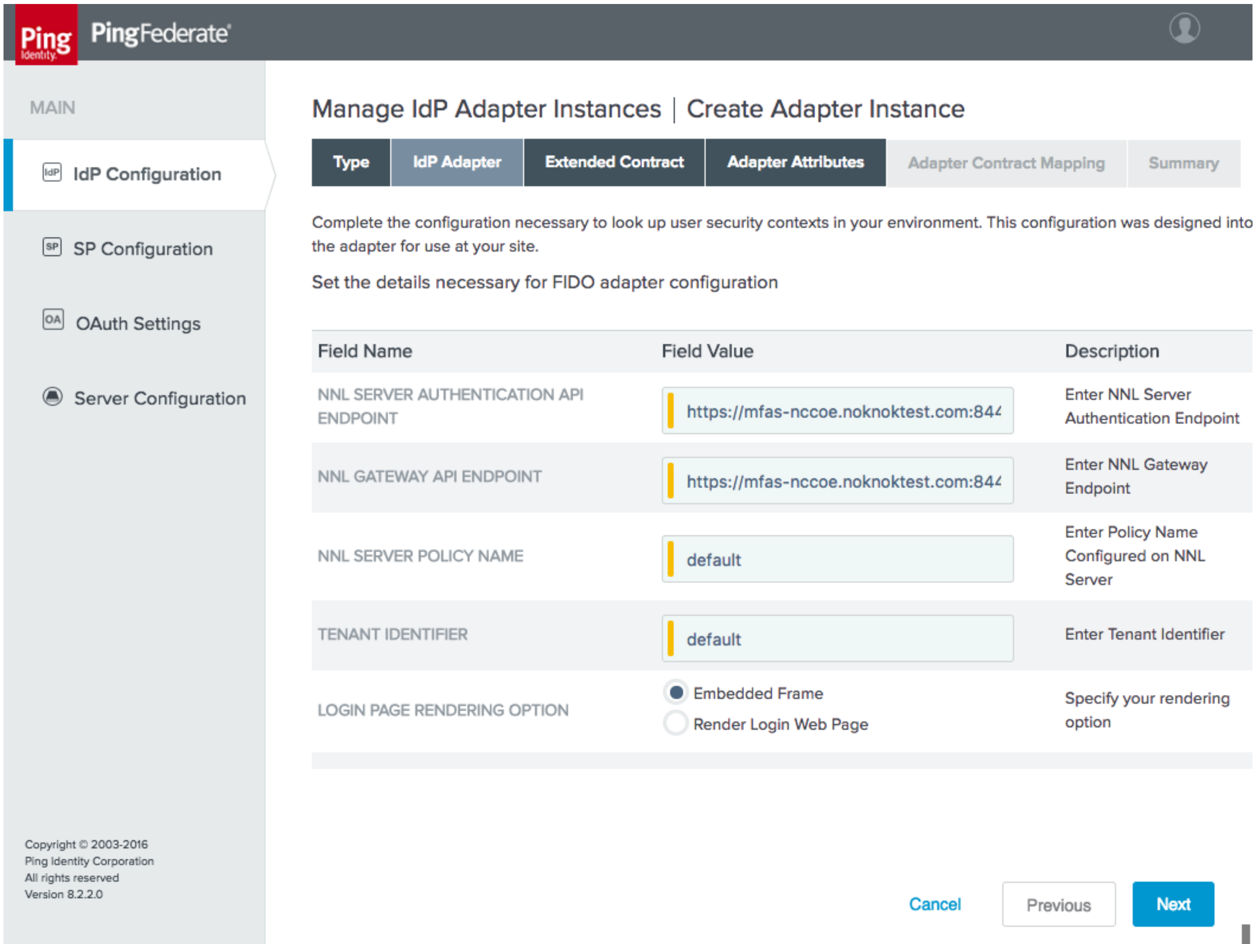
Figure 3-11 Create Adapter Instance



b. On the **IdP Adapter** tab, specify the URLs for the Nok Nok Labs API and Gateway endpoints (Figure 3-12).

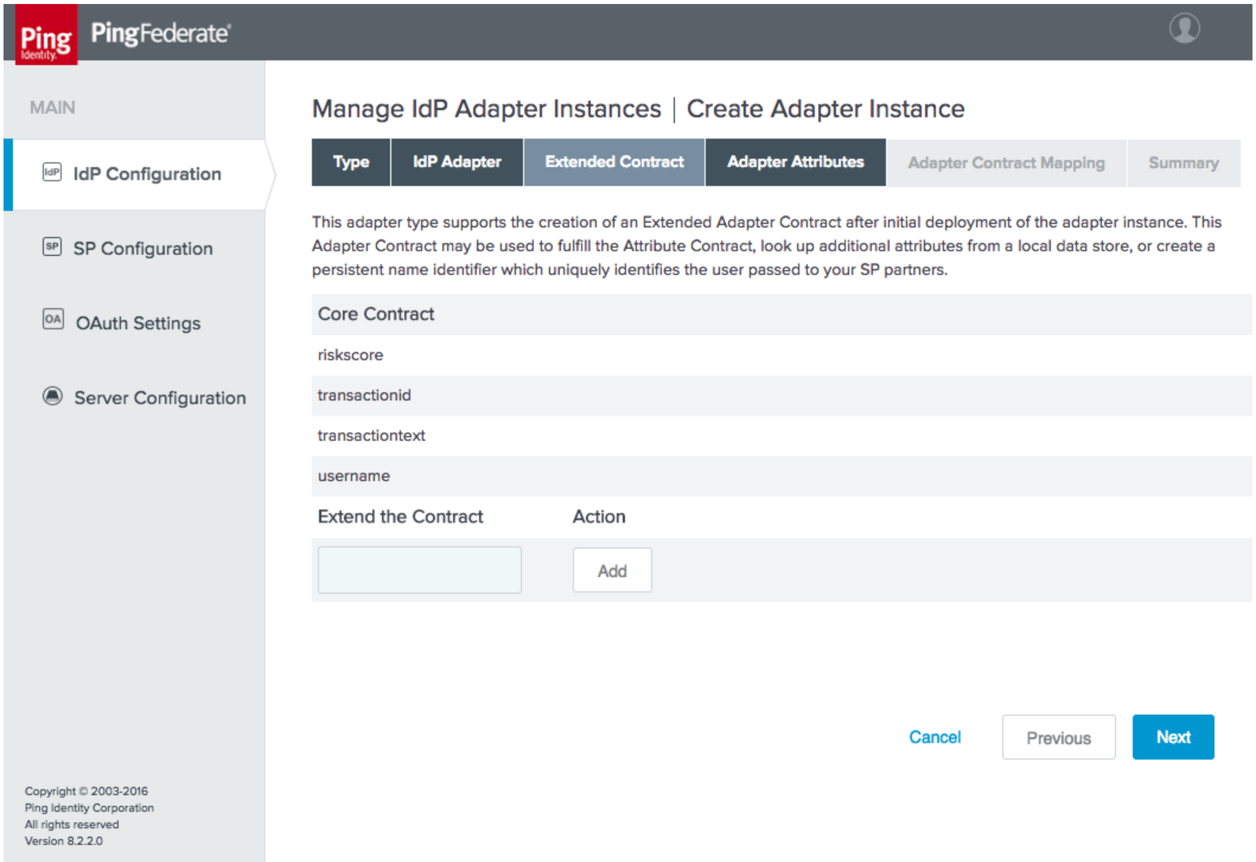
i. The **NNL SERVER POLICY NAME** field can be used to select a custom policy, if one has been defined on the Nok Nok Labs server; for this build, the default policy was used.

Figure 3-12 FIDO Adapter Settings



c. The **Extended Contract** tab was also left as the default for the adapter, which provides the **riskscore**, **transactionid**, **transactiontext**, and **username** values (Figure 3-13). If desired, additional attributes could be added to the contract and looked up in a user directory, based on the username returned from the adapter.

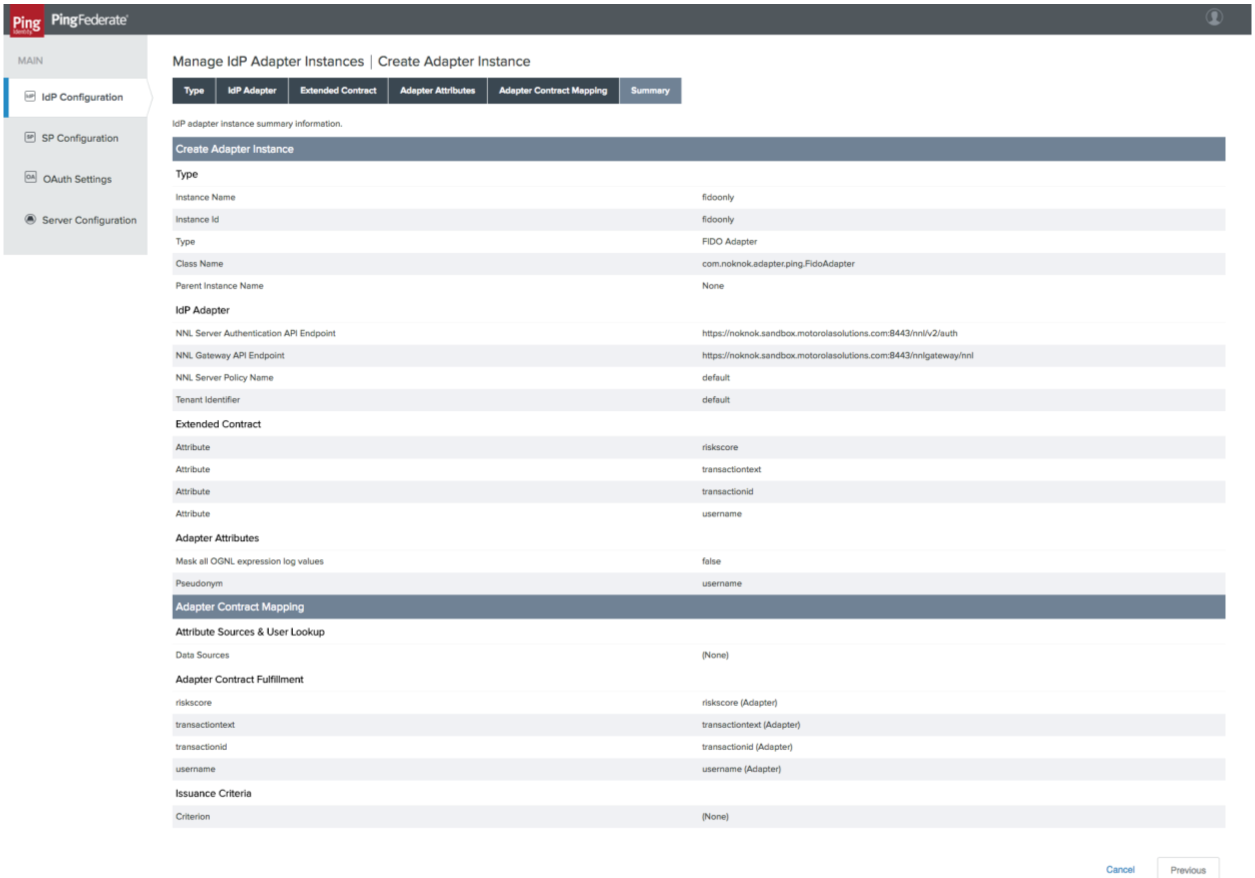
Figure 3-13 FIDO Adapter Contract



d. On the **Adapter Attributes** tab, select the **Pseudonym** checkbox for **username**. Pseudonyms were not used in the lab build, but a selection is required on this tab.

e. There is no need to configure an adapter contract, unless attributes have been added on the **Extended Contract** tab. Clicking **Done** and then **Save** completes the configuration of the adapter. Clicking the adapter name in the list of adapters brings up the Adapter Instance **Summary** tab, which lists all of the configured settings (Figure 3-14).

Figure 3-14 FIDO Adapter Instance Summary

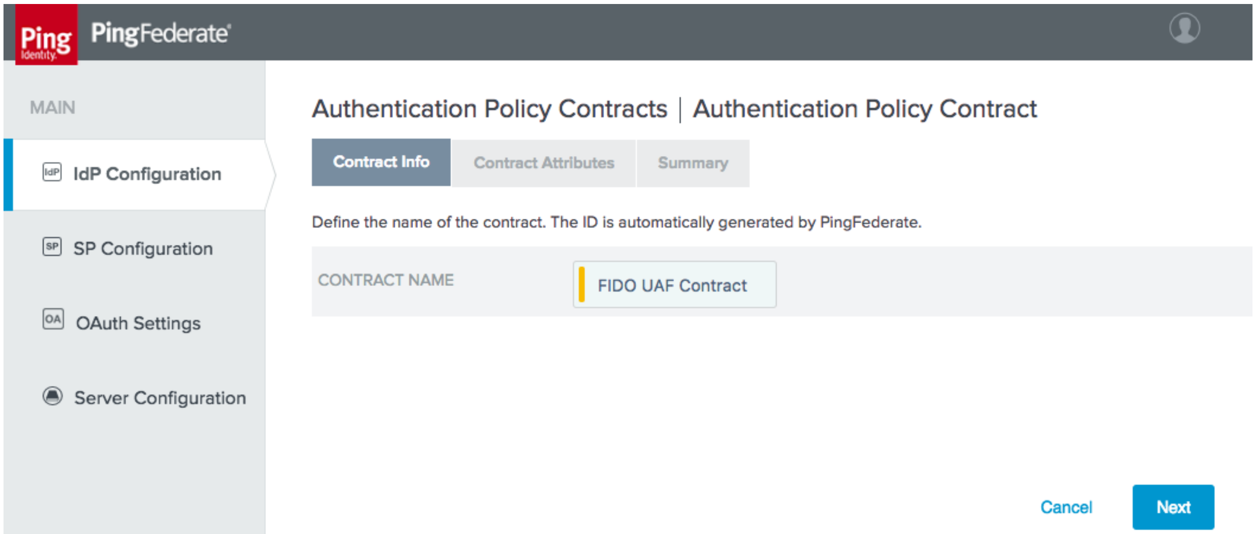


Some additional configurations are needed to tie this authentication adapter to the issuance of an OAuth token. It is possible to directly map the adapter to the access token context, but because the adapter will be incorporated into an authentication policy in this case, an Authentication Policy Contract Mapping is used instead.

3.4.1.2 Create Policy Contract

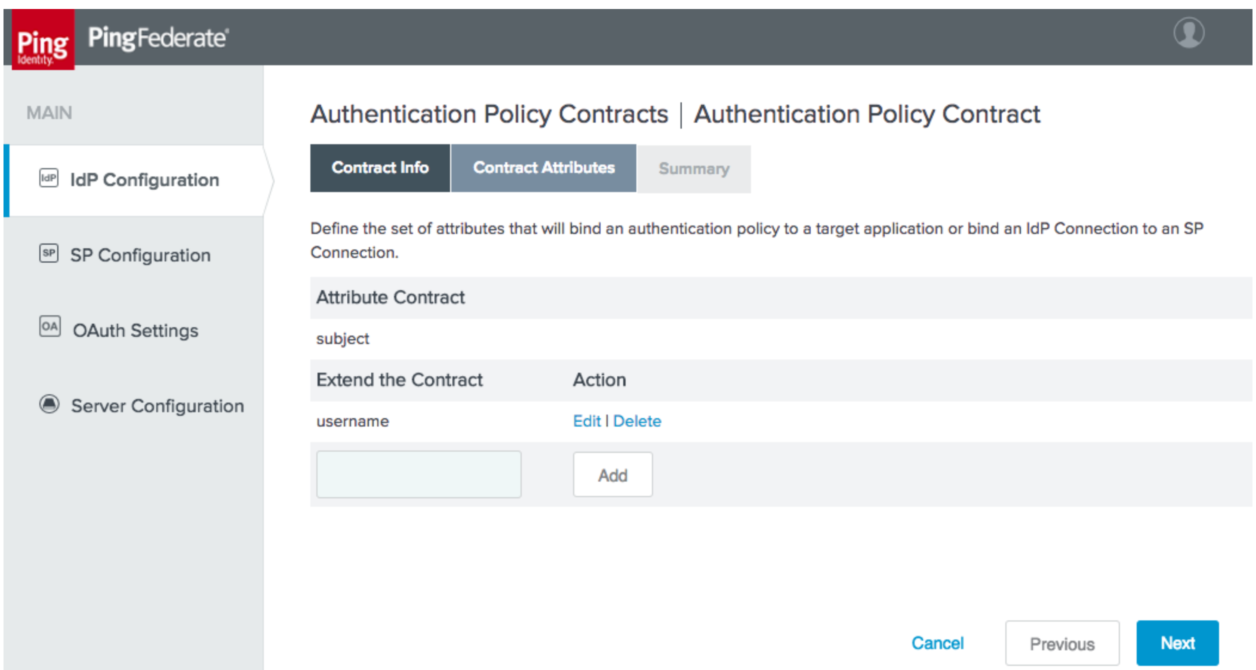
1. To create a Policy Contract, navigate to the **IdP Configuration** section tab, and select **Policy Contracts** under **Authentication Policies**. A policy contract defines the set of attributes that will be provided by an authentication policy.
2. Click **Create New Contract**.
    a. On the **Contract Info** tab, give the contract a meaningful name (Figure 3-15).

Figure 3-15 Policy Contract Information



b. On the **Contract Attributes** tab, add a value called **username** (Figure 3-16).

Figure 3-16 Policy Contract Attributes

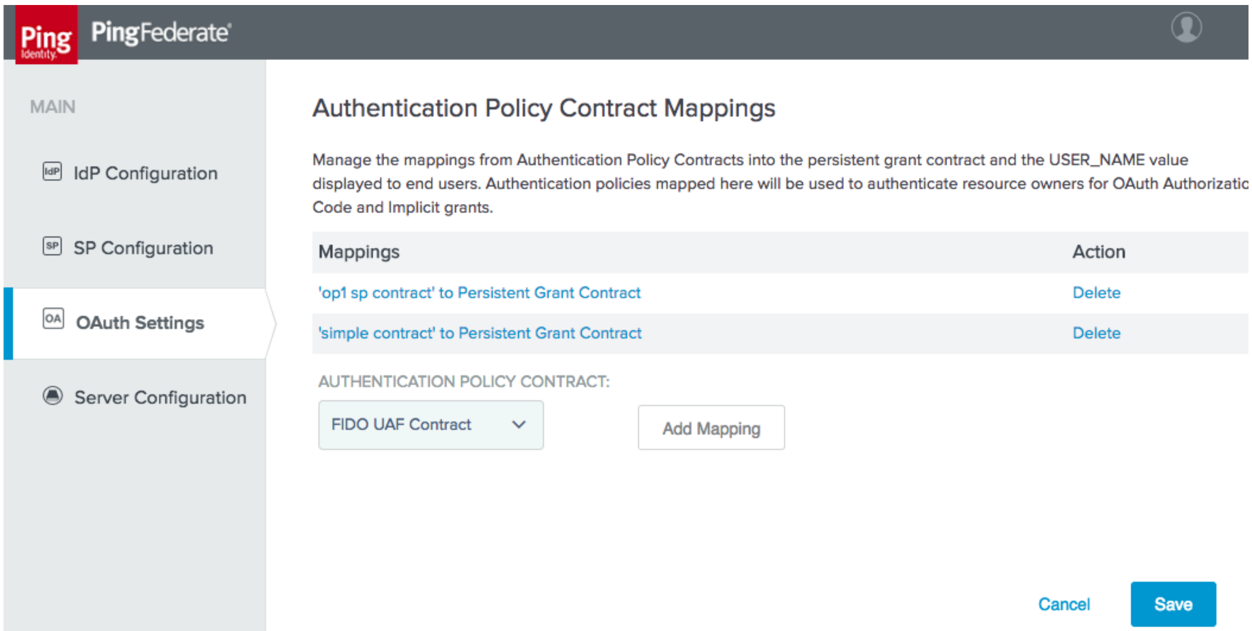


c. Click **Done**, and then click **Save** to save the new contract.

3.4.1.3 Create Policy Contract Mapping

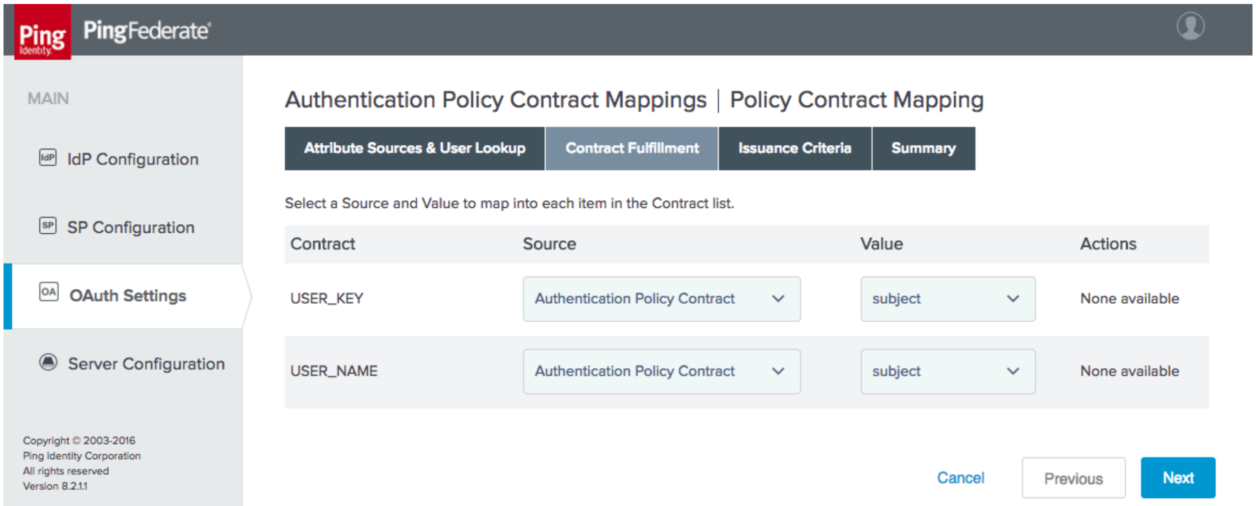
1. Create a mapping from the policy contract to the OAuth persistent grant. Click the **OAuth Settings** section tab, and then click **Authentication Policy Contract Mapping** under **Token & Attribute Mapping**.
    a. Select the newly created policy contract, and then click **Add Mapping** (Figure 3-17).

Figure 3-17 Create Authentication Policy Contract Mapping



2. An attribute source could be added at this point to look up additional user attributes, but this is not necessary. Click **Save**.
3. Skip the **Attribute Sources & User Lookup** tab.
4. On the **Contract Fulfillment** tab, map both **USER_KEY** and **USER_NAME** to the **subject** value returned from the policy contract (Figure 3-18).

Figure 3-18 Authentication Policy Contract Fulfillment



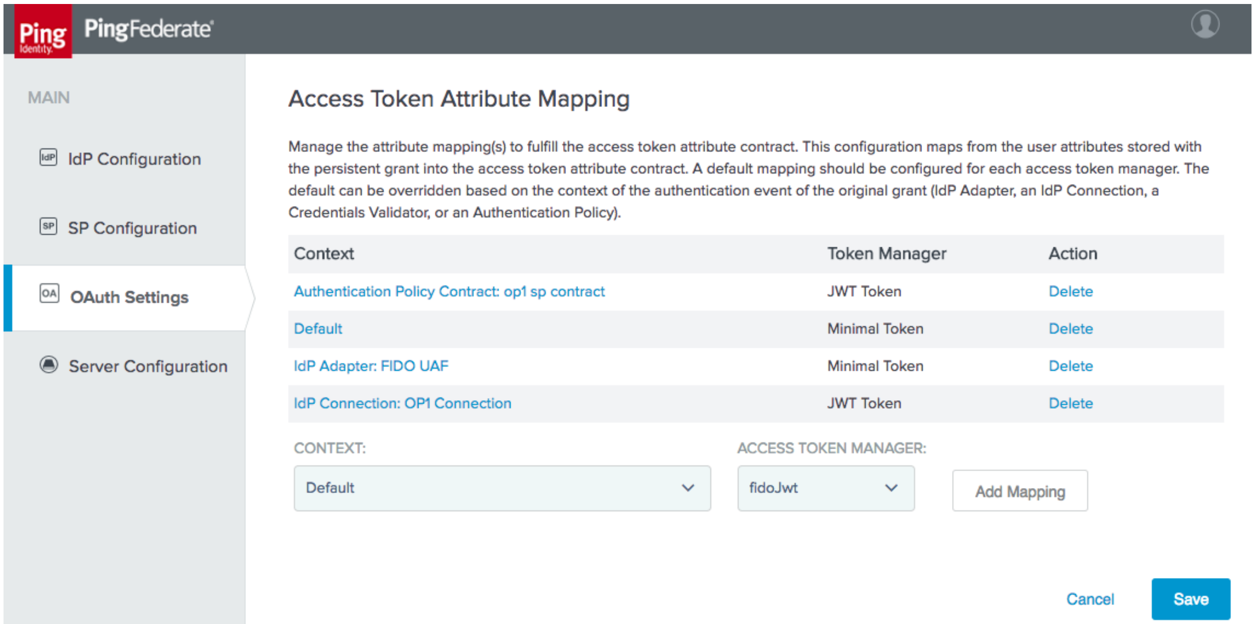
5. No issuance criteria were specified. Click **Next**, and then click **Save** to complete the mapping.

3.4.1.4 Create Access Token Mapping

Finally, an access token mapping needs to be created. In this simple case, the adapter only provides a single attribute (username) and it is stored in the persistent grant, so a default attribute mapping can be used.

1. On the **OAuth Settings** section tab, under **Token & Attribute Mapping**, click **Access Token Mapping**.
   a. Select **Default** for the **CONTEXT** (Figure 3-19).
   b. Select the **ACCESS TOKEN MANAGER** created previously (Figure 3-19).

Figure 3-19 Create Access Token Attribute Mapping

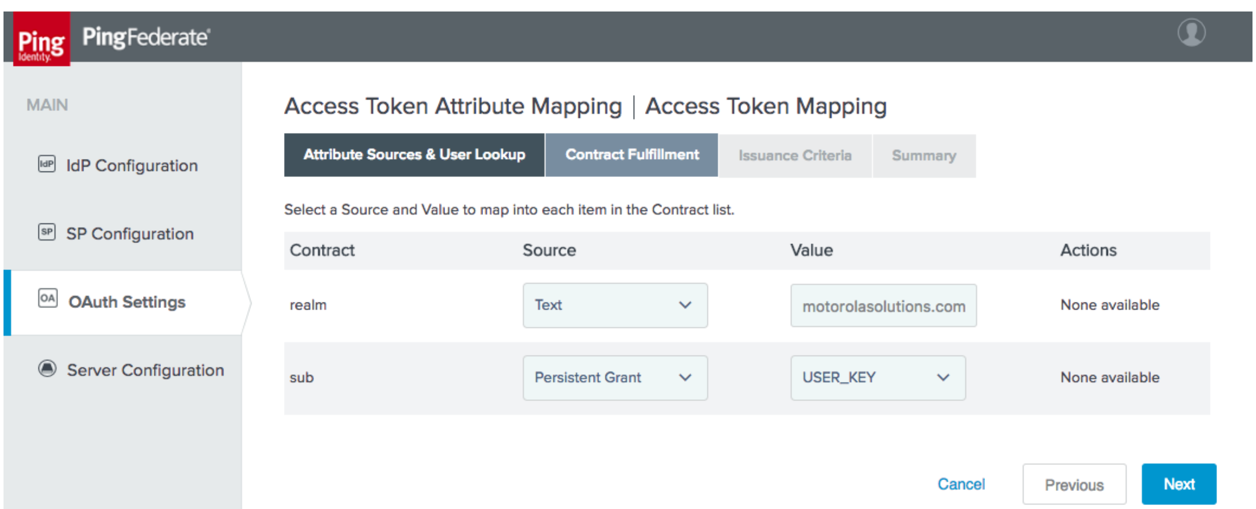


c. Click **Add Mapping**.

d. Click **Next** to skip the **Attribute Sources & User Lookup** tab.

e. On the **Contract Fulfillment** tab, configure sources and values for the **realm** and **sub** contracts (Figure 3-20). In this case, **realm** is set to the text string **motorolasolutions.com**. Click **Next**.

Figure 3-20 Access Token Mapping Contract Fulfillment



f. Click **Next** through the **Issuance Criteria** tab, and then click **Save**.

2. To complete the setup for direct authentication, the FIDO UAF adapter needs to be included in an authentication policy as described in Section 3.4.4.2.

3.4.2 How to Configure SAML Authentication

This section explains how to configure the AS to accept SAML authentication assertions from a SAML 2.0 IdP. This configuration is for RP-initiated SAML web browser SSO, where the authentication flow begins at the AS and the user is redirected to the IdP. Here, it is assumed that all of the steps outlined in Section 3.4 have been completed, particularly enabling the SP role and protocols.

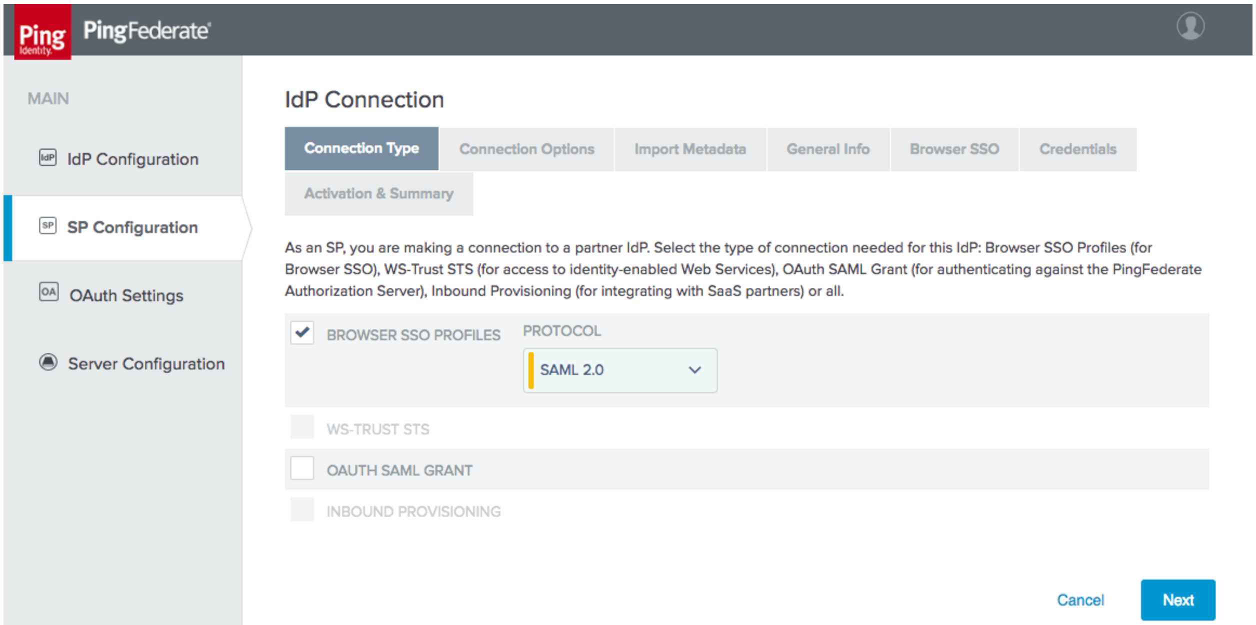
3.4.2.1 Create IdP Connection

Establishing the relationship between the AS and IdP requires coordination between the administrators of the two servers, which will typically belong to two separate organizations. The administrators of the SAML IdP and RP will need to exchange their **BASE URL** and **SAML 2.0 ENTITY ID** values (available on the **Federation Info** tab under **Server Settings**) to complete the configuration. The IdP administrator must also provide the signing certificate of the IdP. If assertions will be encrypted, the AS administrator will need to provide the IdP administrator with the certificate to be used for the public key. Alternatively, administrators can export their SAML metadata and provide it to the other party to automate parts of the setup.

1. On the **SP Configuration** section tab, click **Create New** under **IdP Connections**.

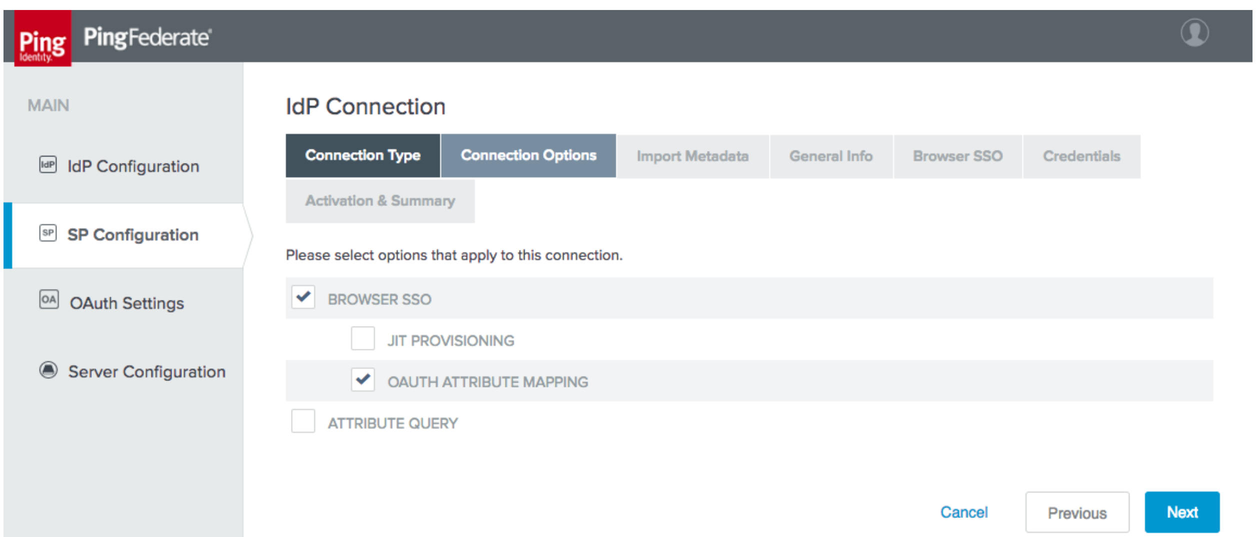
   a. On the **Connection Type** tab, select **BROWSER SSO PROFILES**, and choose **SAML 2.0** for the **PROTOCOL** (Figure 3-21). If these options are not present, ensure that the roles are selected correctly in **Server Settings**.

Figure 3-21 Create IdP Connection



b. On the **Connection Options** tab, select **BROWSER SSO**, and then under it, **OAUTH ATTRIBUTE MAPPING** (Figure 3-22).

