Android Security Paper 2023

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Introduction

Android uses industry-leading security practices to keep user devices safe. We work closely with device partners, developers, security experts, researchers, and academic leaders to ensure the security of the platform. Android's robust, layered security approach is critical for enterprises that must contend with ongoing threats. Organizations require strong security and privacy to protect their data while also giving employees the flexibility to use mobile devices for essential tasks.

This security paper outlines the Android approach to out-of-the-box mobile security and privacy for consumers, business, and government customers. It details the strengths of the Android platform, the range of management APIs available to control enterprise environments, and the role of Google Security Services in preventing threats and abuse.

Android offers a layered security strategy with unique ways to keep data and devices safe. Beyond hardware and operating system protections, Android uses multi-profile support with device-management options that enable the separation of work and personal data, keeping company and personal data secure and isolated from each other. Google Play Protect offers built-in malware protection, identifying potentially harmful applications (PHAs), and is continually working to keep data and devices safe.

This paper also details how the open source Android platform enables best-in-class enterprise security by leveraging the collective intelligence of the Android ecosystem. Overall, this paper is designed to help organizations in their decisions to implement Android and take advantage of its robust security tools.

About the Android Operating System

When Android was being developed, the state-of-the-art in consumer operating system security was provided by memory management systems. For example, both Windows and Unix workstations used protected memory features to provide robust security between users of a device: multiple users could have their own logins to the device, with fully protected separation of all of their apps and data, as if they were on different devices. However, within an individual user's purview, security was more limited. Protected memory was used to prevent applications from gaining highly privileged access to the kernel or accidentally corrupting each other but with essentially no security between the applications themselves. That is, a single user on a device could install applications on it, which couldn't interact with other users, but had fairly free reign within the device.

Installing an application in these operating systems effectively allowed that application to run as the user, with the ability to do almost everything the user could do. This situation was problematic, as the user needed significant trust in every application installed. One of the greatest security values the web brought was that web pages were treated as untrusted and, as such, were limited in what they could do.

Consider, for example, the difference between using a web page for an email client vs. using an application. Navigating to a web page to try an email client can be done without concern since that web page will not have any unsafe access to the user's device (unless the user allows it). Installing an email app means the user must carefully evaluate whether or not to trust its developer, with the knowledge that the app can access everything on the device (and that even if the app is later uninstalled, the device may never behave the way it did before the installation).

This situation was already driving users away from native desktop apps. It was simply not viable for mobile devices and, as these devices were already becoming central to their owners' lives, users were even less able or willing to have such trust in various applications.

There were a few ways to address these new security requirements on mobile platforms:

Use web technology

This leveraged the robust security model of the web, however, it required adding significant extensions to enable all of the application use cases needed for phones, as well as extensions to its security model. It did not allow native code, which is very problematic for critical classes of apps like games. Web tech, designed for desktops, was too heavyweight to run on mobile hardware at that point.

Use Java or a similar virtual environment

This more directly mapped to the kinds of apps being written for mobile devices, but had the same critical problem of requiring apps to be written in that language with no support for native code. Mobile Information Device Profile is an example of this approach.

Use code signing

This, along with source of app restrictions, ensures the user can only install approved apps from a single source. In these cases, the app could still run on the device with almost full access like a traditional desktop system (and use native code and other tools), but with a single distribution point vetting all apps to ensure they are safe to the user. This approach was increasingly common in carrier stores and other places.

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One of Android's goals was to create an open and secure platform for mobile devices and a wide array of other device form factors, while allowing users to install apps from different sources. From Android's point of view, if mobile was the next big computing platform, anything that could be installed without sacrificing security and privacy shouldn't be entirely under the control of a single entity. To maintain this openness and still protect user safety, the operating system itself needed a much more robust application security model, where installing an application did not effectively make it a user of the device.

For Android to be a viable open and secure platform for our users, we had to find a way to allow native code in apps: the importance of gaming, media, and other scenarios meant being limited to running in a virtualized language was too much overhead. In addition, it was already clear that these virtualized languages tended to have frequent security holes due to the complicated interactions between the various security domains within them.

> ## Thus, Android adopted a security solution built on the Linux kernel using protected memory and a novel isolation process.

A related area of development in operating systems was **capability-based systems**, where processes essentially start out with no capabilities (such as access to files and hardware like microphones), then are explicitly given specific abilities based on what they are being created for. The implementations at that time were generally either research systems or designed more for use in embedded systems rather than general-purpose operating systems.

The foundation of Android's security is the Linux kernel.

The Linux kernel has been in widespread use for years and is used in millions of security-sensitive environments. Through its history of constantly being researched, attacked, and fixed by thousands of developers, Linux has become a stable and secure kernel trusted by many corporations and security professionals. Devices launching with Android 11 and higher are required to use the latest long-term support (LTS) kernel that is regularly maintained upstream with security updates and bug fixes.

Android's overall security design is built on top of only the Linux kernel itself, thus it is fairly free to rebuild its user space above to suit its needs. Given that Linux comes with extremely robust multi-user support, this is leveraged for a new application-centric security model in Android. A "user" in Linux is just an arbitrary 32-bit integer (called a UID, the term we will use going forward to distinguish these from the regular Linux user concept) that fully separates it from other UIDs within the kernel.
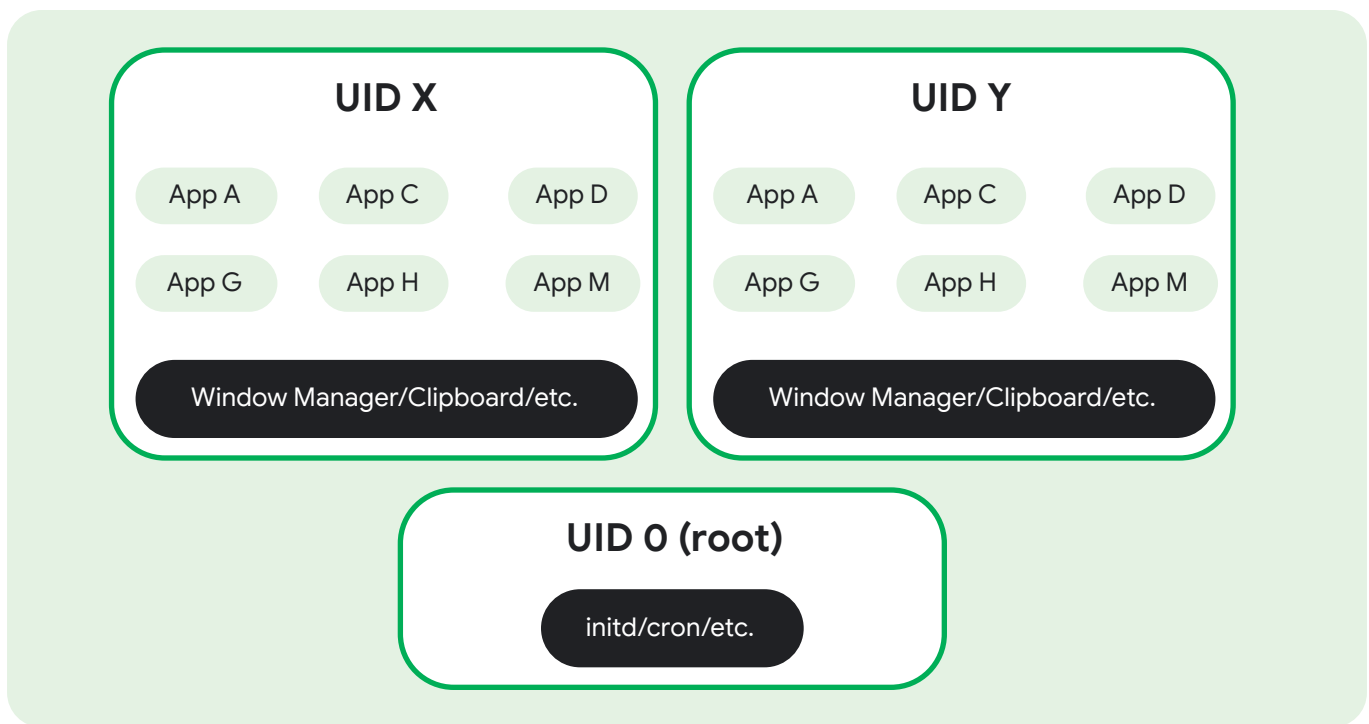
Figure 1. Traditional relationship between users, apps, and system services in Linux

Instead of being a user, Android maps a UID to an application. Each application installed on the device is assigned its own UID, and the kernel ensures it is naturally isolated from other UIDs (and hence other apps). With this extensive use of UIDs, Android also makes a deliberate effort to minimize the amount of code running as root (UID 0). For example, a focused `installd` service provides the minimal functionality needed to manage the overall filesystem (such as creating and destroying the storage for UID sandboxes), and most parts of the system run in their own UID sandboxes.
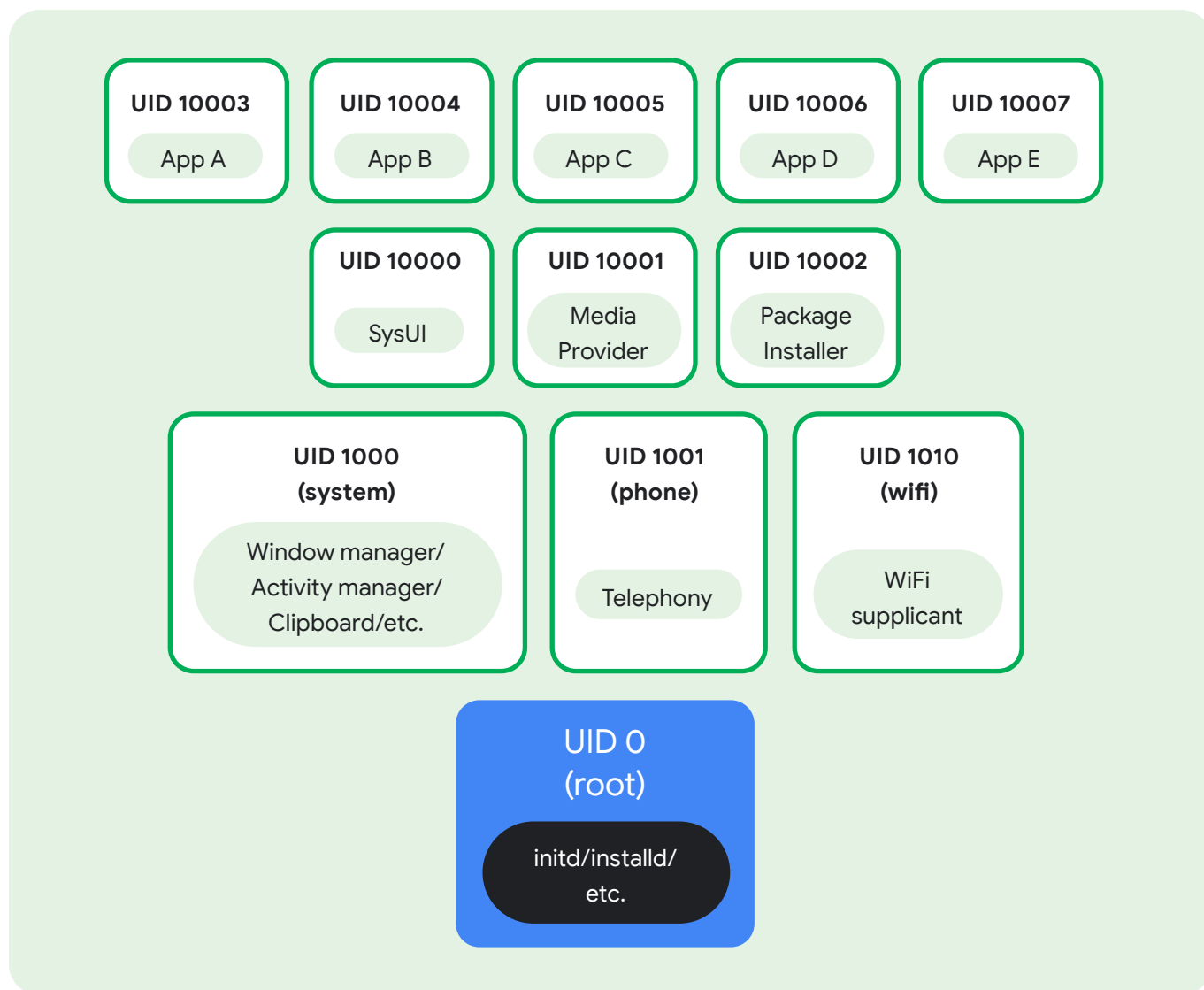
Figure 2. Resulting security architecture

Any interactions between UIDs must be explicitly allowed by Android, much like a capability-based system.

To define the sandboxes for applications, there must be some concept of a secure identity of that application. A well-established way to do this is with a signing certificate, where the application provides a public key identifying who its source is and a private key to sign the code. The operating system then uses the public key to verify that the application came from the author it claims by verifying it against its signing certificate.

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In traditional implementations of code signing, the public certificate is chained to a root certificate. This root certificate can come only from a limited set of certificate authorities responsible for controlling the public certificates charged to them, so their identities can be trusted.

In the development of mobile platforms before Android's creation, the platform owner or carrier (or a combination) would serve as the sole Certificate Authority (CA). For each app being installed, the platform would verify the app was signed by the platform's CA, effectively controlling which apps the user was allowed to install.

Android explicitly did not want platform and/or device providers to have absolute control over what users can install on their device, but still needed a robust way to securely identify applications. Android applications are still signed with a cryptographically secure certificate as previously described, but it does not need to use certificate authorities. Instead, each app's certificate stands on its own and can only be used to securely determine whether two apps came from the same author. This allows Android to enforce core security guarantees, such as "this update to app X came from the original author of the current version of the app" while allowing users to install apps from multiple sources.

