



CHAPTER 16

LDAP Directory Integration

Revised: January 21, 2013; OL-21733-18

Directories are specialized databases that are optimized for a high number of reads and searches, and occasional writes and updates. Directories typically store data that does not change often, such as employee information, user policies, user privileges, and group membership on the corporate network.

Directories are extensible, meaning that the type of information stored can be modified and extended. The term *directory schema* defines the type of information stored, its container (or attribute), and its relationship to users and resources.

The Lightweight Directory Access Protocol (LDAP) provides applications with a standard method for accessing and potentially modifying the information stored in the directory. This capability enables companies to centralize all user information in a single repository available to several applications, with a remarkable reduction in maintenance costs through the ease of adds, moves, and changes.

This chapter covers the main design principles for integrating a Cisco Unified Communications system based on Cisco Unified Communications Manager (Unified CM) with a corporate LDAP directory. The main topics include:

- [What is Directory Integration?, page 16-2](#)

This section analyzes the various requirements for integration with a corporate LDAP directory in a typical enterprise IT organization.

- [Directory Access for Unified Communications Endpoints, page 16-3](#)

This section describes the technical solution to enable directory access for Cisco Unified Communications endpoints and provides design best-practices around it.

- [Directory Integration with Unified CM, page 16-5](#)

This section describes the technical solutions and provides design considerations for directory integration with Cisco Unified CM, including the LDAP synchronization and LDAP authentication functions.

The considerations presented in this chapter apply to Cisco Unified CM as well as the following applications bundled with it: Cisco Extension Mobility, Cisco Unified Communications Manager Assistant, WebDialer, Bulk Administration Tool, and Real-Time Monitoring Tool.

For Cisco Unity, refer to the *Cisco Unity Design Guide* and to the following white papers: *Cisco Unity Data and the Directory*, *Active Directory Capacity Planning*, and *Cisco Unity Data Architecture and How Cisco Unity Works*, also available at

<http://www.cisco.com>

What's New in This Chapter

Table 16-1 lists the topics that are new in this chapter or that have changed significantly from previous releases of this document.

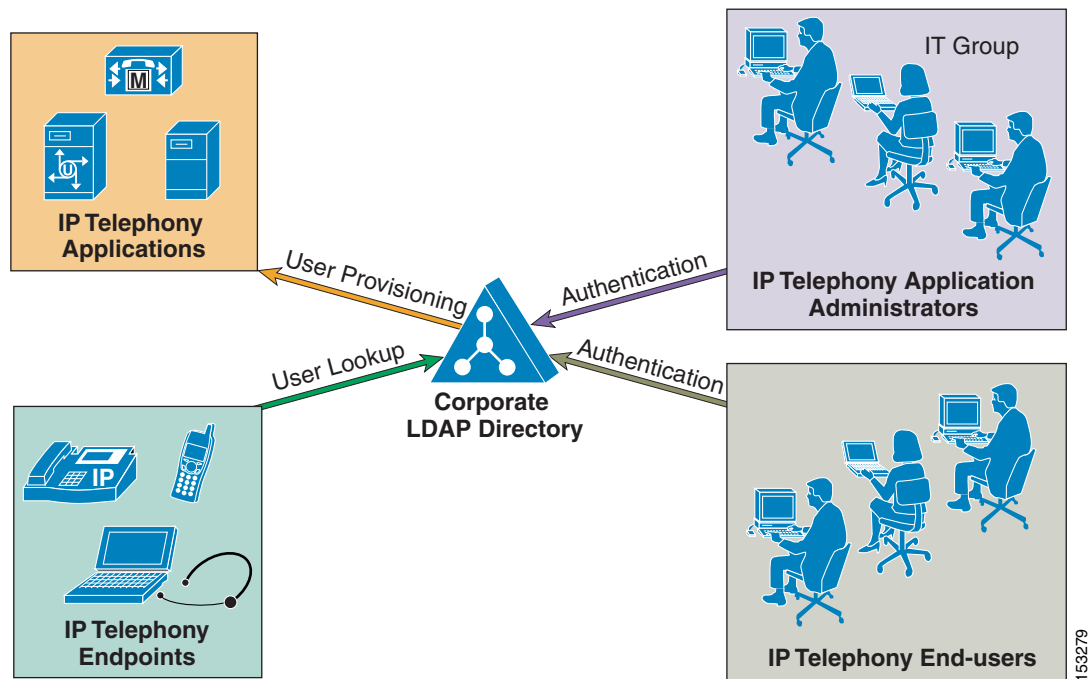
Table 16-1 *New or Changed Information Since the Previous Release of This Document*

New or Revised Topic	Described in	Revision Date
Capacity limits for LDAP directory synchronization	Capacity Planning for Unified CM Database Synchronization, page 16-27	April 30, 2012
LDAP directory types supported by Cisco Unified CM	Table 16-3	April 30, 2012
Multi-forest LDAP synchronization	Unified CM Multi-Forest LDAP Synchronization, page 16-18	November 15, 2010
Filtering	User Filtering for Directory Synchronization and Authentication, page 16-23	April 2, 2010

What is Directory Integration?

Integrating voice applications with a corporate LDAP directory is a common task for many enterprise IT organizations. However, the exact scope of the integration varies from company to company, and can translate into one or more specific and independent requirements, as shown in Figure 16-1.

Figure 16-1 *Various Requirements for Directory Integration*



One common requirement is to enable user lookups (sometimes called the "white pages" service) from IP phones or other voice and/or video endpoints, so that users can dial contacts quickly after looking up their numbers in the directory.

Another requirement is to provision users automatically from the corporate directory into the user database for applications. This method avoids having to add, remove, or modify core user information manually each time a change occurs in the corporate directory.

Authentication of end-users and administrators of the voice and/or video applications using their corporate directory credentials is also a common requirement. Enabling directory authentication allows the IT department to deliver single log-on functionality while reducing the number of passwords each user needs to maintain across different corporate applications.

As shown in [Table 16-2](#), within the context of a Cisco Unified Communications system, the term *directory access* refers to mechanisms and solutions that satisfy the requirement of user lookups for Cisco Unified Communications endpoints, while the term *directory integration* refers to mechanisms and solutions that satisfy the requirements of user provisioning and authentication (for both end users and administrators).

Table 16-2 **Directory Requirements and Cisco Solutions**

Requirement	Cisco Solution	Cisco Unified CM Feature
User lookup for endpoints	Directory access	Cisco Unified IP Phone Services SDK
User provisioning	Directory integration	LDAP Synchronization
Authentication for Unified Communications end users	Directory integration	LDAP Authentication
Authentication for Unified Communications application administrators	Directory integration	LDAP Authentication

The remainder of this chapter describes how to address these requirements in a Cisco Unified Communications system based on Cisco Unified CM.



Note

Another interpretation of the term *directory integration* revolves around the ability to add application servers to a Microsoft Active Directory domain in order to centralize management and security policies. Cisco Unified CM is an appliance that runs on a customized embedded operating system, and it cannot be added to a Microsoft Active Directory domain. Server management for Unified CM is provided through the Cisco Real Time Monitoring Tool (RTMT). Strong security policies tailored to the application are already implemented within the embedded operating system.

Directory Access for Unified Communications Endpoints

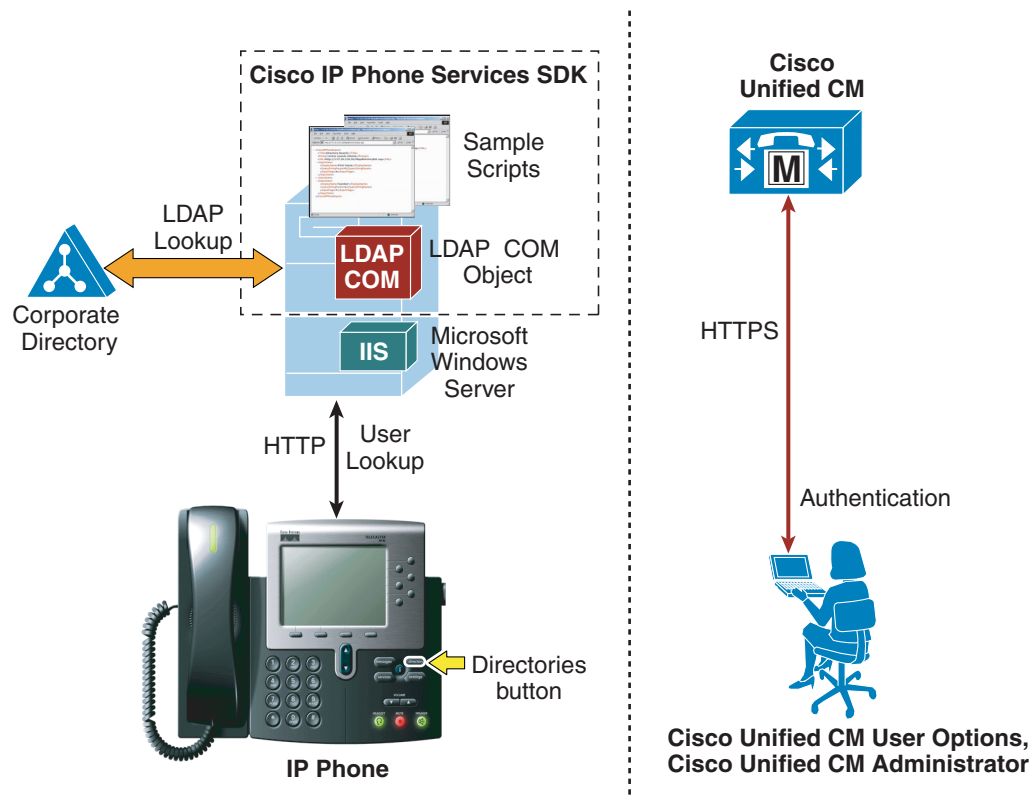
This section describes how to configure corporate directory access to any LDAP-compliant directory server to perform user lookups from Cisco Unified Communications endpoints (such as Cisco Unified IP Phones). The guidelines contained in this section apply regardless of whether Unified CM or other Unified Communications applications have been integrated with a corporate directory for user provisioning and authentication.

Cisco Unified IP Phones equipped with a display screen can search a user directory when a user presses the Directories button on the phone. The IP Phones use Hyper-Text Transfer Protocol (HTTP) to send requests to a web server. The responses from the web server contain specific Extensible Markup Language (XML) objects that the phone interprets and displays.