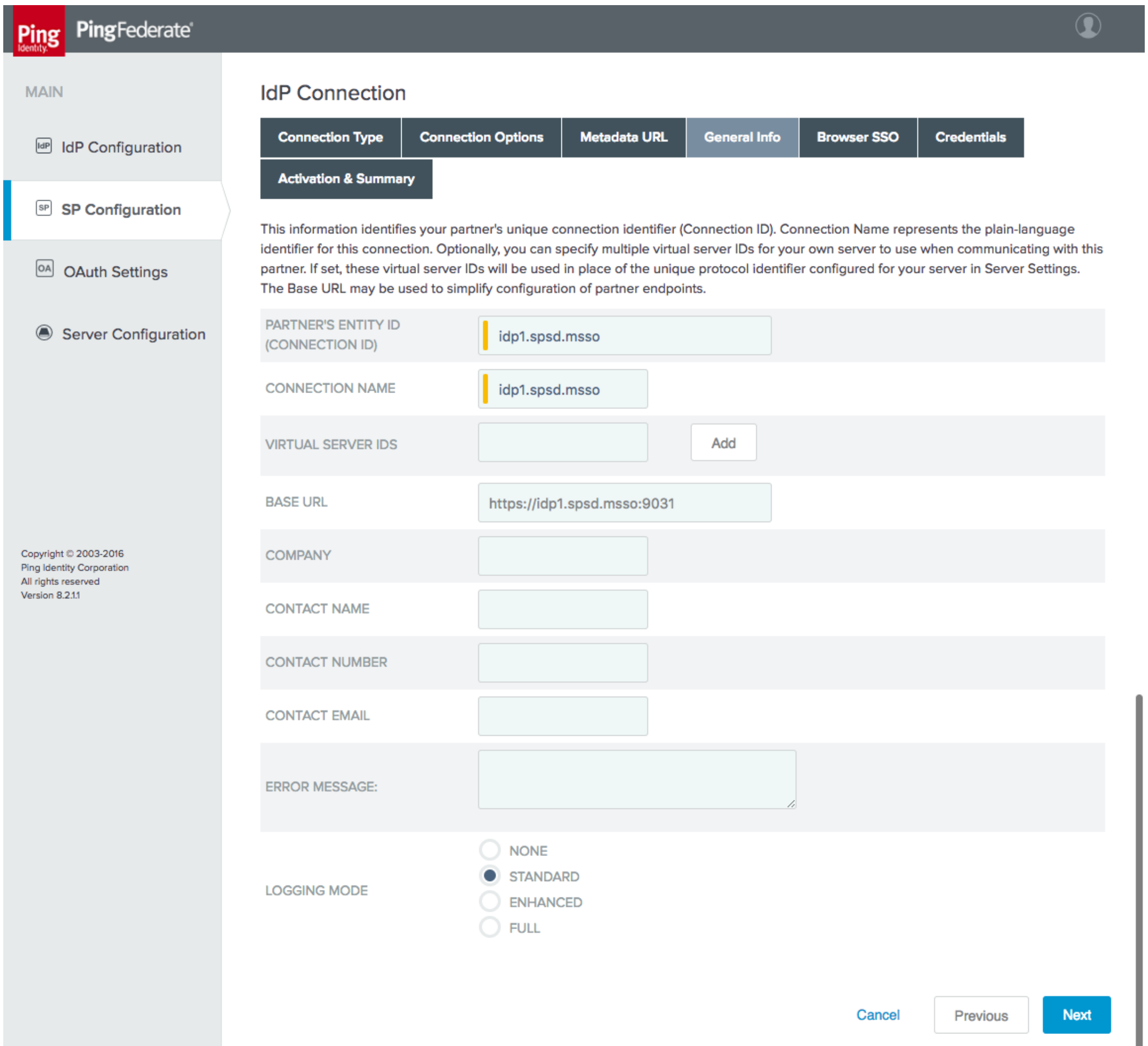
Figure 3-22 IdP Connection Options



c. Metadata import was not configured for the lab build; therefore, skip the **Import Metadata** tab.

d. On the **General Info** tab, enter the **PARTNER'S ENTITY ID (CONNECTION ID)** and **BASE URL** of the IdP, and provide a **CONNECTION NAME** (Figure 3-23).

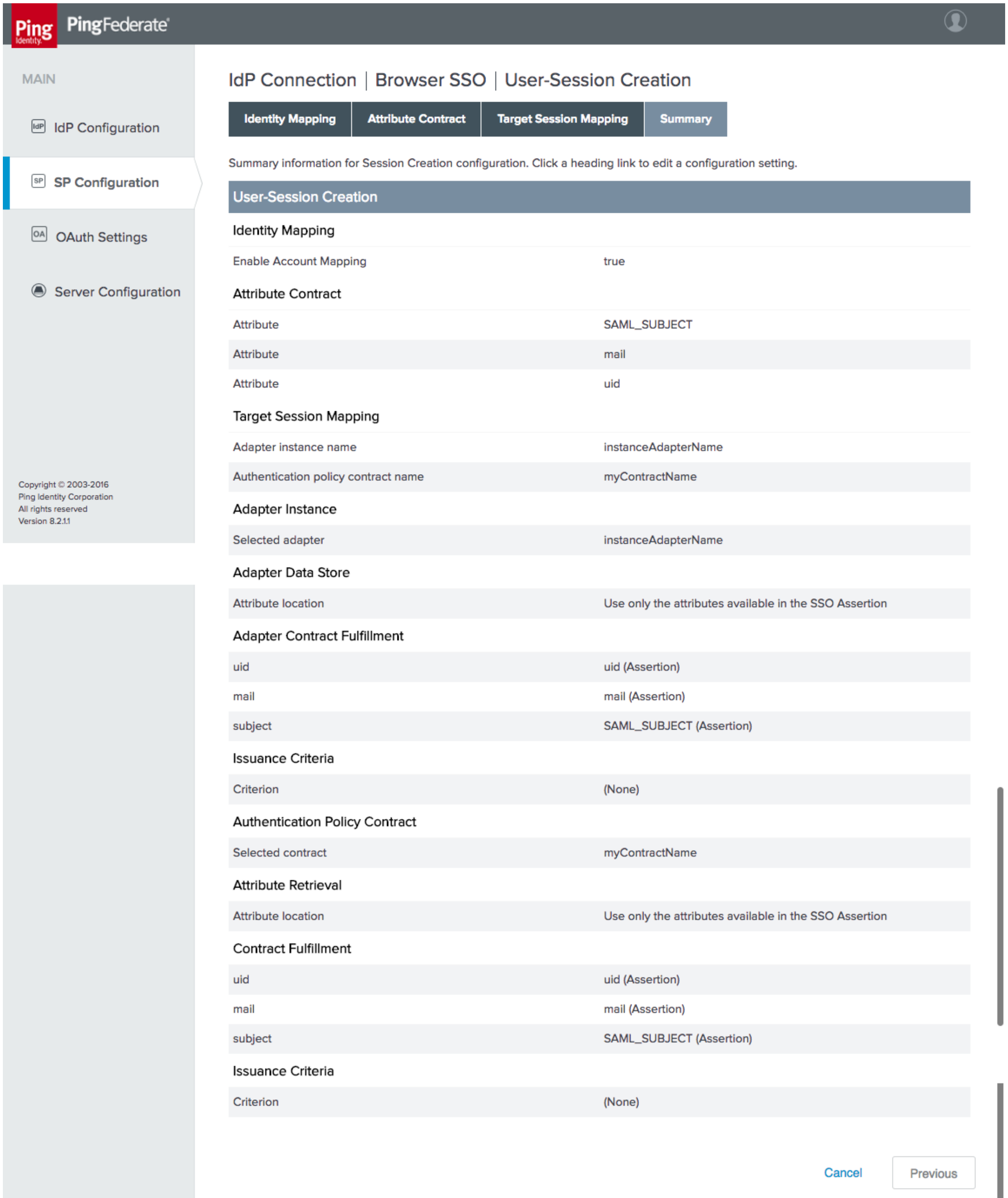
Figure 3-23 IdP Connection General Info



e. On the **Browser SSO** tab, click **Configure Browser SSO**. The Browser SSO setup has multiple sub-pages.

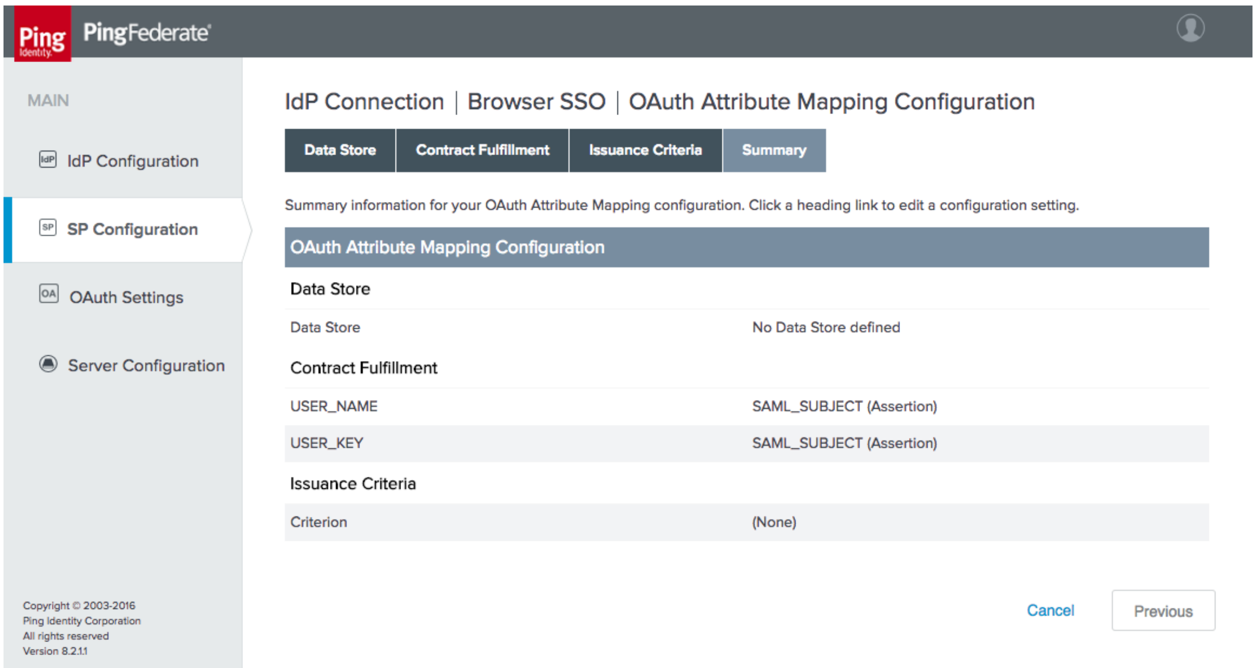
i. On the **SAML Profiles** tab, select **SP-Initiated SSO**. The **User-Session Creation** settings are summarized on the **Summary** tab; they extract the user ID and email address from the SAML assertion (Figure 3-24).

Figure 3-24 IdP Connection–User-Session Creation



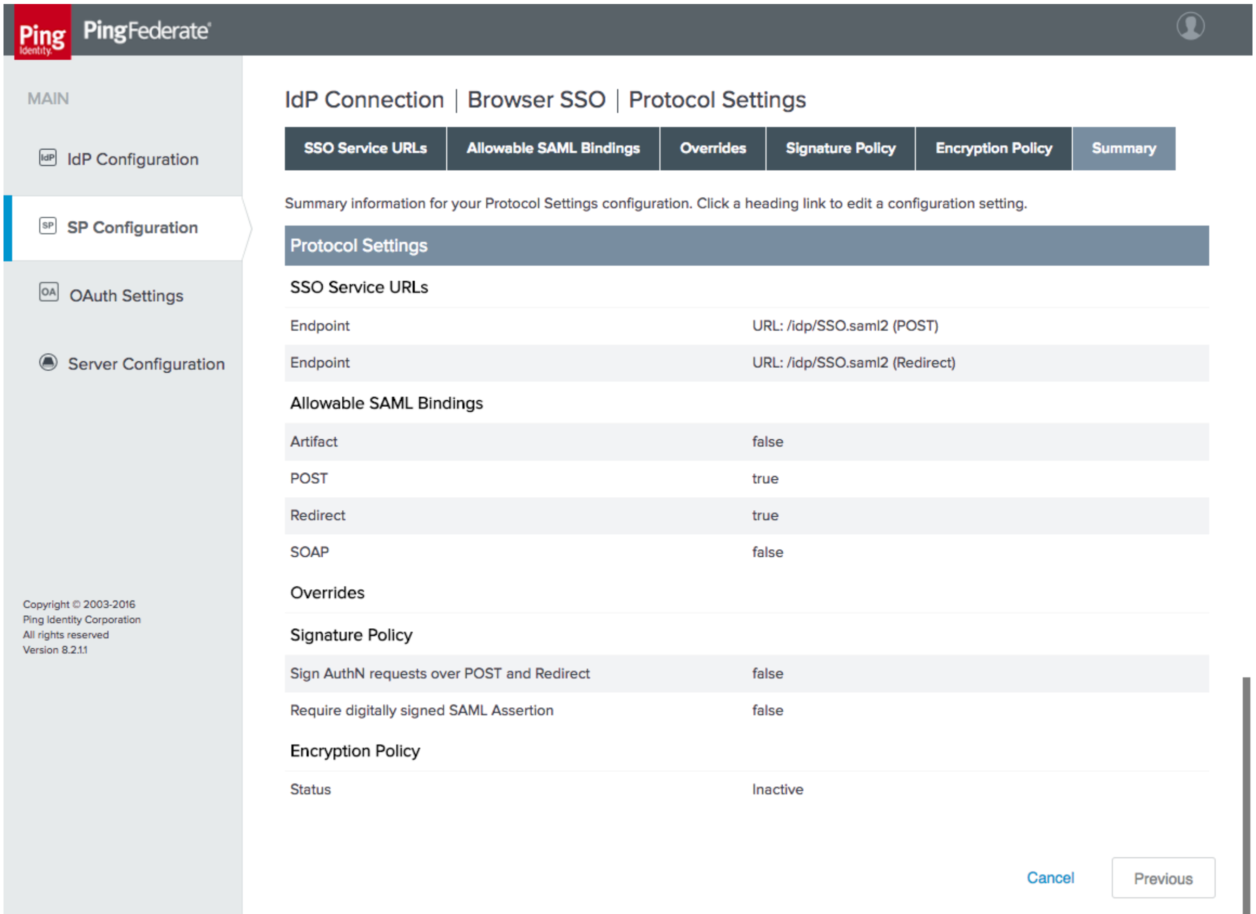
ii. On the **OAuth Attribute Mapping Configuration** tab, select **MAP DIRECTLY INTO PERSISTENT GRANT**. Configure the OAuth attribute mapping as shown in Figure 3-25. This maps both required values in the persistent grant context to the SAML subject. Click **Next**, then **Next** again to skip the **Issuance Criteria** tab. Click **Save.**

Figure 3-25 IdP Connection OAuth Attribute Mapping



iii. Click **Next** to proceed to the **Protocol Settings** tab. The **Protocol Settings** configure specifics of the SAML protocol, such as the allowed bindings. Configure these as shown in Figure 3-26. When finished, click **Save**, which will return you to the **Browser SSO** tab of the **IdP Connection** settings.

Figure 3-26 IdP Connection–Protocol Settings

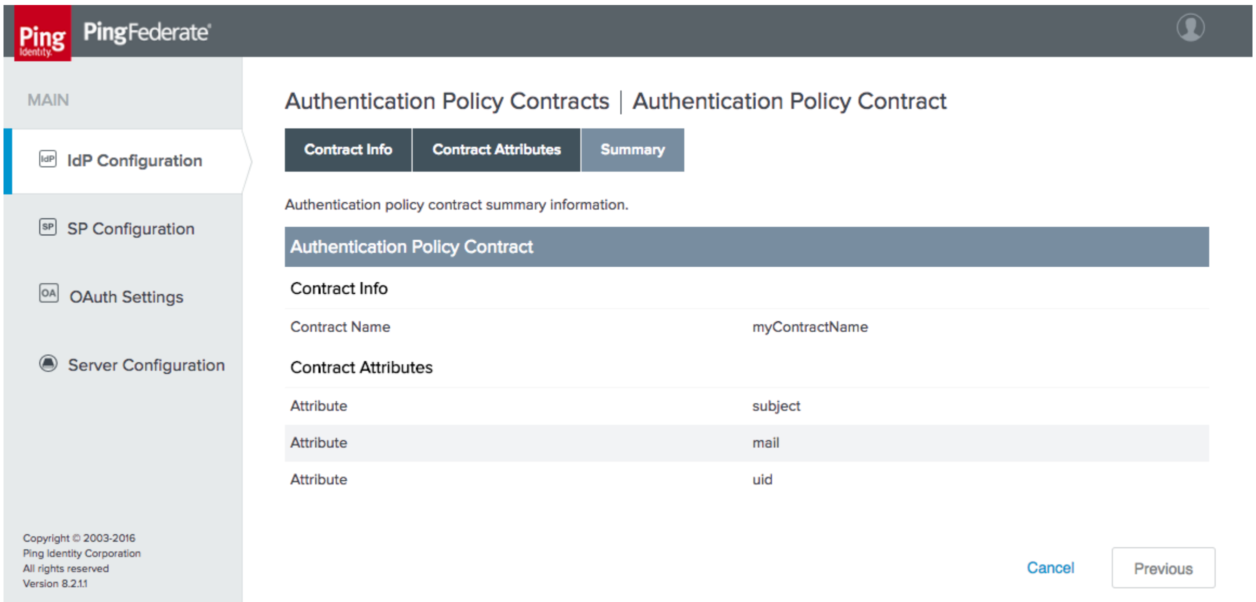


f. Click **Next**. On the **Credentials** tab, the IdP's signing certificate can be uploaded. This is not necessary if the certificate is signed by a trusted CA.

3.4.2.2 Create Policy Contract

1. Create a policy contract as described in Section 3.4.1.2, with the attributes **subject**, **mail**, and **uid** (Figure 3-27).

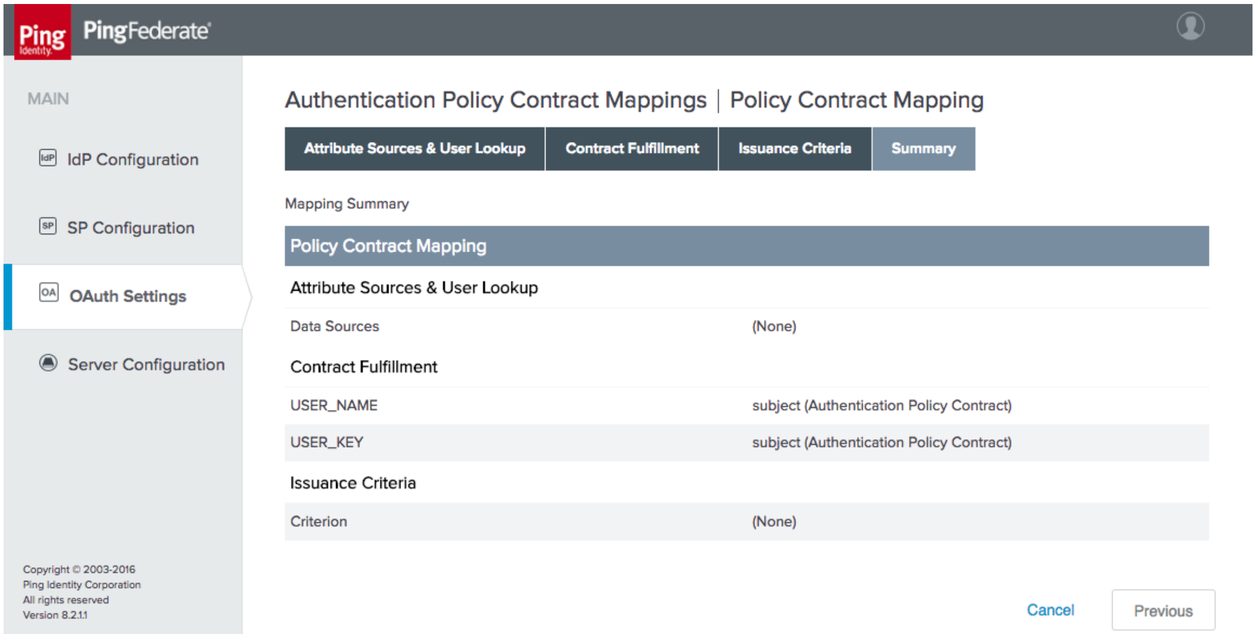
Figure 3-27 Policy Contract for SAML RP



3.4.2.3 Create Policy Contract Mapping

1. Create an OAuth policy contract mapping for the newly created policy as described in Section 3.4.1.3, mapping **USER_NAME** and **USER_KEY** to **subject** (Figure 3-28).

Figure 3-28 Contract Mapping for SAML RP



2. To complete the setup for SAML authentication, kspd.msso adapter needs to be included in an authentication policy as described in Section 3.4.4.2.

3.4.3 How to Configure OIDC Authentication

As with the configuration of a SAML IdP connection, integrating the AS with an OIDC IdP requires coordination between the administrators of the two systems. The administrator of the IdP must create an OIDC client registration before the connection can be configured on the AS side. The AS administrator must provide the redirect URI and, if encryption of the ID Token is desired, a public key. Unlike with SAML, there is no metadata file to exchange; however, if the IdP supports the OIDC discovery endpoint, the client can automatically obtain many of the required configuration settings from the discovery URL.

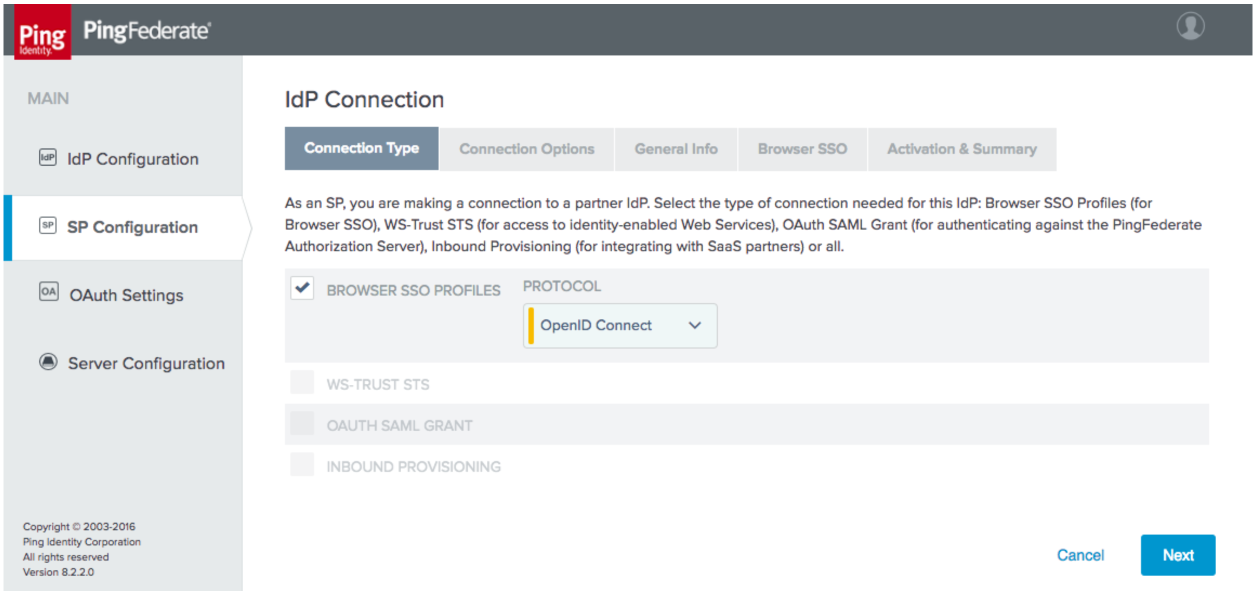
This section assumes that the AS role and OIDC SP support have been enabled via **Server Settings**, as described in Section 3.4. This section also uses the same authentication policy contract as the SAML authentication implementation. Create the policy contract as described in Section 3.4.2.2, if it does not already exist.

3.4.3.1 Create IdP Connection

1. On the **SP Configuration** section tab, click **Create New** under **IdP Connections**.

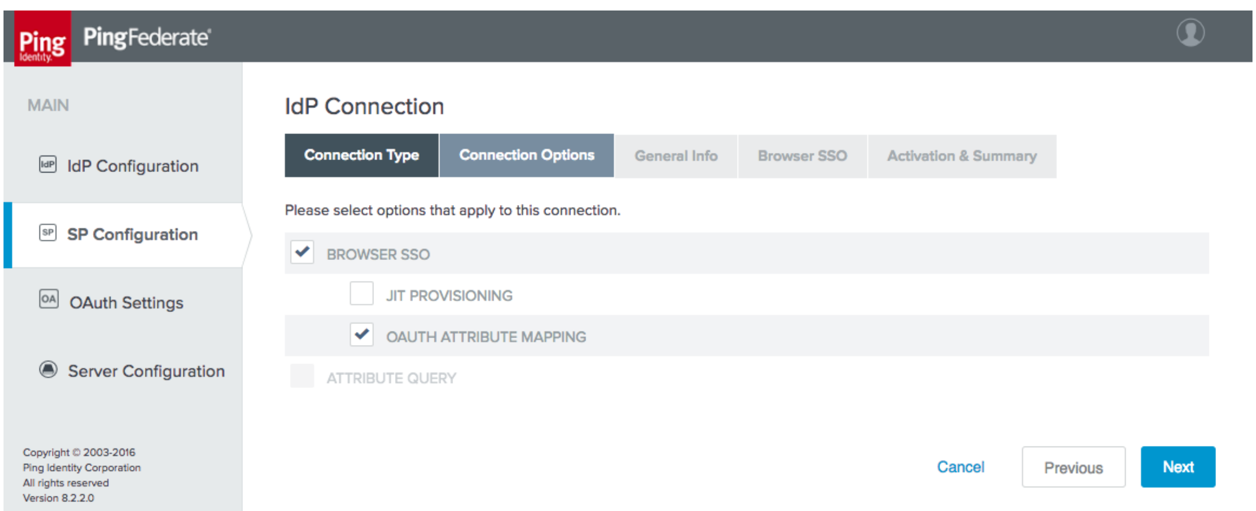
    a. On the **Connection Type** tab, select **BROWSER SSO PROFILES**, and then under it, select **OpenID Connect** for the **PROTOCOL** (Figure 3-29).

Figure 3-29 IdP Connection Type



b. On the **Connection Options** tab, select **BROWSER SSO**, and then under it, select **OAUTH ATTRIBUTE MAPPING** (Figure 3-30).

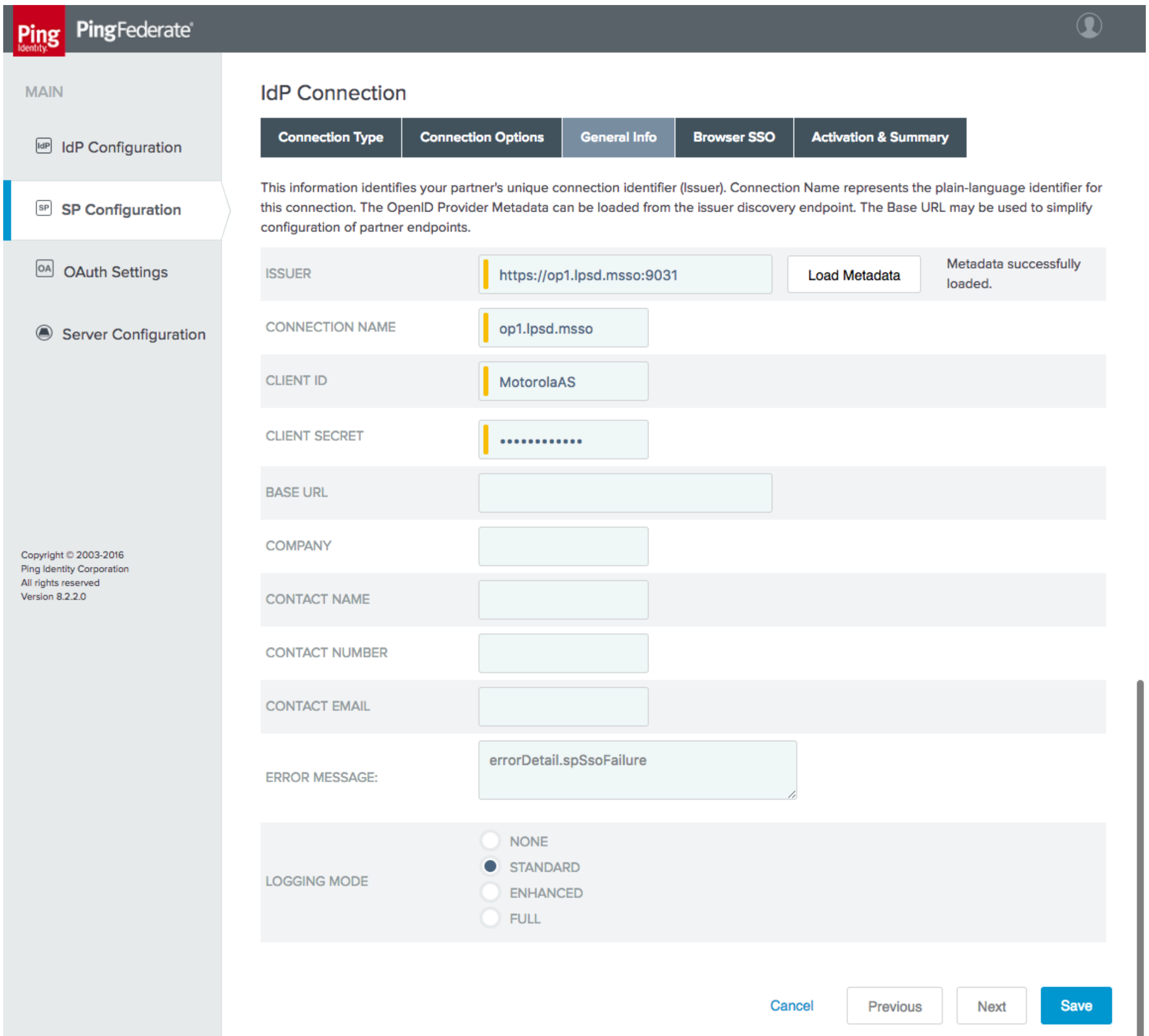
Figure 3-30 IdP Connection Options



c. On the **General Info** tab, enter the **ISSUER** value for the IdP (Figure 3-31). This is the **BASE URL** setting available on the **Federation Info** tab, under the **Server Configuration** section tab on the IdP. Then click **Load Metadata**, which causes the AS to query the IdP's discovery endpoint. The message "Metadata successfully loaded" should appear.

Provide a **CONNECTION NAME,** and enter the **CLIENT ID** and **CLIENT SECRET** provided by the IdP administrator.

Figure 3-31 IdP Connection General Info

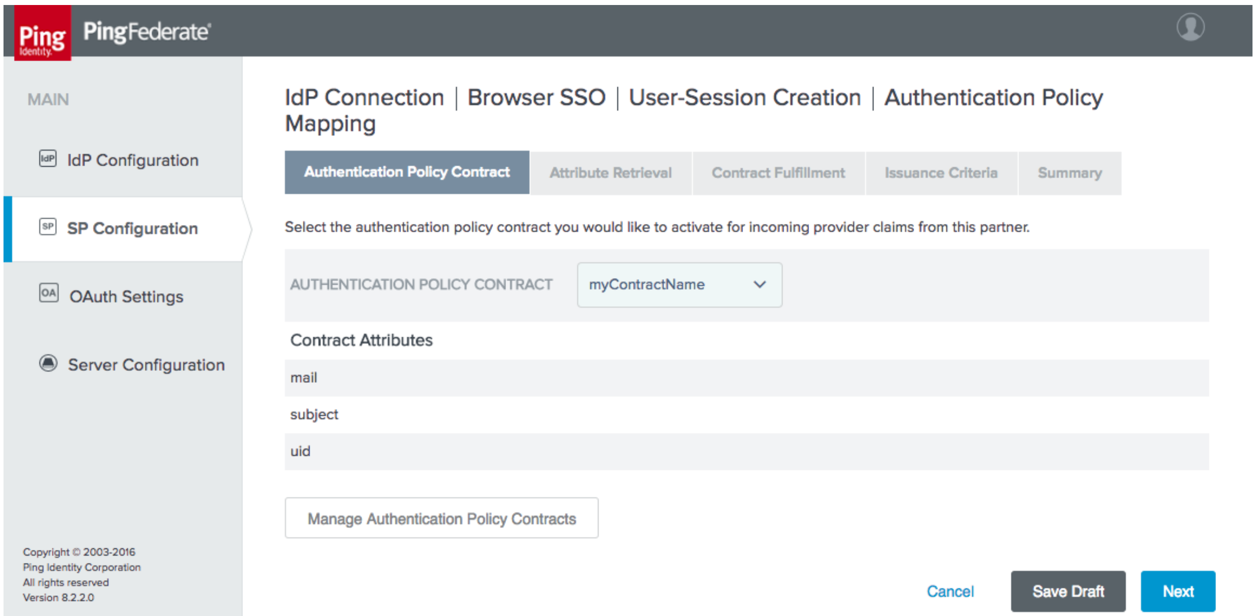


d. On the **Browser SSO** tab, click **Configure Browser SSO**, then click **Configure User-Session Creation**. The **User-Session Creation** page will appear.

   i. On the **Target Session Mapping** tab, click **Map New Authentication Policy**.

ii. On the **Authentication Policy Contract** tab, select the **AUTHENTICATION POLICY CONTRACT** created in Section 3.4.2.2 (in the example shown in Figure 3-32, it is called **myContractName**). If the policy contract has not been created, click **Manage Authentication Policy Contracts**, and create it now.

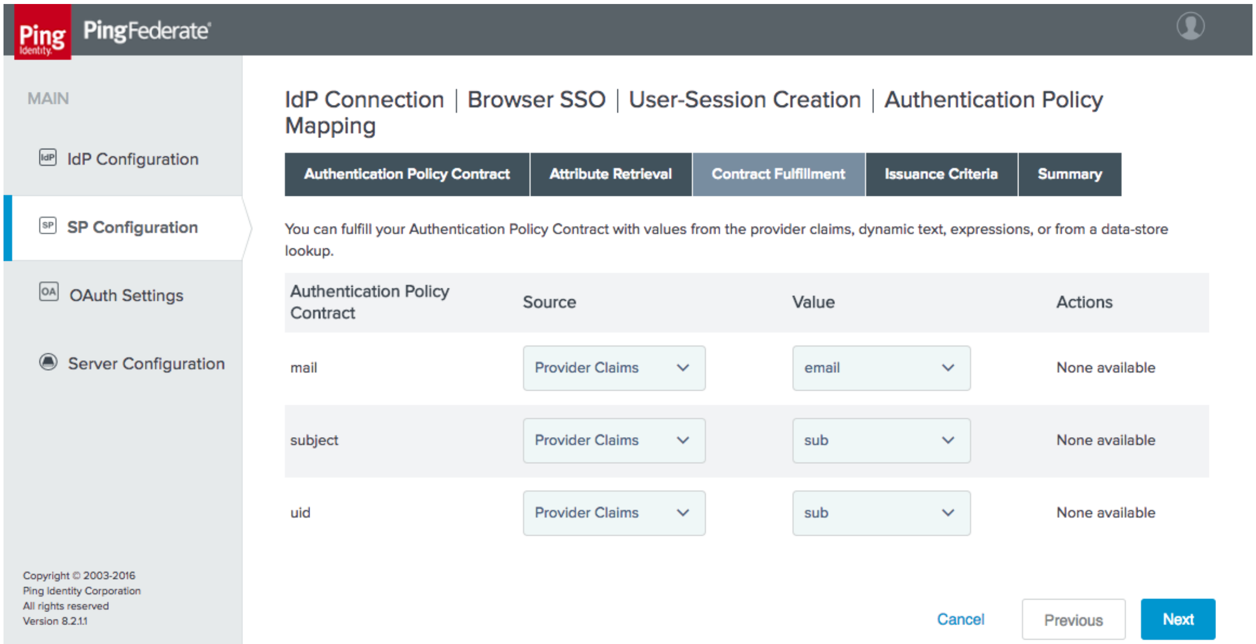
Figure 3-32 IdP Connection Authentication Policy Contract



iii. On the **Attribute Retrieval** tab, leave the default setting (use only the attributes available in the provider claims).

iv. On the **Contract Fulfillment** tab, map the **mail**, **subject**, and **uid** attributes to the **email**, **sub**, and **sub** provider claims (Figure 3-33).