Apps are generally built to execute in the Android Runtime and interact with the operating system through a framework that describes system services, platform APIs, and message formats. A variety of high-level and lower-level languages, such as Java, Kotlin, Rust, and C/C++ are allowed and can operate within the same application sandbox. Note that these languages are not part of the Android security model: both native and VM code in an application are running in the same sandbox, and don't have different security semantics.

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The overall layers of the Android software stack can be visualized as below, though the actual security sandboxing layers are much more fine-grained.

Security by design

Firmware Integrity and Trust
Key management, Attestation, TrustZone, Baseband Security, Verified boot

OS Integrity and Trust
Android Virtualization Framework, Memory Safety, Kernel hardening, Application sandboxing, API hardening

Application Integrity and Trust
Malware prevention, App store policy

User Integrity and Trust
Authentication

Supply Chain Security
Vulnerability mitigation, Remove key provisioning

Figure 3. Android's security by design

Android uses hardware and software protections to achieve strong defenses. Security starts at the hardware level, where the user is authenticated with lock screen credentials. Android operating system, once installed, is immutable. That is, an attacker cannot make persistent modifications to the operating system. Verified Boot ensures the system software has not been tampered with, and hardware-assisted encryption and key handling help protect data in transit and at rest.

Android's core security model is based on protecting the user on-device through a robust security design with app sandboxing. Application sandboxing isolates and protects Android apps, preventing malicious apps from accessing private information. Android also protects access to internal operating system components, to help prevent vulnerabilities from becoming exploitable. Mandatory, always-on encryption helps keep data safe, even if devices fall into the wrong hands. Encryption is protected with Keystore keys, which store cryptographic keys in a container, making it harder to extract from a device. Developers can use Android KeyStore with Jetpack Security safely and easily. In total, Android leverages hardware and software to keep devices safe.

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At the software layer, built-in protection is essential to helping Android devices stay safe. **Google Play Protect** is the world's most widely deployed threat detection service, actively scanning over 125 billion apps on devices every day to monitor for harmful behavior. Google Play Protect scans all applications including public apps from Google Play, system apps updated by original equipment manufacturers (OEMs) and carriers, and sideloaded apps.

Apps

Alarm, Browser, Calculator, Camera, Clock, Contacts, IM Dialer, Email, Media Player, Photo Album, SMS/MMS, Voice Dial

Framework

Content Providers, Activity Manager, Location Manager, View System, Package Manager, Notification Manager, Resource Manager, Telephony Manager, Window Manager

Native Libraries

Audio Manager, LIBC, SSL, Freetype, Media, OpenGL/ES, SQLite, Webkit, Surface Manager

Runtime

Core Libraries, Android Runtime (ART)

HAL

Audio, Bluetooth, Camera, DRM, External Storage, Graphic, Input, Media, Sensors, TV

Linux Kernel

Drivers: Audio, Binder IPC, Bluetooth, Camera Display, Keypad Shared Memory, USB Wi-fi, Power Management

Secure Element

Trusted Execution Environment

Figure 4. The Android software stack

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Android is an open source software stack created for a wide array of devices with different form factors. Android incorporates industry-leading security features and the Android team works with developers and device OEMs to keep the Android platform and ecosystem safe. A robust security model is essential to enable a vigorous ecosystem of apps and devices built on and around the Android platform and supported by cloud services. As a result, through its entire development lifecycle, Android has been subjected to a rigorous security program.

Applications running on Android are signed and isolated into application sandboxes associated with their application signature. The application sandbox defines the privileges available to the application.

Android Compatibility Program

The **Android Compatibility Program** defines the technical details of the Android platform and provides tools for OEMs to ensure developer applications run on a variety of devices. This compatibility program consists of three key components:

- The **Android Open Source Project** source code

- The **Compatibility Definition Document (CDD)**, representing the "policy" aspect of compatibility

- The **Compatibility Test Suite (CTS)**, representing the "mechanism" of compatibility

To build an Android-compatible mobile device, follow this three-step process:

1   Obtain the **Android software source code**. This is the source code for the Android platform that you port to your hardware.

2   Comply with the Android CDD (**PDF**, **HTML**), which enumerates the software and hardware requirements of a compatible Android device.

3   **Pass the CTS**. Use the CTS as an ongoing aid to evaluate compatibility during the development process.

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After complying with the CDD and passing the CTS, your device is Android compatible. This means Android apps in the ecosystem provide a consistent experience when running on your device. It also helps to ensure that device manufacturers comply with mandated security requirements. The CDD has guidelines covering many security areas, including hardware and software.

After building an Android-compatible device, manufacturers can apply for a Google Mobile Services (GMS) license. GMS is required to manage Android devices using Android Enterprise and also adds all of the Google security services (such as Play Integrity API, Google Play Protect, and SafeBrowsing), Google applications (such as Google Play, YouTube, Google Maps, Gmail), and **APIs** to help support functionality across devices. GMS is not part of the Android Open Source Project (AOSP) and is only available through a Google license.

For information on how to request a GMS license, see our Contact/Community page →

Hardware-backed Security

Android leverages underlying hardware features to enable strong device security.

Trusted Execution Environment

The processor provides the Trusted Execution Environment (TEE) (TrustZone on ARM devices). This secondary, isolated environment, the TEE, "virtualizes" the main processor and creates a secure, trusted execution environment. Many confidential operations in Android — such as device unlock, credential unlock, and biometrics — need to be done in a constrained, isolated environment. The TEE provides such an environment.

In Android, the main OS, called the Rich Execution Environment (REE), is often referred to as "untrusted," meaning it cannot access certain areas of RAM, hardware registers, and write-once fuses where secret data (such as device-specific cryptographic keys) are stored by the manufacturer. Software running on the REE delegates any operations that require the use of secret data to the TEE.

A TEE consists of a separate, small operating system (TEE OS) along with mini-apps that provide critical services to Android (for example, biometrics and device unlock). While the TEE runs on the same processor as Android, the Arm hardware architecturally isolates the Android Linux kernel and apps from the TEE. This hardware-mediated isolation is another defense-in-depth measure adopted by Android to protect critical user data and device secrets. Google Pixel devices use the open source operating system called **Trusty**.

Only the TEE can access device-specific keys required to decrypt protected content. The REE sees only the encrypted content, providing a high level of security and protection against software-based attacks. There are many uses for a TEE, such as biometrics, device unlock, mobile payments, secure banking, multi-factor authentication, device reset protection, and replay-protected persistent storage.

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The TEE is responsible for some of the most security-critical operations on the device, including:

1   **Lock screen passcode verification:** available on devices that support a secure lock screen. Lock screen verification is provided by the TEE unless an even more secure environment. For example, a secure element such as the Titan M, is available.

2   **Fingerprint template matching:** available on devices that have a fingerprint sensor.

3   **Protection and management of KeyStore keys:** available on devices that support a secure lock screen.

4   **Digital Rights Management (DRM):** an extensible framework that lets apps manage rights-protected content according to the license constraints associated with the content.

5   **Protected Confirmation:** leverages a hardware-protected user interface called Trusted UI to facilitate high assurance to critical transactions. Protected Confirmation is an optional capability for device manufacturers to implement for devices running Android 9 and above.

Verified Boot

Verified Boot ensures that all executed code comes from a trusted source (usually device OEMs), rather than from an attacker or corruption. It establishes a full chain of trust, starting from a hardware-protected root of trust — to the bootloader, the boot partition, and other verified partitions including system, vendor, and optionally OEM partitions. During device boot-up, each stage verifies the integrity and authenticity of the next stage before handing over execution.

In addition to ensuring that devices are running a safe version of Android, Verified Boot checks for the correct version of Android with **rollback protection**. Rollback protection helps to prevent a possible exploit from becoming persistent by ensuring devices only update to newer versions of Android. That is, a kernel compromise (or physical attack) cannot install an older, more vulnerable, version of the OS on a system and boot it. Device manufacturers must integrate rollback protection and ensure that a device's rollback state is stored in tamper-evident storage.

Application developers wishing to measure the boot time device state and integrity, and communicate it to their backend (for example, to apply different policies for devices that don't meet an acceptable integrity state), can use **KeyStore Key Attestation**. By checking the attestation certificates and their signatures, it's possible to get a high level of assurance whether the bootloader is locked, whether verified boot is enabled, and whether the patch level of Android and vendor-provided software meets certain requirements. Key Attestation is mandatory to implement for any Android device shipping with Android 8.1 and higher.

Android Keystore System

The **Android Keystore system** is a foundation of data protection and authentication on devices. It stores cryptographic keys in a hardware-backed container, usually a Trusted Execution Environment, making Android compromises insufficient to extract private keys. Keystore restricts when and how keys can be used, such as requiring user authentication for key use or restricting keys to be used only in certain cryptographic modes. These restrictions are enforced by the secure hardware on the device.

Additionally, devices running Android 9 or higher can optionally provide a StrongBox KeyMint, an implementation of the KeyMint HAL that resides in a dedicated hardware security module. The module contains its own CPU, secure storage, a true random number generator, and additional mechanisms to resist package tampering and unauthorized sideloading of apps. When checking keys stored in the StrongBox KeyMint, the system corroborates a key's integrity with the TEE. For Android 11 devices that use a **StrongBox security chip**, admins of company-owned devices can **request device unique attestation** using individual attestation certificates.

On Android 13 devices, Keystore supports **symmetric cryptographic primitives** such as AES (Advanced Encryption Standard), HMAC (Keyed-Hash Message Authentication Code), and asymmetric cryptographic algorithms (including Elliptic Curve, RSA2048, RSA4096, and Curve 25519). Access controls are specified during key generation and enforced for the lifetime of the key.

For devices that support a secure lock screen, Keystore must be backed by secure hardware. Enterprise customers are provided strong assurances that even in the event of a kernel compromise, Keystore keys are not extractable from the secure hardware, thus protecting corporate authentication credentials.

Keystore Key Attestation

Devices that launched with Android 8.0 and higher are required to support **Key Attestation**, which empowers a server to gain assurance about the properties of the device and the keys generated on the device. On devices that ship with key attestation and Google Play services, the root certificate is signed with a Google attestation root key, indicating the device is a certified Google-Android device. These attestation keys can be used to sign trustworthy statements about important device integrity properties, such as if the bootloader is locked and which security patch levels the various Android partitions are running.

Enterprise customers managing personal or company-owned devices can additionally request device identifiers (IMEI, serial number) within the attestation, which ensures only known devices are enrolled into the enterprise and there's a clear inventory of devices holding enterprise data.

All this helps customers ensure their fleet of devices are patched and behaving as expected.

Learn more about verifying hardware-backed keys with Key Attestation →

KeyChain

The **KeyChain class** provides access to private keys and their corresponding certificate chains in credential storage. KeyChain is often used by Chrome, Virtual Private Networks (VPNs), and enterprise apps to access keys imported by the user or by the Enterprise Mobility Management (EMM) Device Policy Controller (DPC) deployed on managed devices.

Whereas the KeyStore is for non-shareable app-specific keys, KeyChain is for system- or profile-wide keys that may be used by multiple apps with the approval of the EMM DPC or the user. For example, an EMM DPC can import a key that Chrome will use to access an enterprise website.

Android 10 and higher use several improvements to the **KeyChain API**. When an app calls **KeyChain.choosePrivateKeyAlias**, devices now filter the list of certificates a user can choose from based on the issuers and key algorithms specified in the call. KeyChain no longer requires a device to have a screen lock before keys or **CA certificates** can be imported.

A benefit for enterprise customers with Android 11 is that the EMM DPC can generate their KeyChain keys for TLS client certificates directly in secure hardware and obtain a signed attestation record. This guarantees that the keys cannot be extracted from the device or intercepted in transit.

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Key Decryption on Unlocked Devices

Android 9 and higher take advantage of the **unlockedDeviceRequired** flag. This option determines whether the Keystore requires the screen to be unlocked before allowing usage of a specified key. These types of keys are well suited for encrypting sensitive data stored on-disk, such as health and enterprise data. The flag, which is enforced by the secure hardware, provides users a higher assurance that the data cannot be decrypted while the device is locked should their phone be lost or stolen.

Version Binding (Anti-Rollback Protection)

In **Keymaster and KeyMint**, all keys are additionally bound to the security patch level of the Android image. This ensures that an attacker who discovers a weakness in an old version of the Android system or TEE software cannot roll a device back to a vulnerable version and compromise secrets by using those vulnerabilities. The effects of this are most immediately obvious when considering that the device encryption key used to decrypt a device's data partition cannot be used if the device version has been rolled back, cryptographically sealing away all data on the device from a malicious attacker.

Keys can (and must) be upgraded and bound to newer versions of the security patch levels as users take OTAs, but they can never be downgraded and rolled back. This is a transparent process between KeyStore and KeyMint that happens without the developer needing to take any explicit actions.

User Authentication

Android implements a tiered authentication model which is a conceptual classification of all the different authentication methods on Android, how they relate to each other, and how they are constrained based on this classification. The **Android Compatibility Definition Document** specifies the implementation requirements for **secure lock screen** and **biometric security**.