By default, Cisco Unified IP Phones are configured to perform user lookups against Unified CM's embedded database. However, it is possible to change this configuration so that the lookup is performed on a corporate LDAP directory. In this case, the phones send an HTTP request to an external web server that operates as a proxy by translating the request into an LDAP query which is then processed by the corporate directory. The web server encapsulates the LDAP response into an XML object that is sent back to the phone using HTTP, to be rendered to the end user.

Figure 16-2 illustrates this mechanism in a deployment where Unified CM has not been integrated with the corporate directory. Note that, in this scenario, Unified CM is not involved in the message exchange. The authentication mechanism to Unified CM web pages, shown on the right half of Figure 16-2, is independent of how directory lookup is configured.

Figure 16-2 *Directory Access for Cisco Unified IP Phones Using the Cisco Unified IP Phone Services SDK*



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In the example shown in Figure 16-2, the web server proxy function is provided by the Cisco LDAP Search Component Object Model (COM) server, which is included in the Cisco Unified IP Phone Services Software Development Kit (SDK). You can download the latest Cisco Unified IP Phone Services SDK from the Cisco Developer Community at

<http://developer.cisco.com/web/ipps/home>

The IP Phone Services SDK can be installed on a Microsoft Windows web server running IIS 4.0 or later, but it cannot be installed on a Unified CM server. The SDK includes some sample scripts to provide simple directory lookup functionality.

To set up a corporate directory lookup service using the IP Phone Services SDK, perform the following steps:

-
- | | |
|---------------|---|
| Step 1 | Modify one of the sample scripts to point to your corporate LDAP directory, or write your own script using the LDAP Search COM Programming Guide provided with the SDK. |
| Step 2 | In Unified CM, configure the URL Directories parameter (under System > Enterprise Parameters) to point to the URL of the script on the external web server. |
| Step 3 | Reset the phones to make the changes take effect. |
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**Note**

If you want to offer the service only to a subset of users, configure the URL Directories parameter directly within the Phone Configuration page instead of the Enterprise Parameters page.

In conclusion, the following design considerations apply to directory access with the Cisco Unified IP Phone Services SDK:

- User lookups are supported against any LDAP-compliant corporate directory.
- When querying Microsoft Active Directory, you can perform lookups against the Global Catalog by pointing the script to a Global Catalog server and specifying port 3268 in the script configuration. This method typically results in faster lookups. Note that a Global Catalog does not contain a complete set of attributes for users. Refer to Microsoft Active Directory documentation for details.
- There is no impact on Unified CM when this functionality is enabled, and only minimal impact on the LDAP directory server.
- The sample scripts provided with the SDK allow only a minimal amount of customization (for example, you can prefix a digit string to all returned numbers). For a higher degree of manipulation, you will have to develop custom scripts, and a programming guide is included with the SDK to aid in writing the scripts.
- This functionality does not entail provisioning or authentication of Unified CM users with the corporate directory.

Directory Integration with Unified CM

This section describes the mechanisms and best practices for directory integration with Cisco Unified CM to allow for user provisioning and authentication with a corporate LDAP directory. This section covers the following topics:

- [Cisco Unified Communications Directory Architecture, page 16-7](#)

This section provides an overview of the user-related architecture in Unified CM.

- [LDAP Synchronization, page 16-10](#)

This section describes the functionality of LDAP synchronization and provides design guidelines for its deployment, with additional considerations for Microsoft Active Directory.

- [LDAP Authentication, page 16-19](#)

This section describes the functionality of LDAP authentication and provides design guidelines for its deployment, with additional considerations for Microsoft Active Directory.

[Table 16-3](#) specifies the currently supported LDAP directories for both synchronization and authentication on Cisco Unified Communication Manager.

Table 16-3 LDAP Directory Support

LDAP Directory Type	Cisco Unified CM 6.x	Cisco Unified CM 7.x	Cisco Unified CM 8.x
Microsoft Active Directory 2000	Yes	Yes	No longer supported
Microsoft Active Directory 2003 R1/R2	R1/R2 supported (32 bit only)	R1/R2 supported (32 bit only)	R1/R2 supported (32 bit only)
Microsoft Active Directory 2008 R1/R2	R1 supported (32 bit only)	R1 supported (32 bit only)	R1 supported (32 bit only)
Microsoft ADAM 2003 R1/R2	No	R1/R2 supported (32 bit only)	R1/R2 supported (32 bit only)
Microsoft Active Directory LDS 2008 R1/R2	No	No	R1 supported
Netscape 4.x	Yes	No longer supported ¹	No longer supported ¹
iPlanet 5.0	Yes	No longer supported ¹	No longer supported ¹
iPlanet 5.1	Yes	Yes	Yes
SunOne 5.2	Yes	Yes	Yes
SunOne 6.1.x and 6.2.x	Yes	Yes	Yes
Sun One 6.3.xm	No	Supported with Unified CM 7.1(4) and later releases	Yes
Sun DS 7.0	No	Supported with Unified CM 7.1(4) and later releases	Yes
OpenLDAP 2.3.39	No	Supported with Unified CM 7.1(2) and later releases	Yes
OpenLDAP 2.4	No	Supported with Unified CM 7.1(2) and later releases	Yes

1. The directory vendor indicates that this solution has reached End of Life.



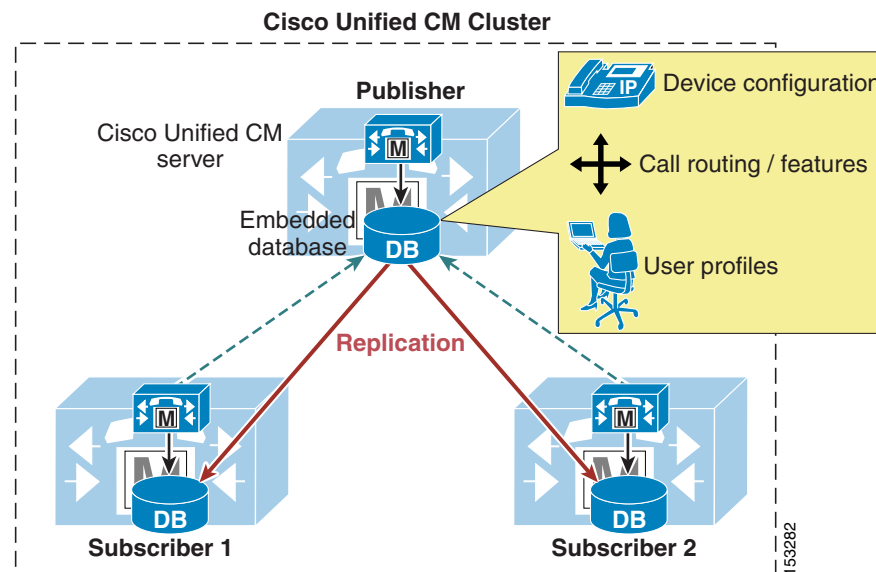
Note

All Microsoft Directory products listed in [Table 16-3](#) have equivalent support by Cisco Unified CM. All references to AD in this document are applicable to all the Microsoft products listed in this table.

Cisco Unified Communications Directory Architecture

Figure 16-3 shows the basic architecture of a Unified CM cluster. The embedded database stores all configuration information, including device-related data, call routing, feature provisioning, and user profiles. The database is present on all servers within a Unified CM cluster and is replicated automatically from the publisher server to all subscriber servers.

Figure 16-3 Cisco Unified CM Architecture



By default, all users are provisioned manually in the publisher database through the Unified CM Administration web interface. Cisco Unified CM has two types of users:

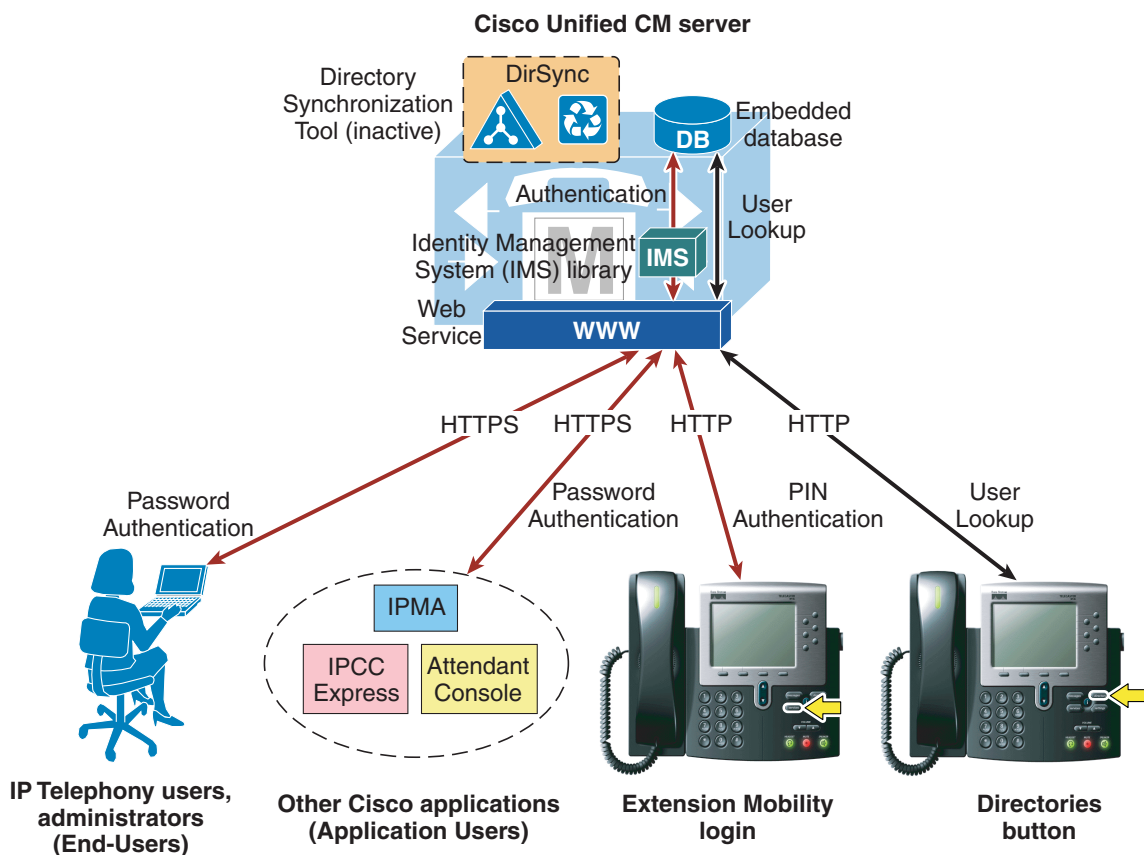
- **End users** — All users associated with a physical person and an interactive login. This category includes all Unified Communications users as well as Unified CM administrators when using the User Groups and Roles configuration (equivalent to the Cisco Multilevel Administration feature in prior Unified CM versions).
- **Application users** — All users associated with other Cisco Unified Communications features or applications, such as Cisco Attendant Console, Cisco Unified Contact Center Express, or Cisco Unified Communications Manager Assistant. These applications need to authenticate with Unified CM, but these internal "users" do not have an interactive login and serve purely for internal communications between applications.