Figure 3-33 IdP Connection Policy Contract Mapping



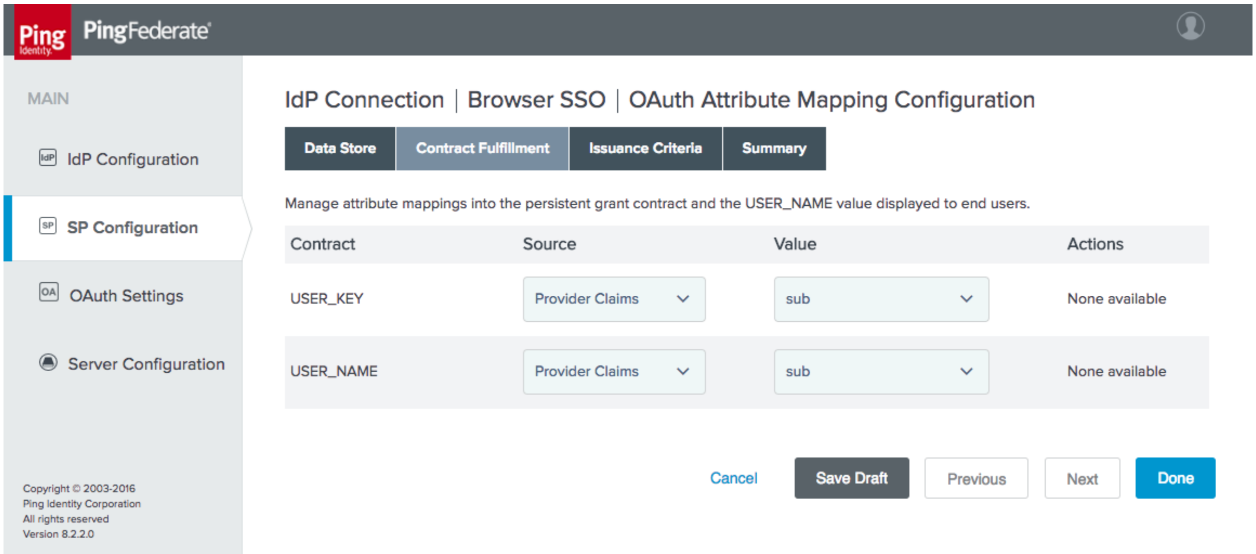
v. No **Issuance Criteria** were configured; therefore, skip the **Issuance Criteria** tab.

vi. Click **Next**, then **Done**, and then click **Done** again to exit the **User-Session Creation** tab.

vii. On the **OAuth Attribute Mapping Configuration** tab, select **Map Directly into Persistent Grant**, and then click **Configure OAuth Attribute Mapping**.

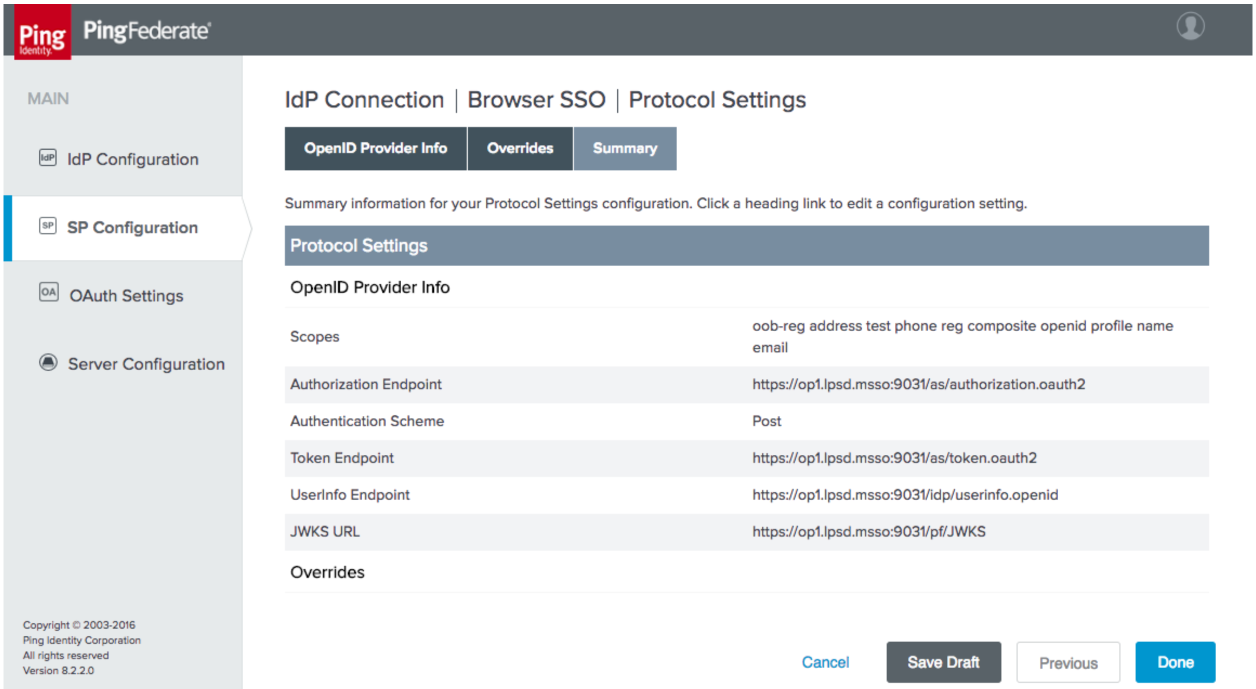
viii. Click **Next** to skip the Data Store tab. On the **Contract Fulfillment** tab, map both **USER_NAME** and **USER_KEY** to the **sub** provider claim (Figure 3-34).

Figure 3-34 IdP Connection OAuth Attribute Mapping



ix. Click **Done** to exit the **OAuth Attribute Mapping Configuration** setup. The **Protocol Settings** should be automatically populated through the information gathered from the discovery endpoint (Figure 3-35). If necessary, the scopes to be requested can be customized on the **Protocol Settings** tab; in the lab, these settings were left at the default.

Figure 3-35 IdP Connection Protocol Settings

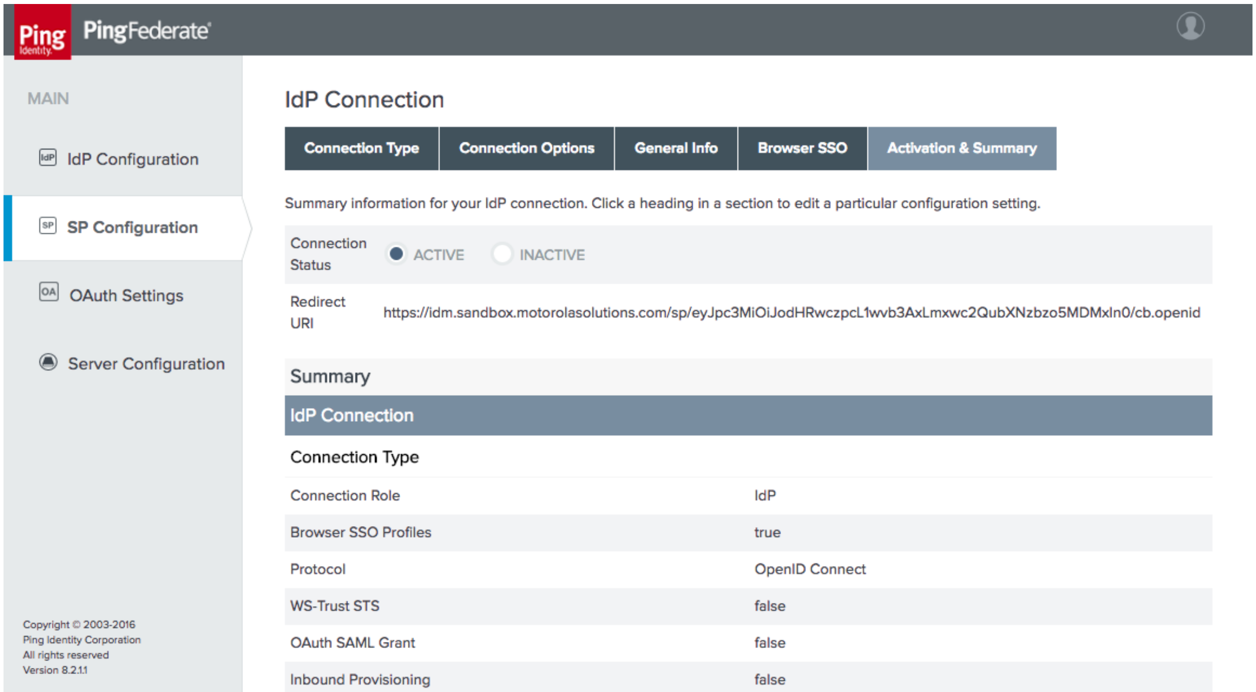


x. Click **Done** to exit the **Browser SSO** configuration setup.

e. On the **Activation & Summary** tab, a **Redirect URI** will be generated (Figure 3-36). Provide this information to the IdP administrator, as it needs to be configured in the OpenID Client settings on the IdP side.

i. The **Connection Status** can also be configured to **ACTIVE** or **INACTIVE** on this tab.

Figure 3-36 IdP Connection Activation and Summary



f. Click **Save** to complete the **IdP Connection** setup.

3.4.3.2 Create the Policy Contract Mapping

The same policy contract mapping created earlier for the SAML integration can also be used for OIDC integration, as the attribute names are identical. If this policy contract mapping has not already been created, refer to Section 3.4.2.3 to create it.

3.4.4 How to Configure the Authentication Policy

3.4.4.1 Install the Domain Selector Plugin

When a single AS is integrated with multiple IdPs, it needs a means of determining which IdP can authenticate each user. In the lab build, a domain selector is used to determine whether the AS should authenticate the user locally, redirect to the SAML IdP, or redirect to the OIDC IdP. The domain selector prompts the user to enter the user's email address or domain. The specified domain is used to select which branch of the authentication policy should be applied. Upon successful authentication, the domain selector sets a cookie in the browser to record the domain selection to avoid prompting the user each time that the user authenticates.

PingFederate includes sample code for a Domain Selector plugin. Before the Domain Selector can be used in an authentication policy, it must be built. The source code for the selector is located under the PingFederate directory, in the directory `sdk/plugin-src/authentication-selector-example`.

1. Complete the following steps to build the selector:

   a. Edit the `build.local.properties` file in the PingFederate SDK directory to set the target plugin as follows:

   ```
   target-plugin.name=authentication-selector-example
   ```

   b. Run the following commands to build and install the plugin:

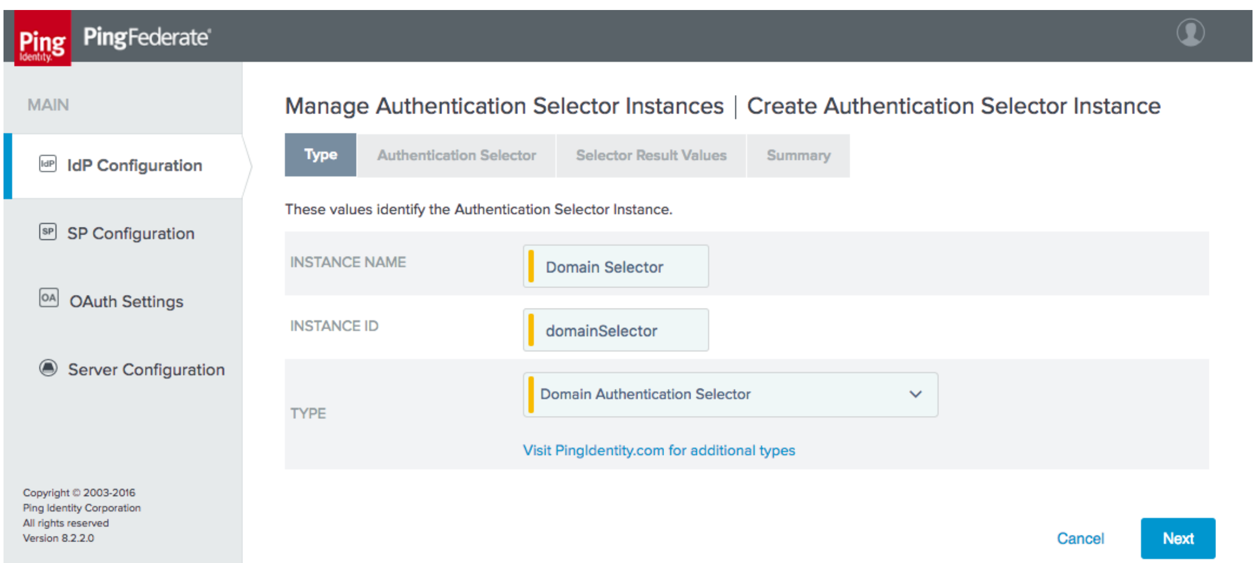
   ```
   $ ant clean-plugin
   $ ant jar-plugin
   $ ant deploy-plugin
   $ sudo service pingfederate restart
   ```

2. Once installed, the Domain Selector can be configured with the required values. On the **IdP Configuration** section tab, click **Selectors** under **Authentication Policies**.

3. Click **Create New Instance**.

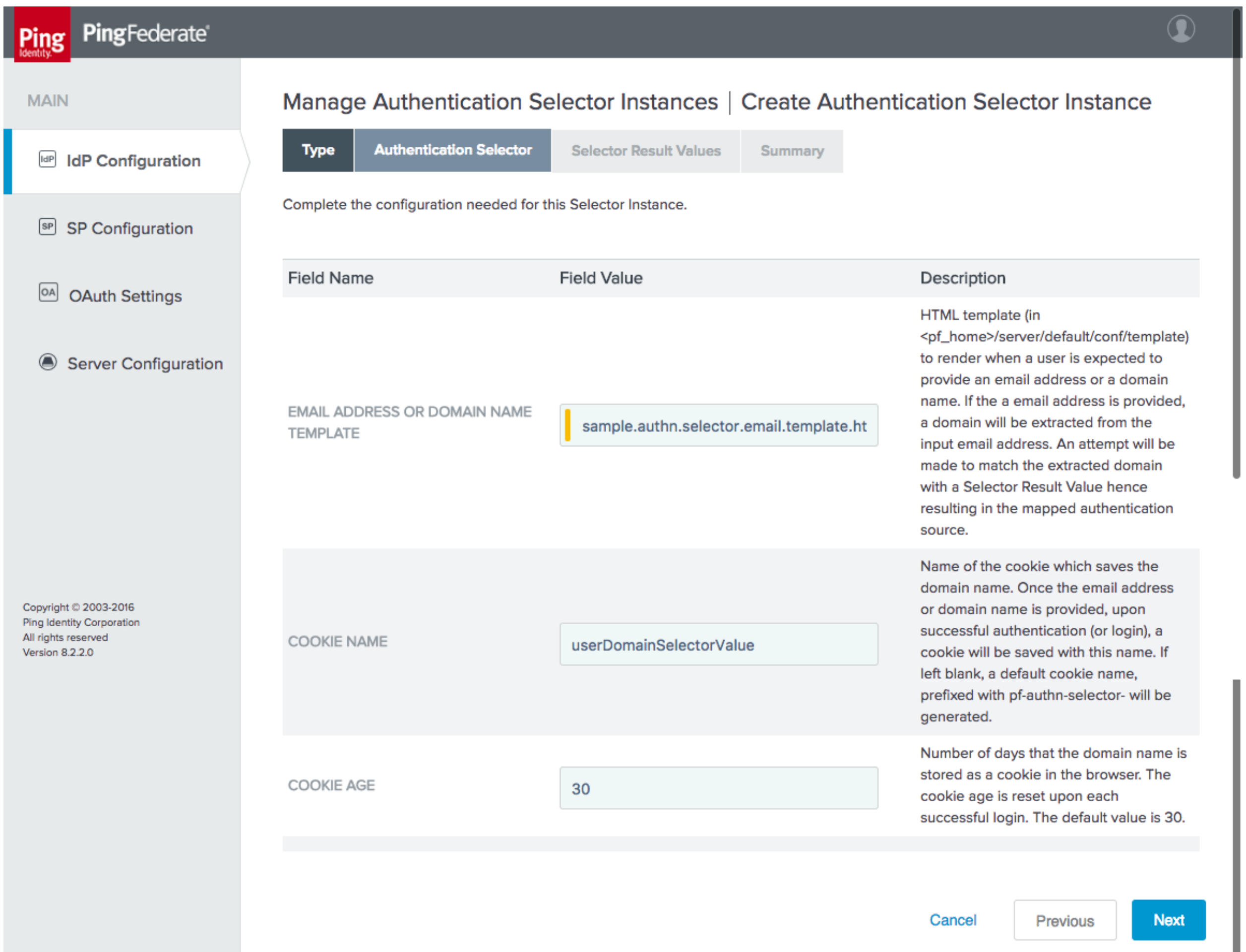
   a. On the **Type** tab, provide a meaningful name and ID for the selector instance (Figure 3-37). For the **TYPE**, select **Domain Authentication Selector**.

Figure 3-37 Authentication Selector Instance



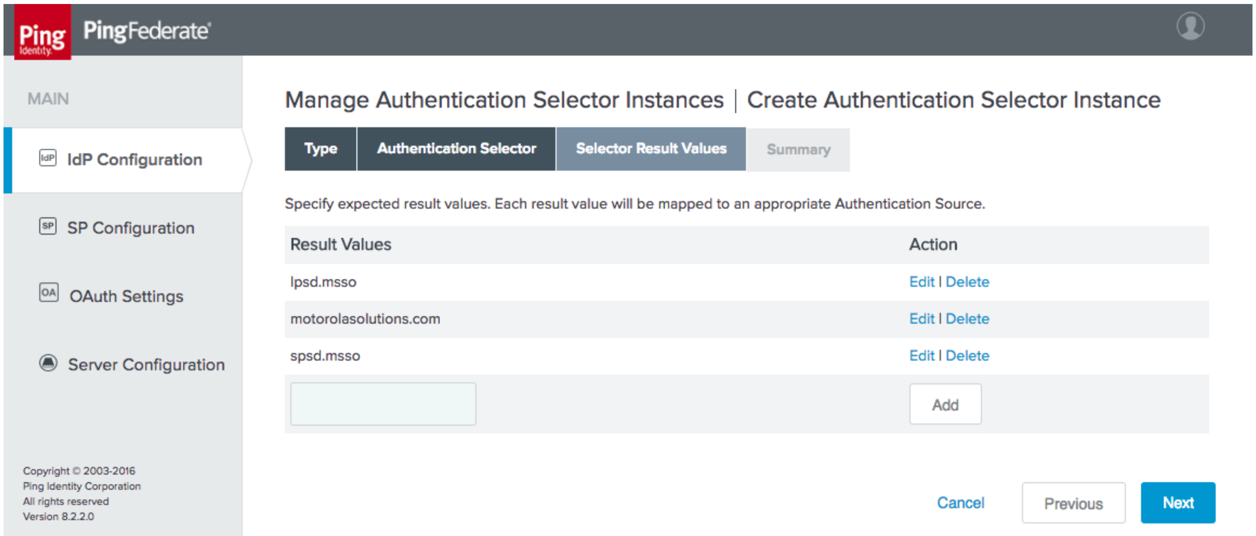
b. The next tab, **Authentication Selector**, prompts for the HyperText Markup Language (HTML) template for the page that will prompt the user to enter the domain or email address (Figure 3-38). The default value will use the template delivered with the adapter; if desired, a custom template can be used instead to modify the appearance of the page. Provide a cookie name, which will be used to persist the domain selection. Finally, the age of the cookie can be modified. By default, users will be prompted again to enter their domain after 30 days.

Figure 3-38 Authentication Selector Details



c. On the **Selector Result Values** tab, specify the expected domain values (Figure 3-39). When the domain selector is used in an access policy, different policy branches will be created for each of these values. In this case, if the domain is *motorolasolutions.com*, the user will be authenticated locally; if it is *lpsd.msso* or *spsd.msso*, the user will be redirected to the corresponding IdP to authenticate.

Figure 3-39 Selector Result Values



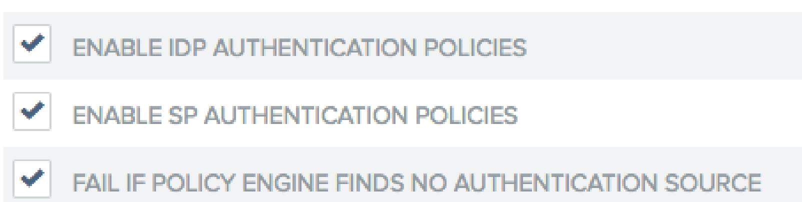
d. Click **Done**, and then click **Save** to complete the selector configuration.

3.4.4.2 Define the Authentication Policy

1. On the IdP Configuration page, click **Policies** under **Authentication Policies**.

   a. Select the three checkboxes at the top of the **Manage Authentication Policies** page, which are shown in Figure 3-40.

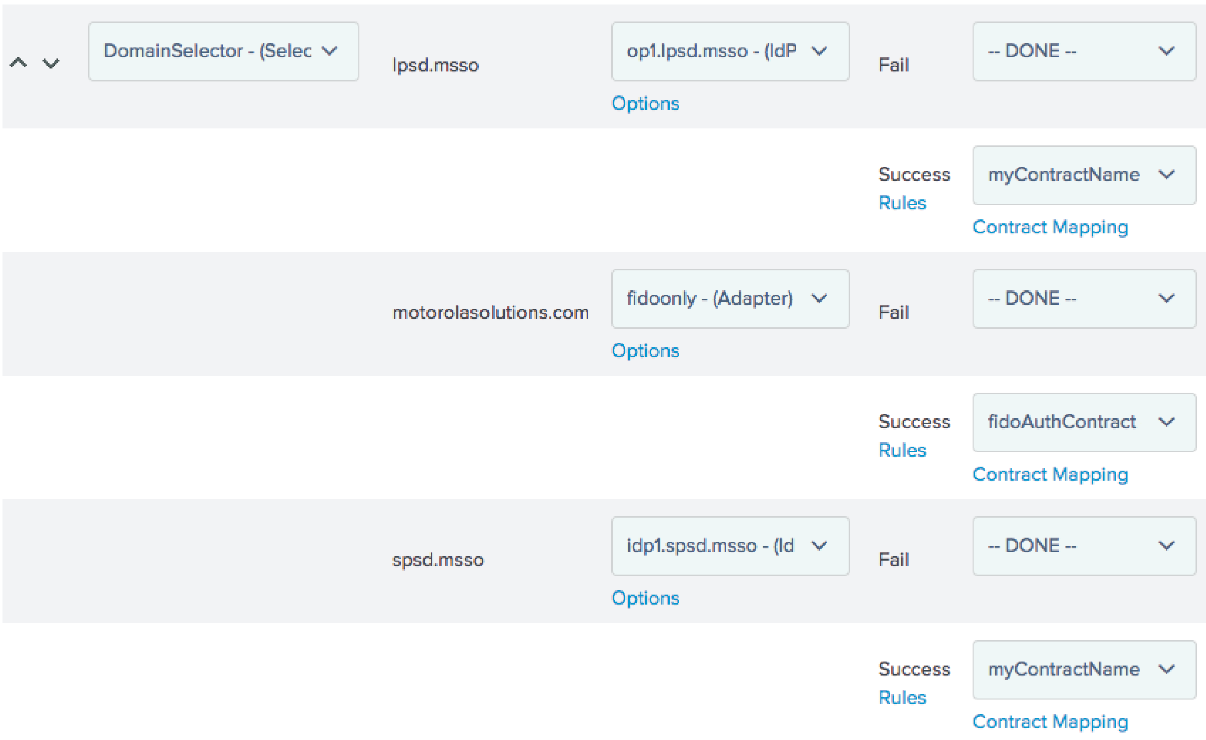
Figure 3-40 Policy Settings



   b. Select the **Domain Selector** as the first element in the policy (Figure 3-41). This will create policy branches for the three values defined for the policy selector.

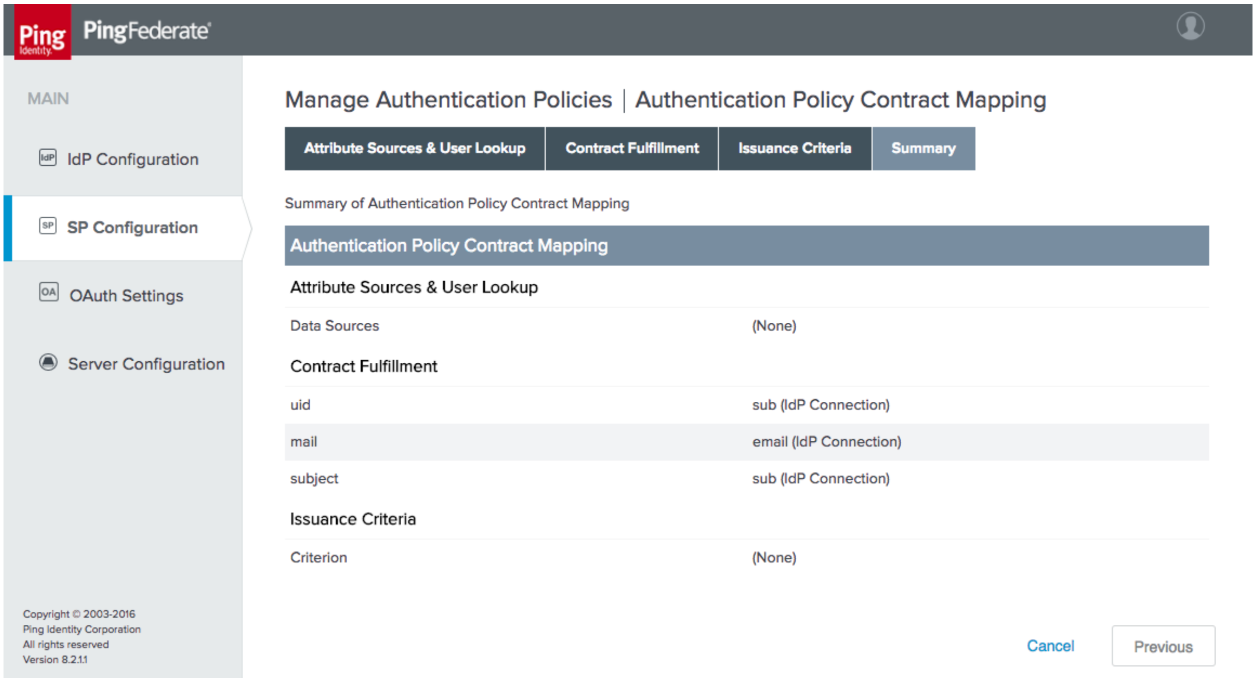
      i. Select the corresponding authentication mechanism for each domain. The example shown in Figure 3-41 uses the IdP connections for the **lpsd.msso** and **spsd.msso**, as well as the "fidoonly" adapter for local authentication of users in the **motorolasolutions.com** domain.

Figure 3-41 Authentication Policy



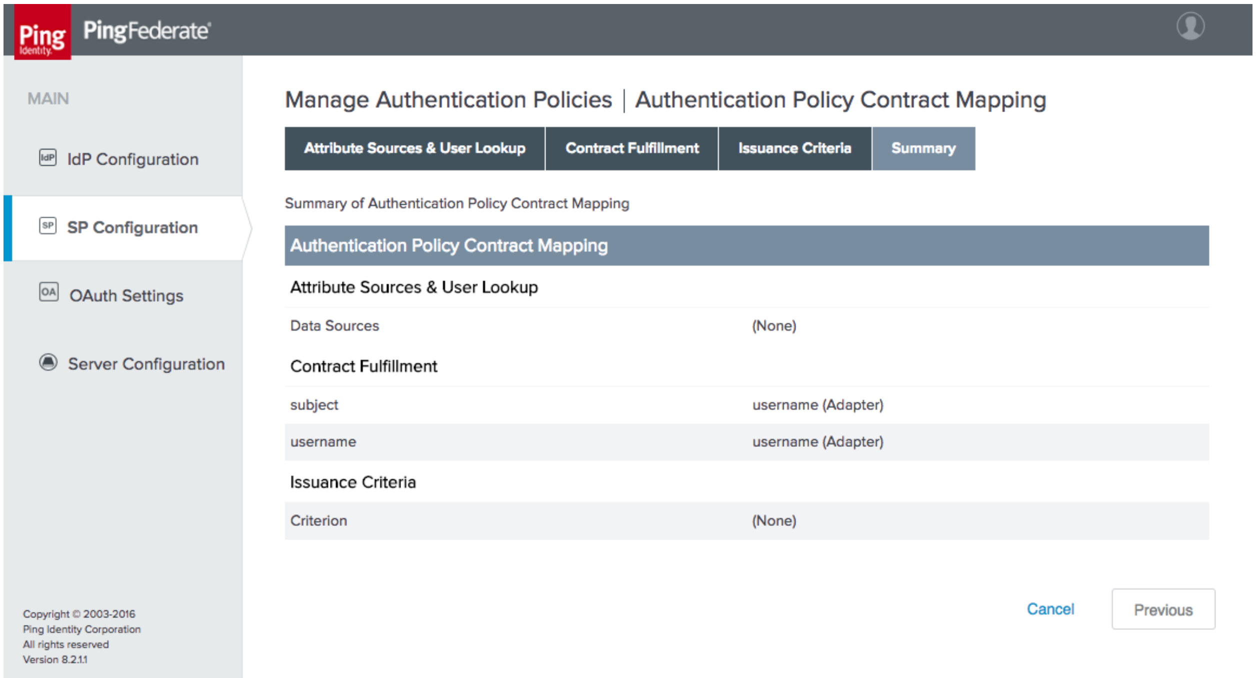
ii. There is no need to specify **Options** or **Success Rules**. For the two IdP connections, apply the **myContractName** policy contract upon success, with the contract mapping configured as shown in Figure 3-42.

Figure 3-42 Policy Contract Mapping for IdP Connections



c. For the "fidoonly" adapter, apply the **fidoAuthContract** with the contract mapping shown in Figure 3-43.

Figure 3-43 Policy Contract Mapping for Local Authentication



This completes the configuration of the AS.

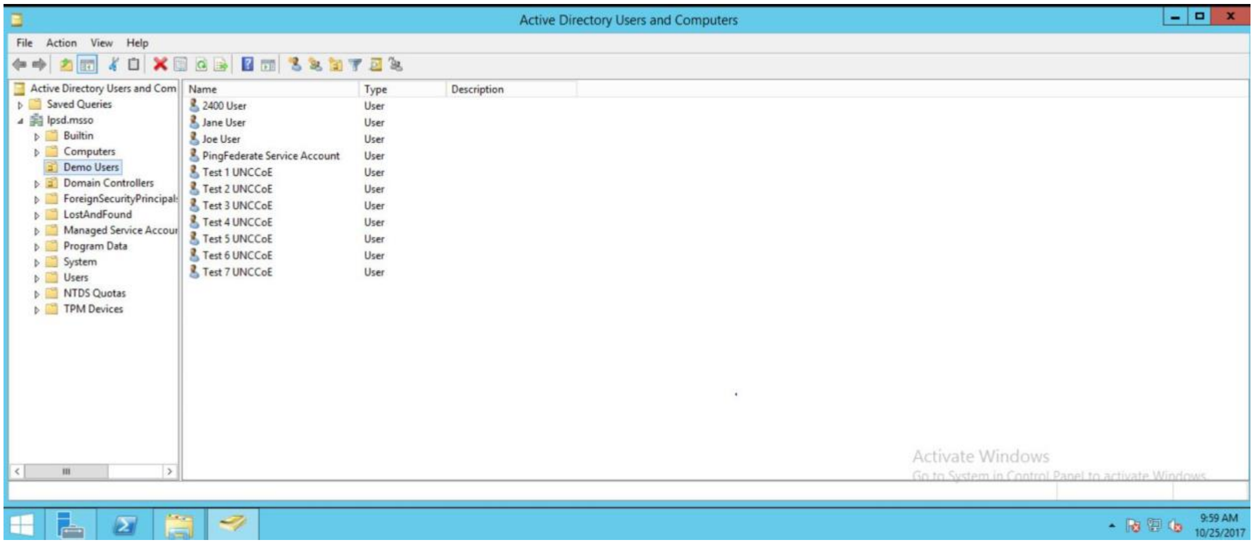
4 How to Install and Configure the Identity Providers

PingFederate 8.3.2.0 was used for the SAML and OIDC IdP installs. The system requirements and installation process for PingFederate are identical to the OAuth AS installation documentation in Section 3.1 and Section 3.2. The IdP configuration sections pick up the installation process after the software has been installed, at the selection of roles and protocols.

4.1 How to Configure the User Store

Each IdP uses its own AD forest as a user store. AD was chosen due to its widespread use across many organizations. For the purposes of this project, any LDAP directory could have served the same purpose, but in a typical organization, AD would be used for other functions, such as workstation login and authorization to applications, shared drives, printers, and other services. The **Active Directory Users and Computers** console (Figure 4-1) was used to create user accounts and set attributes.

Figure 4-1 Active Directory Users and Computers

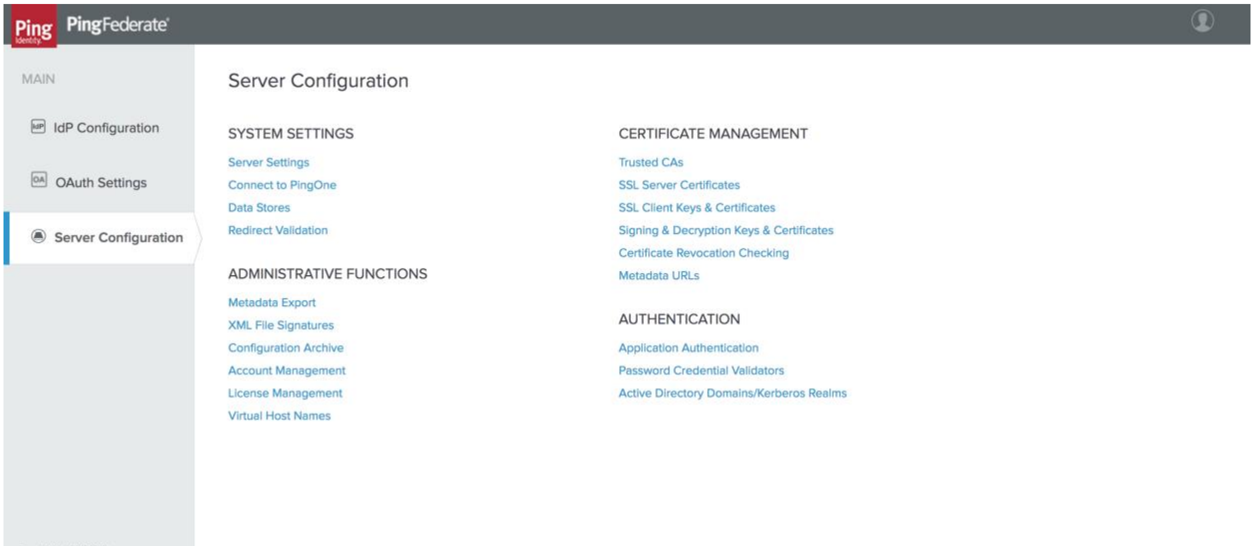


In addition to the user accounts that log in to the lab applications, a service account must be created to enable the IdP to access and query the AD. This user's LDAP Distinguished Name (DN) and password (in the example shown in Figure 4-1) are used in the PingFederate directory integration described below.

The procedure for connecting a PingFederate IdP to an LDAP directory is the same for a SAML or OIDC IdP. Documentation is provided at https://documentation.pingidentity.com/pingfederate/pf82/index.shtml#concept_configuringLdapConnection.html.

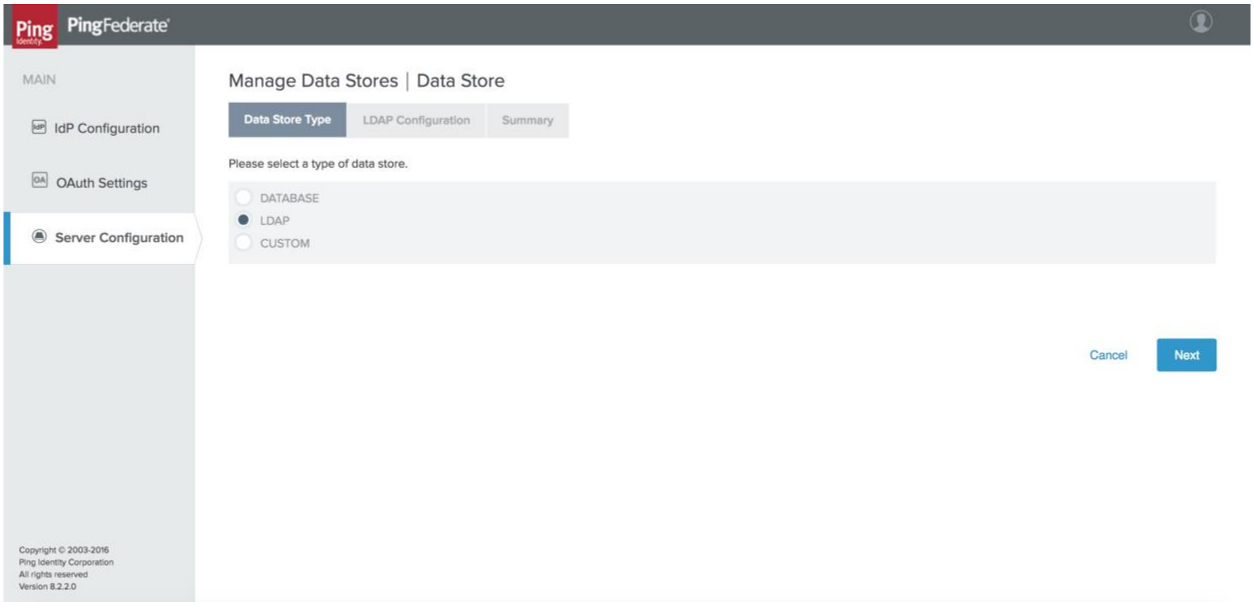
1. To start the process, click the **Server Configuration** section tab on the left side of the PingFederate administrative console. The screen shown in Figure 4-2 will appear.