Authentication methods are classified into three buckets of decreasing levels of security and commensurately increasing constraints. The primary tier is the least constrained in the sense that users only need to re-enter a primary modality under certain situations (for example, after each boot or every 72 hours) to use its capability. The secondary and tertiary tiers cannot be set up and used without having a primary modality enrolled first and they have more constraints further restricting their capabilities.
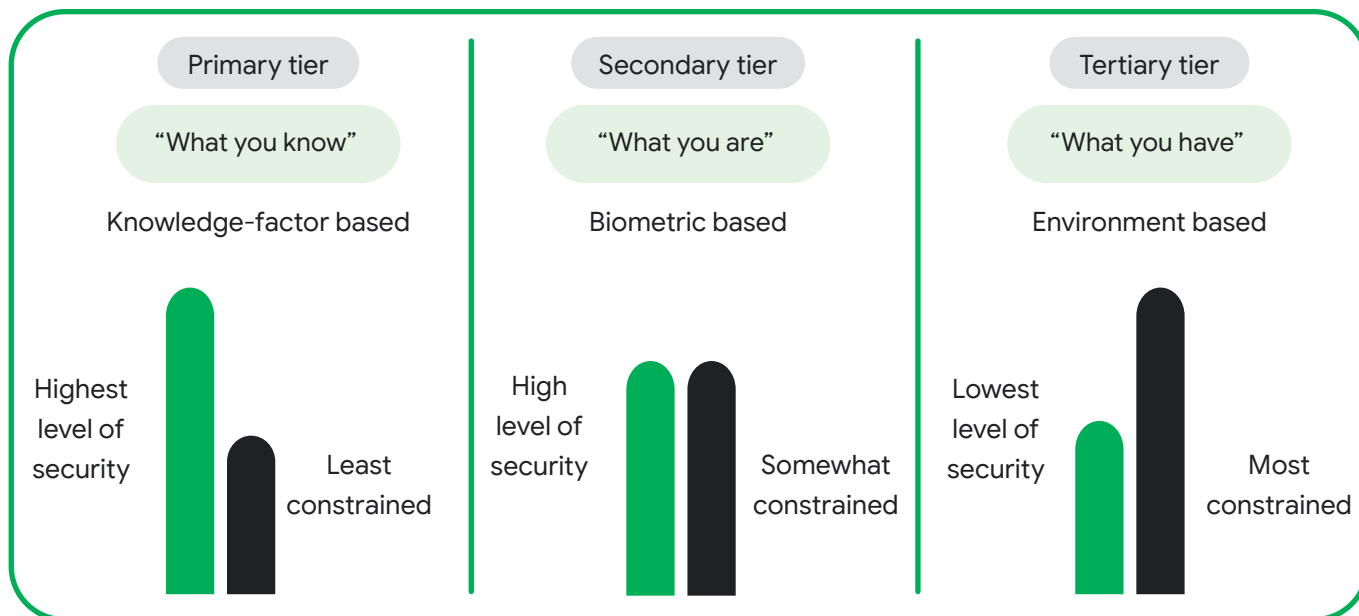
Figure 5. Android tiered authentication model

Gatekeeper

Android supports **Gatekeeper** for PIN/pattern/password authentication. The Gatekeeper subsystem performs this authentication in the TEE, enrolling and verifying passwords via a Hash-Based Message Authentication Code (HMAC) with a hardware-backed secret key. Gatekeeper enforces rate limiting of password guesses.

Weaver

On supported devices, PIN/pattern/password authentication is further hardened with **Weaver**, a hardware abstraction layer that leverages secure persistent storage of secret values that may only be read when the corresponding key has been presented. Weaver runs inside discrete tamper-resistant hardware (a Secure Element or a dedicated secure enclave). Weaver is used to map the user's PIN/pattern/password, which might be low-entropy, to a high-entropy secret value with rate limiting enforced by the tamper-resistant hardware. If the correct PIN/pattern/password is presented within the rate limiting policy, the high-entropy secret value is made available to Android and is used to decrypt secrets associated with the user, such as the user's credential-encrypted key for file-based encryption.

Figure 6. Security hardware provides numerous protections on the device

Biometrics

Devices can use biometric authentication to safeguard private information and essential corporate data accessible through devices used in an enterprise setting. The **BiometricPrompt API** is accessible to developers for integrating biometric authentication into their apps.

The Android framework includes face and fingerprint biometric authentication. Android can be customized to support other forms of biometric authentication, such as Iris scans. To participate in the BiometricPrompt class, biometric implem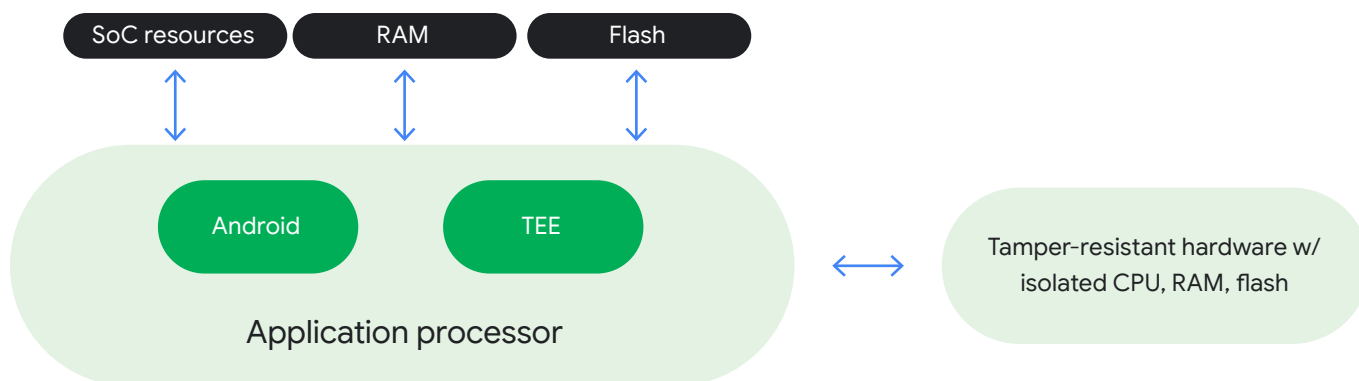entations must meet security specifications for Class 2 or 3 as required in the **CDD**. Only Class 3 biometrics allow third-party applications to access Android Keystore keys.

Biometric authentication typically depends on the outcome of a False Accept Rate (FAR), however, Android uses additional metrics to help device manufacturers evaluate their security:

- **Spoof Acceptance Rate (SAR)**: Defines the metric of the chance that a biometric model accepts a previously recorded, known good sample. For example, with voice unlock, this would measure the chances of unlocking a user's phone using a recorded sample of them saying: "Ok, Google." We call such attacks Spoof Attacks, also known as Impostor Attack Presentation Match Rate (IAPMR).

- **Imposter Acceptance Rate (IAR):** Defines the metric of the chance that a biometric model accepts input that is meant to mimic a known good sample. For example, in the Smart Lock trusted voice (voice unlock) mechanism, this would measure how often someone trying to mimic a user's voice (using similar tone and accent) can unlock their device. We call such attacks Imposter Attacks.

- **False Acceptance Rate (FAR):** Defines the metric of how often a model mistakenly accepts a randomly chosen incorrect input. While this is a useful measure, it does not provide sufficient information to evaluate how well the model stands up to targeted attacks.

Biometric sensors are classified based on their biometric security performance (for example, SAR and FAR) and on the security of the biometric pipeline. **Test methodology** is available to assist in measuring the implementation of these unlock methods and GMS devices must follow specific biometric security test protocols. Additionally, Android device manufacturers can access recommendations of **system security best practices** for using biometric authentication.

In Android 9 and higher, the **BiometricPrompt API** system provides biometric authentication dialogs to be used on behalf of an application. This creates a consistent look, feel, and placement for the dialog, and gives users greater confidence they're authenticating with biometrics using a trusted credential tracker. To help control the level of security for an app's data, Android 11 provides several improvements to biometric authentication that are extended in the Jetpack Biometric library. This improves the ability of an app to use the Biometric capabilities built into Android 11. Android 12 introduces the **BiometricManager.Strings API**, which provides localized strings for apps that use BiometricPrompt for authentication. These strings are intended to be device-aware and provide more specificity about which authentication type(s) may be used. Android 12 also includes support for under-display fingerprint sensors.

The BiometricPrompt API is used in conjunction with the Android Keystore system, which provides hardware-backed cryptography for secure key storage in a secure environment, such as a Trusted Execution Environment (TEE) or Secure Element (SE) like Strongbox.

Fingerprint Authentication

On devices with a fingerprint sensor, users can enroll one or more fingerprints and use those fingerprints to unlock the device and perform other tasks. Android uses the **Fingerprint Hardware Interface Definition Language (HIDL)**, or a newer **Fingerprint Android Interface Definition Language (AIDL)** introduced in Android 12, to connect to a vendor-specific library and fingerprint hardware, such as a fingerprint sensor.

> **Note:** Older HIDL interfaces will be deprecated in the near future, and are strongly recommended to migrate to newer AIDL interfaces for improved security and added features.

Face Authentication

Face authentication allows users to unlock their device simply by looking at the front of their device. Android 10 and higher support the face authentication stack that can securely process camera frames, preserving security and privacy during face authentication on supported hardware. Android 10 and higher also provide a method for security-compliant implementations to enable application integration for transactions, such as online banking or other services. Android 12 and higher support a newer **Face Android Interface Definition Language (AIDL)** for more secure sensor operations. Older **Face Hardware Interface Definition Language (HIDL)** interfaces will be deprecated in the near future, and are strongly recommended to migrate to newer AIDL interfaces for improved security and added features.

Additional Authentication Methods

Android supports the Trust Agent Framework to unlock the device. Google **Smart Lock** uses this framework to allow a device to remain unlocked as long as it stays with the user for up to four hours, as determined by certain user presence or other signals.

However, Smart Lock does not meet the same level of assurance as other unlock methods on Android and is not allowed to unlock auth-bound KeyStore keys. Organizations can disable Trust Agents using the **KEYGUARD_DISABLE_TRUST_AGENTS** flag in their EMM policies.

Protected Confirmation

Android Protected Confirmation leverages a hardware-protected user interface (Trusted UI) to perform critical transactions outside the operating system in devices that run Android 9 or above. This provides users with even more assurance that a critical action has been executed securely and helps developers verify a user's action intent with a very high degree of confidence. When an app invokes Protected Confirmation, control is passed to the Trusted UI, where transaction data is displayed and user confirmation of the data's correctness is obtained.

Once confirmed, the intention is cryptographically authenticated and tamper-proof when conveyed to the relying party. In total, the transaction has higher protection and security relative to other forms of secondary authentication.

This can be especially useful in a number of user moments, like during mobile payment transactions, that greatly benefit from additional verification and security.

Memory Safety

Memory safety bugs, and errors in handling memory in native programming languages like C and C++, are an industry-wide problem with negative consequences to software stability, security, and ultimately user experience. Throughout the industry, across different companies and products, these bugs represent a large fraction of reported security vulnerabilities.

To improve the security and user experience of the operating system, Android has been investing in the development of technologies to address this problem:

- **Sanitizers** such as HWASan help find memory safety bugs in pre-release testing

- **GWP-ASan and KFENCE** allow probabilistic detection of memory safety bugs in production

- **Rust** is a modern native programming language that is memory safe

Sanitizers

Android has supported HWASan since Android 10. This tool has been used extensively for Android platform development, preventing many bugs from making it into Android releases. The app developer workflow for using HWASan has been significantly improved in Android 14 and we hope it will gain more widespread usage.

GWP-ASan and KFENCE

GWP-ASan and KFENCE are probabilistic memory detection tools for production usage in userspace and the kernel, respectively. When enabled, a small number of allocations are guarded against memory safety bugs. Even with a small sample rate for the guarded allocations, when deployed at scale they can effectively detect memory safety bugs. This is used for some 1P apps and is available for 3P applications. Android 14 introduces a "recoverable" GWP-ASan mode that is enabled by default for all 3P applications.

Rust

Android 12 introduced Rust as a language for platform development. Rust provides memory and thread safety at performance levels similar to C/C++. Rust is the preferred choice for new native projects in the Android platform.

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Operating System Security

Android utilizes a "defense in depth" approach to help keep the operating system secure. With each version of Android, the operating system is further hardened to have the right defenses for the ongoing threats that users face.

Sandboxing

Enforcement of Android's security model starts with sandboxing of applications and system services. Hardware components like a TEE help further isolate sensitive processes and data such as cryptographic operations and key storage. Process isolation provides the foundation for sandboxing of userspace processes. Every app runs in its own UID and is thus isolated from the operating system components and other apps. SELinux brings Mandatory Access Control policies and is the primary means by which the isolation among processes, apps, and system services is achieved.

- **Kernel Sandboxing** enforces restrictions on what actions the kernel may take and limits userspace access to kernel entry points such as device drivers.

- **System Process Sandboxing** applies sandboxing to all processes such as the media frameworks, telephony stack, WiFi services, and Bluetooth components.

- **Application Sandboxing** uses SELinux and a unique user ID (UID) to isolate apps from each other and the system. This sandbox keeps the application and its data secure.

- **Other areas of separation** include the **TEE** and userspace components. For example, the Android **Keymint** integrates the keystore into the TEE, which guards cryptographic key storage from exposure and tampering. An attacker cannot read key material stored in the Keymint even if the kernel is fully compromised. Android 9 and higher devices with dedicated tamper-resistant hardware can store keys in the StrongBox Keymint. This implementation mitigates against the most sophisticated attacks such as cold boot memory attacks, power analysis, and other invasive attacks that can allow privilege escalation.

SELinux

Android uses **Security-Enhanced Linux** (SELinux) to enforce mandatory access control (MAC) over all processes, including those with root/superuser privileges. SELinux enables Android to better protect and confine system services, restrict access to app data and system logs, isolate potentially malicious apps, and protect users from potential security vulnerabilities.

SELinux operates on the principle of default denial: Anything not explicitly allowed is denied.