Table 16-4 lists the application users created by default in the Unified CM database, together with the feature or application that uses them. Additional application users can be created manually when integrating other Cisco Unified Communications applications (for example, the **ac** application user for Cisco Attendant Console, the **jtapi** application user for Cisco Unified Contact Center Express, and so forth).

Table 16-4 Default Application Users for Unified CM

Application User	Used by:
CCMAdministrator	Unified CM Administration (default "super user")
CCMQRTSecureSysUser	Cisco Quality Reporting Tool
CCMQRTSysUser	
CCMSysUser	Cisco Extension Mobility
IPMASecureSysUser	Cisco Unified Communications Manager Assistant
IPMASysUser	
WDSecureSysUser	Cisco WebDialer
WDSysUser	

Based on these considerations, [Figure 16-4](#) illustrates the default behavior in Unified CM for user-related operations such as lookups, provisioning, and authentication.

Figure 16-4 Default Behavior for User-Related Operations for Unified CM

End users access the Unified CM User Options page via HTTPS and authenticate with a user name and password. If they have been configured as administrators by means of User Groups and Roles, they can also access the Unified CM Administration pages with the same credentials.

Similarly, other Cisco features and applications authenticate to Unified CM via HTTPS with the user name and password associated with their respective application users.

The authentication challenge carried by the HTTPS messages are relayed by the web service on Unified CM to an internal library called Identity Management System (IMS). In its default configuration, the IMS library authenticates both end users and application users against the embedded database. In this way, both "physical" users of the Unified Communications system and internal application accounts are authenticated using the credentials configured in Unified CM.

End users may also authenticate with their user name and a numeric password (or PIN) when logging into the Extension Mobility service from an IP phone. In this case, the authentication challenge is carried via HTTP to Unified CM but is still relayed by the web service to the IMS library, which authenticates the credentials against the embedded database.

In addition, user lookups performed by Unified Communications endpoints via the Directories button communicate with the web service on Unified CM via HTTP and access data on the embedded database.

The importance of the distinction between End Users and Application Users becomes apparent when integration with a corporate directory is required. As mentioned in the previous section, this integration is accomplished by means of the following two separate processes:

- LDAP synchronization

This process uses an internal tool called Cisco Directory Synchronization (DirSync) on Unified CM to synchronize a number of user attributes (either manually or periodically) from a corporate LDAP directory. When this feature is enabled, users are automatically provisioned from the corporate directory. This feature applies only to End Users, while Application Users are kept separate and are still provisioned via the Unified CM Administration interface. In summary, End Users are defined in the corporate directory and synchronized into the Unified CM database, while Application Users are stored only in the Unified CM database and do not need to be defined in the corporate directory.

- LDAP authentication

This process enables the IMS library to authenticate user credentials against a corporate LDAP directory using the LDAP standard Simple_Bind operation. When this feature is enabled, End User passwords are authenticated against the corporate directory, while Application User passwords are still authenticated locally against the Unified CM database. Cisco Extension Mobility PINs are also still authenticated locally.

Maintaining and authenticating the Application Users internally to the Unified CM database provides resilience for all the applications and features that use these accounts to communicate with Unified CM, independently of the availability of the corporate LDAP directory.

Cisco Extension Mobility PINs are also kept within the Unified CM database because they are an integral part of a real-time application, which should not have dependencies on the responsiveness of the corporate directory.

The next two sections describe in more detail LDAP synchronization and LDAP authentication, and they provide design best-practices for both functions.

**Note**

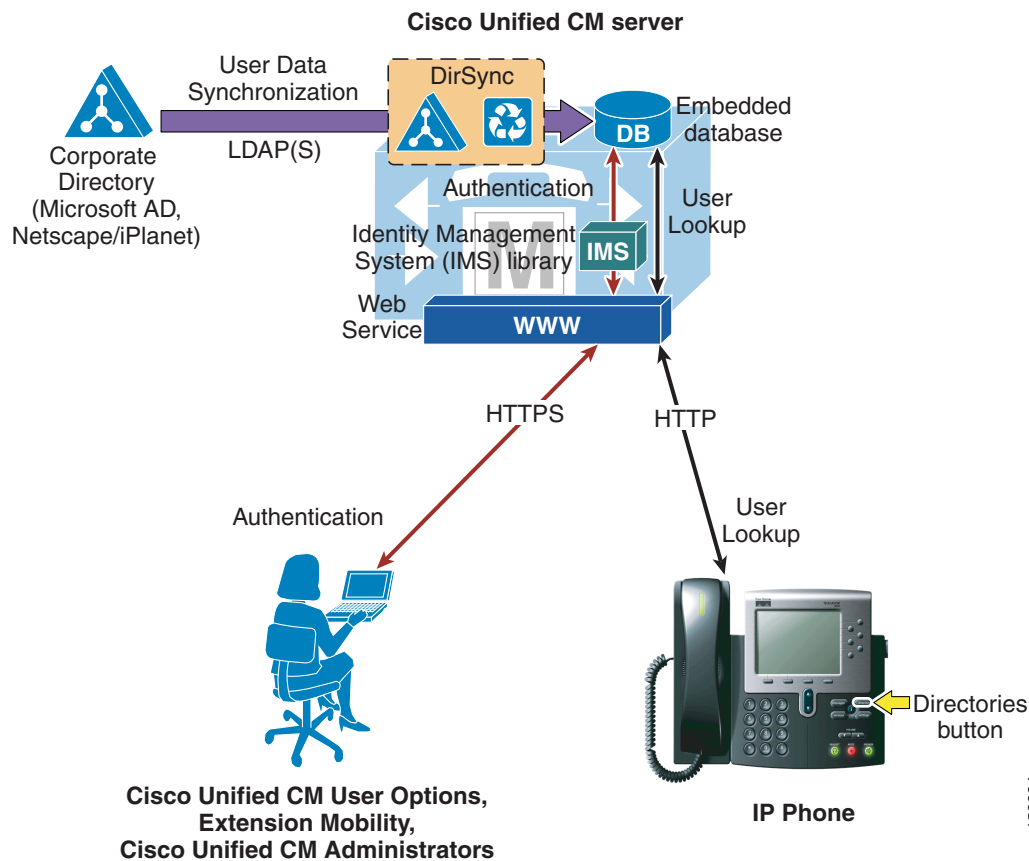
As illustrated in the section on [Directory Access for Unified Communications Endpoints, page 16-3](#), user lookups from endpoints can also be performed against a corporate directory by configuring the Cisco Unified IP Phone Services SDK on an external web server.

LDAP Synchronization

Synchronization of Unified CM with a corporate LDAP directory allows the administrator to provision users easily by mapping Unified CM data fields to directory attributes. Critical user data maintained in the LDAP store is copied into the appropriate corresponding fields in the Unified CM database on a scheduled or on-demand basis. The corporate LDAP directory retains its status as the central repository. Unified CM has an integrated database for storing user data and a web interface within Unified CM Administration for creating and managing user accounts and data. When LDAP synchronization is enabled, the local database is still used, but the Unified CM facility to create end-user accounts is disabled. Management of end-user accounts is then accomplished through the interface of the LDAP directory. (See Figure 16-5.) Accounts for application users can still be created and managed using the Unified CM Administration web interface.

The user account information is imported from the LDAP directory into the database located on the Unified CM publisher server. Information that is imported from the LDAP directory may not be changed by Unified CM. Additional user information specific to Cisco Unified Communications is managed by Unified CM and stored only within its local database. For example, device-to-user associations, speed dials, call forward settings, and user PINs are all examples of data that is managed by Unified CM and does not exist in the corporate LDAP directory. The user data is then propagated from the Unified CM publisher server to the subscriber servers through the built-in database synchronization mechanism.

Figure 16-5 Enabling Synchronization of User Data



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When LDAP synchronization is activated, only one type of LDAP directory may be chosen globally for the cluster at any one time. Also, one attribute of the LDAP directory user is chosen to map into the Unified CM User ID field. Unified CM uses standard LDAPv3 for accessing the data.

Cisco Unified CM imports data from standard attributes. Extending the directory schema is not required. Table 16-5 lists the attributes that are available for mapping to Unified CM fields. The data of the directory attribute that is mapped to the Unified CM User ID must be unique within all entries for that cluster. The attribute mapped to the Cisco UserID field must be populated in the directory and the **sn** attribute must be populated with data, otherwise those records are skipped during this import action. If the primary attribute used during import of end-user accounts matches any application user in the Unified CM database, that end user is not imported from the LDAP directory.

Table 16-5 lists the attributes that are imported from the LDAP directory into corresponding Unified CM user fields, and it describes the mapping between those fields. Some Unified CM user fields might be mapped from one of several LDAP attributes.