Figure 4-2 Server Configuration



2. Click **Data Stores** under **SYSTEM SETTINGS**.
3. On the next screen, click **Add New Data Store**.
    a. The screen shown in Figure 4-3 will appear. On the **Data Store Type** tab, select **LDAP** for the data store type.
        i. Click **Next**.

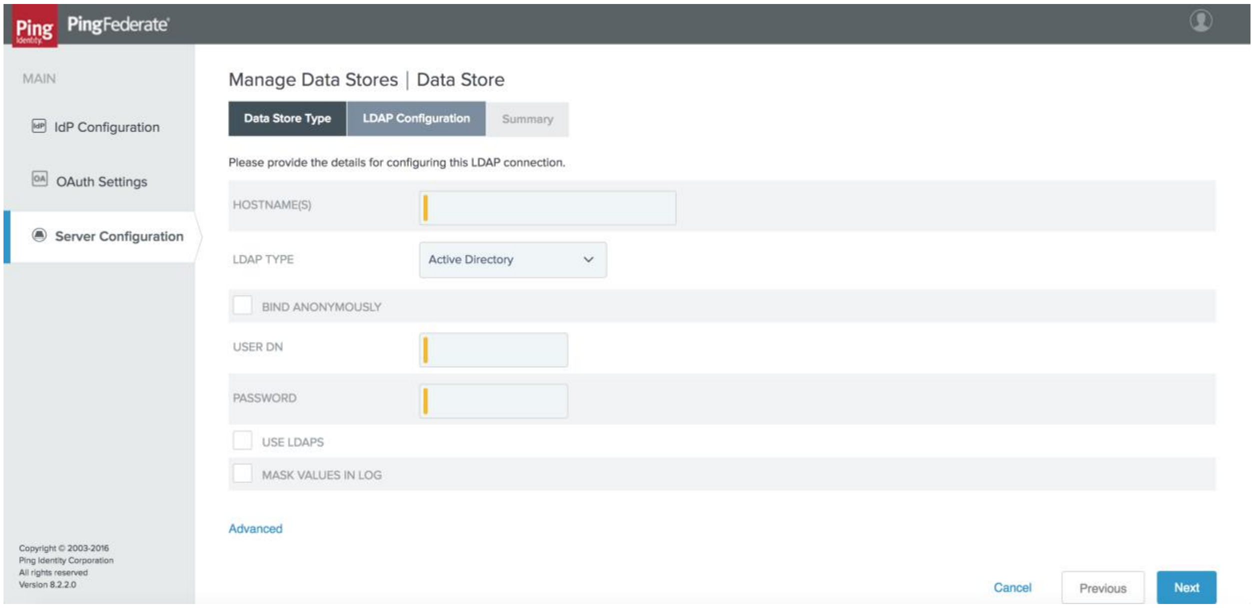
Figure 4-3 Data Store Type



b. On the **LDAP Configuration** tab, enter the connection parameters for your AD or LDAP environment (Figure 4-4). Some notes on the fields on this tab are provided below. Click **Save** to exit the LDAP configuration screen once the required settings have been entered.

- **HOST NAME(S)**: Enter the Fully Qualified Domain Name (FQDN) or the complete Internet Protocol (IP) address of an AD domain controller. A port number can be specified if AD is running on non-standard ports.
- **LDAP TYPE**: This is the LDAP server in use—AD in this case.
- **BIND ANONYMOUSLY**: For AD environments, allowing anonymous BIND (Berkeley Internet Name Domain) is not recommended.
- **USER DN**: This is the Distinguished Name of the PingFederate user account created in AD; in this build architecture, this account is used only for querying AD, so it does not require any special privileges.
- **PASSWORD**: This is the password for the PingFederate AD user.
- **USE LDAPS**: This can be enabled if AD is configured to serve LDAP over TLS.
- **MASK VALUES IN LOG**: This prevents attributes returned from this data source from being exposed in server logs.

Figure 4-4 LDAP Data Store Configuration

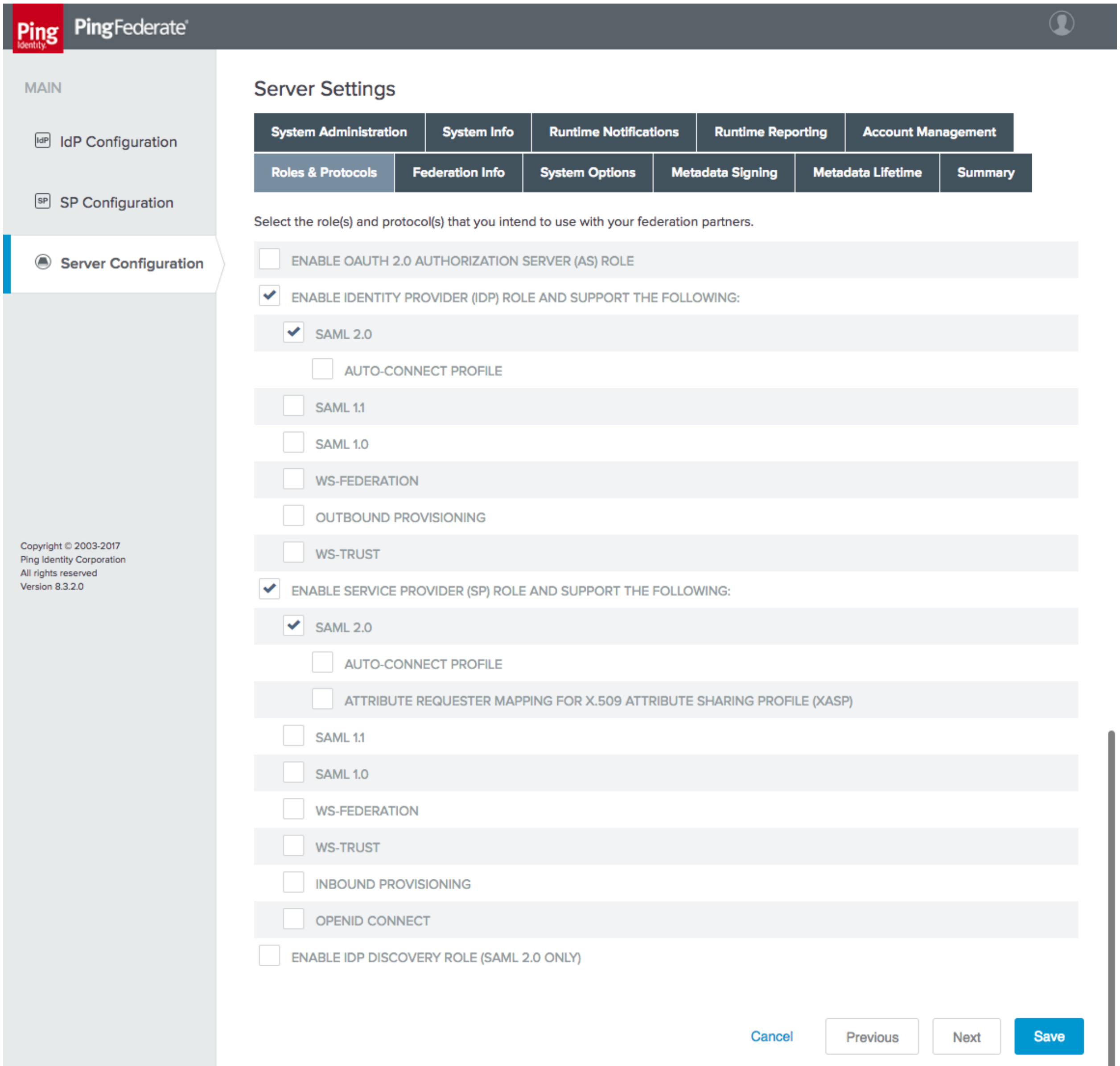


4.2 How to Install and Configure the SAML Identity Provider

1. On the **Server Configuration** screen, click **Server Settings**.

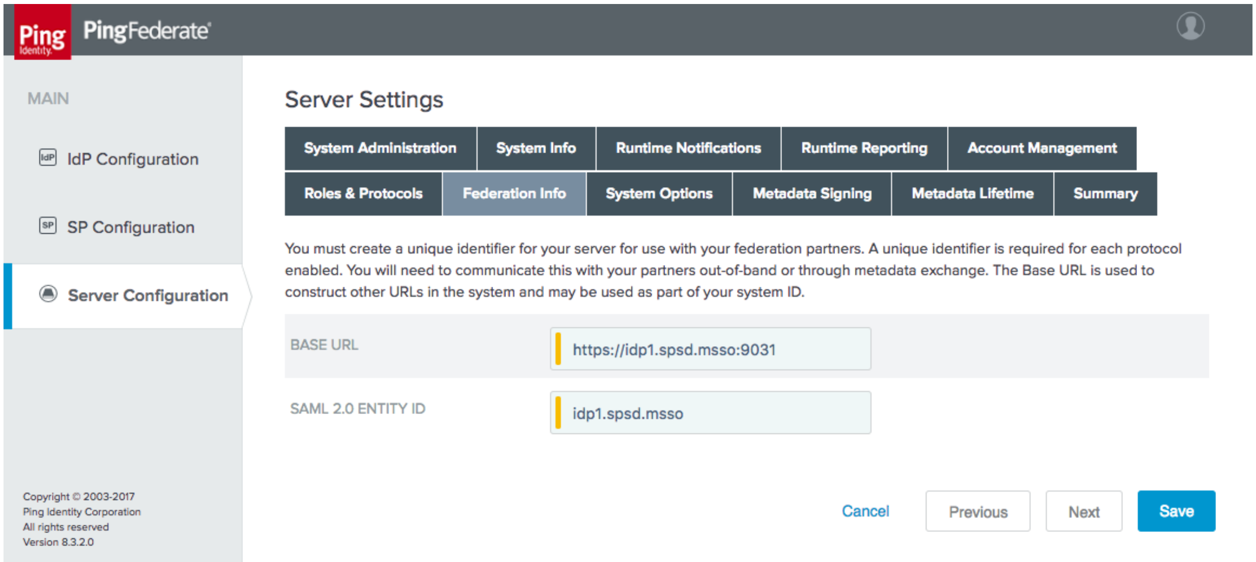
    a. On the **Roles & Protocols** tab, enable roles and protocols to configure the server as a SAML IdP (Figure 4-5).

Figure 4-5 Server Roles for SAML IdP



b. On the **Federation Info** tab, specify the **BASE URL** and **SAML 2.0 ENTITY ID** of the IdP (Figure 4-6). The **BASE URL** should be a URL resolvable by your mobile clients. The **ENTITY ID** should be a meaningful name that is unique among federation partners; in this case, the FQDN of the server is used.

Figure 4-6 SAML IdP Federation Info



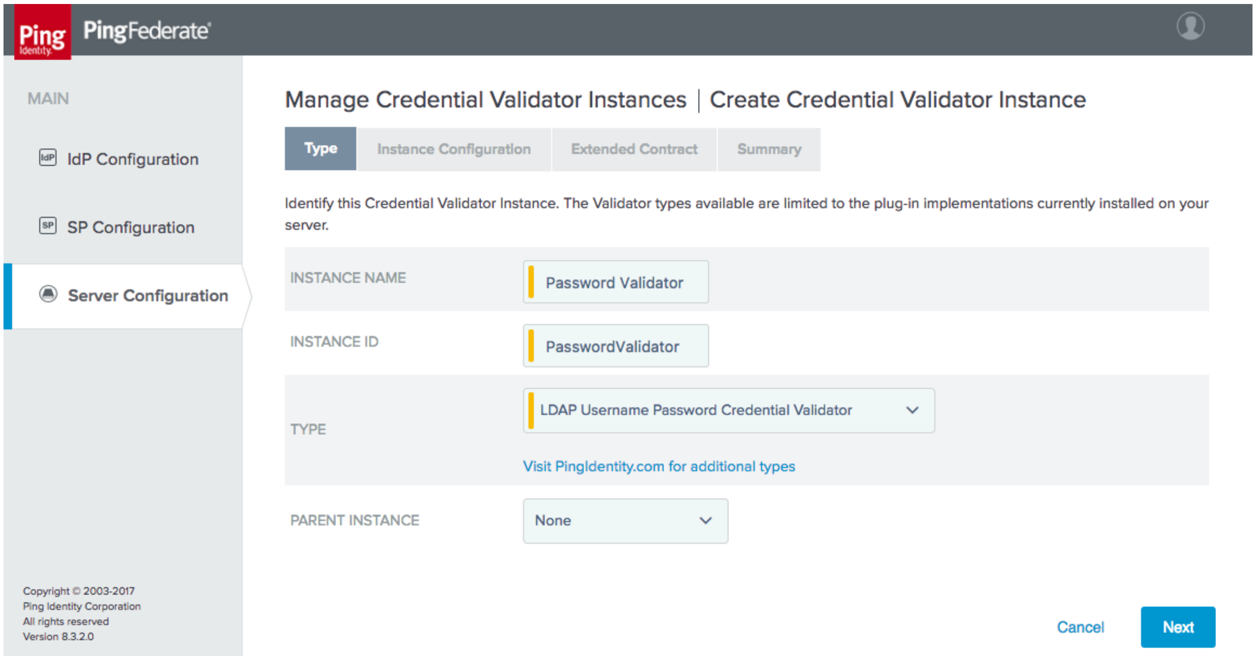
4.2.1 Configuring Authentication to the IdP

This example configures an authentication policy that requires the user to authenticate with username and password and then with a FIDO U2F token.

4.2.1.1 Configure the Password Validator

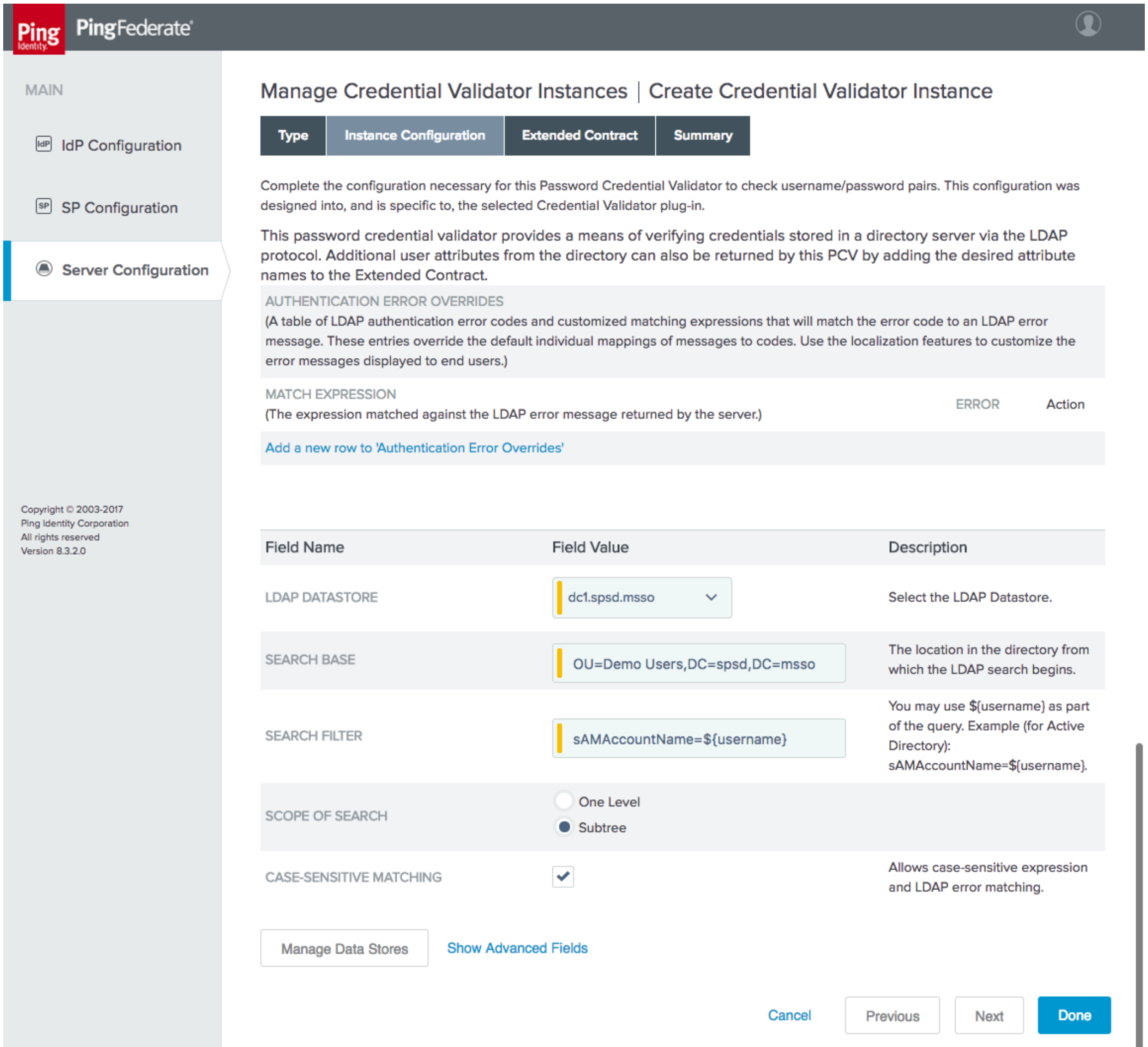
1. On the **Server Configuration** section tab, click **Password Credential Validators** under **Authentication**.
2. Click **Create New Instance**.
    a. On the **Type** tab, for the **TYPE**, choose **LDAP Username Password Credential Validator** (Figure 4-7). This example will authenticate AD usernames and passwords by using the AD data store defined in Section 4.1.

Figure 4-7 Create Password Credential Validator



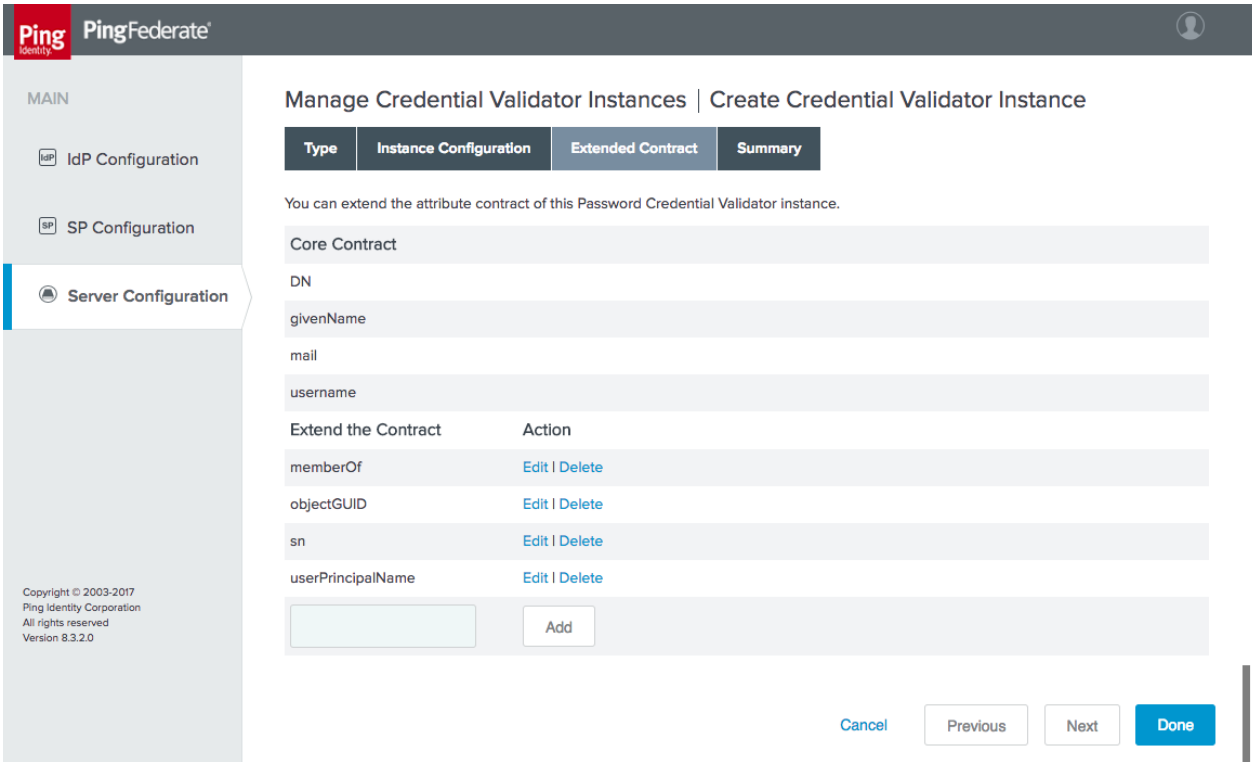
b. On the **Instance Configuration** tab, specify the parameters for searching the LDAP directory for user accounts (Figure 4-8). Select the data store created in Section 4.1, and enter the appropriate search base and filter. This example will search for a *sAMAccountName* matching the username entered on the login form.

Figure 4-8 Credential Validator Configuration



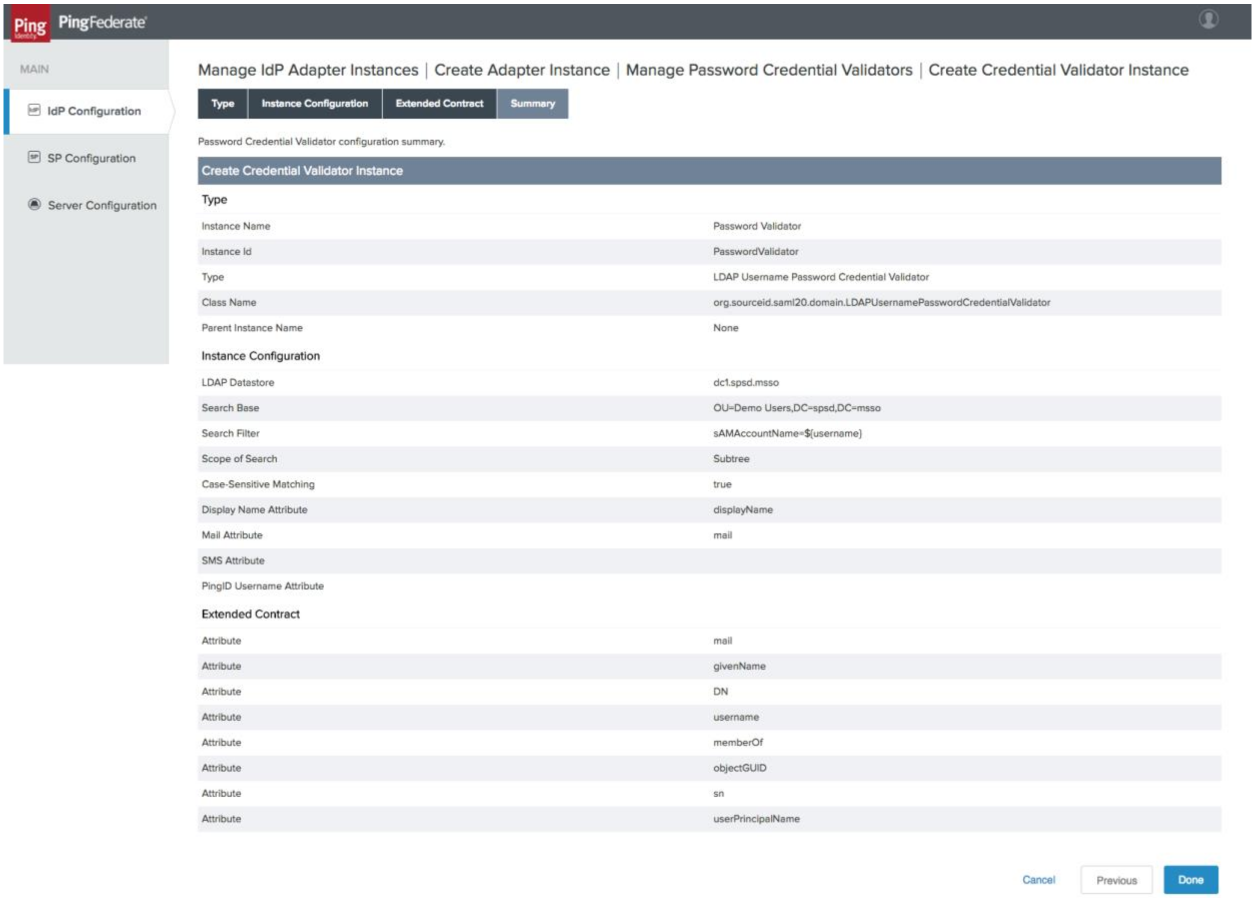
c. The **Extended Contract** tab enables the retrieval of additional attributes from the LDAP server, which can be used in assertions to RPs (Figure 4-9). The example shown in Figure 4-9 adds several AD attributes to the contract.

Figure 4-9 Password Credential Validator Extended Contract



d. Finally, the **Summary** tab shows all of the values for the configured validator (Figure 4-10).

Figure 4-10 Password Validator Summary

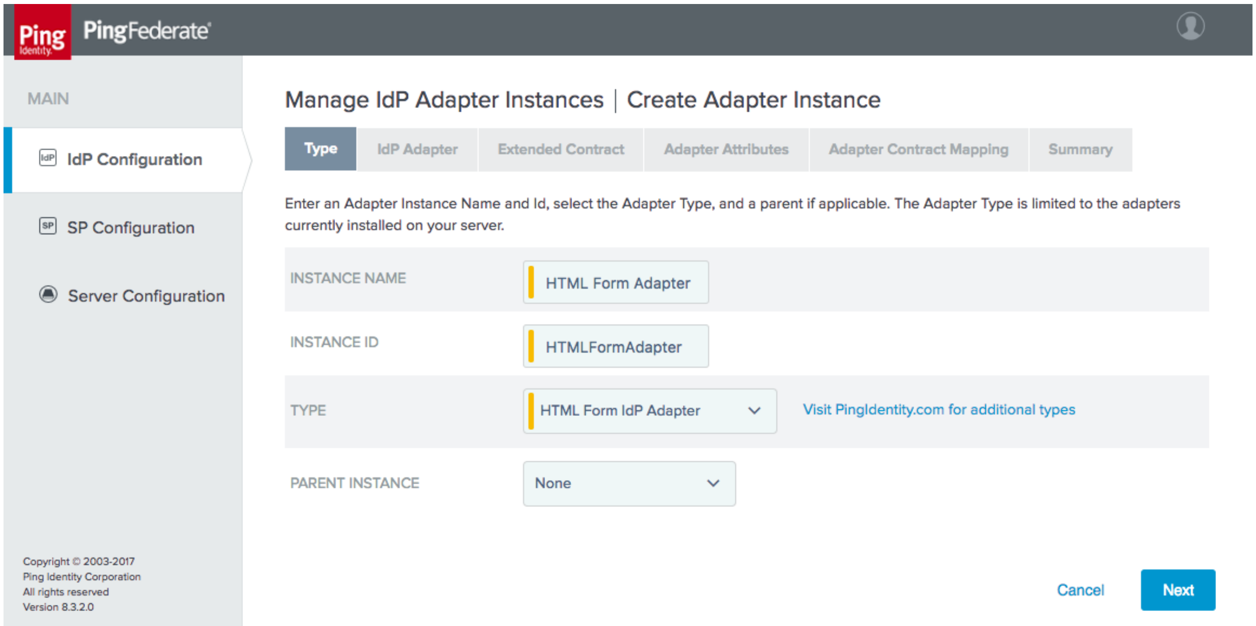


e. Click **Done**, and then click **Save** to complete the setup of the password validator.

4.2.1.2 Configure the HTML Form Adapter

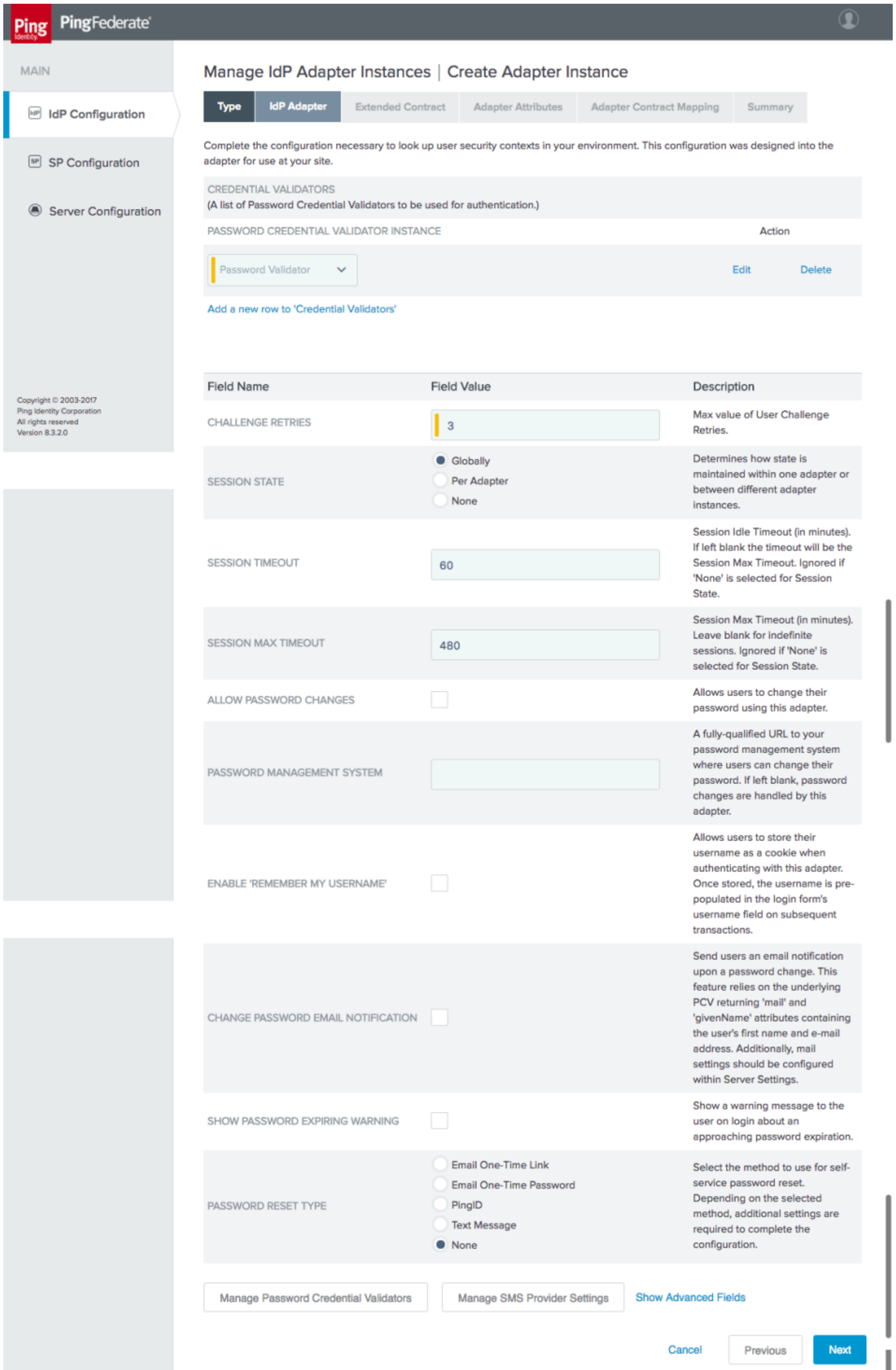
1. On the **IdP Configuration** section tab, click **Adapters**.
2. Click **Create New Instance**.
   a. On the **Type** tab, create the name and ID of the adapter, and select the **HTML Form IdP Adapter** for the **TYPE** (Figure 4-11).

Figure 4-11 HTML Form Adapter Instance



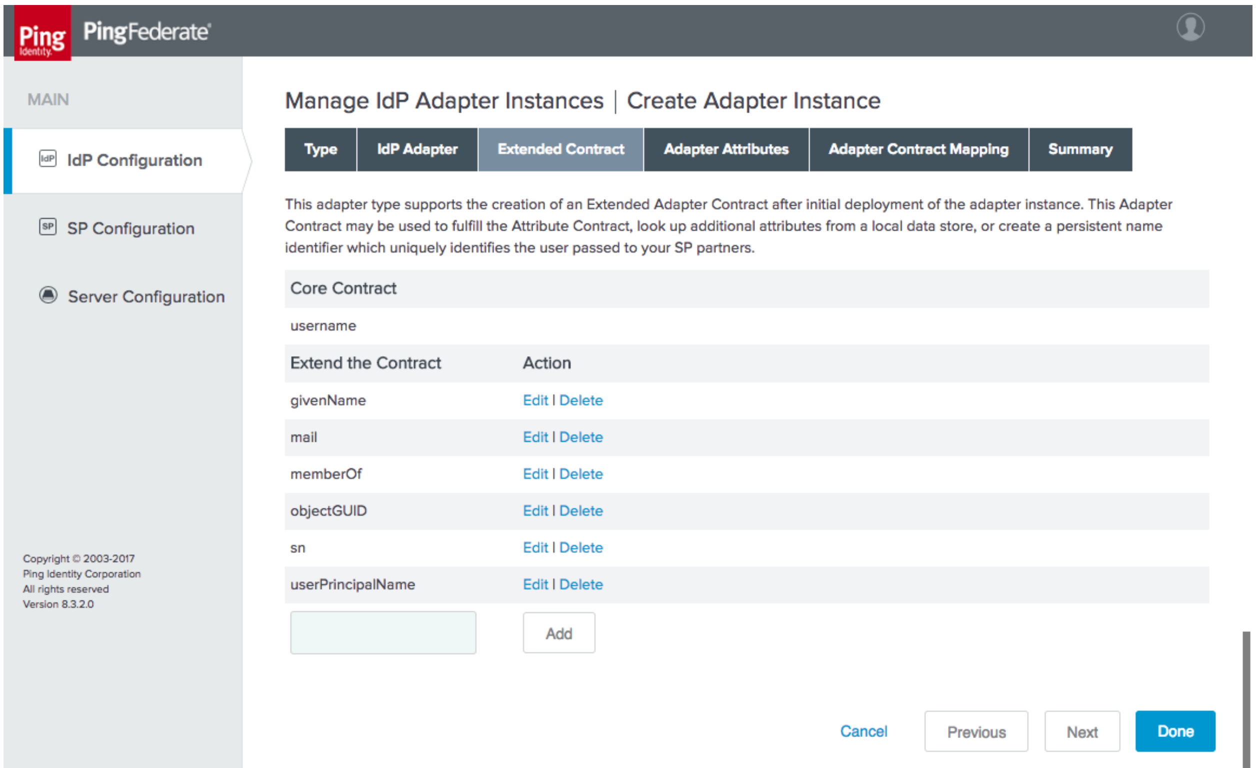
b. On the **IdP Adapter** tab, add the **Password Validator** instance created in the previous section (Figure 4-12). This tab provides several options for customizing the login page and supporting password resets and password recovery that would be relevant to a Production deployment. In the lab, password resets were not supported, and these fields were left at their default values.

Figure 4-12 Form Adapter Settings



c. On the **Extended Contract** tab, the same attributes returned from AD by the Password Validator are added to the adapter contract, to make them available for further use by the IdP (Figure 4-13).

Figure 4-13 Form Adapter Extended Contract



d. On the **Adapter Attributes** tab, select the **Pseudonym** checkbox for the **username** attribute.

e. There is no need to configure anything on the **Adapter Contract Mapping** tab, as all attributes are provided by the adapter. Click **Done**, and then click **Save** to complete the Form Adapter configuration.