Android includes SELinux and a corresponding security policy for components in AOSP. Disallowed actions are prevented and all attempted violations are logged via Linux tools: dmesg prints the message buffer of the kernel, and **logcat** is a command-line tool that dumps a log of system messages.

With the **Android system architecture**, SELinux is used to enforce a separation between the Android framework and the device-specific vendor components such that they run in different processes and communicate with each other via a set of allowed vendor interfaces implemented as **Hardware Abstraction Layers** (HALs).

Seccomp Filter

In conjunction with SELinux, Android uses **Seccomp** to further restrict entry points to the kernel by blocking access to system calls that are not explicitly included in an allowlist. Seccomp is a one-way trapdoor — once a process relinquishes certain system calls, it can never gain it back again. Seccomp is applied to processes in the media frameworks and all applications. Apps may optionally provide their own seccomp filter to further reduce the set of allowed system calls.

Unix Permissions

Android uses Linux/Unix permissions to further isolate application resources. Android assigns a UID to each application and runs each user in a separate process. Apps are not allowed to access each other's files or resources just as different users on Linux are isolated from each other.

Anti-Exploitation

Android enables **exploit protection** mitigations such as **Control Flow Integrity** and **Integer Overflow Sanitization**. New compiler-based mitigations have been added to make bugs harder to exploit and prevent certain classes of bugs from becoming vulnerabilities. This expands existing compiler mitigations, which direct the runtime operations to safely abort the processes when undefined behavior occurs.

Android 10 introduced **BoundsSanitizer** (BoundSan), which adds instrumentation to insert bounds checks around array accesses. These checks are added if the compiler cannot prove at compile time that the access will be safe and if the size of the array will be known at runtime. BoundSan is deployed in Bluetooth, media codecs, and other components throughout the platform.

Unintended integer overflows can cause memory corruption or information disclosure vulnerabilities in variables associated with memory accesses or memory allocations. To combat this, Clang's **UndefinedBehaviorSanitizer** (UBSan) was added to signed and unsigned integer overflow sanitizers to **harden the media framework**. In Android 9 and higher, the UBSan was expanded to **cover more components** which improved build system support. This is designed to add checks around arithmetic operations/instructions — which might overflow — to safely abort a process if an overflow does happen. These sanitizers can mitigate an entire class of memory corruption and information disclosure vulnerabilities where the root cause is an integer overflow, such as the original Stagefright vulnerabilities. As a side effect, components hardened with these mitigations also have better quality and stability.

Android 10 and higher employ **Scudo**, a hardened memory allocator which employs multiple defense-in-depth strategies to detect and prevent use-after-free, double-free, and bounds-violations. This provides additional hardening of the platform and prevents memory unsafe errors from becoming exploits.

User and Data Privacy

Protecting user privacy is fundamental to Android. Limiting background apps' access to device sensors, restricting information retrieved from Wi-Fi scans, and implementing new permission groups related to phone calls and phone states help ensure more user privacy. These changes affect all apps running on Android 9 and higher, regardless of the target SDK or Android version.

Android 10 expanded users' control and privacy over data and app functionalities, offering improved transparency for both users and IT administrators regarding access to data and user location.

Android Work Profile creates a separate, self-contained profile on Android devices that isolates corporate data from personal apps and data. A Work Profile can be added to a personal device in a **BYOD** setting or on a **company-owned device** used for both work and personal purposes. With this separate profile, the user's apps and data in the personal profile are outside of IT control.

When a Work Profile is added to a device, in order to provide complete transparency, the EMM DPC displays the terms of use and provides information relevant to data collection and visibility. The user must review and accept the user license agreement to set up a Work Profile. Users can view Work Profile settings through **Settings > Accounts.**

Developers are encouraged to ensure their apps are compliant with the latest **privacy changes**. Android 10 and higher places restrictions on accessing data and system identifiers, accessing camera and networking information, and making certain changes to the permissions model.

Restricting Access to Device Identifiers

When not connected to a network, Android provides random MAC addresses when probing new networks. On Android 9, the device can use a randomized MAC address when connecting to a Wi-Fi network if enabled by a developer option. In Android 10 and higher, the system transmits randomized MAC addresses by default for both probe requests and connected networks. Additionally, device IMEI, IMSI, and serial numbers can only be accessed by privileged system apps, helping to prevent persistent tracking of users.

App Permissions

Permissions protect the privacy of Android users and provide transparency about what resources or information apps want to access. For apps to access system features, such as camera and the web, or user data, such as contacts and SMS, an Android app must explicitly request permission. These permission prompts are designed so the user has clear visibility into the request and the opportunity to approve or deny it.
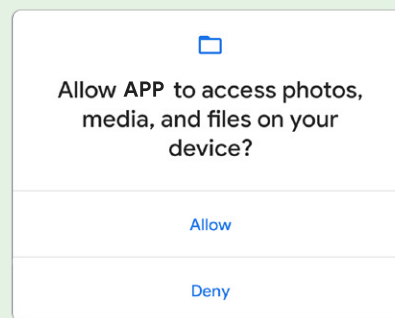
Allow APP to access photos, media, and files on your device?

Allow

Deny

Figure 7. Users are prompted to set permissions for apps

Android 🤖

A central design point of the Android security architecture is that no app, by default, has permission to perform any operations that would adversely impact other apps, the operating system, or the user. This includes reading or writing the user's private device data (such as contacts, SMS, or MMS messages), reading or writing another app's files, performing network access, and keeping the device awake.

Android uses **runtime permissions**, which presents a dialog for the user to grant access to the specified permission at runtime.

This gives users more control than install time permissions, streamlining the installation. When an app requests permissions the user can decide between:

- **Approve** — grant the app access to data; or

- **Deny** — requested permissions are not granted to the app.

To further empower users to minimize data access, certain runtime dialogs allow users to select from granting access while using the app, only this time, or don't allow. Additional optionality is provided to users.

These options are presented for each permission requested by the app. Granting location permissions doesn't grant storage access. For example, a user can choose to give a camera app access to the camera but not to the device location. Users can revoke permissions at any time, even if the app targets a lower API level. Android 13 (API level 33) and higher supports a runtime permission for sending non-exempt **notifications from an app**. This gives users control over which permission notifications they see.

Android has mechanisms in place to restrict access to sensitive data. Android auto-resets permissions for apps that target Android 6 or higher and have not been used for a few months. This action has the same effect as if the user viewed a permission in system settings and changes an app's access level to **deny**. Starting from Android 9 and higher, only the apps running in the foreground (or in a foreground service) are allowed to access the microphone, camera, or the sensors. As for location, starting with Android 10, background access requires an **additional background location permission**. Furthermore, Android 11 introduced an additional privacy restriction on location, camera, and microphone, which provides users the option to grant permissions only for a single use (that is, **one-time permissions**). In addition, Android 12 introduced the option for users to grant access only to their **approximate location**. Finally, in Android 14, starting with apps that share location data with third-parties, the system runtime permission dialog now includes a clickable section that highlights the app's data-sharing practices, including information such as why an app may decide to share data with third parties.

Users also have access to **provide better control** over the use of device identifiers. Privacy-sensitive persistent device identifiers are either no longer accessible or gated behind a runtime permission. For example, APIs that access the Wi-Fi MAC address have been removed except on fully managed devices.

On enterprise devices, DPCs can deny permissions on behalf of the user using the **setPermissionPolicy** API, a feature of managed Google Play.

Location Control

Apps can provide relevant information to the user using **location APIs**. For example, if an app helps the user navigate a delivery route, it needs to continually access the device location to provide the right assistance. Location is useful in many scenarios and Android provides tools for developers to request the necessary permissions while giving users a choice in what they allow.

Apps that use location services must request location permissions so the user has visibility and control over this access. Runtime permissions for location have been available since Android 6, where users have been able to allow or deny permission for location access to each app. In Android 10, a new option was added for users to grant location permission to apps only when the app was being used. In addition, in Android 11, a one-time location option was added as well.

The user can choose to allow an app **all-the-time** access to device location. After an app accesses device location in the background after the user makes this choice, the system may show a notification, reminding the user that the app has access to location even when it is not being used.

In Android 12, users gained the ability to grant an app access to their approximate location, rather than their precise location. A lot of apps require location permissions in order to operate properly but these permissions expose more information than a lot of users are comfortable sharing. Giving users the ability to choose between approximate location and precise location allows some apps to continue to function without the app knowing the user's precise location.

Learn more about location updates →

Per-use Access to All Device Logs

Because device logs can contain sensitive information, Android 13 introduced a per-use prompt for apps requesting access to all device logs, giving users the ability to allow or deny access. The system denies background requests for access to all device logs automatically and prominently displays a prompt with the app name and a warning about the content so the user can make an informed decision to allow or deny access. This eliminates persistent access to all device logs [logcat] reducing potential privacy risks.

Learn more about Device Logs →

Privacy Indicators

Runtime permissions in Android 6 and higher give users control over when they allow audio from a device's microphone or video from a device's camera to be recorded. Before an app can record, a user must either grant or deny it permission through a dialog the system presents. Android 12 provides users with transparency by displaying indicators on the status bar when an app uses a private data source through the cameras and microphone. Users can also completely disable mic and camera access for all apps using two toggles in quick settings.

Files and Media Access

To give users more control over their files and to limit file clutter, apps targeting Android 10 and higher are subject to new file access controls, or **scoped storage**, by default. Apps have unrestricted access to only their own app-specific directory, accessed using **Context.getExternalFilesDir()** or Context.getFilesDir() — and to create files in organized **collections** on shared storage.

In order to read media files created by other apps in shared storage, apps must request the permissions READ_MEDIA_IMAGES, READ_MEDIA_VIDEO, or READ_MEDIA_AUDIO. If the user approves these runtime permissions, they will have read access to the file types requested. A further dangerous permission (ACCESS_MEDIA_LOCATION) must be requested to have access to photo or video location metadata. Apps must request explicit approval from the user to modify or delete a file that it has received access to via one of the media permissions.

> **To further mitigate the potential for any data loss, EMM administrators are able to prevent their organization's users from accessing external storage, such as an SD card connected to their device.**

Photo Picker

As an alternative to the photo and video permissions, apps are recommended to use the photo picker to ask users to select media files.

The photo picker is a browsable interface that presents the user with their media library, sorted by date from newest to oldest, and integrates easily with apps without requiring media storage permissions. The photo picker allows users to browse their photo gallery and select specific items to share with an app instead of granting broad permissions to the whole media library. Enterprise customers can quickly add a photo selection feature to their apps without having to develop a complex in-house picker from scratch. It also eliminates the need to maintain complex logic for handling permissions and querying MediaStore, saving development time.

Figure 8. With photo picker, users can select which media to share with apps

The photo picker was launched in 2022 to all GMS devices running Android 11 and above.

Android

Limited Access to Background Sensors

Android 9 and above limits the ability for background apps to access user input and sensor data. If an app is running in the background, the system applies the following restrictions:

- Application cannot access the microphone or camera

- Sensors that use the **continuous** reporting mode, such as accelerometers and gyroscopes, don't receive events

- Sensors that use the **on-change** or **one-shot** reporting modes don't receive events

If an app needs to detect sensor events on devices, it must use a **foreground service**.

Lockdown Mode

A user can enable a lockdown option to further restrict access to the device. This mode displays a power button option that turns off Smart Lock, biometric unlocking, and notifications on the lock screen. It can be enabled via **Settings > Lock screen preferences > Lockdown mode**. Enterprise administrators can remotely lock the Work Profile and evict the encryption key from memory on enterprise devices by leveraging **this capability**.

Privacy Dashboard and Permission Manager

Android's data privacy dashboard provides users with valuable insights into how their data is being accessed by apps. The dashboard grants users a clear overview of which apps have accessed their location, camera, microphone, and other device data. Giving users this information helps them make informed decisions about allowing or revoking permissions to their apps.

Users can also check which apps have the same permission setting and change an app's permission in the Permission Manager.

Read more about Android's privacy dashboard →
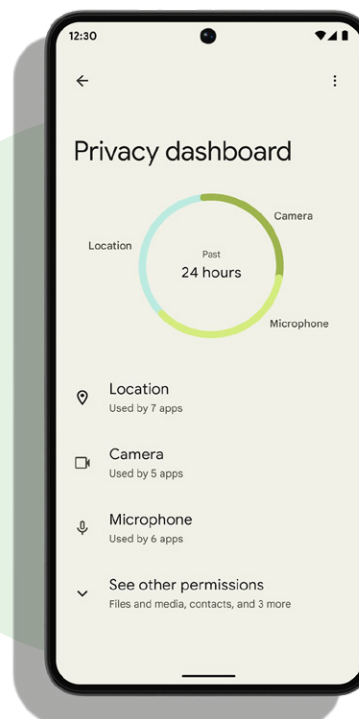
Figure 9. Users can easily see how data is being accessed

Android 🤖

Private Compute Core

Android's Private Compute Core (PCC) is an open source, secure environment that is isolated from the rest of the operating system and apps. Introduced in Android 12, it brings a new layer of privacy to the Android ecosystem. PCC enables on-device processing for features like live caption, now playing, Smart Reply, and many others by eliminating the need to send data to the cloud for processing.

Learn more about Android's private compute services →

Android 🤖

Network Security

In addition to data-at-rest security — protecting information stored on the device — Android provides network security for data-in-transit to protect data sent to and from Android devices.

Android provides secure communications over the Internet for web browsing, email, instant messaging, and other Internet apps, by supporting **Transport Layer Security (TLS)**.