Table 16-5 Synchronized LDAP Attributes and Corresponding Unified CM Field Names

Unified CM User Field	Microsoft Active Directory	Active Directory Application Mode (ADAM) or Active Directory Lightweight Directory Service (AD LDS)	Netscape, iPlanet, or Sun ONE	OpenLDAP
User ID	One of: sAMAccountName mail employeeNumber telephoneNumber userPrincipalName	One of: uid mail employeeNumber telephoneNumber userPrincipalName	One of: uid mail employeeNumber telephonePhone	One of: uid mail employeeNumber telephonePhone
First Name	givenName	givenName	givenname	givenname
Middle Name	One of: middleName initials	One of: middleName initials	initials	initials
Last Name	sn	sn	sn	sn
Manager ID	manager	manager	manager	manager
Department	department	department	departmentnumber	departmentnumber
Phone Number	One of: telephoneNumber ipPhone	One of: telephoneNumber ipPhone	telephonenumber	telephonenumber
Mail ID	One of: mail sAMAccountName	One of: mail uid	One of: mail uid	One of: mail uid

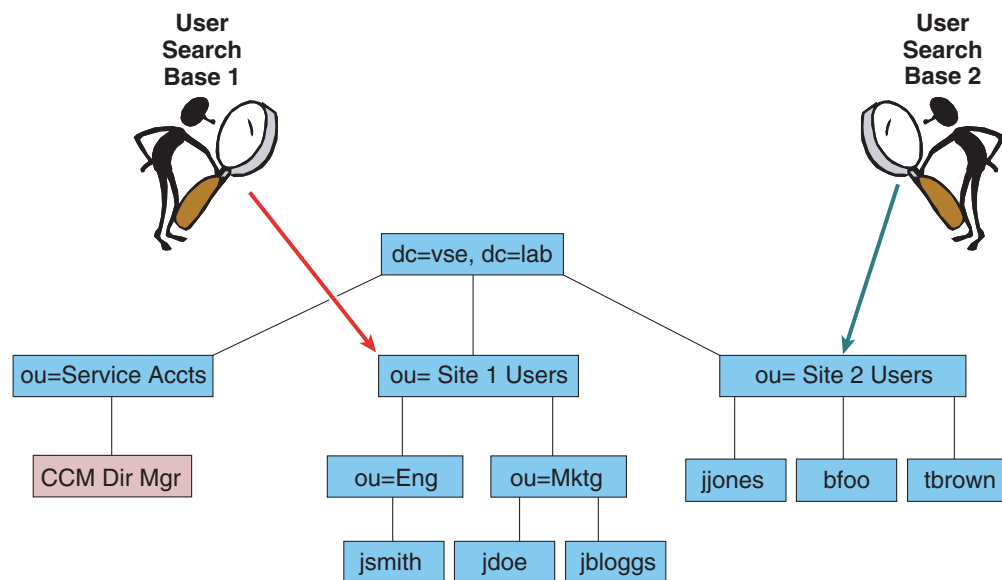
Table 16-6 contains a list of additional attributes that are imported by the Dirsynch process and copied into the Unified CM database but are not displayed in the administrator user configuration web pages. The attribute msRTCSIP-PrimaryUserAddress is populated in AD when Microsoft OCS is used. This table is included for completeness.

Table 16-6 Synchronized LDAP Attributes that Are Not Displayed

Unified CM User Field	Microsoft Active Directory	Netscape, iPlanet, or Sun ONE	OpenLDAP
objectGUID	objectGUID	Not applicable	Not applicable
OCSPrimaryUserAddress	msRTCSIP-PrimaryUserAddress	Not applicable	Not applicable
Title	title	Title	title
Home Phone Number	homePhone	Homephone	hometelephonenumber
Mobile Phone Number	mobile	Mobile	Mobiletelephonenumber
Pager Number	pager	Pager	pagertelephonenumber

The synchronization is performed by a process called Cisco DirSync, which is enabled through the Serviceability web page. When enabled, it allows one to five synchronization agreements to be configured in the system. An agreement specifies a search base that is a position in the LDAP tree where Unified CM will begin its search for user accounts to import. Unified CM can import only users that exist in the domain specified by the search base for a particular synchronization agreement.

In [Figure 16-6](#), two synchronization agreements are represented. One synchronization agreement specifies User Search Base 1 and imports users jsmith, jdoe and jbloggs. The other synchronization agreement specifies User Search Base 2 and imports users jjones, bfoo, and tbrown. The CCMDirMgr account is not imported because it does not reside below the point specified by a user search base. When users are organized in a structure in the LDAP directory, you can use that structure to control which user groups are imported. In this example, a single synchronization agreement could have been used to specify the root of the domain, but that search base would also have imported the Service Accts. The search base does not have to specify the domain root; it may specify any point in the tree.

Figure 16-6 User Search Bases

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To import the data into the Unified CM database, the system performs a bind to the LDAP directory using the account specified in the configuration as the LDAP Manager Distinguished Name, and reading of the database is done with this account. The account must be available in the LDAP directory for

Unified CM to log in, and Cisco recommends that you create a specific account with permissions to allow it to read all user objects within the sub-tree that was specified by the user search base. The sync agreement specifies the full Distinguished Name of that account so that the account may reside anywhere within that domain. In the example in [Figure 16-6](#), CCMDirMgr is the account used for the synchronization.

It is possible to control the import of accounts through use of permissions of the LDAP Manager Distinguished Name account. In this example, if that account is restricted to have read access to ou=Eng but not to ou=Mktg, then only the accounts located under Eng will be imported.

Synchronization agreements have the ability to specify multiple directory servers to provide redundancy. You can specify an ordered list of up to three directory servers in the configuration that will be used when attempting to synchronize. The servers are tried in order until the list is exhausted. If none of the directory servers responds, then the synchronization fails, but it will be attempted again according to the configured synchronization schedule.

Synchronization Mechanism

The synchronization agreement specifies a time for synchronizing to begin and a period for re-synchronizing that can be specified in hours, days, weeks, or months (with a minimum value of 6 hours). A synchronization agreement can also be set up to run only once at a specific time.

When synchronization is enabled for the first time on a Unified CM publisher server, user accounts that exist in the corporate directory are imported into the Unified CM database. Then either existing Unified CM end-user accounts are activated and data is updated, or a new end-user account is created according to the following process:

1. If end-user accounts already exist in the Unified CM database and a synchronization agreement is configured, all pre-existing accounts are marked inactive in Unified CM. The configuration of the synchronization agreement specifies a mapping of an LDAP database attribute to the Unified CM UserID. During the synchronization, accounts from the LDAP database that match an existing Unified CM account cause that Unified CM account to be marked active again.
2. After the synchronization is completed, any accounts that were not set to active are permanently deleted from Unified CM when the garbage collection process runs. Garbage collection is a process that runs automatically at the fixed time of 3:15 AM, and it is not configurable. The deletion of Unified CM accounts that do not match LDAP directory accounts is necessary because Unified CM cannot manage accounts while synchronization is configured.
3. Subsequently when changes are made in the corporate directory, the synchronization from Microsoft Active Directory occurs as a full re-synchronization at the next scheduled synchronization period. On the other hand, the iPlanet and Sun ONE directory products perform an incremental synchronization triggered by a change in the directory. The following sections present examples of each of these two scenarios.



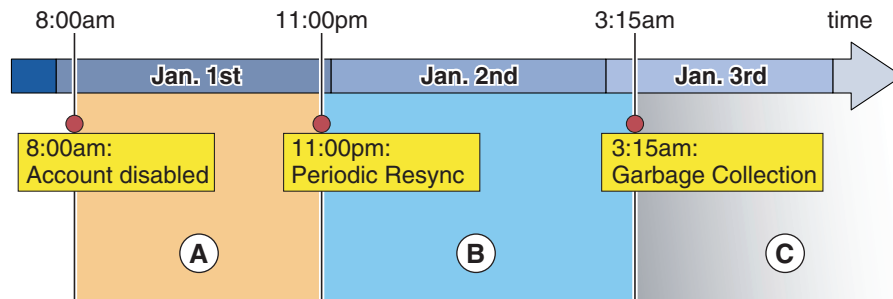
Note

Once users are synchronized from LDAP into the Unified CM database, deletion of a synchronization configuration will cause users that were imported by that configuration to be marked inactive in the database. Garbage collection will subsequently remove those users.

Account Synchronization with Active Directory

Figure 16-7 shows an example timeline of events for a Unified CM deployment where LDAP Synchronization and LDAP Authentication have both been enabled. The re-synchronization is set for 11:00 PM daily.

Figure 16-7 Change Propagation with Active Directory



After the initial synchronization, the creation, deletion, or disablement of an account will propagate to Unified CM according to the timeline shown in Figure 16-7 and as described in the following steps:

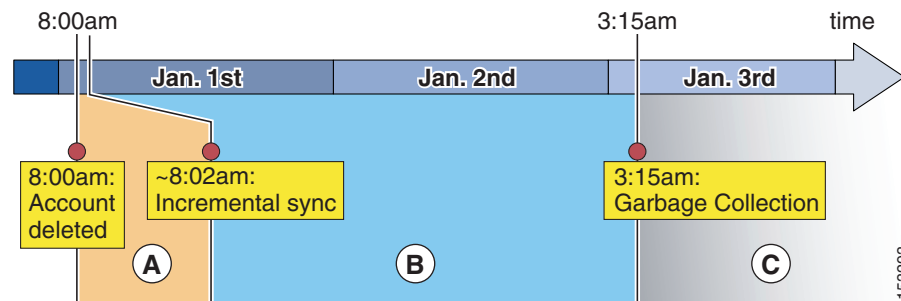
1. At 8:00 AM on January 1, an account is disabled or deleted in AD. From this time and during the whole period A, password authentication (for example, Unified CM User Options page) will fail for this user because Unified CM redirects authentication to AD. However, PIN authentication (for example, Extension Mobility login) will still succeed because the PIN is stored in the Unified CM database.
2. The periodic re-synchronization is scheduled for 11:00 PM on January 1. During that process, Unified CM will verify all accounts. Any accounts that have been disabled or deleted from AD will at that time be tagged in the Unified CM database as inactive. After 11:00 PM on January 1, when the account is marked inactive, both the PIN and password authentication by Unified CM will fail.
3. Garbage collection of accounts occurs daily at the fixed time of 3:15 AM. This process permanently deletes user information from the Unified CM database for any record that has been marked inactive for over 24 hours. In this example, the garbage collection that runs at 3:15 AM on January 2 does not delete the account because it has not been inactive for 24 hours yet, so the account is deleted at 3:15 AM on January 3. At that point, the user data is permanently deleted from Unified CM.

If an account has been created in AD at the beginning of period A, it will be imported to Unified CM at the periodic re-synchronization that occurs at the beginning of period B and will immediately be active on Unified CM.

Account Synchronization with iPlanet or Sun ONE

The iPlanet and Sun ONE products support incremental synchronization agreements and use a different synchronization timeline than Microsoft Active Directory. The synchronization makes use of the Persistent Search mechanism defined by an IETF Draft and supported by many LDAP implementations. Figure 16-8 shows an example of this synchronization timeline for a Unified CM deployment with LDAP Synchronization and LDAP Authentication both enabled.