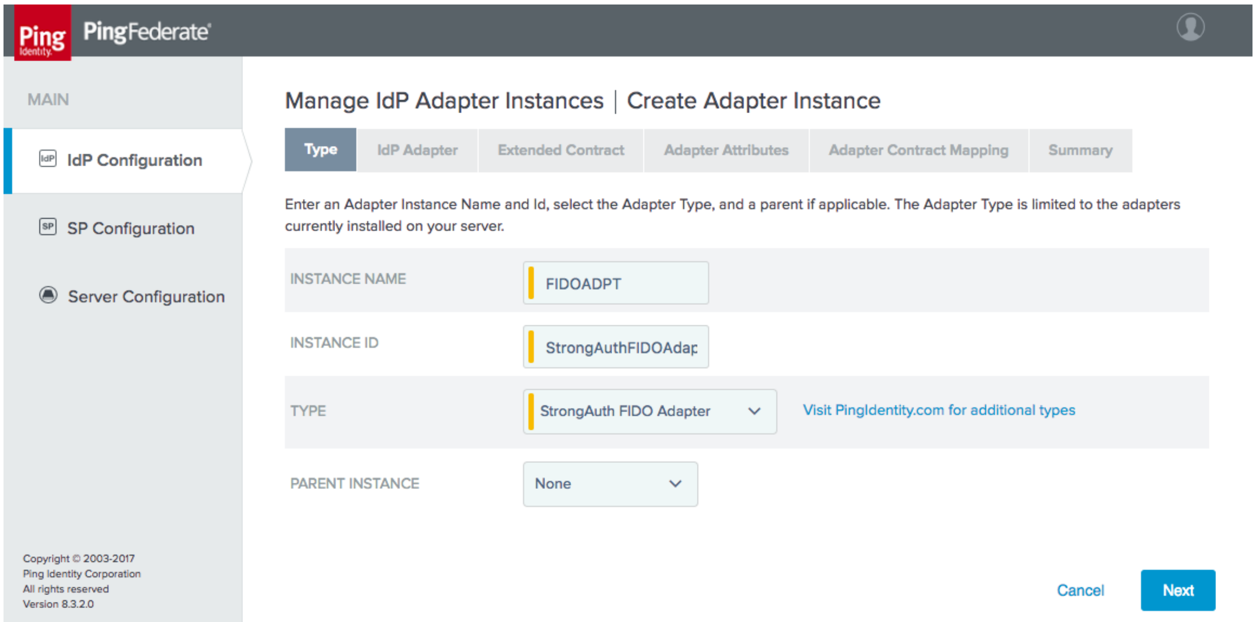
4.2.1.3 Configure the FIDO U2F Adapter

Before this step can be completed, the FIDO U2F server, StrongKey CryptoEngine (SKCE), must be installed and configured, and the StrongKey U2F adapter for PingFederate must be installed on the IdP. See Section 6 for details on completing these tasks.

1. On the **IdP Configuration** section tab, click **Adapters**.
2. Click **Create New Instance**.

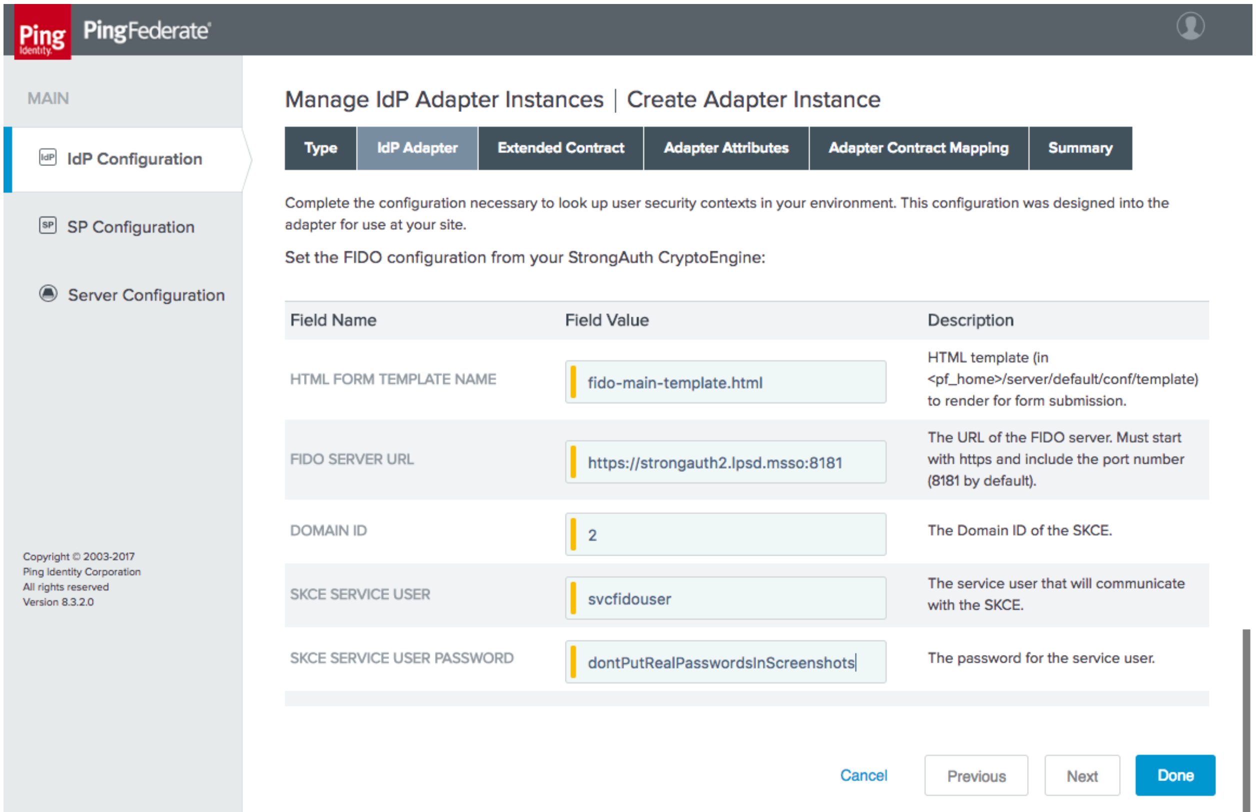
a. Enter meaningful values for **INSTANCE NAME** and **INSTANCE ID**. For the **TYPE,** select "StrongAuth FIDO Adapter." Click **Next**.

Figure 4-14 Create U2F Adapter Instance



b. On the **IdP Adapter** tab, keep the default value of the **HTML FORM TEMPLATE NAME** to use the template that is provided with the StrongKey U2F plugin, or specify a custom template if desired to change the design of the user interface (Figure 4-15). The **FIDO SERVER URL**, **DOMAIN ID**, **SKCE SERVICE USER**, and **SKCE SERVICE USER PASSWORD** are determined in the setup of the SKCE; refer to Section 6 for details.

Figure 4-15 U2F Adapter Settings



c. There is no need to extend the contract for the U2F adapter; therefore, skip the **Extended Contract** tab.

d. On the **Adapter Attributes** tab, select the **Pseudonym** checkbox for the **username** attribute.

e. There is also no need for an **Adapter Contract Mapping**; therefore, skip the **Adapter Contract Mapping** tab.

f. Click **Done**, and then click **Save**.

4.2.1.4 Configure the Authentication Policies

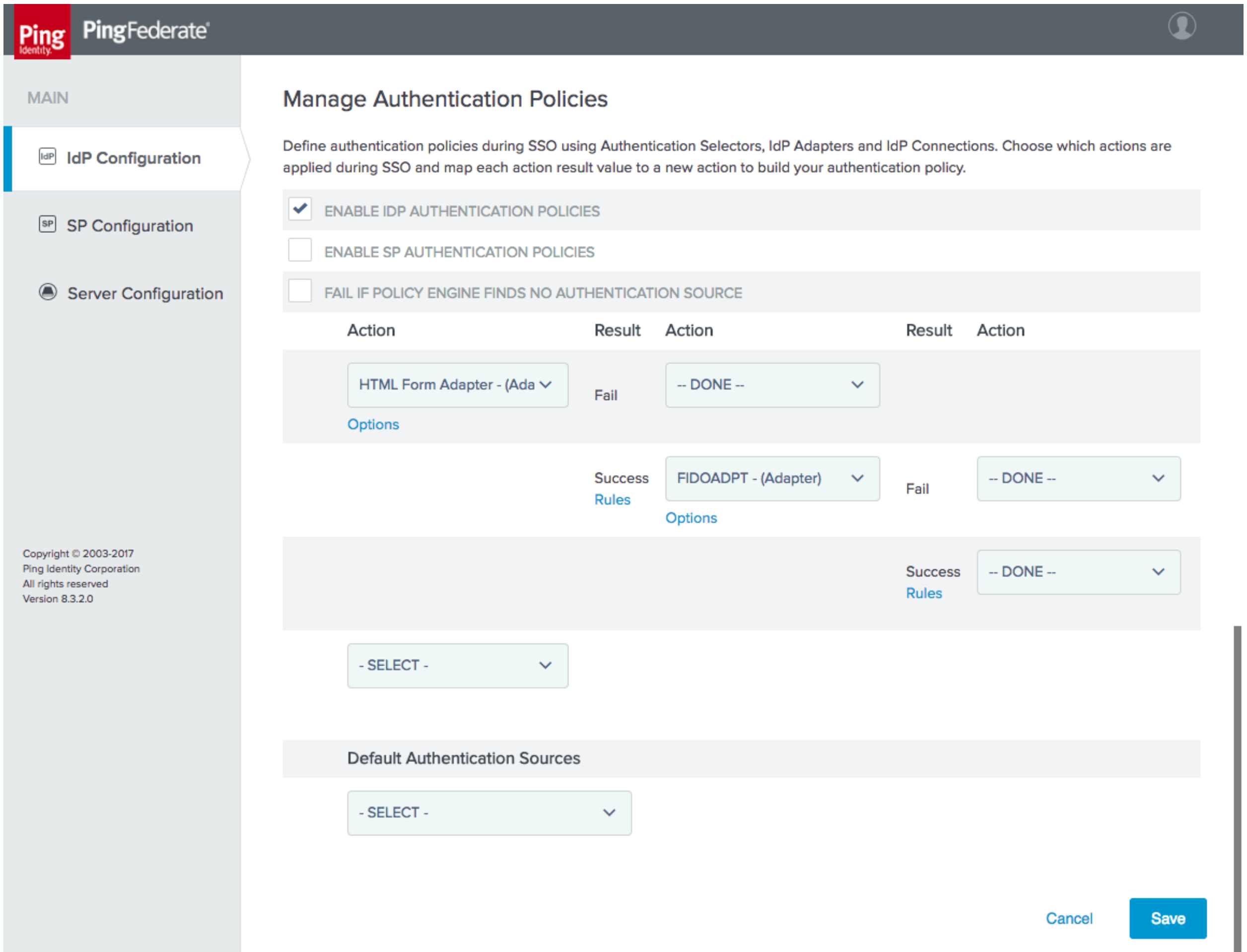
1. On the **IdP Configuration** page, click **Policies**.

    a. Under **Manage Authentication Policies**, click the **ENABLE IDP AUTHENTICATION POLICIES** checkbox, and create a policy that starts with the **HTML Form Adapter** action (Figure 4-16).

i. On the **Success** branch, add the FIDO U2F adapter (**FIDOADPT**) for the **Action**.

ii. Click **Save**.

Figure 4-16 IdP Authentication Policy



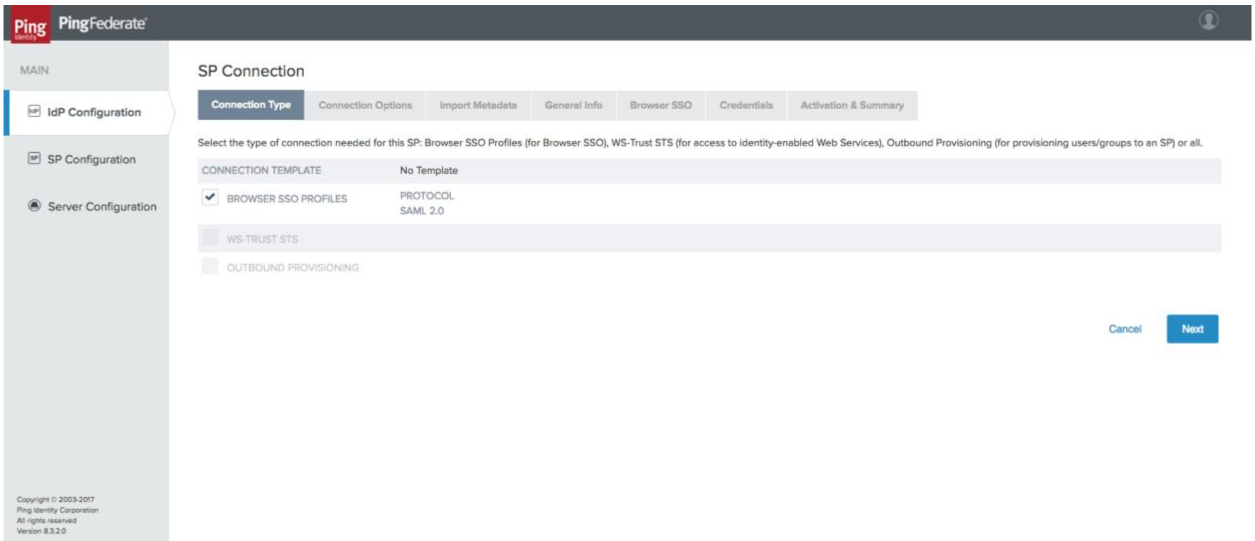
4.2.2 Configure the SP Connection

Each RP that will receive authentication assertions from the IdP must be configured as an SP connection. As explained in Section 3.4.2.1, this activity requires coordination between the administrators of the IdP and the RP to provide the necessary details to configure the connection. Exchanging metadata files can help automate some of the configuration process.

This section documents the configuration for the SP connection between the SAML IdP in the NCCoE lab and the OAuth AS in the Motorola Solutions cloud instance.

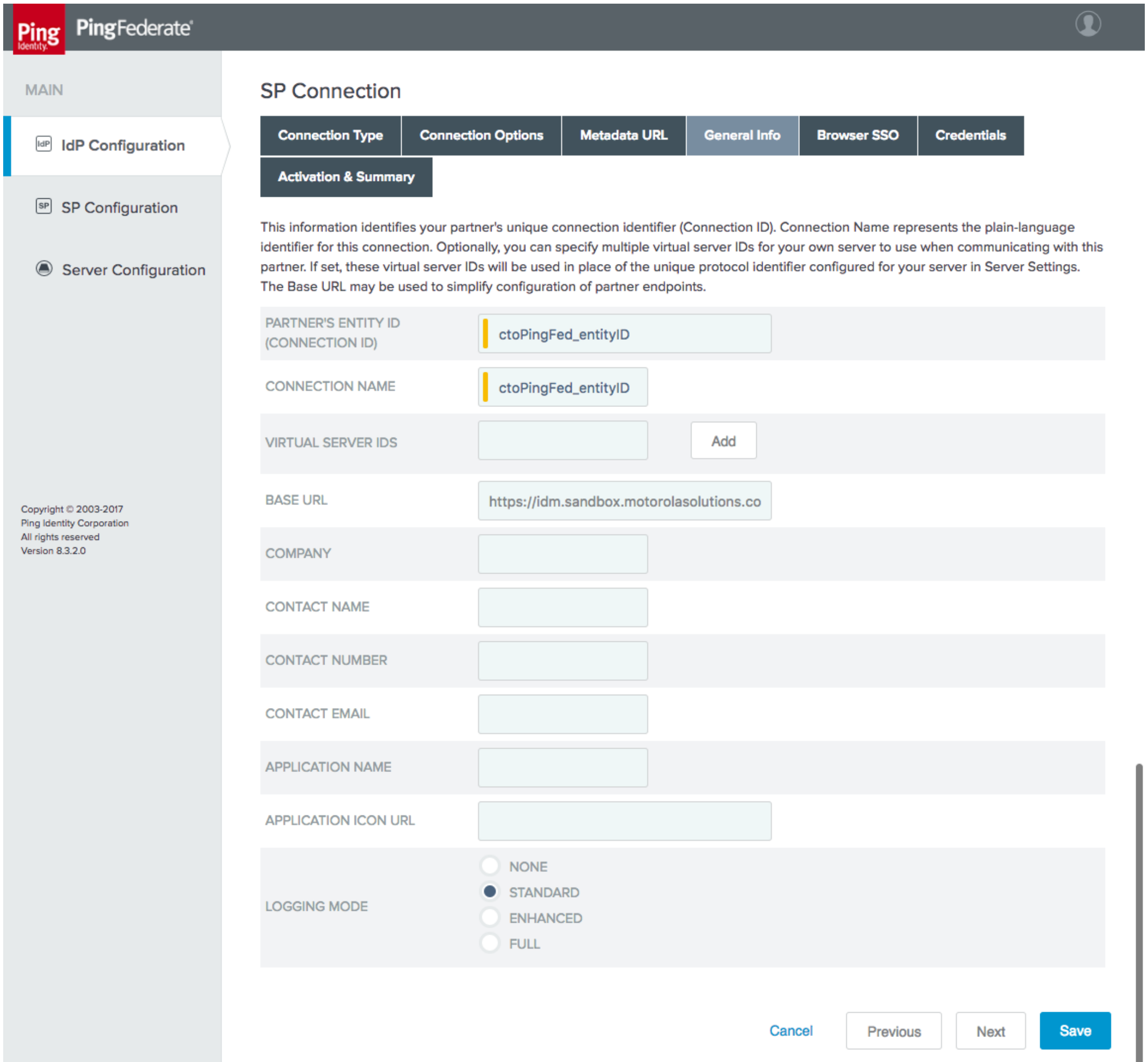
1. To create a new SP connection, click the **IdP Configuration** section tab, and then click **Create New** under **SP Connections**.
    a. On the **Connection Type** tab, select **BROWSER SSO PROFILES**, and select the **SAML 2.0** protocol (Figure 4-17). In this case, SAML 2.0 is pre-selected because no other protocols are enabled on this IdP.

Figure 4-17 SP Connection Type



    b. On the **Connection Options** tab, only **BROWSER SSO** needs to be selected.
    c. If metadata for the SP is available, it can be imported on the **Import Metadata** tab. This metadata can be specified in the form of a file upload or URL.
    d. On the **General Info** tab, enter the **PARTNER'S ENTITY ID (CONNECTION ID)** (Figure 4-18); this must match the **ENTITY ID** configured on the **Federation Info** tab in the **Server Configuration** of the SP. The SP's **BASE URL** should also be added on this **General Info** tab.

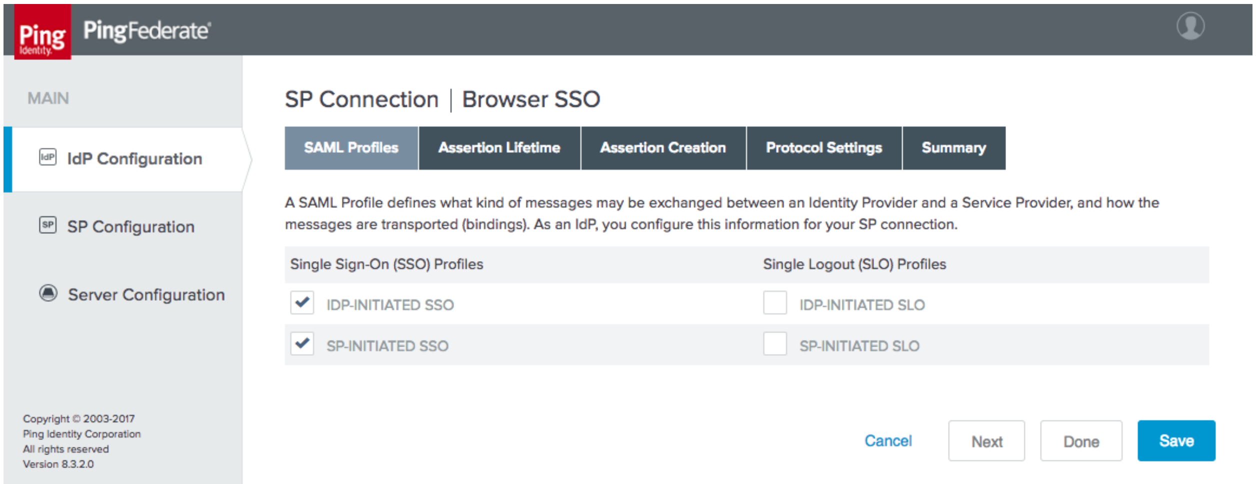
Figure 4-18 SP Connection General Info



e. On the **Browser SSO** tab, click **Configure Browser SSO**. This opens another multi-tabbed configuration screen.

   i. On the **SAML Profiles** tab, different SSO and Single Log-Out (SLO) profiles can be enabled (Figure 4-19). Only **SP-INITIATED SSO** is demonstrated in this lab build.

Figure 4-19 SP Browser SSO Profiles

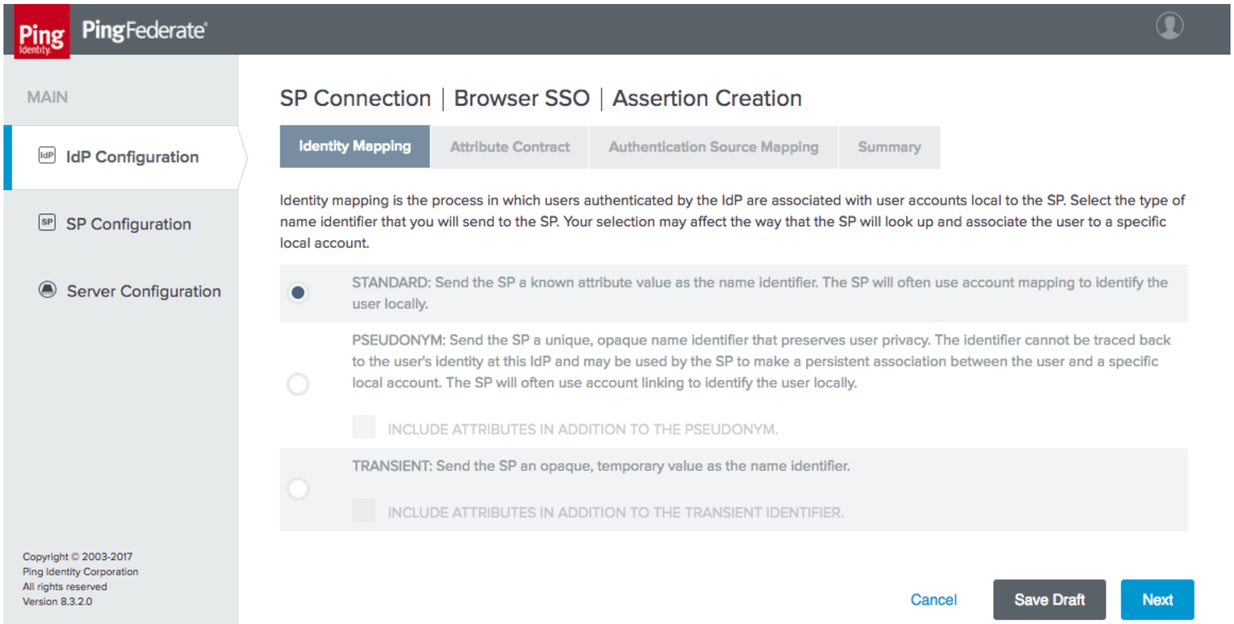


ii. On the **Assertion Lifetime** tab, time intervals during which SPs should consider assertions valid can be configured in minutes before and after assertion creation. In the lab, these were both set to the default of five minutes.

iii. On the **Assertion Creation** tab, click **Configure Assertion Creation**. This opens a new multi-tabbed configuration screen.

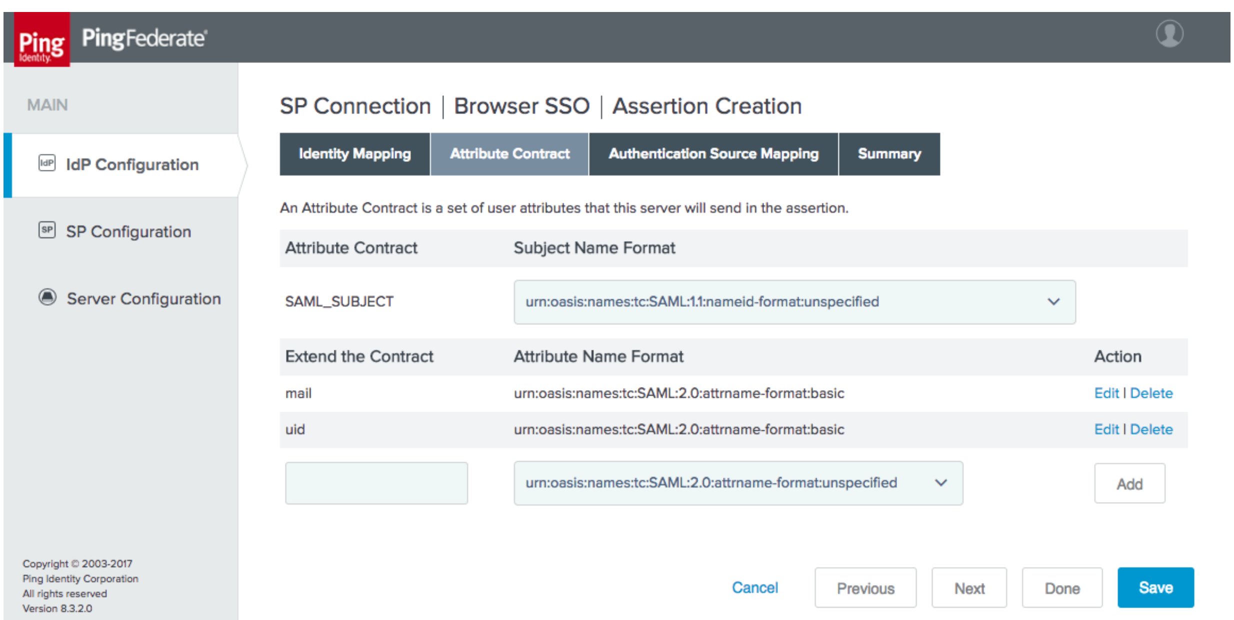
1) On the **Identity Mapping** tab, select the **STANDARD** mapping (Figure 4-20). The other options are more suitable for situations where identifiers are sensitive or where there are privacy concerns over the tracking of users.

Figure 4-20 Assertion Identity Mapping



2) On the **Attribute Contract** tab, extend the contract to include the **mail** and **uid** attributes with the basic name format (Figure 4-21). Other attributes can be added here as needed.

Figure 4-21 Assertion Attribute Contract



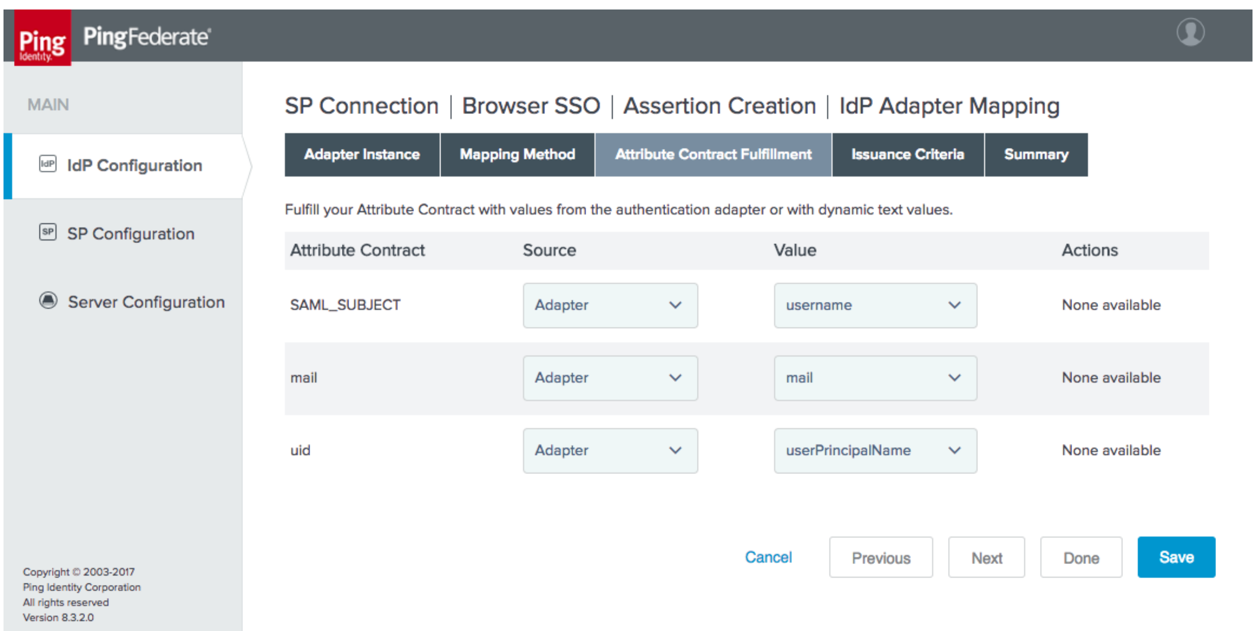
3) On the **Authentication Source Mapping** tab, attributes provided by authentication adapters and policy contracts can be mapped to the assertion attribute contract, identifying which data will be used to populate the assertions. The FIDO U2F adapter and the HTML Form Adapter should appear under **Adapter Instance Name**. Select the HTML Form Adapter, as it can provide the needed attributes from LDAP via the Password Validator and the AD data store connection. This brings up another multi-tabbed configuration screen.

   a) The **Adapter Instance** tab shows the attributes that are returned by the selected adapter. Click **Next**.

   b) The **Mapping Method** tab provides options to query additional data stores to build the assertions, but in this case, all of the required attributes are provided by the HTML Form Adapter. Select **USE ONLY THE ADAPTER CONTRACT VALUES IN THE SAML ASSERTION**.

   c) On the **Attribute Contract Fulfillment** tab, map the **SAML_SUBJECT**, **mail**, and **uid** attributes to the **username**, **mail**, and **userPrincipalName** adapter values (Figure 4-22).

Figure 4-22 Assertion Attribute Contract Fulfillment



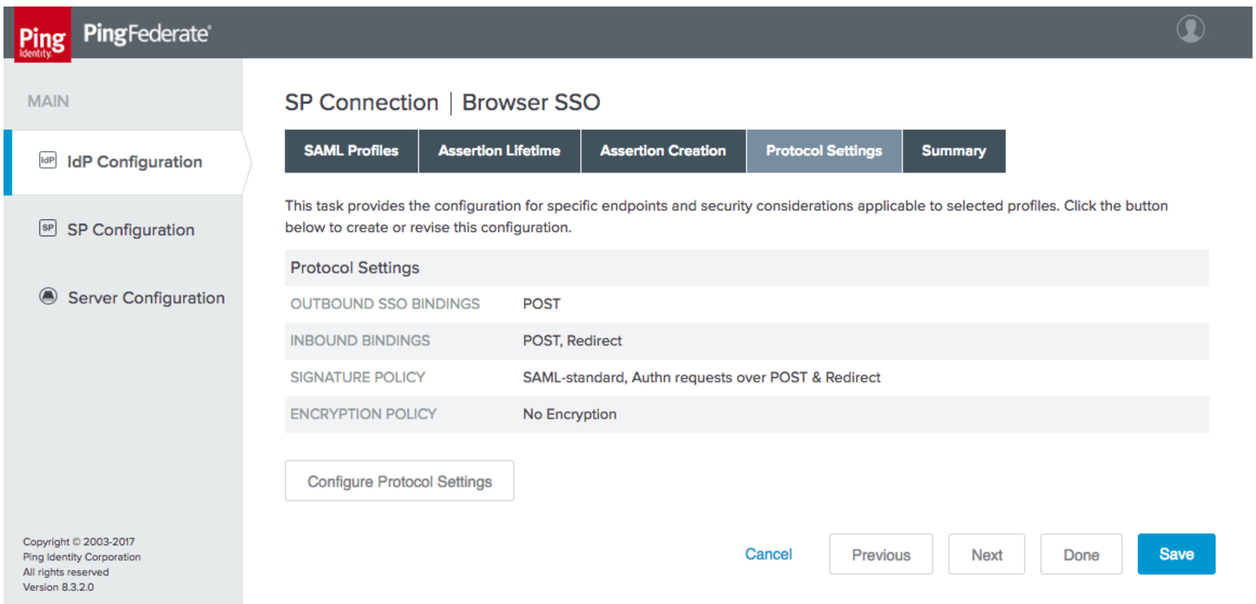
d) No **Issuance Criteria** are required; therefore, skip the **Issuance Criteria** tab.

e) Click **Done** to exit the IdP Adapter Mapping.

4) Click **Done** to exit the Assertion Creation.

iv. On the **Protocol Settings** tab, options such as additional SAML bindings, signature policy details, and assertion encryption policies can be specified (Figure 4-23). For the lab build, these values were left at their default settings.

Figure 4-23 Browser SSO Protocol Settings



v. Click **Done** to exit Browser SSO.

f. On the **Credentials** tab, the certificate to use for signing assertions can be specified. A self-signed certificate can be generated by PingFederate, or a trusted certificate can be obtained and uploaded. Click **Configure Credentials** to create or manage signing credentials.

g. On the **Activation & Summary** tab, the connection status can be set to **ACTIVE**. All configured settings for the SP connection are also displayed for verification.

h. Click **Save** to complete the SP connection configuration.

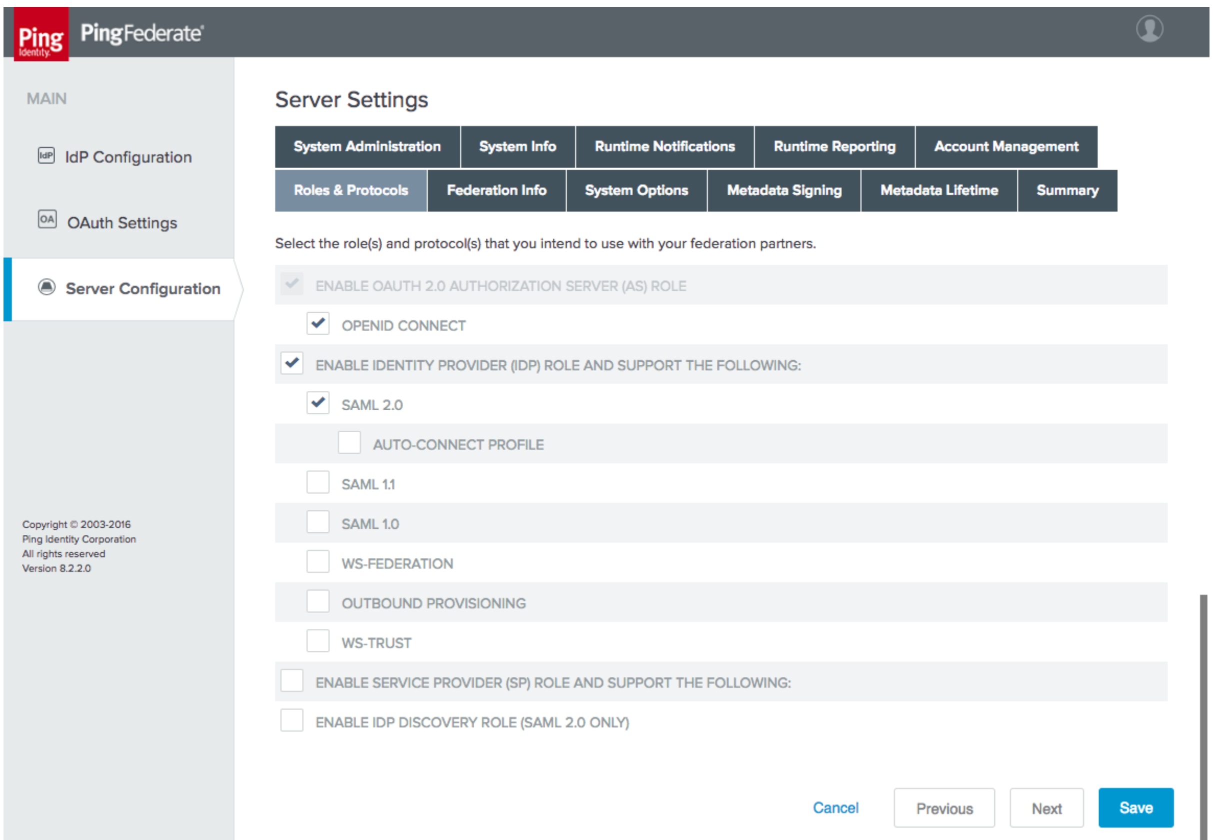
This completes the configuration of the SAML IdP.