DNS over TLS

Android 9 and higher includes built-in support for Domain Name System (DNS) over TLS. Users or administrators can enable a Private DNS mode in the Network and Internet settings. Android 10 further extends the capabilities for administrators to configure DNS over TLS and prevent users from changing DNS settings, thus preventing DNS query leakage.

TLS by Default

Android helps keep data safe by protectingnetwork traffic that enters or leaves a device with **TLS**. On Android 9 and above, the defaults for **Network Security Configuration** block all cleartext (unencrypted HTTP) traffic. Developers must explicitly opt-in to specific domains to use cleartext traffic in their applications. Android Studio also warns developers when their app includes a potentially insecure Network Security Configuration.

To prevent accidental unencrypted connections, the **android:usesCleartextTraffic** manifest attribute enables apps to indicate that they do not intend to send network traffic without encryption.
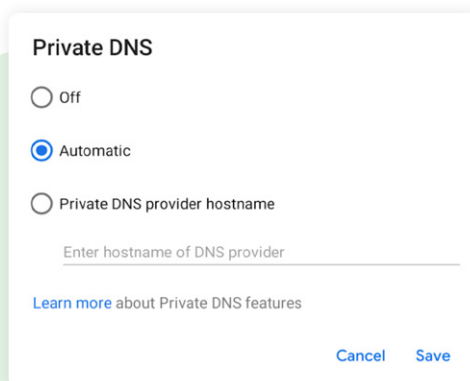
Figure 10. The Private DNS feature in the settings is enabled by default, with an option to input a private DNS provider hostname

Android

Android 10 and higher uses **TLS 1.3** by default for all TLS connections. TLS 1.3 is a major revision to the TLS standard with performance benefits and enhanced security. It is also more private as it encrypts more of the handshake process and offers stronger security by no longer supporting certificates signed with Secure Hash Algorithm 1 (SHA 1). Benchmarks indicate secure connections can be established as much as 40% faster with TLS 1.3 compared to TLS 1.2.

> **Learn more about TLS 1.3 implementation** →

Cellular Connectivity

Independently of the application of TLS, when a mobile device connects to a cellular network for data, voice, or messaging connectivity, the link layer presents unique security and privacy challenges that are distinctive of cellular telephony. Adversarial networks, such as **False Base Stations (FBS) and Stingrays**, exploit weaknesses in cellular connectivity in a number of ways, such as traffic interception, malware sideloading, and sophisticated dragnet surveillance.

For example, an adversarial network (that is, false base stations) can disable cellular link-level encryption by silently downgrading the connection to a legacy 2G protocol with weak encryption and no mutual authentication, or by forcing the use of null-ciphers. This exposes circuit-switched voice and SMS telephony traffic that is not end-to-end encrypted to passive interception.

Android acknowledges the far-reaching implications of these attack vectors, particularly for at-risk users, and prioritizes hardening cellular telephony.

Android 12 introduced an **option to disable 2G support** at the modem level, which protects users from the inherent security risk from 2G's obsolete security model. Recognizing how critical disabling 2G could be for enterprise customers, Android 14 enables this security feature in Android Enterprise, introducing support for IT admins to restrict the ability of a managed device to **downgrade to 2G connectivity**.

Android 14 also introduces support to reject null-ciphered cellular connections, ensuring that circuit-switched voice and SMS traffic is always encrypted and protected from passive over-the-air interception.

> **Learn more about Android's program to harden cellular connectivity** →

Android 🤖

Wi-Fi

Android 10 and higher support the Wi-Fi Alliance's Wi-Fi Protected Access version 3 (WPA3) and Wi-Fi Enhanced Open standards. **WPA3 and Wi-Fi Enhanced Open** improve overall Wi-Fi security, providing better privacy and robustness against known attacks.

WPA3 is a new WFA security standard for personal and enterprise networks, taking advantage of modern security algorithms and stronger cipher suites. It has two parts: personal and enterprise. WPA3-Enterprise offers stronger authentication and link-layer encryption methods, and an optional 192-bit security mode for sensitive security environments. WPA3-Personal uses simultaneous authentication of equals (SAE) instead of pre-shared key (PSK), providing users with stronger security protections against attacks such as offline dictionary attacks, key recovery, and message forging.

Wi-Fi Enhanced Open is a new WFA security standard for public networks based on opportunistic wireless encryption (OWE). It provides encryption and privacy on open, non-password-protected networks in areas such as cafés, hotels, restaurants, and libraries. Enhanced Open doesn't provide authentication.

Android also supports the WPA2-Enterprise (802.11i) protocol. This is also designed for enterprise networks and can be integrated into a broad range of Remote Authentication Dial-In User Service (RADIUS) authentication servers. The WPA2-Enterprise protocol uses AES-128-CCM authenticated encryption.

In Android 10 and above, QR codes and NFC data used for device provisioning can contain Extensible Authentication Protocol (EAP) configuration and credentials — including certificates. When a person scans a QR code or taps an NFC tag, the device automatically authenticates to a local Wi-Fi network using EAP and starts the provisioning process without any additional manual input.

Learn more about EAP Wi-Fi provisioning →

Android 🤖

VPN

Android supports securely connecting to an enterprise network using a VPN:

- **Always-on VPN**: The VPN can be configured so that apps don't have access to the network until a VPN connection is established, which prevents apps from sending data across other networks.

  - **Always-on VPN** supports VPN clients that implement the **VpnService**. The system automatically starts the VPN after the device boots. Always-on VPN can be enabled for apps in enterprise use cases through the **DevicePolicyManager#setAlwaysOnVpnPackage**.

  - Device owners and profile owners can require work apps to always connect through a specified VPN.

  - Additionally, users can manually set Always-on VPN clients that implement VpnService methods using **Settings > More > VPN.**

  - The option to enable Always-on VPN from settings is available only if the VPN client targets API level 24 or higher.

- **Per User VPN**: On multi-user devices, VPNs are applied per Android user, so all network traffic is routed through a VPN without affecting other users on the device. VPNs are applied per Work Profile, which allows an IT administrator to specify that only their enterprise network traffic goes through the enterprise-Work Profile VPN — not the user's personal profile network traffic.

- **Per Application VPN**: Support to facilitate VPN connections on allowed apps and to prevent VPN connections on disallowed apps.

In Android 10 and higher, VPN apps can set an HTTP proxy for their VPN connection. A VPN app must configure a **ProxyInfo** instance with a host and port, before calling **VpnService.Builder.setHttpProxy()**. The system and many networking libraries use this proxy setting but the system doesn't force apps to proxy HTTP requests.

VPN Service Modes

VPN apps can also discover if the service is running and if lockdown mode is active because of **always-on VPN**. New methods added in Android 10 and higher can help developers adjust the user interface. For example, developers may disable the disconnect button in the VPN application when an always-on VPN controls the lifecycle of the service.

VPN Lockdown Modes

Lockdown modes allow administrators to block network traffic that does not use the VPN and exempt an app that allows it to use any available network if the VPN is down or unreachable. Administrators can also explicitly deny access to all networks for an app and this only allows communication to take place over the VPN.

Third-Party Apps

Google is committed to increasing the use of TLS in all apps and services. As apps become more complex and connect to more devices, it's easier for apps to introduce networking mistakes by not using TLS correctly.

Network security configuration lets apps easily customize their network security settings in a safe, declarative configuration file without modifying app code. These settings can be configured for specific domains, such as opting **out of cleartext traffic**. This helps prevent an app from accidentally regressing due to changes in URLs made by external sources, such as backend servers. This safe-by-default setting reduces the application attack surface while bringing consistency to the handling of network and file-based application data.

Certificate Handling

All new Android devices must ship with the same **CA store**. CAs are a vital component of the public key infrastructure used in establishing secure communication sessions via TLS. Establishing which CAs are trustworthy — and by extension, which digital certificates signed by a given CA are trustworthy — is critical for secure communications over a network.

In addition, improvements in the TLS client certificate handling were added where users are only asked to choose from certificates that match requirements specified by the server (compliance with RFC5246). If there are no certificates to choose from then the user is not presented with any prompt thus protecting them from potential threats.

To further improve these protections, apps that target Android 9 and higher are disallowed to establish unencrypted connections by default. This follows a variety of changes made over the years to better protect Android users. Devices trust only the standardized system CAs maintained in AOSP. Apps can also choose to trust user or admin-added CAs. Trust can be specified across the whole app or only for connections to certain domains.

When device-specific CAs are required, such as a carrier app needing to securely access components of the carrier's infrastructure (for example, SMS/MMS gateways), these apps can include the private CAs in the components/apps themselves. For more details, see **Network Security Configuration**. Improvements were made for local installation of CA certificates that help prevent tricking a user into installing bad CA certificates.

Hypervisor / Virtualization

Android 13 introduced the Android Virtualization Framework (AVF), which brings together different hypervisors under one framework with standardized APIs. It provides secure and private execution environments for executing workloads isolated by hypervisor. AVF-powered protected virtual machines (pVMs) provide a new isolation primitive, stronger than the normal mechanisms provided by the operating system but still very familiar to Android developers. These pVMs are the new Isolated Execution Environments (IEE) critical for many use cases in Android today. Given that the isolation and confidentiality of a pVM are guaranteed by the hypervisor, a pVM will remain secure and uncompromised even in the event of an Android compromise.

The premise of AVF is that it allows for:

1 Isolation without elevated privileges, compared to TrustZone where isolation is implemented by using a higher privilege.

2 Reduction in fragmentation since there are multiple TrustZone (TEE) implementations while AVF abstracts out the different hypervisor providers behind a portable virtual machine environment.

3 Better updatability and portability of the applications in pVMs with resources allocated on-demand.

Android

In general, AVF consists of:

- Virtualization Service API

- Hypervisor (the underlying technology that powers AVF; the Google-provided hypervisor is called pKVM (protected Kernel Virtual Machine))

- Virtual machine monitor

- **Microdroid**, an operating system based on Android for the pVM
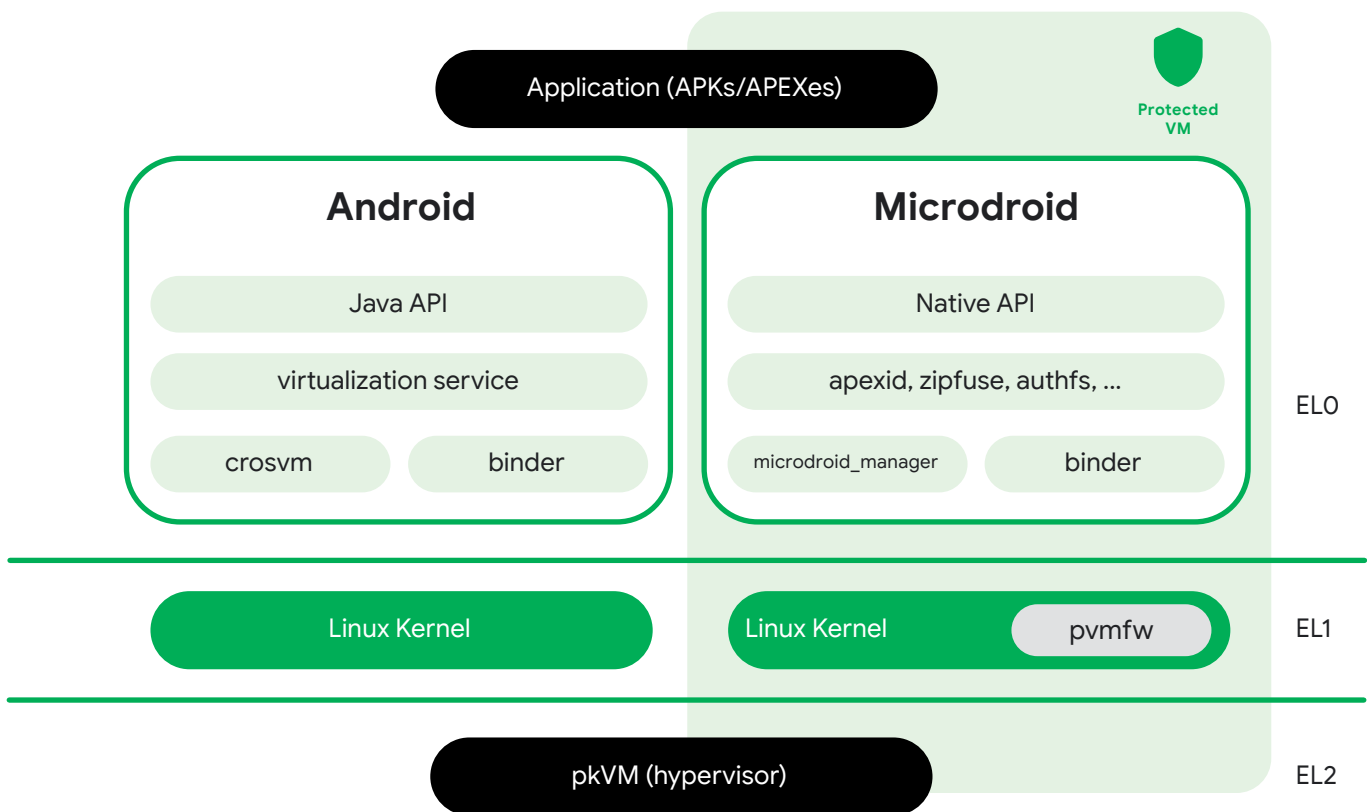

Figure 11. Visual representation of the Android Virtualization Framework with a Protected VM containing a Microdroid

Virtualization Service

VirtualizationService manages all guest VMs, protected or otherwise, running on an Android system, primarily by managing instances of crosvm. It exposes an AIDL API, which system services or apps can use to start, monitor, and stop VMs.