Figure 16-8 Change Propagation with iPlanet and Sun ONE



The example in Figure 16-8 involves the following steps:

1. An account is deleted from the corporate directory at 8:00 AM on January 1, which causes an incremental update to be sent from the LDAP server to Unified CM. Unified CM sets its corresponding copy of the data to inactive. Because LDAP authentication is configured, the user will be unable to log in via password as soon as the LDAP server has deleted the record. Also, the PIN may not be used for login at the moment the Unified CM record is marked inactive.
2. During period B, the user's record is still present in Unified CM, albeit inactive.
3. When the garbage collection runs at 3:15 AM on January 2, the record has not yet been inactive for 24 hours. The data remains in the Unified CM database until the beginning of period C on January 3, when the garbage collection process runs again at 3:15 AM and determines that the record has been inactive for 24 hours or more. The record is then permanently deleted from the database.

Accounts that are newly created in the directory are synchronized to Unified CM via incremental updates as well, and they may be used as soon as the incremental update is received.

Security Considerations

During the import of accounts, no passwords or PINs are copied from the LDAP directory to the Unified CM database. If LDAP synchronization is not enabled in Unified CM, the password for the end user is managed by using Unified CM Administration. The password and PIN are stored in an encrypted format in the Unified CM database. The PIN is always managed on Unified CM. If you want to use the LDAP directory password to authenticate an end user, see the section on [LDAP Authentication](#), page 16-19.

The connection between the Unified CM publisher server and the directory server can be secured by enabling Secure LDAP (SLDAP) on Unified CM and the LDAP server. Secure LDAP enables LDAP to be sent over a Secure Socket Layer (SSL) connection and can be enabled by uploading the SSL certificate from within the Unified CM Platform Administration. For detailed procedure steps, refer to the Unified CM product documentation available at <http://www.cisco.com>. Refer to the documentation of the LDAP directory vendor to determine how to enable SLDAP.

Design Considerations for LDAP Synchronization

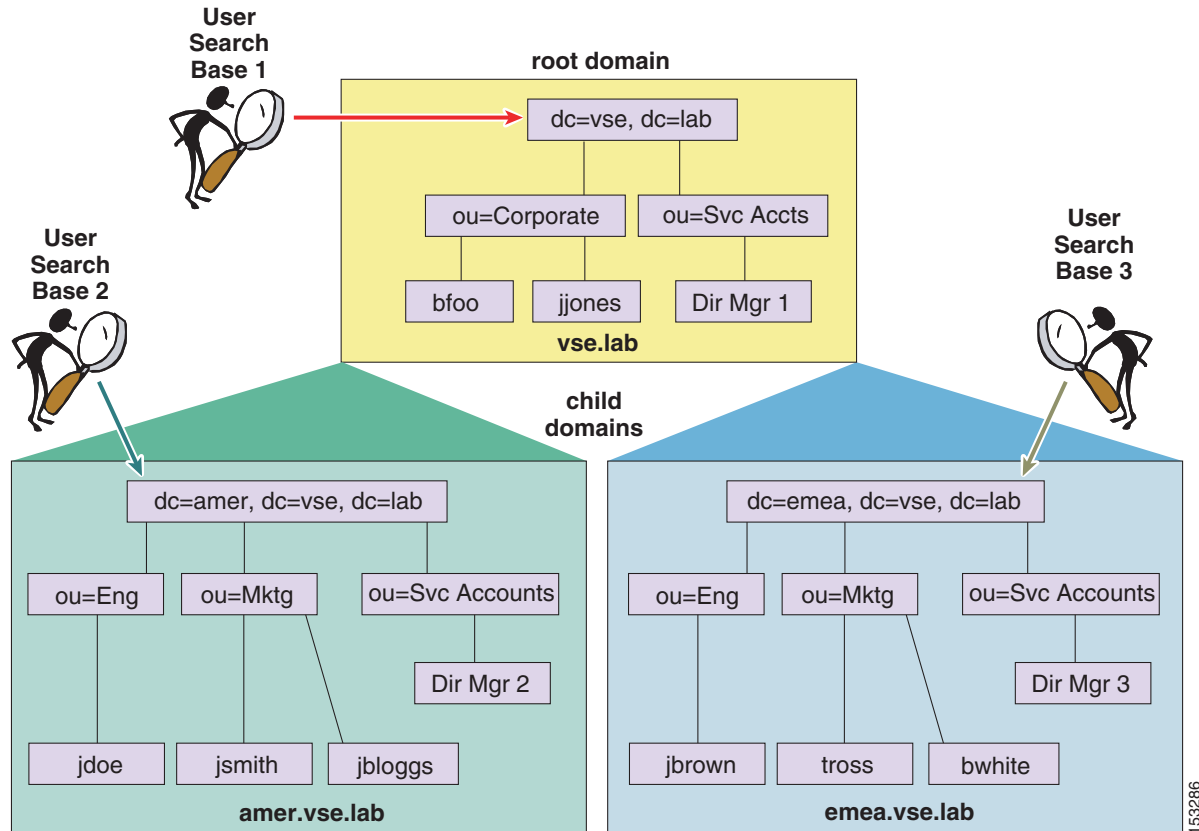
Observe the following design and implementation best practices when deploying LDAP synchronization with Cisco Unified CM:

- Use a specific account within the corporate directory to allow the Unified CM synchronization agreement to connect and authenticate to it. Cisco recommends that you use an account dedicated to Unified CM, with minimum permissions set to "read" all user objects within the desired search base and with a password set never to expire. The password for this account in the directory must be kept in synchronization with the password configuration of the account in Unified CM. If the service account password changes in the directory, be sure to update the account configuration in Unified CM.
- All synchronization agreements on a given cluster must integrate with the same family of LDAP servers.
- Stagger the scheduling of synchronization agreements so that multiple agreements are not querying the same LDAP servers simultaneously. Choose synchronization times that occur during quiet periods (off-peak hours).
- If security of user data is required, enable Secure LDAP (SLDAP) by checking the **Use SSL** field on the LDAP Directory configuration page in Unified CM Administration.
- Ensure that the LDAP directory attribute chosen to map into the Unified CM UserID field is unique within all synchronization agreements for that cluster.
- The attribute chosen as UserID must not be the same as that for any of the Application Users defined in Unified CM.
- The LDAP attribute `sn(lastname)` is a mandatory attribute for LDAP Synchronization of users.
- An existing account in the Unified CM database before synchronization is maintained only if an account imported from the LDAP directory has a matching attribute. The attribute that is matched to the Unified CM UserID is determined by the synchronization agreement.
- Administer end-user accounts through the LDAP directory's management tools, and manage the Cisco-specific data for those accounts through the Unified CM Administration web page.
- LDAP Synchronization is supported only with Microsoft NT LAN Manager (NTLM). Kerberos and NTLMv2 are not supported.
- For AD deployments, the ObjectGUID is used internally in Unified CM as the key attribute of a user. The attribute in AD that corresponds to the Unified CM User ID may be changed in AD. For example, if `sAMAccountname` is being used, a user may change their `sAMAccountname` in AD, and the corresponding user record in Unified CM would be updated.

With all other LDAP platforms, the attribute that is mapped to User ID is the key for that account in Unified CM. Changing that attribute in LDAP will result in a new user being created in Unified CM, and the original user will be marked inactive.

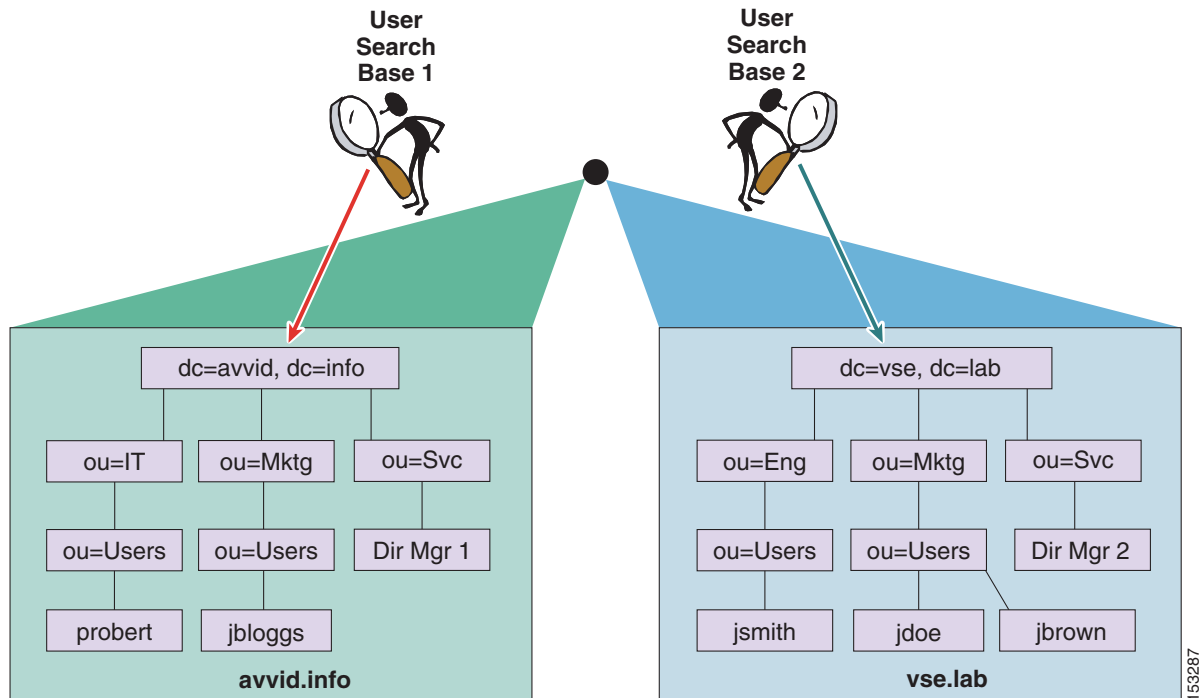
Additional Considerations for Microsoft Active Directory

A synchronization agreement for a domain will not synchronize users outside of that domain nor within a child domain because Unified CM does not follow AD referrals during the synchronization process. The example in [Figure 16-9](#) requires three synchronization agreements to import all of the users. Although Search Base 1 specifies the root of the tree, it will not import users that exist in either of the child domains. Its scope is only VSE.LAB, and separate agreements are configured for the other two domains to import those users.

Figure 16-9 Synchronization with Multiple Active Directory Domains

In [Figure 16-9](#), each of the domains and sub-domains contains at least one domain controller (DC) associated to them, and the three synchronization agreements each specify the appropriate domain controller. The DCs have information only on users within the domain where they reside, therefore three synchronization agreements are required to import all of the users.