4.3 How to Install and Configure the OIDC Identity Provider

1. On the **Server Configuration** section tab, click **Server Settings**.

    a. On the **Roles & Protocols** tab, enable the roles and protocols as shown in Figure 4-24. Although the OIDC IdP does not actually use the SAML protocol, some required configuration settings are unavailable if the IdP role is not enabled.

Figure 4-24 OIDC IdP Roles



    b. On the **Federation Info** tab, specify the **BASE URL** and **SAML 2.0 ENTITY ID**. The **BASE URL** must be a URL that is exposed to clients.

2. On the **OAuth Settings** section tab, click **Authorization Server Settings** to configure general OAuth and OIDC parameters. The OIDC IdP's settings on this page are identical to those for the OAuth AS; refer to Section 3.3 for notes on these settings.

3. On the **OAuth Settings** section tab, click **Scope Management**.
    a. Add the scopes defined in the OpenID Connect Core specification [25]:
        - openid
        - profile
        - email
        - address
        - phone

4.3.1 Configuring Authentication to the OIDC IdP

In the lab architecture, the OIDC IdP supports FIDO UAF authentication through integration with the NNAS and the Nok Nok Labs Gateway, using the Nok Nok FIDO UAF adapter for PingFederate. Configuring UAF authentication to the OIDC IdP cannot be completed until the Nok Nok Labs servers are available and the UAF plugin has been installed on the IdP server as specified in Section 5.

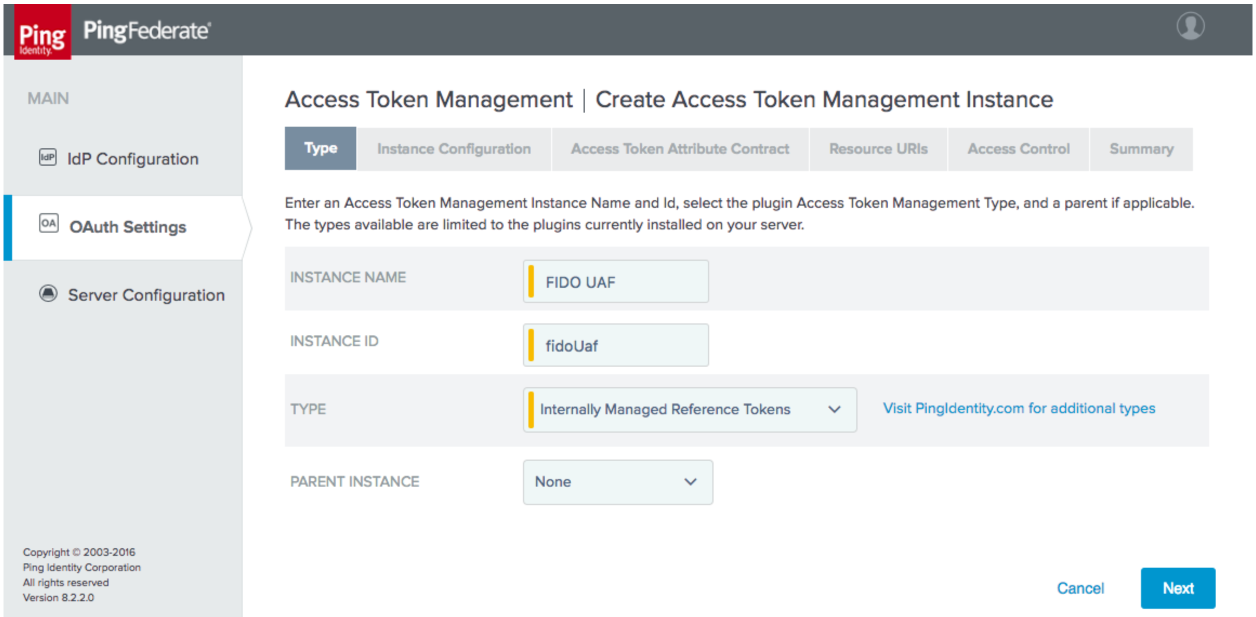
4.3.1.1 Configure the FIDO UAF Plugin

The steps to configure the FIDO UAF plugin for the OIDC IdP are identical to those documented in Section 3.4.1.1 for direct authentication using UAF at the AS. The only difference in the lab build was the URLs for the NNAS and the Nok Nok Labs Gateway, as the AS and the OIDC IdP used two different instances of the Nok Nok Labs server.

4.3.1.2 Configure an Access Token Management Instance

1. On the **OAuth Settings** section tab, click **Access Token Management**.
2. Click **Create New Instance**.
    a. On the **Type** tab, provide an **INSTANCE NAME** and **INSTANCE ID** (Figure 4-25).
        i. Select **Internally Managed Reference Tokens** for the **TYPE**.

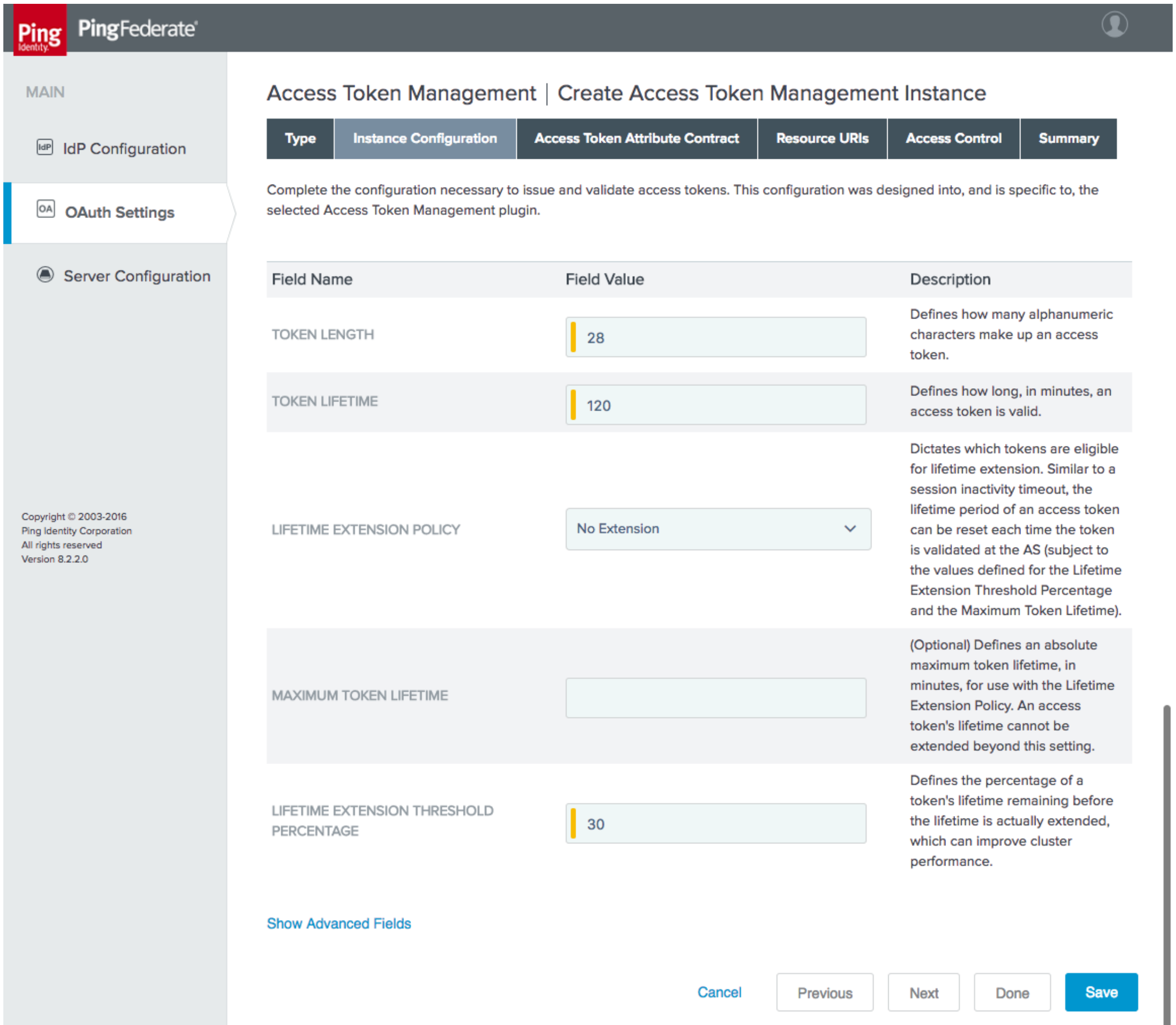
Figure 4-25 Create Access Token Manager



Although we have selected reference tokens, the ID Token is always issued in the form of a JWT. The token that is being configured here is not the ID Token, but rather the access token that will be issued to authorize the RP to call the userinfo endpoint at the IdP to request additional claims about the user. Because this access token only needs to be validated by the OIDC IdP itself, reference tokens are sufficient. In the Authorization Code flow, the RP obtains both the ID Token and the access token in exchange for the authorization code at the IdP's token endpoint.

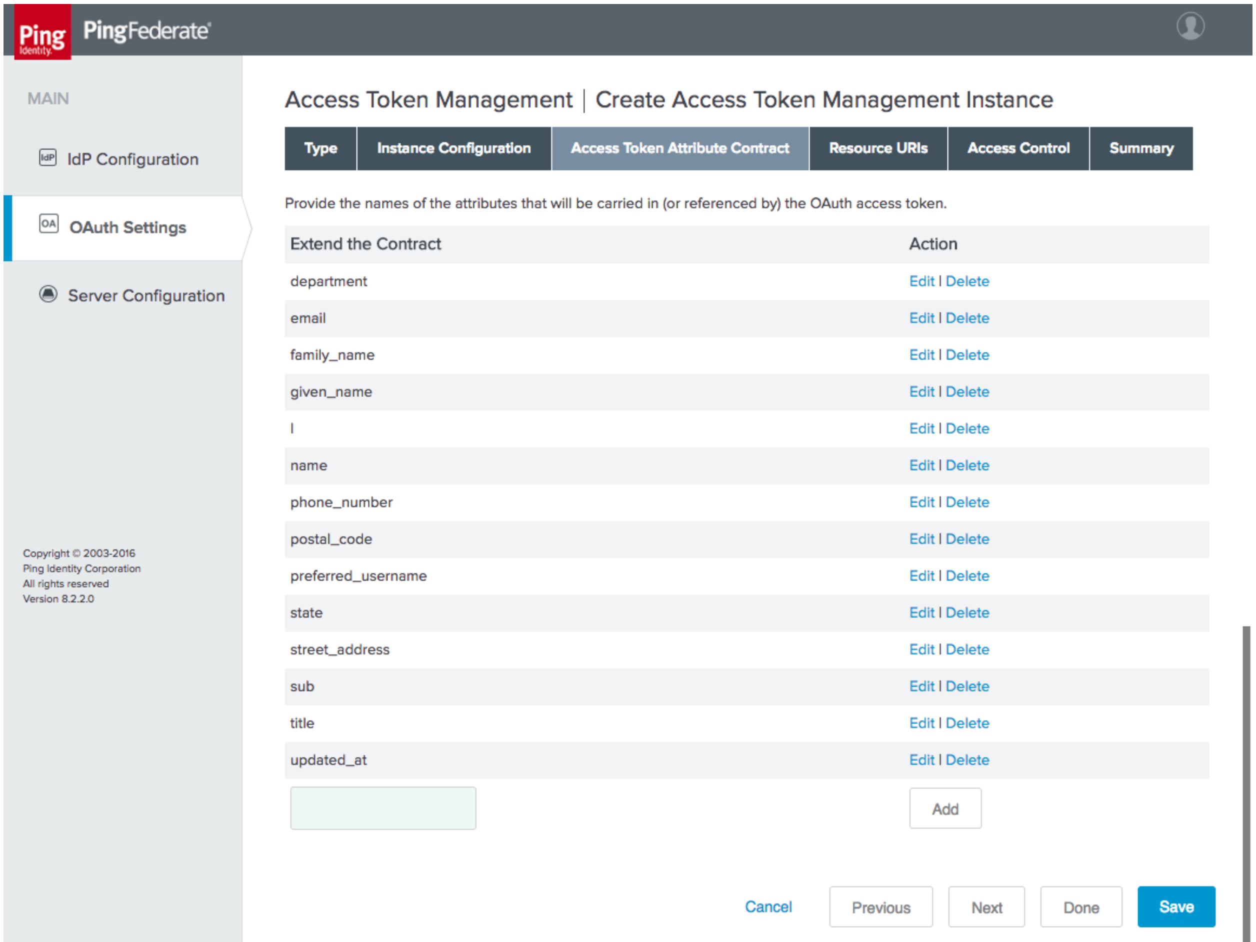
b. Click the **Instance Configuration** tab to configure some security properties of the access token, such as its length and lifetime (Figure 4-26). For the lab build, the default values were accepted.

Figure 4-26 Access Token Manager Configuration



c. On the **Access Token Attribute Contract** tab, extend the contract with any attributes that will be included in the ID Token (Figure 4-27). In the example shown in Figure 4-27, several attributes that will be queried from AD have been added.

Figure 4-27 Access Token Attribute Contract



d. There is no need to configure the **Resource URIs** or **Access Control** tabs; these tabs can be skipped.

e. Click **Done**, and then click **Save**.

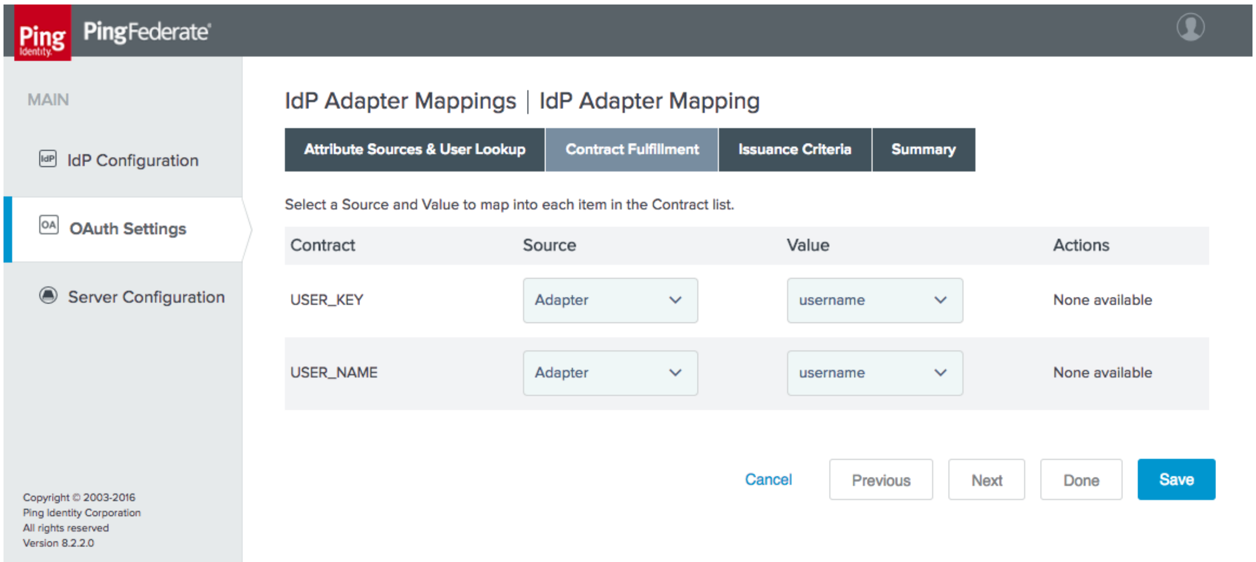
4.3.1.3 Configure an IdP Adapter Mapping

The IdP Adapter Mapping determines how the persistent grant attributes are populated using information from authentication adapters.

1. Click the **OAuth Settings** section tab, and then click **IdP Adapter Mapping**.
2. Select the UAF adapter instance created in Section 4.3.1.1, and then click **Add Mapping**.

a. On the **Contract Fulfillment** tab, map both **USER_KEY** and **USER_NAME** to the **username** value returned from the adapter (Figure 4-28).

Figure 4-28 Access Token Contract Fulfillment

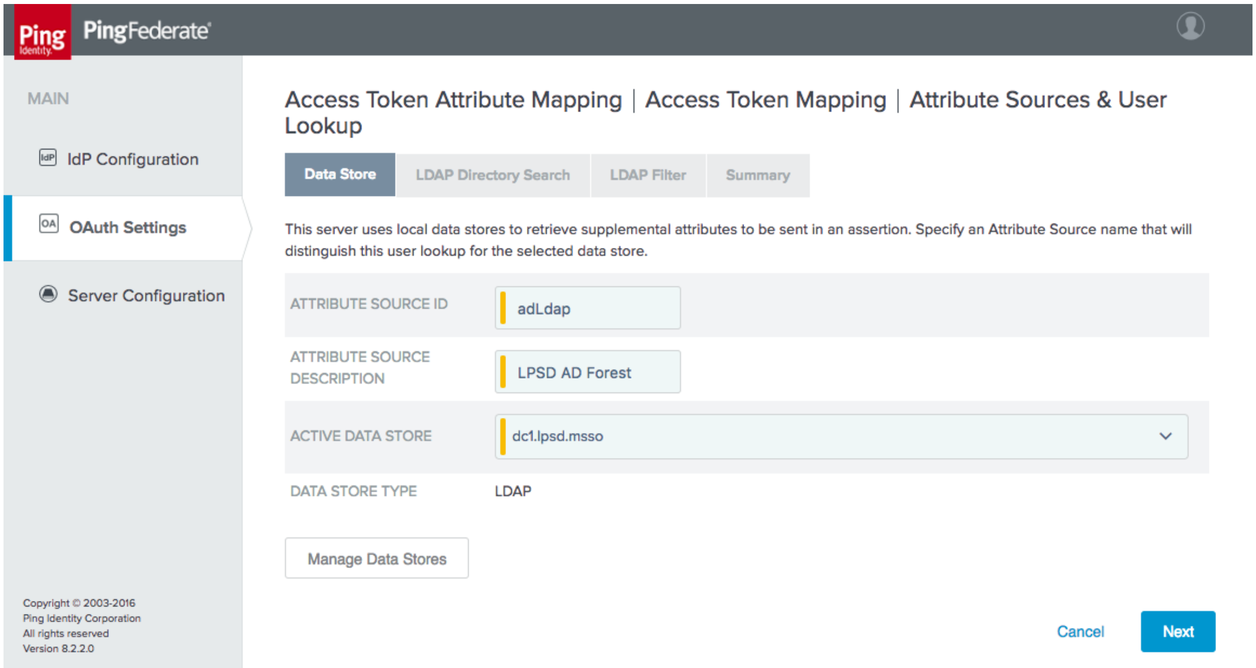


4.3.1.4 Configure an Access Token Mapping

The Access Token Mapping determines how the access token attribute contract is populated. In this example, the values returned from the adapter are supplemented with attributes retrieved from AD, and issuance criteria are used to require the user to be actually found in AD for a token to be issued. Depending on the credential and access life-cycle processes used in a given organization, there may be a lag in deactivating the authenticator or the AD account when a user's access is terminated. Organizations' authentication policies should account for these conditions and should allow or deny access appropriately.

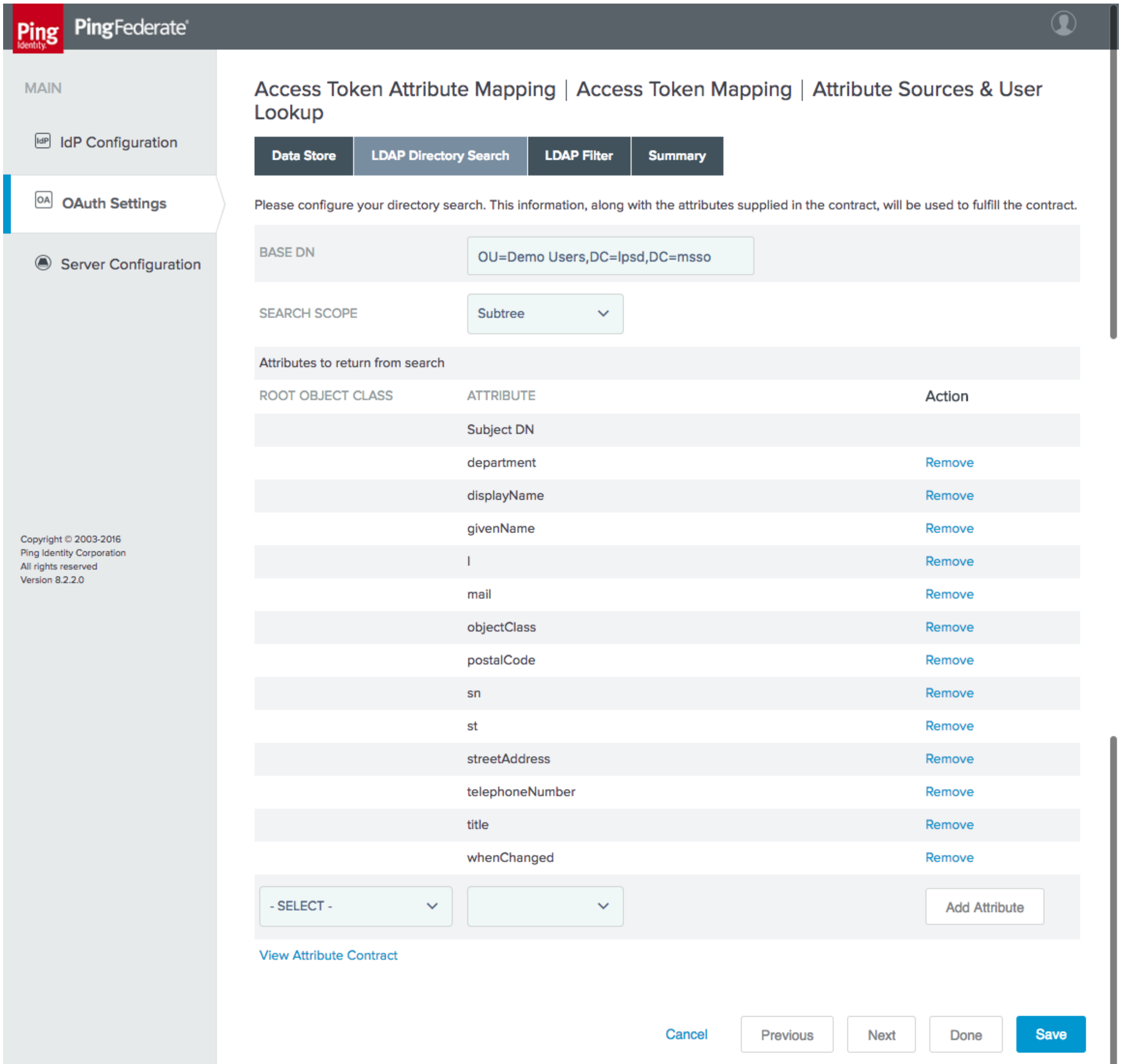
1. On the **OAuth Settings** section tab, click **Access Token Mapping**.
2. Under **CONTEXT** and **ACCESS TOKEN MANAGER**, select the IdP Adapter and Access Token Manager created in the preceding steps, and click **Add Mapping**.
    a. On the **Attribute Sources & User Lookup** tab, click **Add Attribute Source**. This brings up another multi-tabbed configuration.
        i. On the **Data Store** tab, give the attribute source an ID and description (Figure 4-29). For **ACTIVE DATA STORE**, select the user store created in Section 4.1.

Figure 4-29 Data Store for User Lookup



ii. On the **LDAP Directory Search** tab, specify the **BASE DN** and **SEARCH SCOPE**, and add the AD attributes to be retrieved (Figure 4-30). When specifying attributes, it is necessary to first select the root object class that contains the attribute. Common attributes associated with user accounts may be derived from the **User** or **OrganizationalPerson** class, for example. Refer to Microsoft's AD Schema documentation [26] to identify the class from which a given attribute is derived.

Figure 4-30 Attribute Directory Search



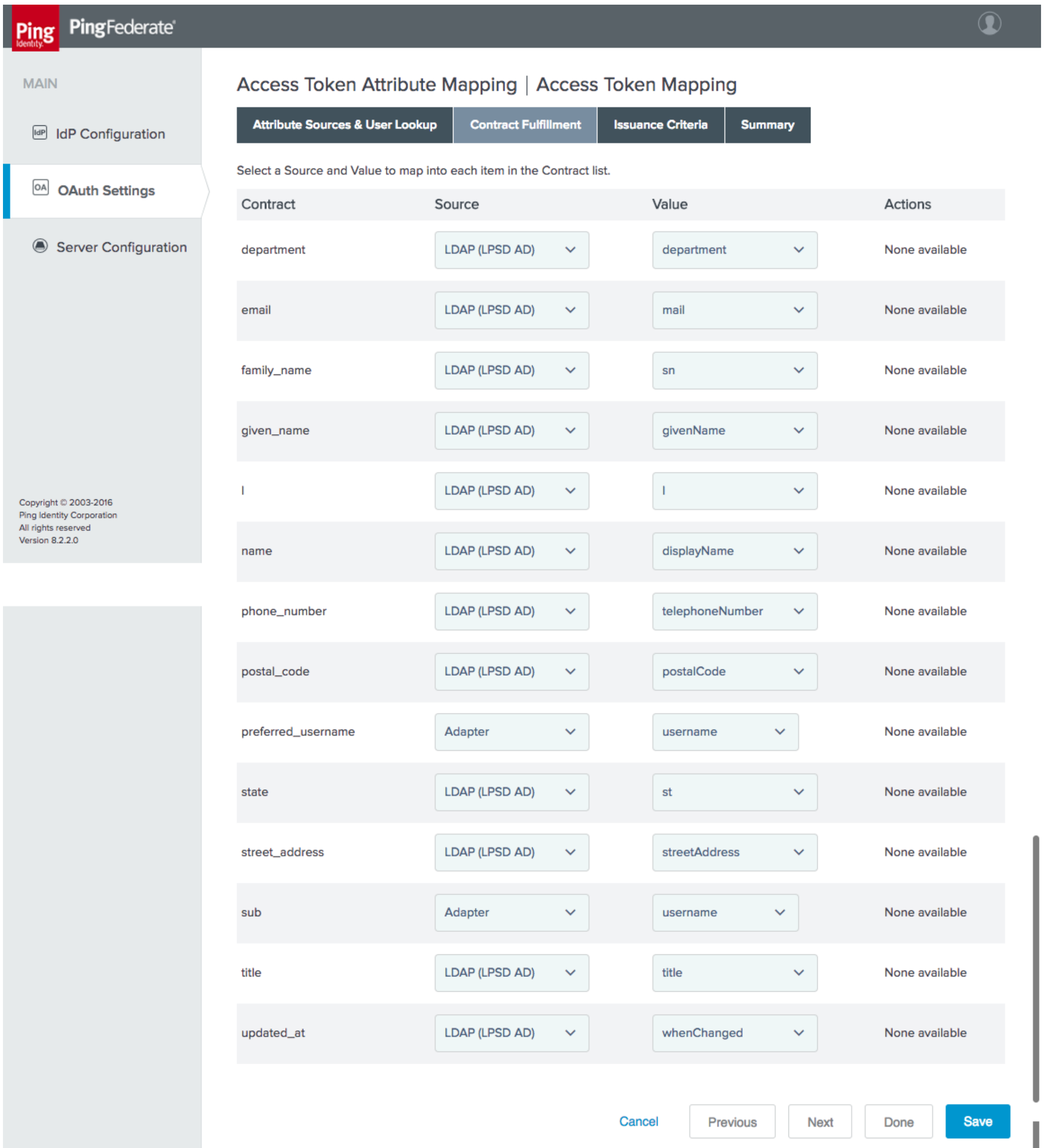
iii. On the **LDAP Filter** tab, create the filter to select the relevant user account. In this example, the username from the adapter is matched against the AD SAM account name:

```
sAMAccountName=${adapter.username}
```

iv. Click **Done** to exit the attribute source configuration.

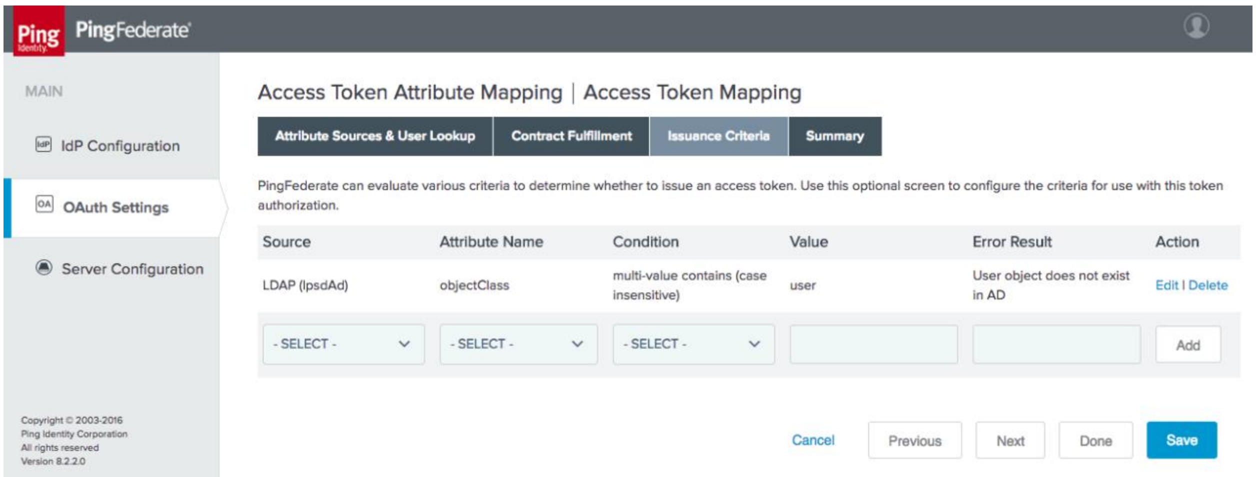
b. On the **Contract Fulfillment** tab, specify the source and value to use for each attribute in the access token attribute contract (Figure 4-31).

Figure 4-31 Access Token Contract Fulfillment



c. On the **Issuance Criteria** tab, define a rule that will prevent token issuance if the user account doesn't exist in AD (Figure 4-32). In this case, the **objectClass** attribute, which all AD objects have, is checked for the **Value** called **user**. If no user account is found in AD, this attribute will have no **Value**, the **Condition** will be false, and the specified **Error Result** will appear in the PingFederate server log.

Figure 4-32 Access Token Issuance Criteria



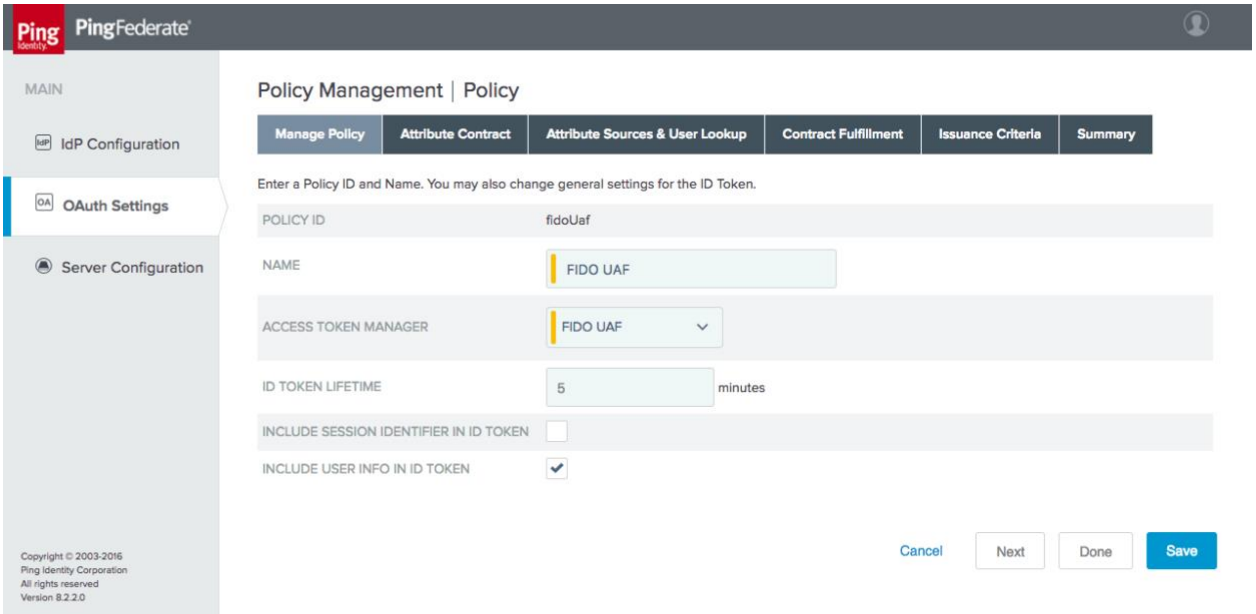
d. Click **Done**, and then click **Save** to finish the Access Token Attribute Mapping configuration.

4.3.1.5 Configure an OIDC Policy

1. On the **OAuth Settings** tab, click **OpenID Connect Policy Management**.
2. Click **Add Policy**.

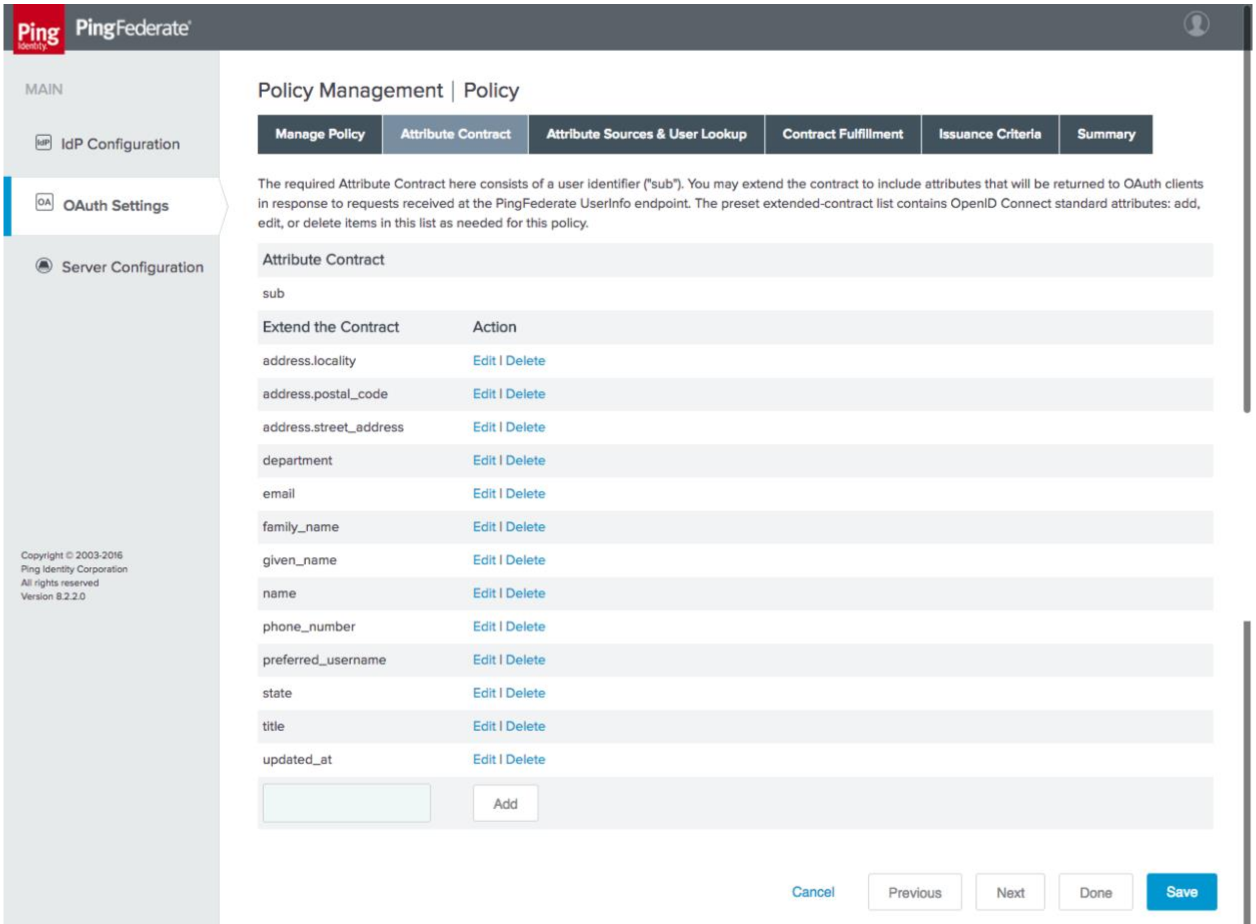
a. On the **Manage Policy** tab, create a **POLICY ID** and **NAME**, and select the **INCLUDE USER INFO IN ID TOKEN** checkbox (Figure 4-33). This selection means that the user's attributes will be included as claims in the ID Token JWT. The advantage of this approach is that the RP can directly obtain user attributes from the ID Token without making additional requests to the IdP. The alternative is to include only a subject claim in the ID Token, and to have the RP call the IdP's userinfo endpoint to obtain additional user attributes.