Hypervisor

Although AVF supports some third-party hypervisors, Google has developed an open source implementation which is included as part of the Android Common Kernel and is released as part of the Generic Kernel Image (GKI). The pKVM is built upon the **Linux KVM hypervisor**, which has been extended with the ability to restrict access to the payloads running in guest virtual machines marked 'protected' at the time of creation. Coupling the hypervisor with the Linux kernel allows for a very tightly integrated communication interface between the two components, leveraging support for existing tools, device drivers, and development flows with relative ease.

Virtual Machine Monitor

crosvm is a virtual machine monitor (VMM) which runs virtual machines through Linux's KVM interface. It focuses on safety with the use of the Rust programming language and a sandbox around virtual devices to protect the host kernel. Each crosvm process runs exactly one instance of a virtual machine.

Microdroid

The pVMs offered with Google's reference AVF implementation come with Microdroid, a minimal OS based on Android. Microdroid provides an off-the-shelf OS image designed to require the least amount of effort from developers to offload a portion of their app into a pVM. Native code is built against Bionic, communication happens over Binder. It allows importing of APEXes from Android and exposes a subset of the Android API, such as keystore for cryptographic operations with hardware-backed keys. Overall, developers should find Microdroid a familiar environment with the tools they've grown accustomed to in the full Android OS.

Application Security

Apps are an integral part of any mobile platform, and users increasingly rely on mobile apps for core productivity and communication tasks.

Android provides multiple layers of application protection, enabling users to download apps for work or personal use to their devices with the peace of mind that they're getting a high level of protection from malware, security exploits, and attacks.

Google Security Services

Google Play Protect and **Play Integrity API** are services on GMS-certified devices that help detect malware and device compromise. Exploitation code is often delivered to devices via malware. Google Play Store security is further enhanced through the work of the **App Defense Alliance**, a collaboration with industry security partners. In addition, Enterprise admins can create allow lists / block lists for the personal Google Play Store to provide greater specificity over which apps are allowed on devices. These resources all help to reduce the likelihood of malware infection.

The Play Integrity API helps developers check that interactions and server requests are coming from their genuine app binary running on a genuine Android device. By detecting potentially risky and fraudulent interactions, such as from tampered app versions and untrustworthy environments, the app's backend server can respond with appropriate actions to prevent attacks and reduce abuse.

EMM partners can use these services to help ensure users cannot sideload applications and must only install applications from trusted app stores (such as Google Play). EMMs can receive the signals from these on-device services to help detect and mitigate compromises.

Jetpack Security

Developers can leverage the Android KeyStore with **Jetpack Security**. With MasterKeys, developers can also create a safe **AES 256 GCM** key out of the box or for advanced use cases that specify settings to control key authorization. Jetpack Security also provides higher-level crypto abstractions for encrypting files (**EncryptedFile**) and SharedPreferences (**EncryptedSharedPreferences**). It is recommended that Jetpack Security be used by all **DPCs**, which control local device policies and system applications on devices, enterprise apps, public apps, and private apps.

Application Signing

Android requires that all apps be digitally signed with a developer key prior to installation. **APK key rotation**, supported in Android 9 and higher, gives apps the ability to change their signing key as part of an APK update. To support key rotation, the **APK signature scheme** has been updated from v2 to v3 to allow old and new keys to be used. When an app rotates its signing key, the previous key attests to the new key, and this previous key remains in the app's signing lineage. These previous keys can be granted certain capabilities to allow the app to interact with other apps still signed by previous keys that are still trusted.

Since APK signing key rotation was initially added to Android, **rotation-related problems** have been discovered in the platform that may affect some apps. To facilitate key rotation for apps that may be exposed to these problems, **APK signature scheme v3.1** was introduced with Android 13. Since this new version is not recognized on earlier platform releases, the rotated key can be used to sign the APK in the v3.1 block and the original key in the v3.0 block. All new key rotations that use **apksigner** will use the v3.1 signature scheme by default to target rotation for Android 13 and higher. An app that has already rotated its signing key can specify the SDK version of Android P as the rotation minimum SDK version to continue using the rotated signing key in the v3.0 block. The v3.1 scheme also supports verified SDK-targeted signing configs allowing multiple use cases such as more restrictive capabilities in the signing lineage for later platform releases while earlier versions can still use the more relaxed capabilities.

Android uses the corresponding certificate to confirm that an update and the installed app being updated are signed with the same key. When the system installs an update to an application, it compares the certificate in the new version with the one in the existing version, and allows the update if the certificate matches. In the case of a signing key rotation, the system checks the signing lineage of the new version — if the signing key of the existing version attests to the new key (or another key that eventually attests to the key used to sign the new version), then the update is allowed.

Android allows apps signed with the same key, either currently or previously in one of the app's signing lineage with the 'SHARED_USER_ID' capability granted, to run in the same process, at the app's request, so that the system treats them as a single application. This capability is accomplished in the manifest with **sharedUserId**. Android provides signature-based permissions enforcement, so that an application can expose functionality to another app that's signed with the same key. If either app has rotated their signing key, a signature permission can still be granted as long as both apps share a common signer in their signing lineage and the declaring app has granted the 'PERMISSION' capability to that previous key. By signing multiple apps with the same key, and using signature-based permissions, an app can share code and data in a secure manner.

> **NOTE:** Shared user IDs cause non-deterministic behavior within the package manager. As such, the sharedUserId capability has been deprecated. Instead, use proper communication mechanisms, such as services and content providers, to facilitate interoperability between shared components. Existing apps can't remove this value, as migrating off a shared user ID is not supported.

Google Play Protect

Google Play Protect is a powerful threat detection service that actively monitors a device to protect it, its data, and apps from malware. The always-on service is built into all devices that have Google Play, protecting more than 3.5 billion devices.

The Google Play Protect service scans devices once every day for harmful behavior and security risks. If it detects an app containing malware, it notifies the user. Google Play Protect may also remove or disable malicious apps automatically as part of its prevention initiative and use the information it gathers to improve the detection of **PHAs**. In addition, the user can opt to have unknown apps sent to Google for further analysis.
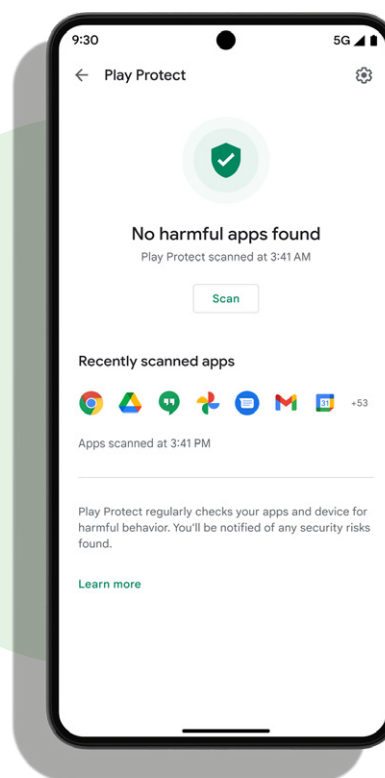

Figure 12. Google Play Protect actively scans for threats

Android is an open platform and users are free to download apps from other sources. If an app carries malicious intent, users need to be protected from it no matter where the app originated. **Google Play Protect's install verification checks apps coming from outside of the Play Store when users try to install it.** If the app is known to be malware, Google Play Protect will stop the installation and prevent it from harming users.

Android's abundant app sources also mean that not all apps will go through Google's threat detection service before they get to user devices. This year, Google Play Protect is expanding its install-time protections for side-loaded apps to bring a new layer of protection to Android. **Install verification now performs real-time threat detection for new apps** from other sources, to help fight emerging threats.

Google Play App Review

The Google Play Store has policies in place to help protect users from malicious actors trying to distribute PHAs.

Developers and their apps are validated in two stages. Developers are first reviewed when they create their developer account based on their real-world identity: name, address, government ID for personal accounts, legal entity details, and DUNS number for organizational accounts. Their apps are then reviewed with additional signals upon app submission. Before applications become available in Google Play, they undergo an application review process to detect possible violations of **Google Play policies**. Google has developed an automated application risk analyzer that performs static and dynamic analysis of APKs to detect potentially harmful app behavior. The analyzer also leverages machine learning to detect harmful behaviors within applications. When Google's application risk analyzer discovers something suspicious, it flags the offending app and refers it to a security analyst for manual review. If an app is found violating the Google Play policies, we take appropriate enforcement action up to and including the termination of developer accounts.

A developer is notified if their app is flagged for a **security issue**. They receive details about how to improve the app and links to support pages for additional guidance. This notification usually includes a timeline for delivering the improvement and the goal is to focus on reducing security vulnerabilities. In some cases, security improvements to apps must be made before a developer can publish any further updates.

Android

Another key element in minimizing risk is the use of updated APIs. Requiring developers to use the most recent APIs encourages support for the most updated features, creating optimal security and performance. Both new apps and app updates must target at least Android 13 (API level 33), to meet **API requirements**.

Every new Android version introduces changes that bring significant security and performance improvements — and enhance the user experience of Android overall. Some of these changes only apply to apps that explicitly declare support through their targetSdkVersion manifest attribute, also known as the target API level. See the **Google Play Developers** documentation for more details on updating to the proper target API level requirement.

Data Protection

Android uses industry-leading security features to protect user data. The platform provides developer tools and services to aid in securing the confidentiality, integrity, and availability of user data.

Encryption

Mandatory encryption on Android protects user data if an Android device is lost or stolen. Android uses **file-based encryption (FBE)**, which enables different directories to be encrypted with different keys.

With FBE, the device boots directly to the lock screen and is fully usable almost immediately when unlocked. Apps can use two kinds of storage locations:

- **Device Encrypted (DE)** storage is available once the device boots, before the user unlocks the device. This storage is protected by a hardware secret and software running in the TEE that checks that Verified Boot is successful before decrypting data.

- **Credential Encrypted (CE)** storage is available only after the user has unlocked the device. In addition to the protections on DE storage, CE keys can only be unlocked after unlocking the device, with protection against brute force attacks in hardware.

Most apps store all data in CE storage and run only after credentials are entered. Apps such as alarm clocks or accessibility services such as Talkback can take advantage of the **Direct Boot** APIs and run before credentials are entered, using DE storage while CE is unavailable.

On devices with more than one user, each user has their own CE and DE keys. Each user's CE key is protected by that user's lockscreen PIN, pattern, or password. Encryption keys are 256 bits long and are generated randomly on-device.

An additional layer of encryption called **metadata encryption** protects filesystem metadata such as directory layouts, file sizes, permissions, and creation/modification times. The metadata encryption key is protected by Keymaster and Verified Boot.

Adiantum

Adiantum is an encryption method designed for devices running Android 9 and higher whose CPUs lack AES instructions. It provides encryption to such devices with little performance overhead and enables a class of lower-powered devices to use strong encryption. The **Android CDD** requires that all new Android devices be encrypted using one of the allowed encryption algorithms.

Backup Encryption

Devices that run Android 9 and higher support **end-to-end encrypted backup**, a capability whereby the backup data is encrypted on the device using a device and user-specific key. The backup server has no ability to decrypt the backup archive.

The backup is encrypted with a randomly generated key that is further encrypted with a hash of the user's lockscreen PIN, pattern, or password. This encrypted key is securely shared with a cohort of secure enclaves located across Google's data centers. None of the data shared with the secure enclave is known to Google, and the device verifies the identity of the secure enclave by checking its root of trust.

With this secure enclave, there is a limited number of incorrect attempts strictly enforced by the custom firmware. By design, this means that no one (including Google) can access a user's backed-up application data without specifically knowing their PIN, pattern, or password.

Android Security Updates

Monthly device updates are an important tool to keep Android users safe.

Every month, Google publishes Android Security Bulletins to update users, partners, and customers on the latest fixes. These security updates are available for Android versions for three years from the date of release.

Android OS uses a feature called project **Treble**, which accelerates the delivery of security fixes, privacy enhancements, and consistency improvements. It enables device manufacturers and silicon vendors to develop and deploy Android updates faster than what was previously possible. All devices that launch with Android 9 and higher are Treble-compliant and take full advantage of the Treble architecture.

Administrators of fully managed devices can install system updates via a system update file in Android 10 and higher devices. With manual system updates, IT administrators can:

- Test an update on a small number of devices before installing them widely

- Avoid duplicate downloads on bandwidth-limited networks

- Stagger installations, or update devices only when they're not being used

Device Manufacturer Partner Updates

Security-critical fixes are pushed to all Pixel devices monthly, direct from Google's over-the-air servers. Pixel firmware images are also available on the **Google Developer site** for manual update and flashing. Many device manufacturer partners follow a similar cadence in their security updates, and many also deliver their own security bulletins:

| Google → | Samsung → | Motorola → |
| Nokia → | Xiaomi → | Zebra → |

Android 🤖

Users can find out whether they're running a recently patched device with the Security Patch Level, a value indicating the security patch level of a build. It's available through the attestation certificate chain, which contains a root certificate that is signed with the Google attestation root key, also visible in the device settings. EMM partners have the capability to call an API to detect which security update is installed and impose compliance rules for outdated devices.

Google Play System Updates

In Android 10 and higher, Google Play System Updates offer a simple and faster method to deliver updates. Key **Android system components** are modularized, and end-user devices receive the components from the Google Play Store or through a partner-provided over-the-air (OTA) mechanism.

The components are delivered as either APK or **APEX** files (APEX is a new file format which loads earlier in the booting process). Important security and performance improvements that previously needed to be part of full OS updates can be downloaded and installed similarly to an app update.

Google Play System Updates are secured by being cryptographically signed. They can also deliver faster security fixes for critical security bugs by modularizing media components, which accounted for nearly 40% of recently patched vulnerabilities, and allowing updates to Conscrypt, the Java Security Provider.