When synchronization is enabled with an AD forest containing multiple trees, as shown in [Figure 16-10](#), multiple synchronization agreements are still needed for the same reasons listed above. Additionally, the UserPrincipalName (UPN) attribute is guaranteed by Active Directory to be unique across the forest and must be chosen as the attribute that is mapped to the Unified CM UserID. For additional considerations on the use of the UPN attribute in a multi-tree AD scenario, see the section on [Additional Considerations for Microsoft Active Directory](#), page 16-21.

Figure 16-10 Synchronization with Multiple AD Trees (Discontiguous Namespaces)

Unified CM sends a default LDAP search filter string to AD when performing the synchronization of accounts. One of the clauses is to not return accounts that have been marked as disabled in AD. An account marked disabled by AD, such as when failed login attempts are exceeded, will be marked inactive if synchronization runs while the account is disabled.

Unified CM Multi-Forest LDAP Synchronization

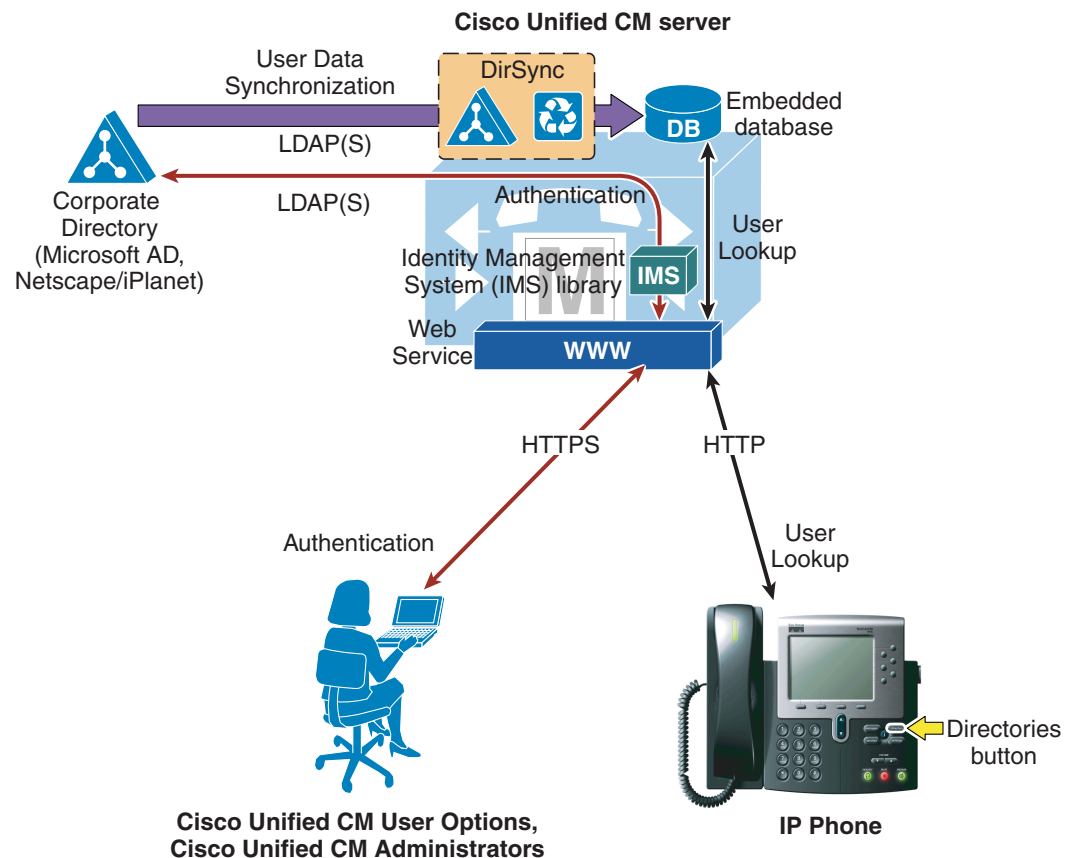
A Unified CM deployment using a multi-forest LDAP infrastructure can be supported by using Active Directory Lightweight Directory Services (AD LDS) as a single forest view integrating with the multiple disparate forests. The integration also requires the use of LDAP filtering (see [User Filtering for Directory Synchronization and Authentication, page 16-23](#)). For full details, refer to the document on *How to Configure Unified Communication Manager Directory Integration in a Multi-Forest Environment*, available at

http://www.cisco.com/en/US/products/sw/voicesw/ps556/products_configuration_example09186a0080b2b103.shtml

LDAP Authentication

The LDAP authentication feature enables Unified CM to authenticate end user passwords against a corporate LDAP directory instead of using the embedded database. This authentication is accomplished with an LDAPv3 connection established between the IMS module within Unified CM and a corporate directory server, as shown in Figure 16-11.

Figure 16-11 Enabling LDAP Authentication



To enable authentication, a single authentication agreement may be defined for the entire cluster. The authentication agreement supports configuration of up to three LDAP servers for redundancy and also supports secure connections LDAP over SSL (SLDAP) if desired. Authentication can be enabled only when LDAP synchronization is properly configured and used.

The following statements describe Unified CM's behavior when authentication is enabled:

- End user passwords are authenticated against the corporate directory by a simple bind operation.
- Application user passwords are authenticated against the Unified CM database.
- End user PINs are authenticated against the Unified CM database.

This behavior is in line with the guiding principle of providing single logon functionality for end users while making the operation of the real-time Unified Communications system independent of the availability of the corporate directory, and is shown graphically in Figure 16-12.

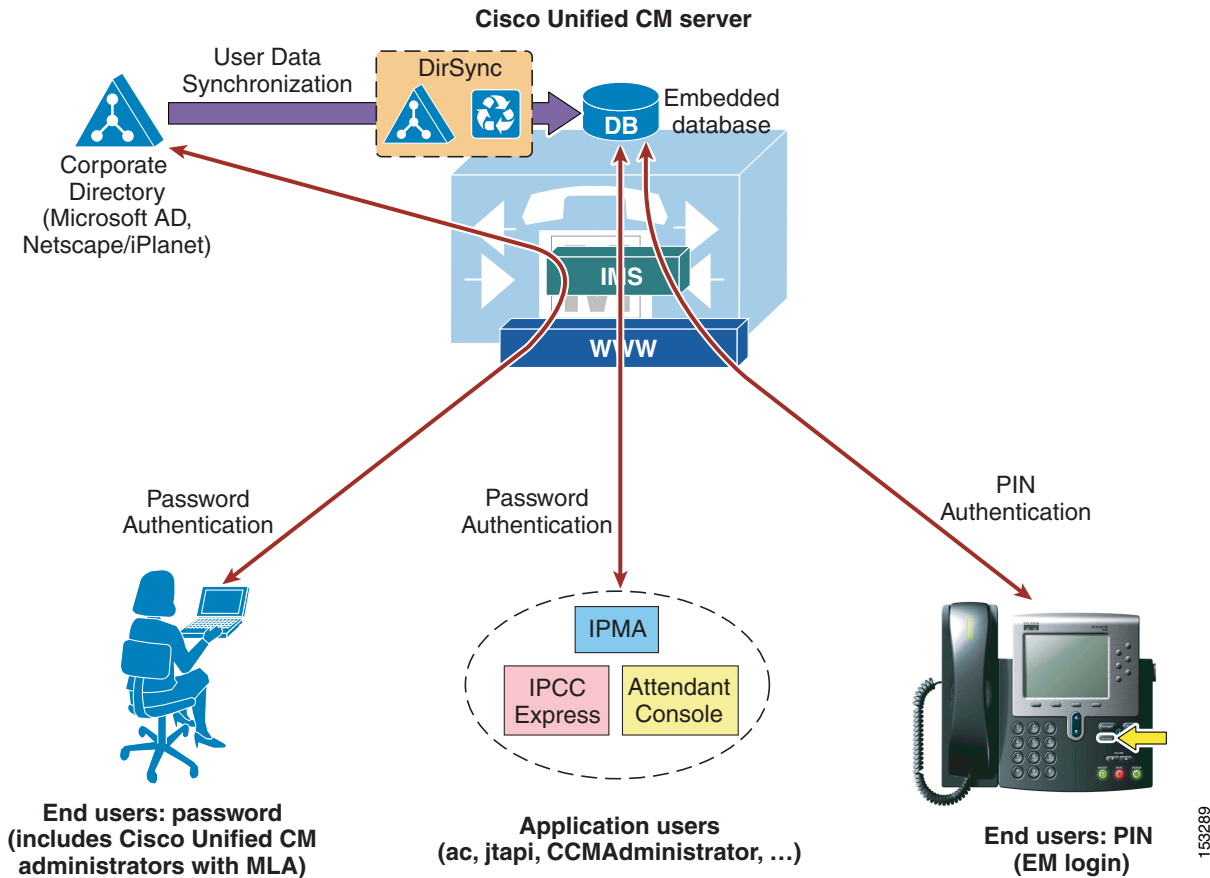
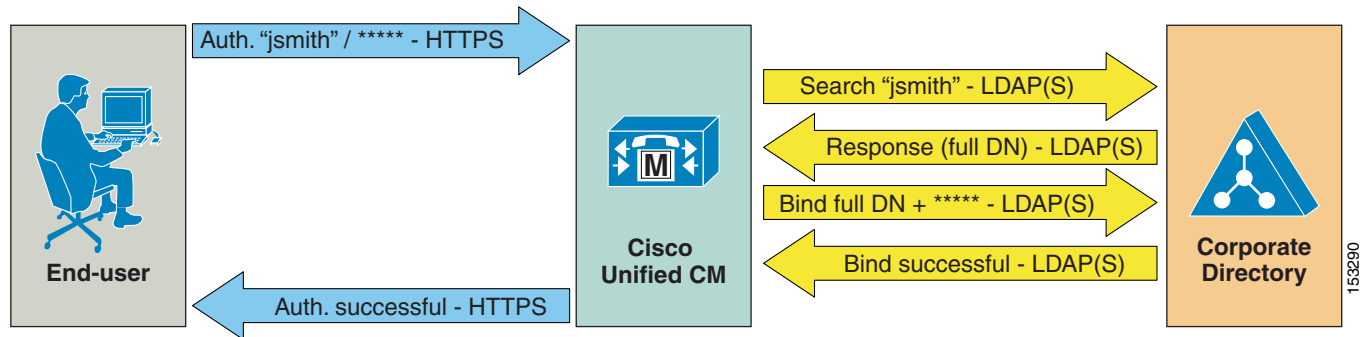
Figure 16-12 Authenticating End User Passwords, Application User Passwords, and End User PINs

Figure 16-13 illustrates the following process, adopted by Unified CM to authenticate an end user against a corporate LDAP directory:

1. A user connects to the Unified CM User Options page via HTTPS and attempts to authenticate with a user name and password. In this example, the user name is jsmith.
2. Unified CM issues an LDAP query for the user name jsmith, using the value specified in the LDAP Search Base on the LDAP Authentication configuration page as the scope for this query. If SLDAP is enabled, this query travels over an SSL connection.
3. The corporate directory server replies via LDAP with the full Distinguished Name (DN) of user jsmith (for example, "cn=jsmith, ou=Users, dc=vse, dc=lab").
4. Unified CM then attempts to validate the user's credentials by using an LDAP bind operation to pass the full DN and password provided by the user.
5. If the LDAP bind is successful, Unified CM allows the user to proceed to the configuration page requested.