Figure 4-33 OIDC Policy Creation



b. On the **Attribute Contract** tab, the set of attributes in the contract can be edited (Figure 4-34). The contract is automatically populated with the standard claims defined in the OIDC Core specification. In the example shown in Figure 4-34, some claims have been removed and others have been added to accommodate the attribute available from AD.

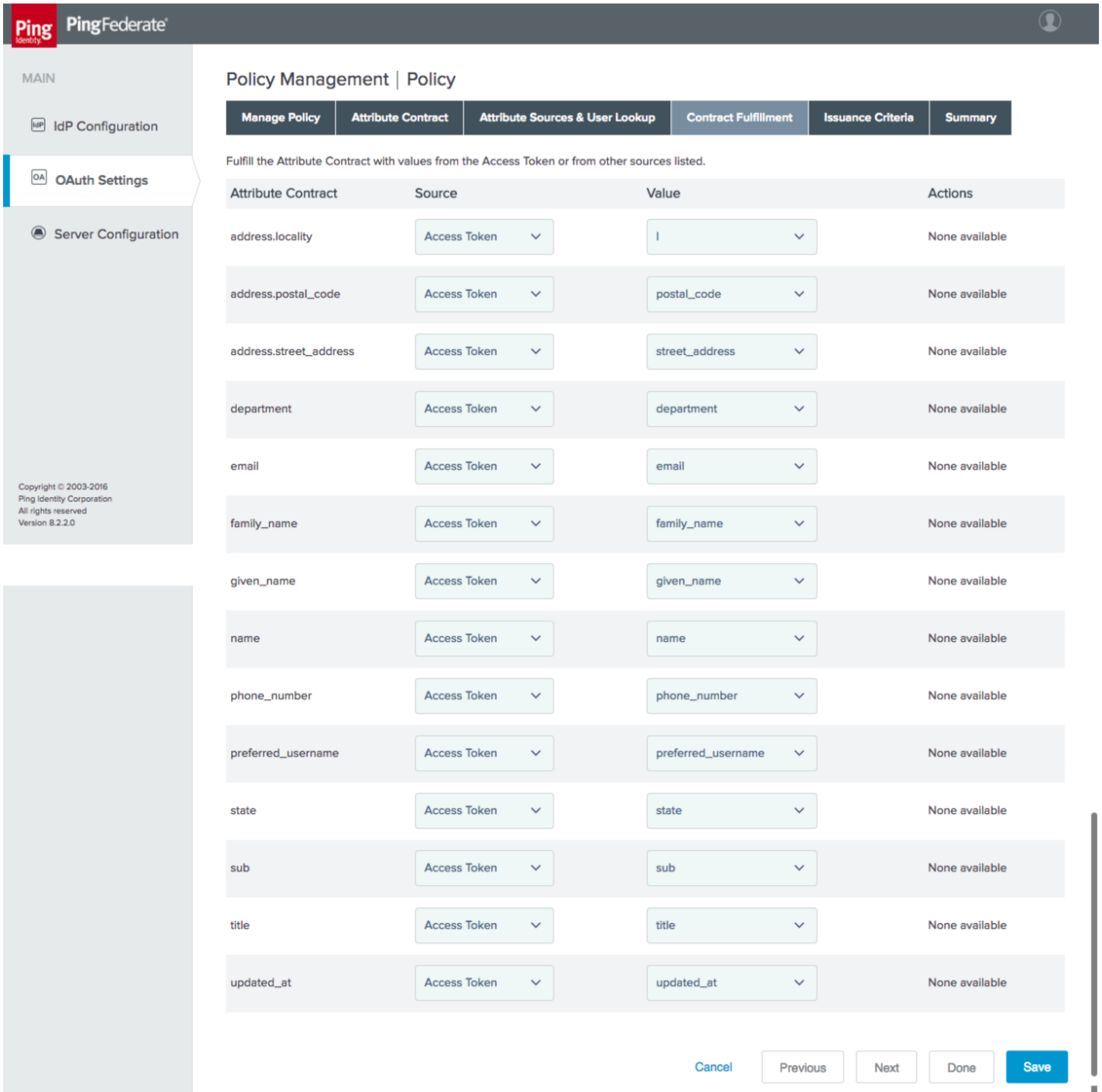
Figure 4-34 OIDC Policy Attribute Contract



c. Skip the **Attribute Sources & User Lookup** tab; there is no need to retrieve additional attributes.

d. On the **Contract Fulfillment** tab, populate the OIDC attributes with the corresponding values from the Access Token context (Figure 4-35).

Figure 4-35 OIDC Policy Contract Fulfillment



e. There is no need for additional issuance criteria; therefore, skip the **Issuance Criteria** tab.

f. Click **Save** to complete the OIDC Policy configuration.

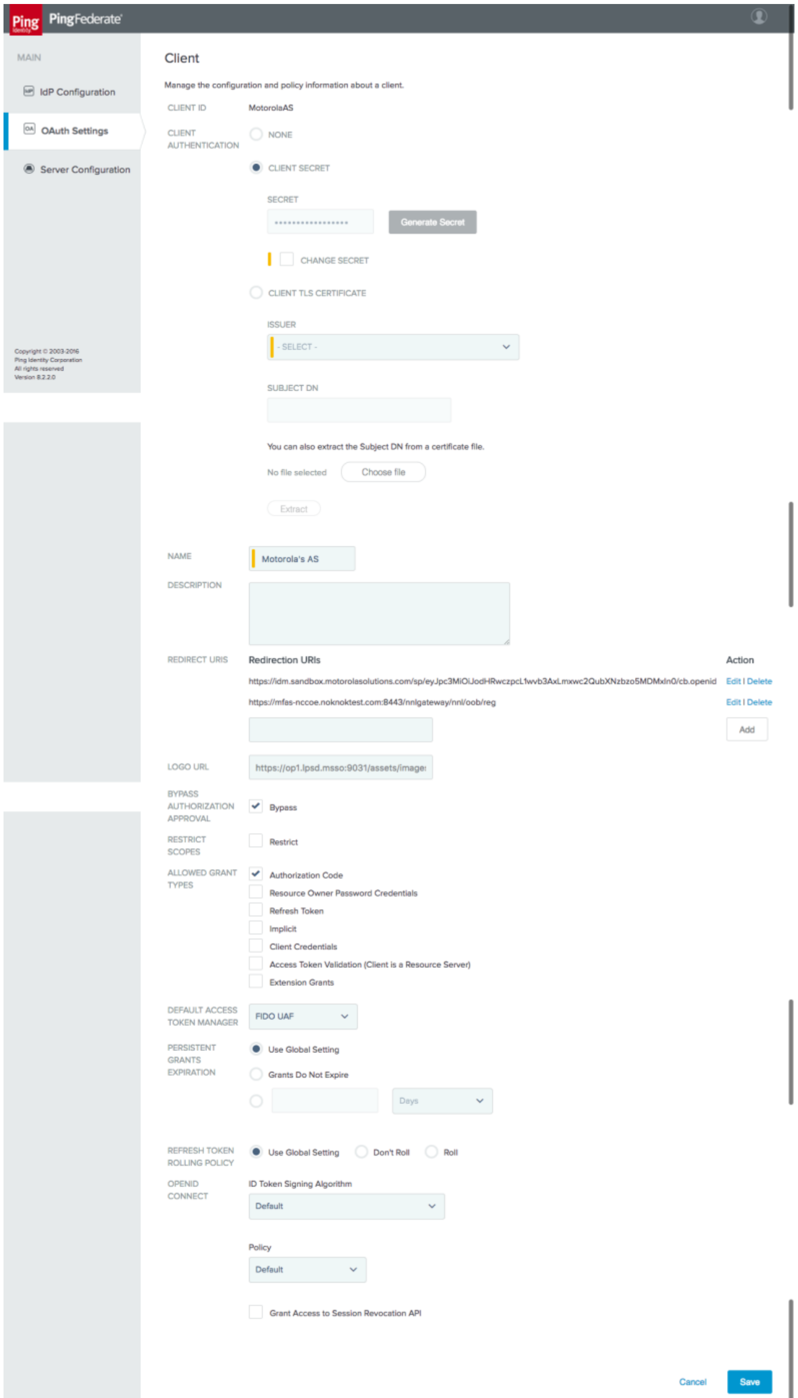
4.3.2 Configuring the OIDC Client Connection

Registering a client at an OIDC IdP is analogous to creating an SP connection at a SAML IdP. Some coordination is required between the administrators of the two systems. The client ID and client secret must be provided to the RP, and the RP must provide the redirect URI to the IdP.

1. To add a client, click the **OAuth Settings** section tab, and then click **Create New** under **Clients**.

    a. Create a **CLIENT ID** and **CLIENT SECRET** (Figure 4-36). If mutual TLS authentication is being used instead, the RP must provide its certificate, which can be uploaded to the client creation page. Only the **Authorization Code** grant type is needed for this integration. In the example shown in Figure 4-36, user prompts to authorize the sharing of the user's attributes with the RP have been disabled in favor of streamlining access to applications.

Figure 4-36 OIDC Client Configuration



This completes configuration of the OIDC IdP.

5 How to Install and Configure the FIDO UAF Authentication Server

For the lab build environment, the Nok Nok Labs S3 Authentication Suite provides FIDO UAF integration. The S3 Authentication Suite can support a variety of different deployments and architectures, as described in the Solution Guide [27]. This section briefly describes the overall deployment architecture used for this build.

The Nok Nok Labs SDKs can be directly integrated into mobile applications, providing UAF client functionality directly within the application. This deployment would be more suitable to use cases that do not involve federation, where the requirement is to authenticate users directly at the application back end. Nok Nok Labs also provides “Out-of-Band” (OOB) integration. OOB can support workflows where a mobile device is used for true OOB authentication of logins or transactions initiated on another device, such as a laptop or workstation. OOB also can be used for authentication flows in a mobile web browser, including OAuth authorization flows or IdP authentication, as implemented in this build by using the AppAuth pattern.

When OOB is used in a cross-device scenario, the user must first register the mobile device by scanning a QR code displayed in the browser. Subsequent authentication requests can be sent by push notification to the registered device. When the OOB flow is initiated in a mobile browser, however, the authentication request can be sent directly to the application running the Nok Nok Labs SDK by using mobile platform technologies to open links directly in mobile applications (*App Links* for Android, or *Universal Links* for iOS). The FIDO client that processes the OOB authentication request can be either a custom application incorporating the Nok Nok Labs SDK, or the Nok Nok Labs Passport application, which provides a ready-made implementation.

The components of the Nok Nok Labs deployment for this build architecture are as follows:

- Nok Nok Labs Passport – provides UAF client functionality as well as Authenticator-Specific Modules (ASMs) and authenticators on the mobile device
- Nok Nok Labs PingFederate UAF Adapter – a PingFederate plugin providing integration between a PingFederate AS or IdP and the NNAS, enabling UAF authentication or transaction verification to be integrated into PingFederate authentication policies
- NNAS – provides core UAF server functionality, including the generation and verification of challenges, as well as APIs for interactions with UAF clients and the PingFederate Adapter
- Nok Nok Labs Gateway – provides a simplified interface to request FIDO operations from the Authentication Server, as well as integration with the existing application session management infrastructure
- Nok Nok Labs Gateway Tutorial Application – a demonstration web application implementation that provides simple U2F and UAF authentication and registration workflows

In a typical production implementation, the gateway functions for authenticator management (registration and de-registration) would typically require strong authentication, implemented through the Gateway's session management integration. Nok Nok Labs' documentation for the PingFederate plugin provides examples for defining a "reg" OAuth scope to request authenticator registration. An OAuth Scope Authentication Selector could be used in a PingFederate authentication policy to trigger the required strong authentication process.

5.1 Platform and System Requirements

The following subsections list the hardware, software, and network requirements for the various Nok Nok Labs components.

5.1.1 Hardware Requirements

Nok Nok Labs specifies the following minimum hardware requirements for the NNAS and Nok Nok Labs Gateway components. The requirements for acceptable performance will depend on the anticipated user population and server load. See the *Enabling Scalability & Availability* section of the *Solution Guide* for architecture guidance on deploying the NNAS in a clustered configuration.

- Processor: 1 CPU
- Memory: 4 GB RAM
- Hard disk drive size: 10 GB

5.1.2 Software Requirements

Complete software requirements for the NNAS are provided in the *Nok Nok Labs Authentication Server Administration Guide* [28]. The major requirements are summarized below:

- OS: Red Hat Enterprise Linux 7 or CentOS 7
- Relational database system: MySQL 5.7.10 or later versions, Oracle Database 12c, or PostgreSQL 9.2 or 9.4
- Application server: Apache Tomcat 8.0.x or 8.5.x
- Java: Oracle JDK Version 8
- Build tool: Apache Ant 1.7 or later versions
- For clustered deployments: Redis 2.8 or later versions
- Google Cloud Messenger (GCM) or Apple Push Notification System (APNS), if using push messages

The Nok Nok Labs PingFederate Adapter is compatible with PingFederate 8.1.3 or later versions.

The Nok Nok Labs Gateway is also deployed in Tomcat.

5.2 How to Install and Configure the FIDO UAF Authentication Server

The installation process for the Authentication Server is documented in the *Administration Guide*. A high-level summary is provided below, with notes relevant to the lab build:

- Install the OS and dependent software, including Java and Tomcat. The database can be installed on the same host as Tomcat, or remotely. Provision a TLS certificate for the server and configure Tomcat to use TLS.
- The configuration for push notifications to support OOB authentication is not required for this build; push notifications would be used when the mobile device is used to authenticate logins or transactions initiated on a separate device.
- Follow the instructions to generate an encryption key and encrypt database credentials in the installation script. Encrypting the push notification credentials is not required, unless that functionality will be used.
- For this lab build, the standalone installation was used. The standalone option uses the PostgreSQL database on the same host as the Authentication Server and also installs the Tutorial application.
- After running the installation script, delete the encryption key (`NNL_ENCRYPTION_KEY_BASE64`) from *nnl-install-conf.sh*.
- For this lab build, the default policies and authenticators were used. In a production deployment, policies could be defined to control the authenticator types that could be registered and used to authenticate.
- Provisioning a Facet ID is not necessary for the OOB integration with Nok Nok Labs Passport, as used in the lab. If the Nok Nok Labs SDK were integrated with a custom mobile application, then the Facet ID would need to be configured, and the *facets.uaf* file would need to be published at a URL where it is accessible to clients.
- Application link/universal link integration (optional) – In the lab, the default setting using an application link under https://app.noknok.com was used. This is acceptable for testing, but in a production deployment, an application link pointing to the IdP's actual domain name would typically be used. It should be noted that the FQDN for the application link must be different from the authentication endpoint (i.e., the IdP's URL) at least by sub-domain.
- Configure tenant-specific and global parameters. For the lab build, a single tenant was used. Many parameters can be left at the default settings. Some notes on specific parameters are provided below:
    - `uaf.application.id` – This should be a URL that is accessible to clients. In a production deployment, the AS may not be accessible, so this may need to be hosted on a different server.

   - `uaf.facet.id` – There is no need to modify the Facet ID setting to enable the use of the Passport application for OOB authentication; however, if other custom applications were directly integrating the Nok Nok Labs SDK, they would need to be added here.

- For a production deployment, client certificate authentication to the Authentication Server should be enabled. This is done by configuring the Tomcat HTTP connector to require client certificates. This requires provisioning a client certificate for the gateway (and any other servers that need to call the Nok Nok Labs APIs). See the notes in Section 5.3 of the *Administration Guide* about configuring the Gateway to use client certificate authentication. A general reference on configuring TLS in Tomcat 8 can be found at https://tomcat.apache.org/tomcat-8.0-doc/ssl-howto.html.

5.3 How to Install and Configure the FIDO UAF Gateway Server

The Nok Nok Labs Gateway application is delivered as a Web Archive (WAR) file that can be deployed to a Tomcat server. For the lab build, it was deployed on the same server as the NNAS.

Configure the required settings in the `nnlgateway.properties` file, including the settings listed below:

- `mfas_location` – NNAS URL
- `server.auth.enabled` – should be set to true; also requires configuring the trust-store settings
- `client.auth.enabled` – see notes in Section 5.2 above; should be enabled for strong client authentication in production deployments; also requires configuring the keystore settings

In addition, the Gateway Tutorial application was installed by deploying the `gwtutorial.war` file and configuring the required URLs in `gwtutorial.properties`.

5.4 How to Install and Configure the FIDO UAF Adapter for the OAuth 2 AS

Nok Nok Labs provided a tar file containing a set of software tools for integration and testing with PingFederate. Version 5.1.0.501 of the Ping Integration library was used for the lab build. The installation process is summarized below; refer to the *Nok Nok PingFederate Adapter Integration Guide* [29] for full details:

1. Extract the *adapter* folder from the *nnl-ping-integration-5.1.0.501.tar* file onto the PingFederate server where the adapter will be installed.
2. Stop PingFederate if it is running, and run the installation script. The path to the PingFederate installation is passed as an argument; run the script by using an account with write access to the PingFederate installation:

   ```
   $ ./adapter-deploy.sh /usr/share/pingfederate-8.2.2/pingfederate
   ```

3. Configure the *adapter.properties* file (located in the PingFederate directory under *server/default/conf*) as required for the server and client TLS authentication settings specified

earlier in the Authentication Server configuration. If push notifications are enabled, configure the relevant settings.

4. The *Configure Session Manager* and *Deploy Nok Nok Gateway OOB* sections of the *Integration Guide* provide settings to use PingFederate to protect the Registration endpoint on the Nok Nok Labs Gateway. This could be used in conjunction with the custom “reg” scope and a PingFederate authentication policy to require strong authentication prior to UAF authenticator registration. This configuration was not tested in the lab.

The *Configure PingFederate Console* section of the *Integration Guide* walks through the complete configuration of a PingFederate OIDC provider. See Section 4.3 of this guide for the procedure to configure the OpenID Provider.

6 How to Install and Configure the FIDO U2F Authentication Server

The SKCE from StrongKey performs the FIDO U2F server functionality in the build architecture. StrongKey’s main product is the StrongKey Tellaro Appliance, but the company also distributes much of its software under the *Lesser General Public License (LGPL)*, published by the Free Software Foundation. SKCE 2.0 Build 163 was downloaded from its repository on *Sourceforge* and was used for this build. For more information, documentation, and download links, visit the vendor’s site at https://sourceforge.net/projects/skce/.

6.1 Platform and System Requirements

The following subsections document the software, hardware, and network requirements for SKCE 2.0.

6.1.1 Software Requirements

StrongKey’s website lists the OSs on which SKCE has been tested:

- CentOS 6.X or 7.X, 64-bit
- Windows 7 Professional, 64-bit

Since SKCE is a Java application, in theory it should be able to run on any OS that supports a compatible version of Java and the other required software. The application was built with the Oracle JDK Version 8, Update 72. For this build, SKCE was installed on a CentOS 7.4 server; therefore, these steps assume a Linux installation.

SKCE can be installed manually or with an installation script included in the download. SKCE depends on other software components, including an SQL database, an LDAP directory server, and the Glassfish Java application server. By default, the script will install MariaDB, OpenDJ, and Glassfish all on a single server. SKCE can also utilize AD for LDAP.

For this build, the scripted installation was used with the default software components. The required software components, which are listed below, must be downloaded prior to running the installation script:

- Glassfish 4.1
- Java Cryptography Extension (JCE) Unlimited Strength Jurisdiction Policy Files 8
- JDK 8, Update 121
- OpenDJ 3.0.0
- MariaDB 10.1.22
- MariaDB Java Client

See StrongKey's scripted installation instructions for details and download links: https://sourceforge.net/p/skce/wiki/Install%20StrongKey%20CryptoEngine%202.0%20%28Build%20163%29%20Scripted/.

To download OpenDJ, you must register for a free account for *ForgeRock BackStage*.

SKCE can also utilize an AD LDAP service. The LDAP directory contains system user accounts for managing the SKCE (generating cryptographic keys, etc.). Data pertaining to registered users and authenticators is stored in the SQL database, not in LDAP.

6.1.2 Hardware Requirements

StrongKey recommends installing SKCE on a server with at least 10 GB of available disk space and 4 GB of RAM.

6.1.3 Network Requirements

The SKCE API is hosted on Transmission Control Protocol (TCP) Port 8181. Any applications that request U2F registration, authentication, or deregistration actions from the SKCE need to be able to connect on this port. Glassfish runs an HTTPS service on this port. Use firewall-cmd, iptables, or any other system utility for manipulating the firewall to open this port.

Other network services listen on the ports listed below. For the scripted installation, where all these services are installed on a single server, there is no need to adjust firewall rules for these services because they are only accessed from localhost.

- 3306 – MariaDB listener
- 4848 – Glassfish administrative console
- 1389 – OpenDJ LDAP service

6.2 How to Install and Configure the FIDO U2F Authentication Server

StrongKey's scripted installation process is documented at https://sourceforge.net/p/skce/wiki/Install%20StrongKey%20CryptoEngine%202.0%20%28Build%20163%29%20Scripted/.

The installation procedure consists of the following steps:

- Downloading the software dependencies to the server where SKCE will be installed
- Making any required changes to the installation script
- Running the script as root/administrator
- Performing post-installation configuration

The installation script creates a "strongauth" Linux user and installs all software under */usr/local/strongauth*. Rather than reproduce the installation steps here, this section provides some notes on the installation procedure:

1. Download the software: Download and unzip the SKCE build to a directory on the server where SKCE is being installed. Download all installers as directed in the SKCE instructions to the same directory.

2. Change software versions as required in the install script: If different versions of any of the software dependencies were downloaded, update the file names in the install script (*install-skce.sh*). Using different versions of the dependencies, apart from minor point-release versions, is not recommended. For the lab build, JDK Version 8u151 was used instead of the version referenced in the instructions. This required updating the `JDK` and `JDKVER` settings in the file.

3. Change passwords in the install script: Changing the default passwords in the delivered script is strongly recommended. The defaults are readily discoverable, as they are distributed with the software. Passwords should be stored in a password vault or other agency-approved secure storage. Once the installation script has been run successfully, the script should be deleted or sanitized to remove passwords. The following lines in the install script contain passwords:

```
LINUX_PASSWORD=ShaZam123          # For 'strongauth' account
GLASSFISH_PASSWORD=adminadmin      # Glassfish Admin password
MYSQL_ROOT_PASSWORD=BigKahuna      # MySQL 'root' password
MYSQL_PASSWORD=AbracaDabra         # MySQL 'skles' password
SKCE_SERVICE_PASS=Abcd1234!        # Webservice user 'service-cc-ce' password
SAKA_PASS=Abcd1234!
SERVICE_LDAP_BIND_PASS=Abcd1234!
```

```
SEARCH_LDAP_BIND_PASS=Abcd1234!
```

4. Set the Application ID URL: The Application ID setting in *install-skce.sh* should point to a URL that will be accessible to clients where the *app.json* file can be downloaded. The default location is a URL on the SKCE server, but the SKCE would not be exposed to mobile clients in a typical production deployment. In the lab, *app.json* was hosted on the PingFederate server hosting the IdP in the following location:

   /usr/share/pingfederate-8.3.2/pingfederate/server/default/conf/template/assets/scripts

   which enables the file to be accessed by clients at the following URL: *https://idp1.spsd.msso:9031/assets/scripts/app.json*.

5. Run the script: *install-skce.sh* must be run as the root user. If the install script terminates with an error, troubleshoot and correct any problems before continuing.

6. (For CentOS 7) Create firewall rule: The install script attempts to open the required port using iptables, which does not work on CentOS 7. In that case, the following commands will open the port:

```
# firewall-cmd --permanent --add-port 8181/tcp
success
# firewall-cmd --reload
success
```

7. Install additional libraries: Depending on how CentOS was installed, some additional libraries may be required to run the graphical key custodian setup tool. In the lab, the SKCE server did not include X11 or a graphical desktop, so the key custodian setup was run over Secure Shell (SSH) with X11 forwarding. To install additional libraries needed for this setup, run the following commands:

```
# yum install libXrender
# yum install libXtst
```

   Note that running the graphical configuration tool over SSH also requires configuring X11 forwarding in the SSH daemon (**sshd**) on the server and using the `-X` command line option when connecting from an SSH client.

8. Run the key custodian setup tool: In production deployments, the use of a Hardware Security Module (HSM) and USB drive for the security officer and key custodian credentials is strongly recommended. In the lab, the software security module was used. Also, the lab setup utilized a single SKCE server; in this case, all instructions pertaining to copying keys to a secondary appliance can be ignored.

9. Restart Glassfish: On CentOS 7, run the following command:

```
$ sudo systemctl restart glassfishd
```

10. Complete Steps 5.1 and 5.2 in the SKCE installation instructions to activate the cryptographic module.

11. Complete Step 5.3 in the SKCE installation instructions to create the domain signing key. When prompted for the Application ID, use the URL referenced above in the Application ID setting of the *install-skce.sh* script.

12. Complete Step 6 if you are installing secondary SKCE instances; this was not done for this build but is recommended for a production installation.

13. Install a TLS certificate (optional): The SKCE installation script creates a self-signed certificate for the SKCE. It is possible to use the self-signed certificate, though PingFederate and any other servers that integrate with the SKCE would need to be configured to trust it. However, many organizations will have their own CAs, and will want to generate a trusted certificate for the SKCE for production use. To generate and install the certificate, follow the steps listed below:

    a. The keystore used by the SKCE Glassfish server is listed below:

    ```
    /usr/local/strongauth/glassfish4/glassfish/domains/domain1/config/keystor
    e.jks
    ```

    b. The default password for the keystore is "changeit".

    c. Use keytool to generate a keypair and certificate signing request. For example, the following commands generate a 2048-bit key pair with the alias "msso," and export a Certificate Signing Request (CSR):

    ```
    $ keytool -genkeypair -keyalg RSA -keysize 2048 -alias msso -keystore
    keystore.jks

    $ keytool -certreq -alias msso -file strongauth.req -keystore
    keystore.jks
    ```

    d. Submit the CSR to your organization's CA, and import the signed certificate along with the root and any intermediates:

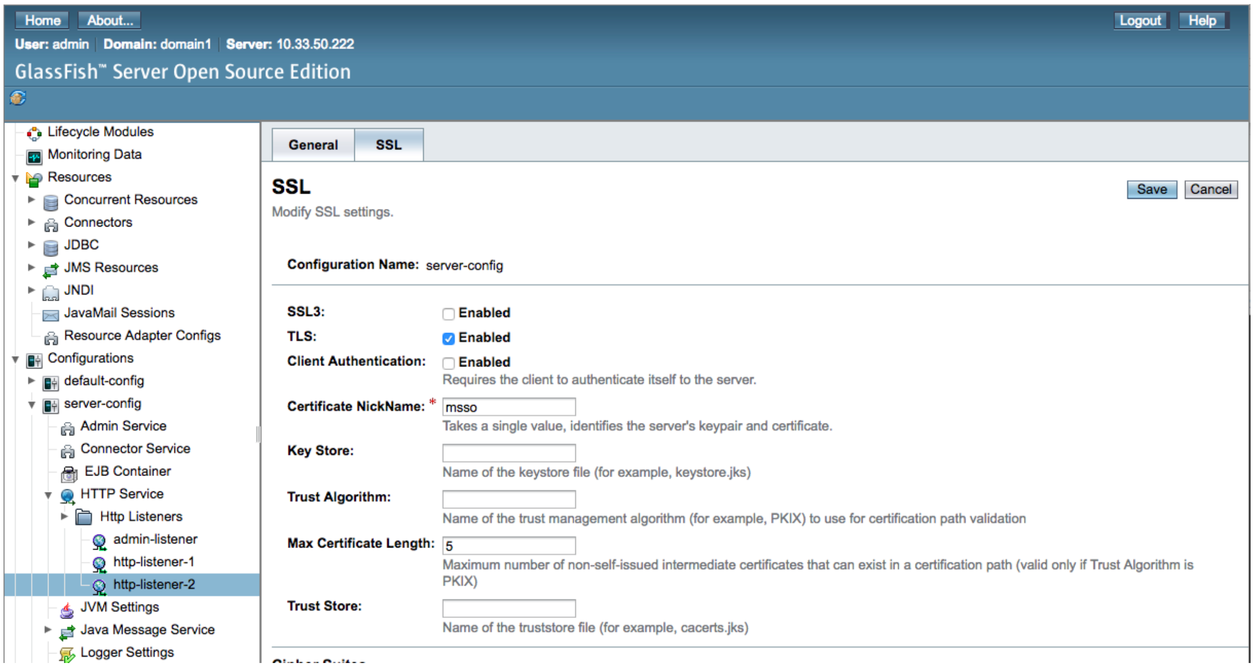
    ```
    $ keytool -import -trustcacerts -alias msso-root -file lab-certs/root.pem
    -keystore keystore.jks

    $ keytool -import -alias msso -file lab-certs/strongauth.lpsd.msso.cer -
    keystore keystore.jks
    ```

    e. To configure the SKCE to use the new certificate, log in to the Glassfish administrative console on the SKCE server. The console runs on Port 4848; the username is "admin," and the password will be whatever was configured for `GLASSFISH_PASSWORD` in the *install-skce.sh* script.

i. Navigate to *Configurations*, *server-config*, *HTTP Service*, *Http Listeners*, *http-listener-2*, as shown in Figure 6-1. On the **SSL** tab, set the **Certificate NickName** to the alias that was created with the “keytool -genkeypair” command above.

Figure 6-1 Glassfish SSL Settings



f. Click **Save**, and then restart glassfish. If logged on as the glassfish user, run the following command:

```
$ sudo service glassfishd restart
```

g. In a browser, access the SKCE web service on Port 8181, and ensure that it is using the newly created certificate.

h. For the FIDO Engine tests below to complete successfully, the main CA trust store for the JDK will need to be updated with your organization’s CA certificate. This can also be done with keytool:

```
$ keytool -import -trustcacerts -file lab-certs/root.pem -keystore
$JAVA_HOME/jre/lib/security/cacerts
```

14. Test the FIDO Engine: Follow the testing instructions under Step 4 at the following URL: https://sourceforge.net/p/skce/wiki/Test%20SKCE%202.0%20Using%20a%20Client%20Program%20%28Build%20163%29/#4test-skcefido-engine.

There are additional tests on that web page to test the other cryptographic functions of the SKCE; however, only the FIDO Engine tests are critical for this build.

If the FIDO Engine tests are completed without errors, proceed to Section 6.3 to integrate the SKCE with the IdP. If any errors are encountered, the Glassfish log file (located at */usr/local/strongauth/glassfish4/glassfish/domains/domain1/logs/server.log*) should contain messages to aid in troubleshooting.

6.3 How to Install and Configure the FIDO U2F Adapter for the IdP

To incorporate FIDO U2F authentication into a login flow at the IdP, some integration is needed to enable the IdP to call the SKCE APIs. In the lab build architecture, FIDO U2F authentication was integrated into a SAML IdP. PingFederate has a plugin architecture that enables the use of custom and third-party adapters in the authentication flow. StrongKey provides a PingFederate plugin to enable PingFederate IdPs (or AS) to support U2F authentication. This section describes the installation of the plugin on a PingFederate server. For details on how to integrate U2F authentication to a login flow, see Section 4.2.1.3.

The StrongKey plugin for PingFederate is delivered in a zip file containing documentation and all of the required program files.

1. To begin the installation process, upload the zip file to the PingFederate server where the StrongKey plugin will be installed, and unzip the files.

2. If Apache Ant is not already installed on the server, install it now by using the server's package manager. For CentOS, this can be done by running the following command:

   ```
   # yum install ant
   ```

3. Once Apache Ant is installed, follow the "Installation" instructions in the *StrongKey – Ping Federate FIDO IdP Adapter Installation Guide* [30], which consist of copying the plugin files to the required directories in the PingFederate installation, and running *build.sh*. If the script runs successfully, it will build the plugin using Ant and restart PingFederate.

4. Follow the steps in "Table 2: Configure the SKCE" in the *Installation Guide*. For this build, the *app.json* file needs to be copied to a browser-accessible location on the PingFederate server where the plugin is being installed. In the lab, we placed it under the following location:

   /usr/share/pingfederate-8.3.2/pingfederate/server/default/conf/template/assets/scripts

5. This enables the *app.json* to be accessed at the URL *https://idp1.spsd.msso:9031/assets/scripts/app.json*. Note that Steps 4 and 5 in Table 2 of the *Installation Guide* are required only if the SKCE is using the default self-signed certificate; if a trusted certificate was installed as described in Section 6.2, then those steps can be skipped.

6. Download the JQuery 2.2.0 library at the URL below, and save it to the scripts folder referenced above: https://code.jquery.com/jquery-2.2.0.min.js.

7. Follow the steps in "Table 3: Configure the Ping Federate Instance" in the *Installation Guide*. Importing the SKCE self-signed certificate is not required if a trusted certificate was created. Installation of the JCE unlimited policy was described in the PingFederate installation instructions in Section 3, so that too can be skipped at this point, if it has already been done. Steps 7–9 should be completed in any case.

8. Follow the steps in "Table 4: Configuring the FIDO Adapter" in the *Installation Guide*. In Step 5, the Domain ID typically should be set to "1," unless you have defined multiple domains in the SKCE. For the username and password, use the values configured earlier in *install-skce.sh*.

9. "Table 5: Ping Federate OAuth Configuration Steps" in the *Installation Guide* provides an example of how to incorporate U2F into a login flow, along with username/password form login, by creating a composite adapter that includes the login form and U2F adapters, and using a selector to activate the composite adapter whenever an OAuth authorization request includes the scope value "ldap." Alternatively, the individual adapters can be called directly in an authentication policy. See Chapter 4 of the *Installation Guide* for additional examples of using U2F in authentication policies.

6.3.1 FIDO U2F Registration in Production

By default, the StrongKey Ping plugin enables the registration of U2F authenticators. In production, an authorized registration process should be established to provide adequate assurance in the binding of the authenticator to a claimed identity. If the FIDO adapter is accessible after single-factor password authentication, organizations may want to disable the registration functionality. See Section B.5 in Volume B of this guide for a discussion of FIDO enrollment.

7 Functional Tests

The MSSO architecture has a number of interoperating components, which can make troubleshooting difficult. This section describes tests than can be performed to validate that individual components are working as expected. If issues are encountered with the overall SSO flow, these tests may help identify the problem area.

7.1 Testing FIDO Authenticators

The FIDO Alliance implements a Functional Certification Program, in which products are evaluated for conformance to the UAF and U2F specifications. Purchasing FIDO-certified authenticators can help avoid potential authenticator implementation issues. Information on the certification program is available at https://fidoalliance.org/certification/, and the FIDO Alliance website also lists certified products.

Some resources are available to help troubleshoot individual authenticators:

- The Yubico demonstration site provides an interface for testing registration and authentication with U2F authenticators: https://demo.yubico.com/u2f.
- The Nok Nok Labs Gateway Tutorial Application supports testing of the registration, authentication, and transaction verification functions of FIDO UAF authenticators.