Conscrypt

The **Conscrypt** module accelerates security improvements and improves device security through regular updates via Google Play System Updates. It uses Java code and a native library to provide the Android TLS implementation as well as a large portion of Android cryptographic functionality such as key generators, ciphers, and message digests. Conscrypt is available as an **open source library**, though it has some specializations when included in the Android platform.

The Conscrypt module uses **BoringSSL**, a native library that is a Google fork of OpenSSL and which is used in many Google products for cryptography and TLS (most notably Google Chrome). The Conscrypt module is distributed as an APEX file that includes the Conscrypt Java code and a Conscrypt native library that dynamically links to Android NDK libraries (such as liblog). The native library also includes a copy of BoringSSL that has been validated (**Certificate #4407**) through NIST's **Cryptographic Module Validation Program (CMVP)**.

Enterprise Identity, Security & Management

Device and Profile Management

Android Enterprise offers tools and support for organizations of any size to securely manage their devices. **EMM** providers have access to Android Enterprise's holistic set of **APIs** to build robust management solutions that meet the demands of modern security and privacy. Choosing the right EMM provider is important for any enterprise to enforce policies, wipe data, manage apps, and track device inventory. Android Enterprise can help with recommended EMM providers but organizations are free to choose any EMM solution that fits their needs.

Device Management For Any Scenario

Work Profile

Work Profile offers a unique enterprise experience, security, and privacy model for employees and employers alike. Based on Android's multi-user architecture, it runs as a separate Android user from the personal profile. Both users run simultaneously, offering a combined UI experience that allows employees to easily transition between work and personal, while maintaining strict data separation within the OS to keep work data secure and personal profile data private from the Work Profile. Apps, notifications, and widgets from the Work Profile have a blue badge icon to distinguish them from their personal counterparts.
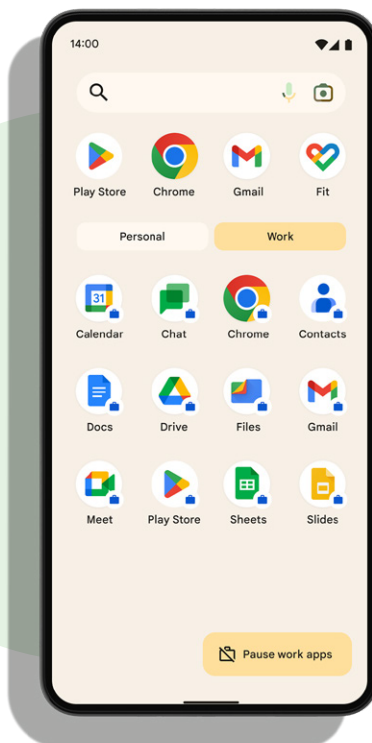
Figure 13. Users can easily toggle between work and personal apps

With the Work Profile, work and personal profile data are stored and accessed separately, where typically only apps running in the corresponding profile have access to data stored within that profile. The Work Profile has its own apps, its own Downloads folder, and its own KeyChain. It is encrypted using its own encryption key, and it can have a separate passcode to gate access whenever a work app is launched.

Work Profile can be set up on devices owned by the organization as well as devices personally owned by employees. If the employee owns the device, the Work Profile can be added or removed by the employee at any time. If the organization owns the device, the Work Profile cannot be removed unless the company relinquishes ownership of the device to the employee, leaving the personal profile intact while removing the Work Profile and any ability for IT to re-claim ownership of that device. Organizations can exercise full management control over **company-owned devices** issued to employees. There are two deployment options available for these types of company-owned devices: **Work Profile**, and **fully managed device.**

Device management for any scenario

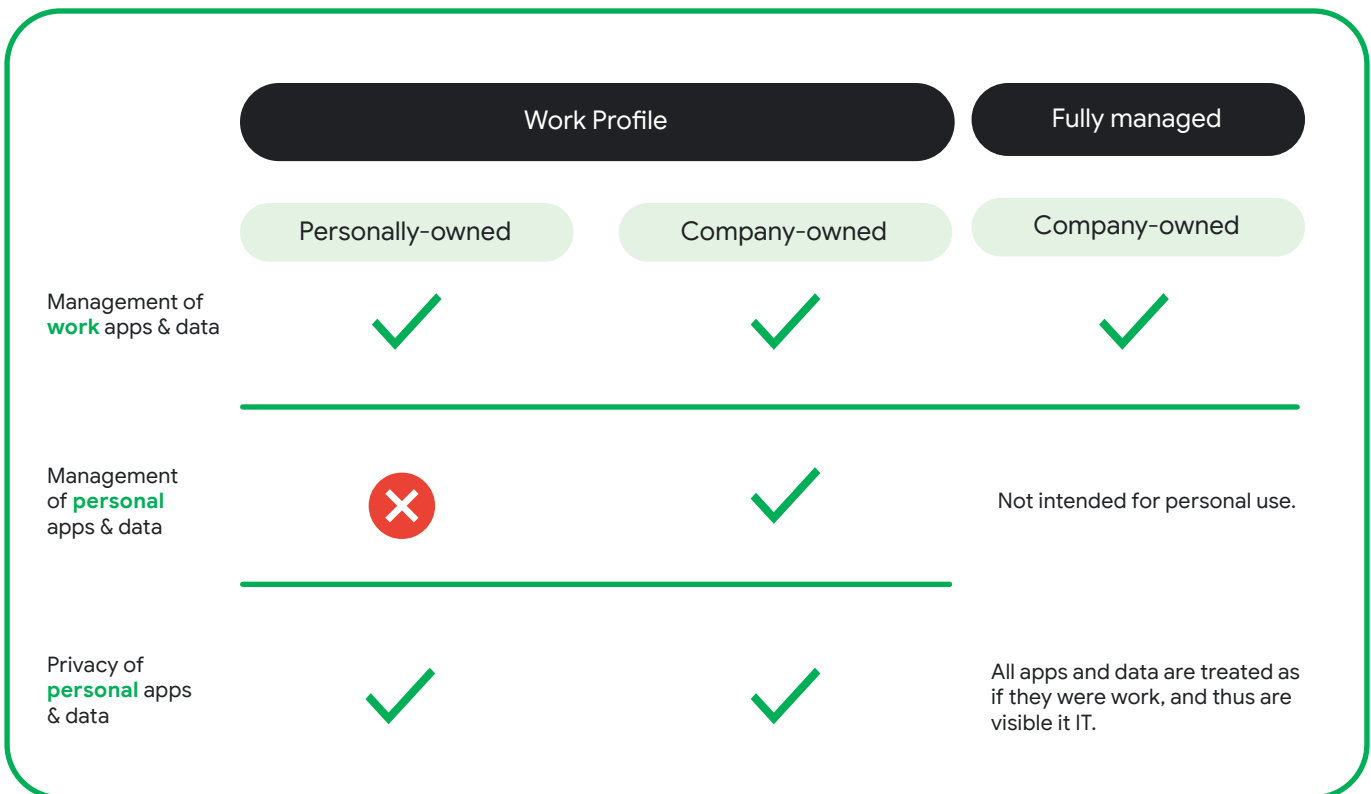|	Work Profile		Fully managed
	Personally-owned	Company-owned	Company-owned
Management of **work** apps & data	✓	✓	✓
Management of **personal** apps & data	✗	✓	Not intended for personal use.
Privacy of **personal** apps & data	✓	✓	All apps and data are treated as if they were work, and thus are visible it IT.

Figure 14. How work and personal apps and data are separated with Work Profile

Work Profile for employee-owned devices

Personal devices can be set up with a **Work Profile**. In the Work Profile, the organization has full management control and visibility, including the ability to install or block applications, configure networks and VPNs, and apply a wide range of data loss prevention controls to keep work data safe. This distinct separation gives enterprises what they need to enable secure productivity on personally-owned devices while retaining employee privacy and allowing the user to use the device just like they would a personal device.

Work Profile for mixed-used company-owned devices

Like the Work Profile on a personally-owned device, on a company-owned device, the Work Profile enables secure access to work data without compromising the privacy of personal usage. Unlike with personally-owned devices, however, on company-owned devices the organization has access to additional device-wide features for asset management and restrictions on personal usage, to keep devices compliant with corporate or regulatory requirements. Crucially, these device-wide management features **do not** impact the privacy of personal usage; regardless of who owns the device, the privacy of personal apps and data remains the same as with personally-owned devices.

A wide range of personal usage and asset management features helps Work Profile on company-owned devices stay compliant with some of the most stringent security and policy requirements for company liable devices, while offering a unique personal privacy benefit to employees and employers alike.

Full management for work-only company-owned devices

For devices used exclusively for work, a **fully managed** device offers a single profile, completely managed device experience with the richness of Android's data and asset management features. In fully managed devices, all apps and data are categorized as work, making them both manageable and monitorable by IT administrators.

Full management for dedicated devices

Android's full device management capabilities can also support dedicated device scenarios. An additional set of capabilities for more restricted, tailored device experiences allow organizations to build Android workflows for everything from employee-facing factory and industrial environments, to customer-facing signage and kiosks.

Dedicated devices are typically locked to a single app or set of apps. This model offers granular control over a device's lock screen, status bar, keyboard, and other critical UX components, to keep usage streamlined to the desired business workflow.

Android 🤖

OEMConfig

OEMConfig is an Android standard that enables device manufacturers (OEMs) to offer custom enterprise features that can be enabled by any EMM that supports Android Enterprise. Android's diverse ecosystem of OEMs offers unique and specialized features for a variety of use cases, like hardware barcode scanners, support for specialized encryption requirements, or even granular control of the manufacturer's custom user interface. Where previously custom OEM features meant proprietary APIs that required each EMM to support as its own independent platform, OEMConfig enables a single Android Enterprise integration to unlock any OEMConfig feature on any supported OEM device. EMMs can easily use an OEM-built application that configures all of the unique capabilities of a device.

Device Provisioning

Management is established on a device through one of Android's enterprise provisioning experiences, depending on the use case and management mode suitable for that device. Company-owned devices must be provisioned at the initial setup of a new device, demonstrating corporate ownership of the asset, while personally-owned devices can be set up any time during the device lifecycle.

A number of options exist to provision devices, including:

- **Zero-touch enrollment**: By purchasing devices from a **zero-touch reseller**, administrators can configure devices to automatically provision during device setup.

- **Enrollment link**: End users can navigate to an EMM-generated enrollment URL to provision a Work Profile on their personally-owned devices.

- **QR code**: Company-owned devices can be provisioned by scanning an EMM-generated QR code at the beginning of the device setup.

Learn more about the different Android Enterprise provisioning methods →

Android 🤖

Work Challenge

Android supports a separate passcode for work apps, called work challenge, to enhance the security and manageability of the Work Profile. The work challenge is a separate passcode to the overall device passcode, just for work apps and data. A separate work challenge can be beneficial to administrators and employees for a number of reasons, including:

- The ability to reset the work challenge, in the event employees forget it.

- The ability to enforce stricter, more complex password requirements than is otherwise possible on personally-owned devices.

- The ability for employees to further separate work apps or data from normal device usage (for example, if a spouse or child uses their personal apps).

The work challenge supports all the same biometric methods as the device challenge, making it convenient for employees to quickly authenticate, while also allowing administrators to selectively disallow biometrics for the work challenge without affecting the device challenge. This improves the security of work apps without impacting the convenience of personal apps.

The work challenge is also verified within secure hardware, in line with Android's brute-force protections. By mixing in with a secret from the secure hardware, it is used to derive the Work Profile's separate disk encryption key, which means that an attacker cannot derive the encryption key without either knowing the passcode or breaking the secure hardware.

Data Loss Prevention

By separating work and personal apps and giving administrators full control over the apps and services installed in the Work Profile, Android offers customers complete control over what can access work data on the device. However, there are instances where allowing select work data to be accessed from the personal profile enables improved productivity and convenience for employees. Android Management API offers secure, convenient defaults that strike a good balance for many organizations, but understanding and customizing these features is a good way to deliver the right data loss prevention strategies for any specific customer needs.

Android

Administrators can customize a variety of <u>cross-profile features</u>, such as:

- Whether work contacts can be viewed in personal apps, enabling identification of colleagues in messaging apps or caller ID.

- Whether text copied from one profile (personal or work) can be pasted in the other profile.

- Whether data like URLs or files can be opened or shared to apps in the other profile, and in which direction. For instance, only personal data can be opened in work apps, but no work data can be opened in personal apps.

Application Management

Android Enterprise provides IT administrators with powerful, easy-to-use tools to deploy, configure, and manage applications on a variety of device form factors.

Managed Google Play

On devices managed by an EMM provider, the EMM DPC app controls which work apps may be installed. On GMS devices, Managed Google Play can be used for application management. This enterprise version of Google Play allows IT administrators to easily find, deploy, and manage work apps while minimizing the threat of malware with Google Play Protect scanning and closely controlling employees' access to applications. Managed Google Play provides APIs and iframes to EMM partners that allow their customers to manage apps on Android devices. Newly registered EMM partners may only access Managed Google Play functionality through iframes or the Android Management API.

Using Managed Google Play, organizations can build a customized and secure mobile application storefront for their teams, featuring public and private applications that can be delivered to devices directly from the Managed Google Play store. This eliminates the need to sideload any applications onto devices. Managed Google Play is available for all fully managed devices and devices with a Work Profile, whether they are personally owned (BYOD) or company-owned.

Organizations have two methods of identifying allowed applications:

- **Allowlist:** Users may be restricted to a specific allow-list of permitted applications in the company policy (default behavior). This protects company data by blocking unknown applications from being installed.