Figure 16-13 Authentication Process

Design Considerations for LDAP Authentication

Observe the following design and implementation best-practices when deploying LDAP authentication with Cisco Unified CM:

- Create a specific account within the corporate directory to allow Unified CM to connect and authenticate to it. Cisco recommends that you use an account dedicated to Unified CM, with minimum permissions set to "read" all user objects within the desired search base and with a password set to never expire. The password for this account in the directory must be kept in synchronization with the password configuration of the account in Unified CM. If the account password changes in the directory, be sure to update the account configuration in Unified CM. If LDAP synchronization is also enabled, you can use the same account for both functions.
- Enable LDAP authentication on Unified CM by specifying the credentials of the aforementioned account under LDAP Manager Distinguished Name and LDAP Password, and by specifying the directory subtree where all the users reside under LDAP User Search Base.
- This method provides single logon functionality to all end users: when they log in to the Unified CM User Options page, they can now use their corporate directory credentials.
- Manage end-user passwords from within the corporate directory interface. Note that the password field is no longer displayed in the Unified CM Administration pages when authentication is enabled.
- Manage end-user PINs from the Unified CM Administration web pages or from the Unified CM User Options page.
- Manage Application User passwords from the Unified CM Administration web pages. Remember that these application users facilitate communication and remote call control with other Cisco Unified Communications applications and are not associated with real people.
- Enable single logon for Unified CM administrators by adding their corresponding end user to the Unified CM Super Users user group from the Unified CM Administration web pages. Multiple levels of administrator rights can be defined by creating customized user groups and roles.

Additional Considerations for Microsoft Active Directory

In environments that employ a distributed AD topology with multiple domain controllers geographically distributed, authentication speed might be unacceptable. When the Domain Controller for the authentication agreement does not contain a user account, a search must occur for that user across other domain controllers. If this configuration applies, and login speed is unacceptable, it is possible to set the authentication configuration to use a Global Catalog Server.

An important restriction exists, however. A Global Catalog does not carry the `employeeNumber` attribute by default. In that case either use Domain Controllers for authentication (beware of the limitations listed above) or update the Global Catalog to include the `employeeNumber` attribute. Refer to Microsoft Active Directory documentation for details.

To enable queries against the Global Catalog, simply configure the LDAP Server Information in the LDAP Authentication page to point to the IP address or host name of a Domain Controller that has the Global Catalog role enabled, and configure the LDAP port as 3268.

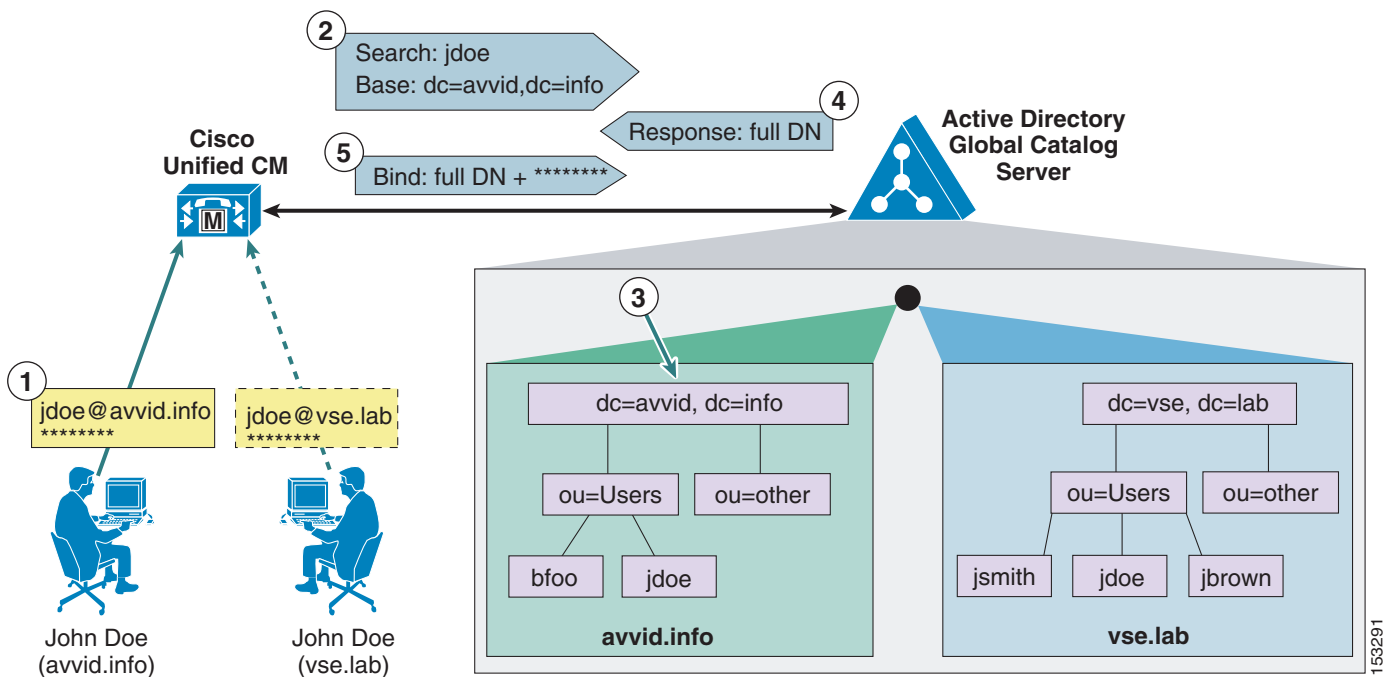
The use of Global Catalog for authentication becomes even more efficient if the users synchronized from Microsoft AD belong to multiple domains, because it allows Unified CM to authenticate users immediately without having to follow referrals. For these cases, point Unified CM to a Global Catalog server and set the LDAP User Search Base to the top of the root domain.

In the case of a Microsoft AD forest that encompasses multiple trees, some additional considerations apply. Because a single LDAP search base cannot cover multiple namespaces, Unified CM must use a different mechanism to authenticate users across these discontinuous namespaces.

As mentioned in the section on [LDAP Synchronization, page 16-10](#), in order to support synchronization with an AD forest that has multiple trees, the `UserPrincipalName (UPN)` attribute must be used as the user ID within Unified CM. When the user ID is the UPN, the LDAP authentication configuration page within Unified CM Administration does not allow you to enter the LDAP Search Base field, but instead it displays the note, "LDAP user search base is formed using userid information."

In fact, the user search base is derived from the UPN suffix for each user, as shown in [Figure 16-14](#). In this example, a Microsoft Active Directory forest consists of two trees, `avvid.info` and `vse.lab`. Because the same user name may appear in both trees, Unified CM has been configured to use the UPN to uniquely identify users in its database during the synchronization and authentication processes.

Figure 16-14 Authentication with Microsoft AD Forests with Multiple Trees



As shown in [Figure 16-14](#), a user named John Doe exists in both the avvid.info tree and the vse.lab tree. The following steps illustrate the authentication process for the first user, whose UPN is `jdoe@avvid.info`:

1. The user authenticates to Unified CM via HTTPS with its user name (which corresponds to the UPN) and password.
2. Unified CM performs an LDAP query against a Microsoft Active Directory Global Catalog server, using the user name specified in the UPN (anything before the @ sign) and deriving the LDAP search base from the UPN suffix (anything after the @ sign). In this case, the user name is `jdoe` and the LDAP search base is `"dc=avvid, dc=info"`.
3. Microsoft Active Directory identifies the correct Distinguished Name corresponding to the user name in the tree specified by the LDAP query. In this case, `"cn=jdoe, ou=Users, dc=avvid, dc=info"`.
4. Microsoft Active Directory responds via LDAP to Unified CM with the full Distinguished Name for this user.
5. Unified CM attempts an LDAP bind with the Distinguished Name provided and the password initially entered by the user, and the authentication process then continues as in the standard case shown in [Figure 16-13](#).

**Note**

Support for LDAP authentication with Microsoft AD forests containing multiple trees relies exclusively on the approach described above. Therefore, support is limited to deployments where the UPN suffix of a user corresponds to the root domain of the tree where the user resides. AD allows the use of aliases, which allows a different UPN suffix. If the UPN suffix is disjointed from the actual namespace of the tree, it is not possible to authenticate Unified CM users against the entire Microsoft Active Directory forest. (It is, however, still possible to use a different attribute as user ID and limit the integration to a single tree within the forest.)

User Filtering for Directory Synchronization and Authentication

Unified CM provides an LDAP Query Filter to optimize directory synchronization performance. Cisco recommends importing only those directory user accounts that will be assigned to Unified Communications resources in each individual cluster. When the number of directory user accounts exceeds the number supported for an individual cluster, filtering must be used to select the subset of users that will be associated on that cluster. The Unified CM synchronization feature is not meant to replace a large-scale corporate directory.

In many cases, a unique search base is all that is needed to control which accounts are synchronized. When a unique search base is not available, a custom LDAP filter might be required. The information in the following sections addresses both methods that can be used to optimize directory synchronization. When any mechanism is used to limit the accounts imported into Unified CM, the default directory lookup configuration will list only those directory entries that exist in the Unified CM database. For directory lookup to access the entire directory, you must configure Unified CM to utilize an external web server. Details of this configuration are not discussed here but are discussed in the Unified CM product documentation available at

http://www.cisco.com/en/US/partner/products/sw/voicesw/ps556/tsd_products_support_series_home.html

Optimizing Unified CM Database Synchronization

The Unified CM Database Synchronization feature provides a mechanism for importing a subset of the user configuration data (attributes) from the LDAP directory store into the Unified CM publisher database. Once synchronization of a user account has occurred, the copy of each user's LDAP account information may then be associated to additional data required to enable specific Unified Communications features for that user. When authentication is also enabled, the user's credentials are used to bind to the LDAP store for password verification. The end user's password is never stored in the Unified CM database when enabled for synchronization and/or authentication.