7.2 Testing FIDO Servers

The StrongKey SKCE documentation includes instructions on testing U2F authenticator registration, authentication, de-registration, and other functions. See Step 14 in Section 6.2.

To test the NNAS, Nok Nok Labs provides the OnRamp mobile application in the Google Play Store and the Apple App Store to test the server APIs with UAF authenticators.

7.3 Testing IdPs

If federated authentication is failing, the issue may lie at the IdP or the AS. The PingFederate server log (located by default under *<pingfederate-directory>/log/server.log*), on both ends, should provide relevant messages.

In some cases, it may be beneficial to look at the assertions being issued by the IdP and to check for the expected attributes. This could be done by integrating a demonstration application as a federation client and debugging the data returned in the assertion. For SAML, projects like SimpleSAMLphp (https://simplesamlphp.org/) provide an implementation that is easy to deploy. It is also possible to perform this testing without installing additional tools.

One method for SAML is to use Chrome Remote Debugging for Android devices: https://developers.google.com/web/tools/chrome-devtools/remote-debugging/.

By logging the authentication flow in the Network pane of Chrome's developer tools, the SAML response can be extracted and viewed. The authentication flow with the SAML IdP configured in this practice guide consists of a series of calls to the *SSO.ping* URL at the IdP. Because the SAML POST binding is used, the final *SSO.ping* response includes an HTML form that submits the SAML response back to the AS. The SAML response can be found in an input element in the page content:


```
<input type="hidden" name="SAMLResponse"
value="PHNhbWxwOlJlc3BvbnNlIFZlcnNpb249IjIuMCIgSUQ9Iko1T2xNNlZxZW5lVnpBU2doSHlsakFLYlI
uOCIgSXNzdWVJbnN0YW50PSIyMDE3LTExLTEzVDEzOjQ5OjE3LjEwMFoiIEluUmVzcG9uc2VUbz0iS2RwMXVfZ
HFPMHlNX2Z0YWVldWJnRjlvMFBYIiBEZXN0aW5hdGlvbj0iaHR0cHM6Ly9pZG0uc2FuZGJveC5tb3Rvcm9sYXN
vbHV0aW9ucy5jb20vc3AvQUNTLnNhbWwyIiB4bWxuczpzYW1scD0idXJuOm9hc2lzOm5hbWVzOnRjOlNBTUw6M
i4wOnByb3RvY29sIj48c2FtbDpJc3N1ZXIgeG1sbnM6c2FtbD0idXJuOm9hc2lzOm5hbWVzOnRjOlNBTUw6Mi4
wOmFzc2VydGlvbiI+aWRwMS5zcHNkLm1zc288L3NhbWw6SXNzdWVyPjxkczpTaWduYXR1cmUgeG1sbnM6ZHM9I
mh0dHA6Ly93d3cudzMub3JnLzIwMDAvMDkveG1sZHNpZyMiPgo8ZHM6U2lnbmVkSW5mbz4KPGRzOkNhbm9uaWN
hbGl6YXRpb25NZXRob2QgQWxnb3JpdGhtPSJodHRwOi8vd3d3LnczLm9yZy8yMDAxLzEwL3htbC1leGMtYzE0b
```

```
iMiLz4KPGRzOlNpZ25hdHVyZU1ldGhvZCBBbGdvcml0aG09Imh0dHA6Ly93d3cudzMub3JnLzIwMDEvMDQveG1
sZHNpZy1tb3JlI3JzYS1zaGEyNTYiLz4KPGRzOlJlZmVyZW5jZSBVUkk9IiNKNU9sTTZWcWVuZVZ6QVNnaEh5b
GpBS2JSLjgiPgo8ZHM6VHJhbnNmb3Jtcz4KPGRzOlRyYW5zZm9ybSBBbGdvcml0aG09Imh0dHA6Ly93d3cudzM
ub3JnLzIwMDAvMDkveG1sZHNpZyNlbnZlbG9wZWQtc2lnbmF0dXJlIi8+CjxkczpUcmFuc2Zvcm0gQWxnb3Jpd
GhtPSJodHRwOi8vd3d3LnczLm9yZy8yMDAxLzEwL3htbC1leGMtYzE0biMiLz4KPC9kczpUcmFuc2Zvcm1zPgo
8ZHM6RGlnZXN0TWV0aG9kIEFsZ29yaXRobT0iaHR0cDovL3d3dy53My5vcmcvMjAwMS8wNC94bWxlbmMjc2hhM
jU2Ii8+CjxkczpEaWdlc3RWYWx1ZT4xdlFpcUNVNmlZYTMzdlFtKzcxbEVsVm1pUUh6T2U5cytBTTdQYTk4Vlp
BPTwvZHM6RGlnZXN0VmFsdWU+CjwvZHM6UmVmZXJlbmNlPgo8L2RzOlNpZ25lZEluZm8+CjxkczpTaWduYXR1c
mVWYWx1ZT4KTHpSbUJhclk2bndGS3ZydjdTL29WYWNJSWRJRUY4eUloV0JXT0NHZ3pyMWtONGVzVi9CU3lLQ1N
XYjhKU1h3QzhWRHNNUnRXOENMNQpVRFV0NTV1OXRCa05Wanh2NWR0NStOYXQ5eWtmdnhXbU9kcGVJVTBzMXNuM
UJHdytkOTRoZUlCYVdJWE1ZOVlRaDlnV3Q2Sll0OVFhCmRGdDZrRUY1S1NDS1FBQVNlbTEyT2xLV29GK2JSbG1
HNGVsbTVMTTh1N0E3Wi9hRnZ1cDNDNmV5ZEpwK1IxaStaK0F6NHlXdmMvNmEKYnlLMTBPZ05pLzBibnprazd3L
0psdHk0ZlVEcVd6bXJyRFpwSEJ4ZkFMVW5UV2RPVDVJeko3bmpMQWtBYVN0NDYwWjUyblpBOGFBYgpVbzA4T0t
EYnZVaS9UZ2xTcUZjcDJSYStCaE9DbUR3OWJvTG9udz09CjwvZHM6U2lnbmF0dXJlVmFsdWU+CjwvZHM6U2lnb
mF0dXJlPjxzYW1scDpTdGF0dXM+PHNhbWxwOlN0YXR1c0NvZGUgVmFsdWU9InVybjpvYXNpczpuYW1lczp0Yzp
TQU1MOjIuMDpzdGF0dXM6U3VjY2VzcyIvPjwvc2FtbHA6U3RhdHVzPjxzYW1sOkFzc2VydGlvbiBJRD0iSF9tL
ldIR29VUVBELjNjVlA0MVhDVVh4YkdLIiBJc3N1ZUluc3RhbnQ9IjIwMTctMTEtMTNUMTM6NDk6MTcuMTU1WiI
gVmVyc2lvbj0iMi4wIiB4bWxuczpzYW1sPSJ1cm46b2FzaXM6bmFtZXM6dGM6U0FNTDoyLjA6YXNzZXJ0aW9uI
j48c2FtbDpJc3N1ZXI+aWRwMS5zcHNkLm1zc288L3NhbWw6SXNzdWVyPjxzYW1sOlN1YmplY3Q+PHNhbWw6TmF
tZUlEIEZvcm1hdD0idXJuOm9hc2lzOm5hbWVzOnRjOlNBTUw6MS4xOm5hbWVpZC1mb3JtYXQ6dW5zcGVjaWZpZ
WQiPnVuY2NvZXRlc3Q0PC9zYW1sOk5hbWVJRD48c2FtbDpTdWJqZWN0Q29uZmlybWF0aW9uIE1ldGhvZD0idXJ
uOm9hc2lzOm5hbWVzOnRjOlNBTUw6Mi4wOmNtOmJlYXJlciI+PHNhbWw6U3ViamVjdENvbmZpcm1hdGlvbkRhd
GEgUmVjaXBpZW50PSJodHRwczovL2lkbS5zYW5kYm94Lm1vdG9yb2xhc29sdXRpb25zLmNvbS9zcC9BQ1Muc2F
tbDIiIE5vdE9uT3JBZnRlcj0iMjAxNy0xMS0xM1QxMzo1NDoxNy4xNTVaIiBJblJlc3BvbnNlVG89IktkcDF1X
2RxTzB5TV9mdGFlZXViZ0Y5bzBQWCIvPjwvc2FtbDpTdWJqZWN0Q29uZmlybWF0aW9uPjwvc2FtbDpTdWJqZWN
0PjxzYW1sOkNvbmRpdGlvbnMgTm90QmVmb3JlPSIyMDE3LTExLTEzVDEzOjQ0OjE3LjE1NVoiIE5vdE9uT3JBZ
nRlcj0iMjAxNy0xMS0xM1QxMzo1NDoxNy4xNTVaIj48c2FtbDpBdWRpZW5jZVJlc3RyaWN0aW9uPjxzYW1sOkF
1ZGllbmNlPmN0b1BpbmdGZWRfZW50aXR5SUQ8L3NhbWw6QXVkaWVuY2U+PC9zYW1sOkF1ZGllbmNlUmVzdHJpY
3Rpb24+PC9zYW1sOkNvbmRpdGlvbnM+PHNhbWw6QXV0aG5TdGF0ZW1lbnQgU2Vzc2lvbkluZGV4PSJIX20uV0h
Hb1VRUEQuM2NWUDQxWENVWHhiR0siIEF1dGhuSW5zdGFudD0iMjAxNy0xMS0xM1QxMzo0OToxNy4xNTNaIj48c
2FtbDpBdXRobkNvbnRleHQ+PHNhbWw6QXV0aG5Db250ZXh0Q2xhc3NSZWY+dXJuOm9hc2lzOm5hbWVzOnRjOlN
BTUw6Mi4wOmFjOmNsYXNzZXM6dW5zcGVjaWZpZWQ8L3NhbWw6QXV0aG5Db250ZXh0Q2xhc3NSZWY+PC9zYW1sO
kF1dGhuQ29udGV4dD48L3NhbWw6QXV0aG5TdGF0ZW1lbnQ+PHNhbWw6QXR0cmlidXRlU3RhdGVtZW50PjxzYW1
sOkF0dHJpYnV0ZSBOYW1lPSJ1aWQiIE5hbWVGb3JtYXQ9InVybjpvYXNpczpuYW1lczp0YzpTQU1MOjIuMDphd
HRybmFtZS1mb3JtYXQ6YmFzaWMiPjxzYW1sOkF0dHJpYnV0ZVZhbHVlIHhzaTp0eXBlPSJ4czpzdHJpbmciIHh
tbG5zOnhzPSJodHRwOi8vd3d3LnczLm9yZy8yMDAxL1hNTFNjaGVtYSIgeG1sbnM6eHNpPSJodHRwOi8vd3d3L
nczLm9yZy8yMDAxL1hNTFNjaGVtYS1pbnN0YW5jZSI+dW5jY29ldGVzdDQ8L3NhbWw6QXR0cmlidXRlVmFsdWU
+PC9zYW1sOkF0dHJpYnV0ZT48c2FtbDpBdHRyaWJ1dGUgTmFtZT0ibWFpbCIgTmFtZUZvcm1hdD0idXJuOm9hc
2lzOm5hbWVzOnRjOlNBTUw6Mi4wOmF0dHJuYW1lLWZvcm1hdDpiYXNpYyI+PHNhbWw6QXR0cmlidXRlVmFsdWU
geHNpOnR5cGU9InhzOnN0cmluZyIgeG1sbnM6eHM9Imh0dHA6Ly93d3cudzMub3JnLzIwMDEvWE1MU2NoZW1hI
iB4bWxuczp4c2k9Imh0dHA6Ly93d3cudzMub3JnLzIwMDEvWE1MU2NoZW1hLWluc3RhbmNlIj51bmNjb2V0ZXN
0NDwvc2FtbDpBdHRyaWJ1dGVWYWx1ZT48L3NhbWw6QXR0cmlidXRlPjwvc2FtbDpBdHRyaWJ1dGVTdGF0ZW1lb
nQ+PC9zYW1sOkFzc2VydGlvbj48L3NhbWxwOlJlc3BvbnNlPg=="/>
```


The “value” string is the base64-encoded SAML response. A few lines of Python can get the SAML response into a readable format. In this example, the value above has been saved to a file called *samlresp.txt*:

```
$ python
Python 2.7.10 (default, Feb 7 2017, 00:08:15)
[GCC 4.2.1 Compatible Apple LLVM 8.0.0 (clang-800.0.34)] on darwin
```

```
Type "help", "copyright", "credits" or "license" for more information.
>>> import base64
>>> import xml.dom.minidom
>>> respFile = open("samlresp.txt", "r")
>>> respStr = base64.b64decode(respFile.read())
>>> respXml = xml.dom.minidom.parseString(respStr)
>>> print(respXml.toprettyxml())
<?xml version="1.0" ?>
<samlp:Response Destination="https://idm.sandbox.motorolasolutions.com/sp/ACS.saml2"
ID="J5OlM6VqeneVzASghHyljAKbR.8" InResponseTo="Kdp1u_dqO0yM_ftaeeubgF9o0PX"
IssueInstant="2017-11-13T13:49:17.100Z" Version="2.0"
xmlns:samlp="urn:oasis:names:tc:SAML:2.0:protocol">
      <saml:Issuer
xmlns:saml="urn:oasis:names:tc:SAML:2.0:assertion">idp1.spsd.msso</saml:Issuer>
      <ds:Signature xmlns:ds="http://www.w3.org/2000/09/xmldsig#">
            <ds:SignedInfo>
                  <ds:CanonicalizationMethod
Algorithm="http://www.w3.org/2001/10/xml-exc-c14n#"/>


                  <ds:SignatureMethod Algorithm="http://www.w3.org/2001/04/xmldsig-
more#rsa-sha256"/>
                  <ds:Reference URI="#J5OlM6VqeneVzASghHyljAKbR.8">
                        <ds:Transforms>
                              <ds:Transform
Algorithm="http://www.w3.org/2000/09/xmldsig#enveloped-signature"/>
                              <ds:Transform
Algorithm="http://www.w3.org/2001/10/xml-exc-c14n#"/>
                        </ds:Transforms>
                        <ds:DigestMethod
Algorithm="http://www.w3.org/2001/04/xmlenc#sha256"/>
<ds:DigestValue>1vQiqCU6iYa33vQm+71lElVmiQHzOe9s+AM7Pa98VZA=</ds:DigestValue>
                  </ds:Reference>
            </ds:SignedInfo>
            <ds:SignatureValue>
LzRmBarY6nwFKvrv7S/oVacIIdIEF8yIhWBWOCGgzr1kN4esV/BSyKCSWb8JSXwC8VDsMRtW8CL5
UDUt55u9tBkNVjxv5dt5+Nat9ykfvxWmOdpeIU0s1sn1BGw+d94heIBaWIXMY9YQh9gWt6JYt9Qa
dFt6kEF5KSCKQAASem12OlKWoF+bRlmG4elm5LM8u7A7Z/aFvup3C6eydJp+R1i+Z+Az4yWvc/6a
byK10OgNi/0bnzkk7w/Jlty4fUDqWzmrrDZpHBxfALUnTWdOT5IzJ7njLAkAaSt460Z52nZA8aAb
Uo08OKDbvUi/TglSqFcp2Ra+BhOCmDw9boLonw==
</ds:SignatureValue>
      </ds:Signature>
      <samlp:Status>
            <samlp:StatusCode Value="urn:oasis:names:tc:SAML:2.0:status:Success"/>
      </samlp:Status>
      <saml:Assertion ID="H_m.WHGoUQPD.3cVP41XCUXxbGK" IssueInstant="2017-11-
13T13:49:17.155Z" Version="2.0" xmlns:saml="urn:oasis:names:tc:SAML:2.0:assertion">
            <saml:Issuer>idp1.spsd.msso</saml:Issuer>
            <saml:Subject>
                  <saml:NameID Format="urn:oasis:names:tc:SAML:1.1:nameid-
format:unspecified">unccoetest4</saml:NameID>
                  <saml:SubjectConfirmation
```

```
Method="urn:oasis:names:tc:SAML:2.0:cm:bearer">
                          <saml:SubjectConfirmationData
InResponseTo="Kdp1u_dqO0yM_ftaeeubgF9o0PX" NotOnOrAfter="2017-11-13T13:54:17.155Z"
Recipient="https://idm.sandbox.motorolasolutions.com/sp/ACS.saml2"/>
                    </saml:SubjectConfirmation>
             </saml:Subject>
             <saml:Conditions NotBefore="2017-11-13T13:44:17.155Z" NotOnOrAfter="2017-
11-13T13:54:17.155Z">
                    <saml:AudienceRestriction>
<saml:Audience>ctoPingFed_entityID</saml:Audience>
                    </saml:AudienceRestriction>
             </saml:Conditions>
             <saml:AuthnStatement AuthnInstant="2017-11-13T13:49:17.153Z"
SessionIndex="H_m.WHGoUQPD.3cVP41XCUXxbGK">
                    <saml:AuthnContext>
<saml:AuthnContextClassRef>urn:oasis:names:tc:SAML:2.0:ac:classes:unspecified</saml:Au
thnContextClassRef>
                    </saml:AuthnContext>
             </saml:AuthnStatement>
             <saml:AttributeStatement>
                    <saml:Attribute Name="uid"
NameFormat="urn:oasis:names:tc:SAML:2.0:attrname-format:basic">
                          <saml:AttributeValue
xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:type="xs:string">unccoetest4</saml:AttributeValue>
                    </saml:Attribute>
                    <saml:Attribute Name="mail"
NameFormat="urn:oasis:names:tc:SAML:2.0:attrname-format:basic">
                          <saml:AttributeValue
xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:type="xs:string">unccoetest4</saml:AttributeValue>
                    </saml:Attribute>
             </saml:AttributeStatement>
      </saml:Assertion>
</samlp:Response>

>>>
```


In the above example, two attributes, `uid` and `mail`, are asserted, but the `mail` attribute does not contain a valid email address.

For OIDC, because the ID Token is retrieved over a back-channel connection between the RP and the IdP, it cannot be observed in browser traffic. As with SAML, creating a test application is one method of testing, but manual testing is also possible by using a few software tools:

1. Register an OIDC client with a client secret and a redirect URI that points to a nonexistent server. A redirect URI value like `https://127.0.0.1/test-url` will work, assuming that you do not have a web server running on your machine. In a desktop browser, submit an authentication request with a URL like the one listed below:

   https://op1.lpsd.msso:9031/as/authorization.oauth2?client_id=marktest&response_type=code&scope=openid%20address%20test%20phone%20openid%20profile%20name%20email

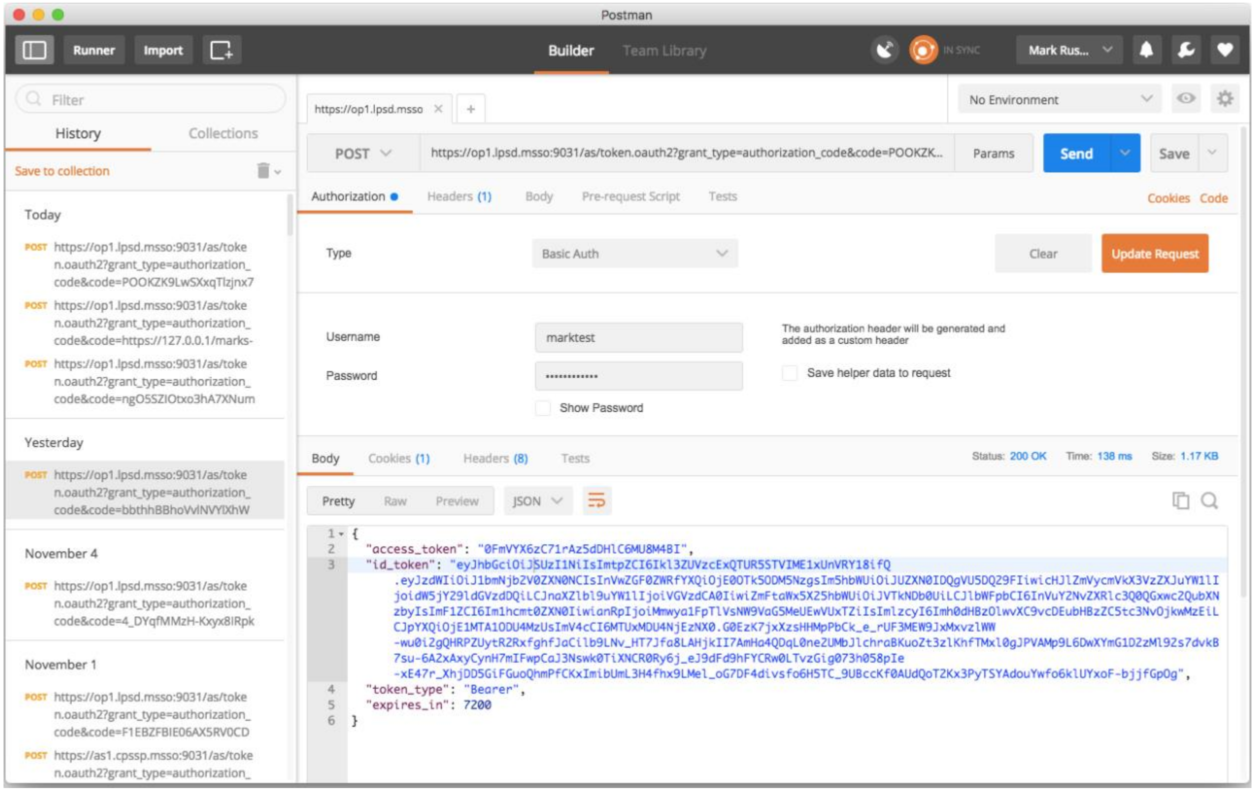
2. Replace the server name and client ID with the correct values for your environment; also make sure that the scope parameter includes `openid` and any other expected scopes. Authenticate to the IdP. In this case, because the FIDO UAF adapter is in use but is being accessed through a desktop browser, it initiates an OOB authentication, which can be completed on the mobile device. Once authentication is completed, the browser will attempt to access the redirect URL, which will result in a connection error because no web server is running on localhost. However, the authorization code can be extracted from the URL:

   https://127.0.0.1/test-url?code=Iv-pND_3o7_aJ5nFMcD-WbrVENrW7w5V75Cupx9G

The authorization code can be submitted to the IdP's token endpoint in a POST to obtain the ID Token. There are numerous ways to do this. Postman is a simple graphical-user-interface tool for testing APIs and can be used to submit the request: https://www.getpostman.com.

Figure 7-1 shows Postman being used to retrieve an ID Token. A POST request is submitted to the OIDC IdP's token endpoint; by default, the token endpoint URL is the base URL, followed by */as/token.oauth2*. The authorization code is included as a query parameter. The client ID and client secret are used as the HTTP basic authorization username and password.

Figure 7-1 Using Postman to Obtain the ID Token



The response body is a JSON object, including the ID Token as well as an access token that can be used to access the userinfo endpoint. As with the SAML assertion, a few lines of Python can render the ID Token (which is a JWT) into a readable format:

```
$ python
Python 2.7.10 (default, Feb 7 2017, 00:08:15)
[GCC 4.2.1 Compatible Apple LLVM 8.0.0 (clang-800.0.34)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> import jwt
>>> import json
>>> idTokenStr =
"eyJhbGciOiJSUzI1NiIsImtpZCI6Ikl3ZUVzcExQTUR5STVIME1xUnVRY18ifQ.eyJzdWIiOiJ1bmN
jb2V0ZXN0NCIsInVwZGF0ZWRfYXQiOjE0OTk5ODM5NzgsIm5hbWUiOiJUZXN0IDQgVU5DQ29FIiwicH
JlZmVycmVkX3VzZXJuYW1lIjoidW5jY29ldGVzdDQiLCJnaXZlbl9uYW1lIjoiVGVzdCA0IiwiZmFta
Wx5X25hbWUiOiJVTkNDb0UiLCJlbWFpbCI6InVuY2NvZXRlc3Q0QGxwc2QubXNzbyIsImF1ZCI6Im1h
cmt0ZXN0IiwianRpIjoiMmwya1FpTlVsNW9VaG5MeUEwVUxTZiIsImlzcyI6Imh0dHBzOlwvXC9vcDE
ubHBzZC5tc3NvOjkwMzEiLCJpYXQiOjE1MTA1ODU4MzUsImV4cCI6MTUxMDU4NjEzNX0.G0EzK7jxXz
sHHMpPbCk_e_rUF3MEW9JxMxvzlWW-
wu0i2gQHRPZUytR2RxfghfJaCilb9LNv_HT7Jfa8LAHjkII7AmHa4QDqL0ne2UMbJlchraBKuoZt3zl
KhfTMxl0gJPVAMp9L6DwXYmG1D2zMl92s7dvkB7su-
6A2xAxyCynH7mIFwpCaJ3Nswk0TiXNCR0Ry6j_eJ9dFd9hFYCRw0LTvzGig073h058pIe-
xE47r_XhjDD5GiFGuoQhmPfCKxImibUmL3H4fhx9LMel_oG7DF4divsfo6H5TC_9UBccKf0AUdQoT2K
```

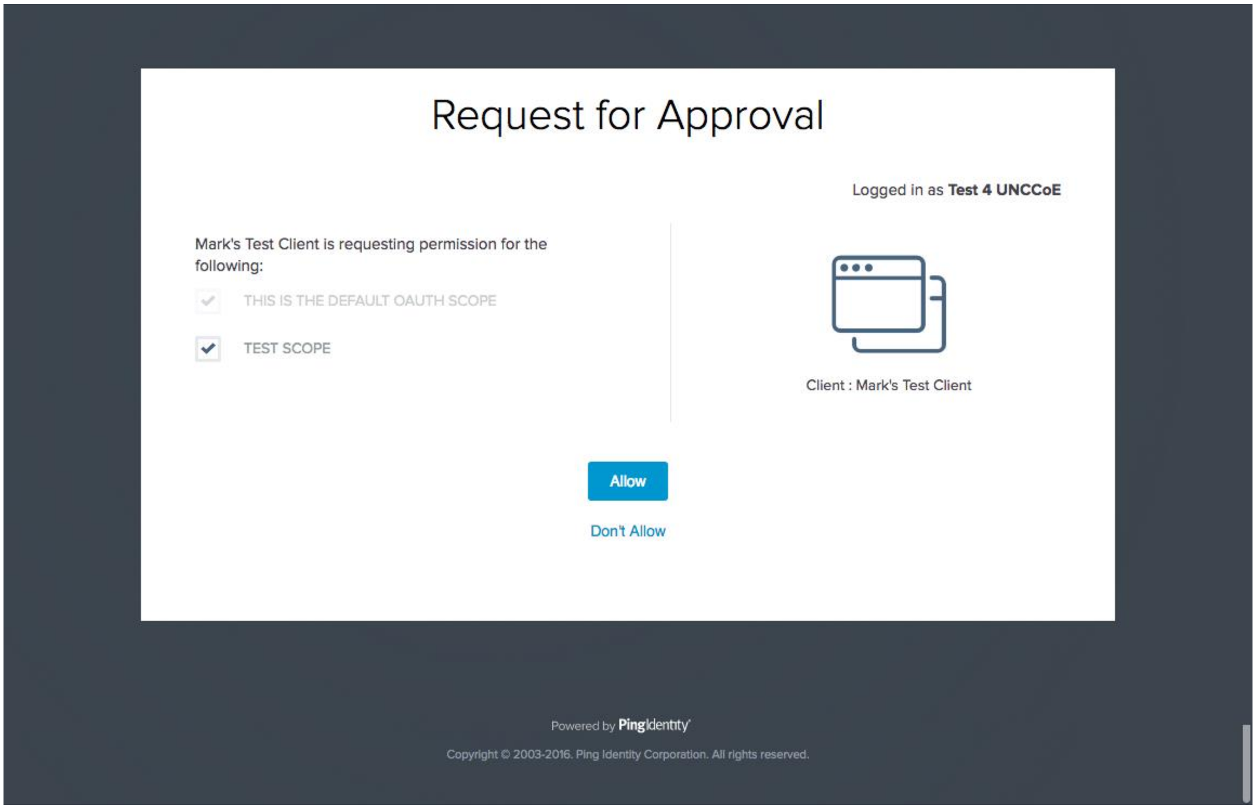
```
x3PyTSYAdouYwfo6klUYxoF-bjjfGpOg"
>>> idToken = jwt.decode(idTokenStr, verify=False)
>>> print json.dumps(idToken, indent=4)
{
    "family_name": "UNCCoE",
    "aud": "marktest",
    "sub": "unccoetest4",
    "iss": "https://op1.lpsd.msso:9031",
    "preferred_username": "unccoetest4",
    "updated_at": 1499983978,
    "jti": "2l2kQiNUl5oUhnLyA0ULSf",
    "given_name": "Test 4",
    "exp": 1510586135,
    "iat": 1510585835,
    "email": "unccoetest4@lpsd.msso",
    "name": "Test 4 UNCCoE"
}
>>>
```

This merely decodes the claims in the JWT without verifying the signature. If there is an issue with signature validation or trust in the signing key, these errors will be reported in the PingFederate server log.

7.4 Testing the AS

One simple step that can help identify problems at the AS is turning on the authorization prompts. This can be done on a per-client basis by deselecting the **BYPASS AUTHORIZATION APPROVAL** setting on the client configuration page, in the **OAuth Settings** section in the AS console. If the authorization prompt is displayed (Figure 7-2), this demonstrates that authentication has succeeded, and the list of scopes being requested by the client is displayed and can be verified.

Figure 7-2 Authorization Prompt

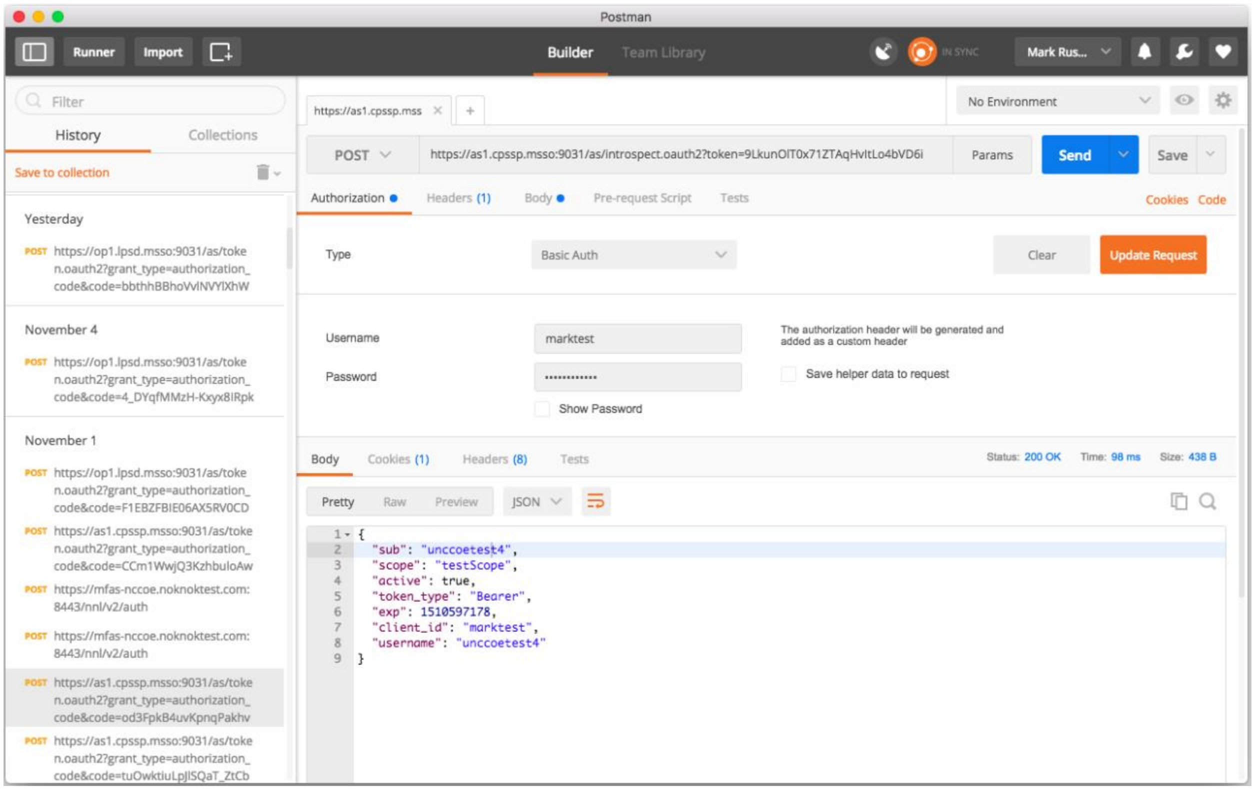


It is also possible to manually obtain an access token by using the same procedure that was used in the previous section to obtain an ID Token; the only difference is that an OAuth request typically would not include the `openid` scope. If the issued access token is a JWT, it can be analyzed using Python as described above.

If the token is not a JWT (i.e., a Reference Token management scheme is in use), the access token can be submitted to the AS's introspection endpoint as specified in RFC 7662 [31]. The default location of the introspection endpoint for PingFederate is the base URL, followed by */as/introspect.oauth2*. The request is submitted as a POST, with the access token in a query parameter called **token**. Basic authentication can be used with the client ID and secret as a username and password. The client must be authorized to call the introspection endpoint by selecting **Access Token Validation (Client is a Resource Server)** under **Allowed Grant Types** in the client configuration on the AS.

Figure 7-3 shows a token introspection request and response in Postman.

Figure 7-3 Token Introspection Request and Response



7.5 Testing the Application

One last potential problem area in this SSO architecture is the back-end application, which must accept and validate access tokens. Troubleshooting methods there will depend on the design of the application. Building robust instrumentation and error reporting into RP applications will help identify problems. If the application validates JWT access tokens, then establishing and maintaining trust in the AS's signing certificate, including maintenance when the certificate is replaced, is essential to avoid validation problems. Clock synchronization between the AS and the RP is also important; a time difference of five minutes or more can cause validation errors as well.

Appendix A Abbreviations and Acronyms

AD	Active Directory
API	Application Programming Interface
App ID	Application Identification
AppAuth	Application Authentication System
AS	Authorization Server
BCP	Best Current Practice
BIND	Berkeley Internet Name Domain
BLE	Bluetooth Low Energy
CA	Certificate Authority
CPSSP	Central Public Safety Service Provider
CPU	Central Processing Unit
CRADA	Cooperative Research and Development Agreement
CSR	Certificate Signing Request
DN	Distinguished Name
DNS	Domain Name System
FIDO	Fast Identity Online
FQDN	Fully Qualified Domain Name
GB	Gigabyte
GHz	Gigahertz
HTML	HyperText Markup Language
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
ID	Identification
IdP	Identity Provider
iOS	iPhone Operating System
IP	Internet Protocol
IT	Information Technology
JCE	Java Cryptography Extension
JDK	Java Development Kit
JSON	JavaScript Object Notation
JWE	JSON Web Encryption
JWT	JSON Web Token
LDAP	Lightweight Directory Access Protocol
LPSD	Local Public Safety Department
MFA	Multifactor Authentication
MSSO	Mobile Single Sign-On
NAT	Network Address Translation
NCCoE	National Cybersecurity Center of Excellence
NFC	Near Field Communication
NIST	National Institute of Standards and Technology

NNAS	Nok Nok Labs Authentication Server
NTP	Network Time Protocol
OIDC	OpenID Connect
OOB	Out-of-Band
OS	Operating System
PIN	Personal Identification Number
PKCE	Proof Key for Code Exchange
PSFR	Public Safety and First Responder
PSX	Public Safety Experience
QR	Quick Response
RAM	Random Access Memory
RFC	Request for Comments
RP	Relying Party
RPM	Red Hat Package Manager
SAML	Security Assertion Markup Language
SDK	Software Development Kit
SKCE	StrongKey CryptoEngine
SLO	Single Log-Out
SP	Service Provider
SPSD	State Public Safety Department
SQL	Structured Query Language
SSH	Secure Shell
SSO	Single Sign-On
TLS	Transport Layer Security
U2F	Universal Second Factor
UAF	Universal Authentication Framework
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
USB	Universal Serial Bus
VLAN	Virtual Local Area Network
VPN	Virtual Private Network

2815 # Appendix B References

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