- **Blocklist:** When using **Android Management API**, Admins also have the option of blocking one or more apps. Users may install any application that is not explicitly marked as 'blocked' in the organization's application policy. EMMs using Android Management API may also set application block lists in the **personal usage policies** of a company-owned device with Work Profile.

Android 🤖

Installation of apps in either the Work Profile or on fully managed devices is possible via two main mechanisms:

1 Users may install permitted applications on-demand through the Managed Google Play application, in their organization's custom Google Play storefront.

2 The EMM may push an application to a device using their DPC. Organizations can 'silently' (without user interaction) install applications on fully managed devices.

Additionally, administrators can enforce update preferences through Managed Google Play. Administrators can push an urgent update, such as security updates, to devices automatically as 'high priority'.

Private Apps

With Managed Google Play, an enterprise customer can publish apps and target them privately (that is, they're only visible and installable by users within that enterprise). Private apps are logically separated in Google's cloud infrastructure from public Google Play for consumers. There are two modes of delivery for private apps:

- **Google-hosted:** By default, Google hosts the APK in its secure, global data centers. This is the recommended option to take full advantage of Google's enterprise-grade security, including SSL downloads and malware security scanning. Google-hosting also allows organizations to take advantage of Google Play app signing. With Google Play app signing, Google manages and protects the app's signing key on behalf of an organization and uses it to sign optimized distribution APKs. Google Play app signing stores the app signing key on Google's secure key enclaves and offers upgrade options to increase security.

- **Externally-hosted:** Enterprise customers host APKs on their own servers, accessible only on their intranet or via VPN. When Managed Google Play makes a request to download an APK from an external server, the request includes a cookie containing a JSON Web Token (JWT). We **recommend** that the organization decodes the JWT to authenticate the download.

In both cases, Google Play stores the app metadata — title, description, graphics, and screenshots. Private apps are held to Play Policies for preventing mobile unwanted software and malware, and cannot be made public.

Android 🤖

Managed Configurations

Managed configurations allow an organization's IT administrator to remotely specify settings for apps. By using managed configurations, administrators can allowlist specific apps for employee use, and selectively approve only the permissions they want their apps to use. Managed configurations allow an IT administrator to remotely control the availability of features, configure settings, or set in-app credentials, via the **Google Play EMM API** or **Android Management API** As an example, an app may have an option to only sync data when a device is connected to Wi-Fi, or allowlist or blocklist specific URLs in the web browser. Managed configuration options can be changed by the developer and updated in Managed Google Play where the EMM will pick up on the changes for new and existing app deployments.

Google Chrome is an example of an enterprise-managed app that implements **policies and configurations** that can be fully managed according to enterprise policies and restrictions.

Applications from Unknown Sources

Administrators may need to prevent the installation of applications from outside Google Play, or apps from unknown sources. Devices and data can be at increased risk when such apps are installed from unverified sources.

To prevent the installation of apps from unknown sources, administrators of fully managed devices and Work Profile can add the **DISALLOW_INSTALL_UNKNOWN_SOURCES** user restriction. When the administrator of a Work Profile adds the restriction, it only applies to the Work Profile. However, the administrator of a Work Profile can place a device-wide restriction by setting a **managed configuration** for Managed Google Play.

Enterprise Identity — Zero Trust Capabilities

The zero-trust security model enables a mobile and remote workforce to securely connect to company resources from virtually anywhere.

Devices are vetted before being granted access to company resources. Companies can use tight, granular controls to specify the level of access whether the devices are connected to a corporate network, from home, or elsewhere. An effective zero-trust implementation requires numerous device signals, context, and controls to make intelligent decisions about access.
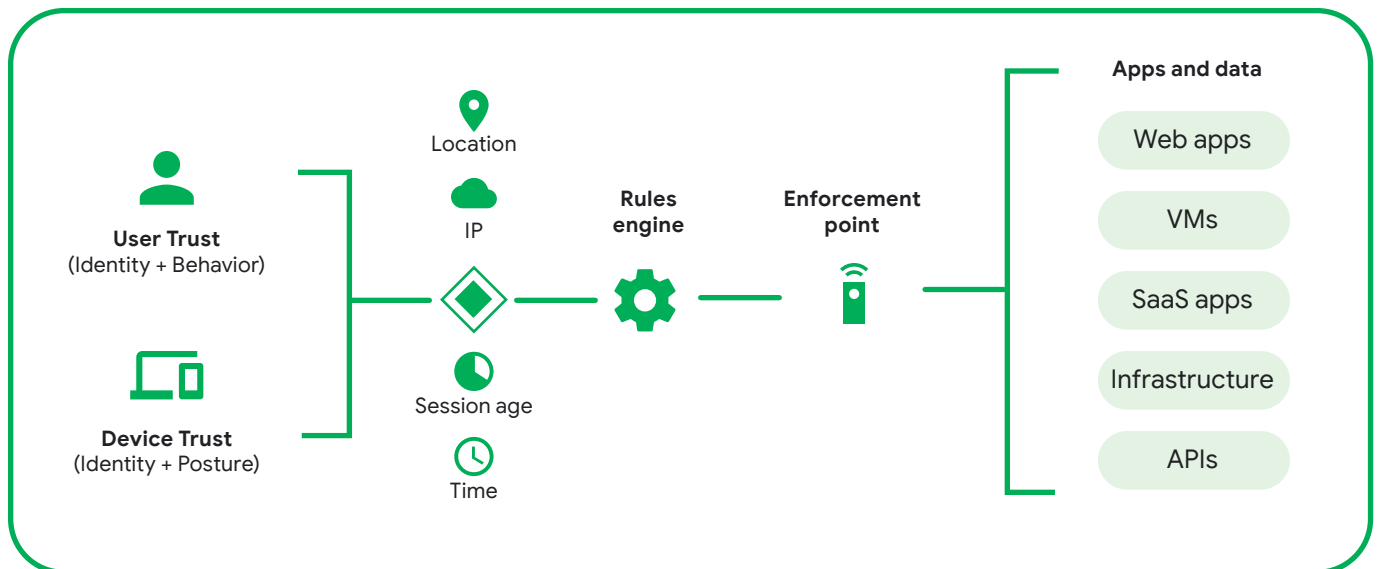

Figure 15: A Zero Trust security model with various device and user signals helping a company determine access

Establishing device trust is critical for zero-trust implementations and this is an area in which Android stands out against other mobility platforms. Android has a wealth of platform features and APIs that our enterprise mobility management and security partners leverage to safeguard backend services and resources. We provide a variety of device signals that administrators can use in building systems to verify the security and integrity of devices. In a zero-trust model, these signals are used to assess whether a device should be allowed to access corporate information. There are currently more than 100 unique device trust signals available across **30 APIs** on Android devices.

Today, through their EMM provider, enterprise customers can **delegate** direct access to on-device signals to their security providers. In 2024, we will be updating the **Android Management API** so businesses can give their security providers direct access to trust signals from a single place, across managed and unmanaged devices.

Android 🤖

Programs

A number of Google-backed initiatives and collaborations help advance the Android ecosystem that supports partners and customers in their use of Android in enterprise settings.

Android Enterprise Recommended

The **Android Enterprise Recommended** technical product validation sets an elevated standard for enterprise devices and solutions. Devices passing the advanced validation requirements meet the highest tier of Android Enterprise specifications for hardware, deployment, security updates, and user experience. Organizations may select devices from the curated list with confidence that they meet a common set of criteria required for inclusion in the Android Enterprise Recommended program. In addition, device manufacturers receive an enhanced level of technical support and training.

Android Enterprise Recommended enterprise mobility management solutions have the most advanced management features and deliver a consistent deployment experience. Knowing that these solutions are backed by enhanced training and technical support allows organizations to choose a mobility solution with confidence.

Learn more about the program's device requirements →

Learn more about the program's enterprise mobility management requirements →

Android Security Rewards Program

The **Android Security Rewards (ASR) program** incentivizes researchers to find and report security issues, providing key assistance to Android security efforts. This program covers security vulnerabilities discovered in the latest available Android versions for Pixel phones and tablets.

Android 🤖

Google Play Security Reward Program

The **Google Play Security Reward Program** helps secure the Android ecosystem by ensuring that Google Play is the most secure app store by incentivizing security researchers to report vulnerabilities discovered in apps hosted on Google Play. All of the most popular apps are included in the program, and developers of newly popular Android apps are invited to opt in.

Developer Data Protection Reward Program

The **Developer Data Protection Reward Program** aims to identify and mitigate data abuse issues in popular Android applications, Chrome extensions, and applications leveraging the Google API. It recognizes the contributions of individuals who help report apps that are violating applicable program policies and are potentially putting user data at risk.

App Security Improvement Program

The **App Security Improvement Program** is a service that helps Google Play developers improve the security of their apps. The program provides tips and recommendations for building more secure apps and identifies potential security issues and mitigations when apps are uploaded to Google Play.

App Defense Alliance

The **App Defense Alliance** launched in 2019 with a mission to protect Android users from bad apps through shared intelligence and coordinated detection between alliance partners. Together, with its members ESET, Lookout, Zimperium, McAfee and Trend Micro, the alliance has been able to reduce the risk of app-based malware and better protect Android users.

In 2022, the App Defense Alliance expanded to include App Security Assessments where authorized lab partners perform testing services for apps distributed through the Play Store, or Google Partners connecting to Google Cloud Services.

Industry Standards and Certifications

Devices running Android and the cloud services they utilize comply with various industry standards. Numerous security certifications demonstrate our strong commitment to the highest security standards.

ISO and SOC Certification

Android Enterprise has received ISO 27001 certification and SOC 2 and 3 reports for information security practices and procedures for Android Management API, zero-touch enrollment and Managed Google Play. This designation ensures these services meet strict industry standards for security and privacy.

Granted by the International Organization for Standardization, ISO 27001 outlines the requirements for an information security management system. It specifies best practices and details a list of security controls regarding information risk management.

The SOC 2 and 3 reports are based on American Institute of Certified Public Accountants (AICPA) Trust Services principles and criteria. To earn this, auditors assess an organization's information systems relevant to security, availability, processing integrity, and confidentiality or privacy.

An independent assessor performed a thorough audit to ensure compatibility with the established principles. The entire methodology of documentation and procedures for data management are reviewed during such audits, and must be made available for regular compliance review.

Learn more about these security designations →

OWASP MAS

OWASP Mobile Application Security (MAS) provides a security standard for mobile apps as well as a comprehensive testing guide to ensure security assessors deliver consistent and comprehensive results. Google first-party apps adhere to MASVS Level 1 requirements as defined by **MASA**. These requirements assess the security and privacy of the application as well as connectivity and authentication to the backend. Independent assessors perform the security assessments on behalf of Google and provide publicly accessible **validation reports**.

Learn more about OWASP MAS →

Government Grade Security

NIST FIPS 140-3/140-2 CMVP & CAVP

Federal Information Processing Standards (FIPS) are standards and guidelines for Federal computer systems that are developed by the National Institute of Standards and Technology (NIST) in accordance with the Federal Information Security Management Act (FISMA) and approved by the Secretary of Commerce. Although FIPS standards are developed for use by the federal government, many in the private sector voluntarily use these standards as well. NIST's **Cryptographic Algorithm Validation Program (CAVP)** provides validation testing of approved cryptographic algorithms and their individual components. The goal of the **Cryptographic Module Validation Program (CMVP)** is to promote the use of validated cryptographic modules and provide Federal agencies with a security metric to use in procuring equipment containing validated cryptographic modules.

Android

Common Criteria/NIAP Mobile Device Fundamentals Protection Profile

Common Criteria is a driving force for the widest available mutual recognition of security products, with 31 participating countries. The **National Information Assurance Partnership (NIAP)** serves as the U.S. representative to the Common Criteria Recognition Arrangement. In partnership with NIST, NIAP approves Common Criteria Testing Laboratories to conduct security evaluations in private sector operations across the U.S. This certification process has enabled the Android team to build some of the requirements to achieve this certification directly into the Android Open Source Project (AOSP), which enables device manufacturers the ability to attain certification in much less time.

DISA Security Technical Implementation Guide (STIG)

STIG is the configuration standard for Department of Defense Information Assurance (IA) and IA-enabled devices/systems. The STIG contains technical guidance to "lock down" information systems/software that might otherwise be vulnerable to a malicious computer attack. The **Google Android 13** and **Google Android 12** STIGs provide a standard implementation for configuring and locking down any Android device using Android Enterprise management controls.

Conclusion

The open source development approach of Android is a key part of its security. Developers, device manufacturers, security researchers, SoC vendors, academics, and the wider Android community create a collective intelligence that locates and mitigates vulnerabilities for the entire ecosystem.

With Android, multiple layers of security support the diverse use cases of an open platform while also enabling sufficient safeguards to protect user and corporate data. Additionally, Android platform security keeps devices, data, and apps safe through tools like app sandboxing, exploit mitigation, and device encryption. A broad range of management APIs gives IT departments the tools to help prevent data leakage and enforce compliance in a variety of scenarios. The Work Profile enables enterprises to create a separate, secure profile on users' devices where apps and critical company data are kept secure and separate from personal information.

Google Play Protect, the world's most widely deployed mobile threat protection service, delivers built-in protection on every device. Powered by Google machine learning, it works to catch and block harmful apps and scan the device to root out any PHAs or malware. Google Safe Browsing in Chrome protects enterprise users as they navigate the web by warning of potentially harmful sites.

Enterprises rely on smart devices for critical business operations, collaboration, and accessing proprietary data and information. Google continues to invest in resources to further strengthen the security of the Android platform, and we look forward to further contributions from the community and seeing how organizations will use Android to drive business success.

Android