User account information is cluster-specific. Each Unified CM publisher server maintains a unique list of those users receiving Unified Communications services from that cluster. Synchronization agreements are cluster-specific, and each publisher has its own unique copy of user account information. Only those users who will be assigned Unified Communications resources should be synchronized with Unified CM. The following is a partial list of common reasons why the entire set of users defined in the LDAP directory should not be imported into the Unified CM cluster:

- Importing users who will not be assigned Unified Communications resources can increase directory synchronization time.
- Importing users who will not be assigned Unified Communications resources can slow Unified CM searches and overall database performance.
- In many cases, the number of user accounts in the LDAP directory store far exceeds the total user capacity of the Unified CM database.

Unified CM has no enforced limit on the number of accounts that may be added to the system. Cisco recommends limiting the number of users to the same quantity as the supported number of endpoints. For example, a full-sized cluster of Cisco MCS-7845 servers can support up to 30,000 endpoints, and the system should be administered to limit the number of users to roughly 30,000. There might be cases where accounts are needed for applications, and some designs might require additional accounts.

Cisco recommends using the control mechanisms described here to minimize the number of user accounts imported, regardless of the LDAP database size. This will improve the speed of the first and subsequent periodic synchronizations and will also improve manageability of the user accounts.

Using the LDAP Structure to Control Synchronization

Many deployments of LDAP directories use the Organizational Unit Name (OU) to group users into a logical order and sometimes hierarchical order. If the LDAP directory has a structure that organizes users into multiple OUs, then it often is possible to use that structure to control the groups of users imported. Each individual Unified CM synchronization agreement specifies a single OU. All active accounts under the specified OU, even within sub-OUs, are imported. Only those users in the OU are synchronized. When multiple OUs containing users are required in a cluster, multiple synchronization agreements are required. When an OU contains users that will not be assigned Unified Communications resources, Cisco recommends omitting those OUs from the directory synchronization.

The same technique may be used with AD, which defines containers. A synchronization agreement may specify a particular container in the directory tree and thereby limit the extent of the import.

Because there are only five synchronization agreements available, LDAP deployments with many OUs or containers can quickly exhaust this technique. One possible method to synchronize users in a multi-OU environment is to control the permissions assigned to the synchronization service account. Configure the synchronization agreement to a tree node that contains a mix of users, and then restrict the system account from read access to selected parts of the subtree. Refer to your LDAP vendor documentation on how to restrict this access.

LDAP Query

Additional control over filtering might be required for any of the following reasons:

- The LDAP directory has a flat structure that does not enable adequate control by configuration of the synchronization agreements. When the aggregate number of users that are imported by all the synchronization agreements is greater than the maximum number of users supported by the Unified CM cluster, then it is necessary to control the number of users imported through filters.
- You want to import a subset of user accounts into the Unified CM cluster, for administrative segmentation of users, to control a subset of users that have access and authentication to the cluster. Any account that is imported into a cluster has some level of access to the web pages and authentication mechanisms, which might not be desirable in some cases.
- The LDAP directory structure does not have an accurate representation of how users are going to be mapped into the Unified CM clusters. For instance, if OUs are set up according to an organizational hierarchy but users are mapped to Unified CM by geography, there might be little overlap between the two.

In these cases, the LDAP Query filter may be used to provide additional control over the synchronization agreements.

LDAP Query Filter Syntax and Server-Side Filtering

Unified CM uses standard LDAP mechanisms for synchronizing data from an LDAP directory store. It utilizes the Search mechanism, as defined by RFC 2251—Lightweight Directory Access Protocol (v3), to send a request to retrieve data from the LDAP server. Also defined by that mechanism is the ability to specify a filter string inside the Search message that is used by the LDAP server to select entries in the database for which to return data. The syntax of the filter string is defined by RFC 2254, The String Representation of LDAP Search Filters. This RFC may be used as a reference for constructing more complex filter strings.

The filter string is embedded within a Search message that is sent by Unified CM to the LDAP server and is executed by the server to select which user accounts will be provided in the response.

Simple Filter Syntax

You can configure a filter by specifying standard attribute names and values that are desired for those attributes. The attributes may also be specified by DN element instead of name. The filter string that is used by Unified CM in LDAP queries is stored internally in the `ldapfilter` table and is the string inserted into the Search message.

A filter is a UTF-8 formatted string that has the following syntax:

(attribute operator value)

or

(operator(filter1)(filter2))

Where *filter1* and *filter2* have the syntax shown in first line, and the *operator* is one of those listed in [Table 16-7](#). The *attribute* corresponds to an LDAP attribute that exists in the directory, *operator* is one of the operators listed in [Table 16-7](#), and *value* corresponds to the actual data value that is requested for the attribute.

Table 16-7 Basic Filter String Operators

Operator	Meaning of Function
!	Logical NOT
&	Logical AND
	Logical OR
*	Wildcard
=	Equal to
>=	Lexicographically greater than or equal to
<=	Lexicographically less than or equal to

An attribute specified in the filter can be any attribute that exists in the LDAP directory store, and it does not have to be one of the attributes that is understood and imported by Unified CM. The attribute is used only on the LDAP server to select data, and the corresponding entries will have a subset of their data imported into Unified CM.

Example 16-1 A Single Condition

```
(givenName=Jack)
```

The filter in [Example 16-1](#) selects any user with a given name of Jack.

Example 16-2 Multiple Conditions May Be Joined with Logical Characters

```
(&(objectclass=user)(department=Engineering))
```

The filter in [Example 16-2](#) selects all users in the engineering department.

Default Filter Strings

The filter string has a default value in the `ldapfilter` table, `typeldapserver`, and that default value depends on the LDAP directory store being used, as indicated by the following cases:

- Default Active Directory (AD) filter string

```
(&(objectclass=user)(!(objectclass=Computer))(!(UserAccountControl:1.2.840.113556.1.4.803:=2)))
```

This default filter selects entries for which the object class is a user but not a computer, and for which the account is not flagged as disabled.

- Default SunOne or Netscape filter string

```
(objectclass=inetOrgPerson)
```

This default filter selects all users for which the object class is `inetOrgPerson`.

- Default OpenLDAP filter string

```
(objectclass=inetOrgPerson)
```

- Default Active Directory Application Mode (ADAM) or Active Directory Lightweight Directory Services (AD LDS) filter string

```
(&(objectclass=user)((objectclass=Computer))(!(msDS-UserAccountDisabled=TRUE)))
```

Extending the Default Filter

Cisco recommends that you use the default filter string and append additional conditions to it. For example:

```
(&(objectclass=user)(!(objectclass=Computer))(!(UserAccountControl:1.2.840.1.13556.1.4.803:=2)))(telephonenumber=919*)
```

This filter selects only users that have a prefix of 919 in their telephonenumber field. The synchronization agreement will import only users with an area code of 919. This example assumes all entries begin with an area code.

For the search filter, you may use any existing attribute or even a custom attribute that is defined in the LDAP directory store. The filter string controls which records are selected by the LDAP server to be returned to Unified CM, but the attributes that are imported are not affected by the filter string. The filter string that is used by Unified CM for LDAP queries is stored internally in the ldapfilter database table, and that string can be up to 1024 characters long. Unified CM can support a custom filter for each LDAP Directory Synchronization agreement.

High Availability

Unified CM LDAP Synchronization allows for the configuration of up to three redundant LDAP servers for each directory synchronization agreement. Unified CM LDAP Authentication allows for the configuration of up to three redundant LDAP servers for a single authentication agreement. You should configure a minimum of two LDAP servers for redundancy. The LDAP servers can be configured with IP addresses instead of host names to eliminate dependencies on Domain Name System (DNS) availability.

Capacity Planning for Unified CM Database Synchronization

The Unified CM Database Synchronization feature provides a mechanism for importing a subset of the user configuration data (attributes) from the LDAP store into the Unified CM publisher database. Once synchronization of a user account has occurred, the copy of each user's LDAP account information may then be associated to additional data required to enable specific Unified Communications features for that user. When authentication is also enabled, the user's credentials are used to bind to the LDAP store for password verification. The end user's password is never stored in the Unified CM database when enabled for synchronization and/or authentication.

User account information is cluster-specific. Each Unified CM publisher server maintains a unique list of those users receiving Unified Communications services from that cluster. Synchronization agreements are cluster-specific, and each publisher has its own unique copy of user account information.

The maximum number of users that a Unified CM cluster can handle is limited by the maximum size of the internal configuration database that gets replicated between the cluster members. Starting with Unified CM release 8.6(1), the maximum number of users that can be configured or synchronized was increased from 60,000 to 80,000. To optimize directory synchronization performance, Cisco recommends considering the following points:

- Directory lookup from phones and web pages may use the Unified CM database or the IP Phone Service SDK. When directory lookup functionality uses the Unified CM database, only users who were configured or synchronized from the LDAP store are shown in the directory. If a subset of users are synchronized, then only that subset of users are seen on directory lookup.
- When the IP Phone Services SDK is used for directory lookup, but authentication of Unified CM users to LDAP is needed, the synchronization can be limited to the subset of users who would log in to the Unified CM cluster.

- If only one cluster exists, and the LDAP store contains fewer than the maximum number of users supported by the Unified CM cluster, and directory lookup is implemented to the Unified CM database, then it is possible to import the entire LDAP directory.
- When multiple clusters exist and the number of users in LDAP is less than the maximum number of users supported by the Unified CM cluster, it is possible to import all users into every cluster to ensure directory lookup has all entries.
- If the number of user accounts in LDAP exceeds the maximum number of users supported by the Unified CM cluster and the entire user set should be visible to all users, it will be necessary to use the Unified IP Phone Services SDK to off-load the directory lookup from Unified CM.
- If both synchronization and authentication are enabled, user accounts that have either been configured or synchronized into the Unified CM database will be able to log in to that cluster. The decision about which users to synchronize will impact the decision on directory lookup support.

**Note**

Cisco supports the synchronization of user accounts up to the limit mentioned above, but it does not enforce this limit. Synchronizing more user accounts can lead to starvation of disk space, slower database performance, and longer upgrade times.
