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Assessing Threats to Mobile Devices & Infrastructure

The Mobile Threat Catalogue

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Reports on Computer Systems Technology

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Abstract

Mobile devices pose a unique set of threats, yet typical enterprise protections fail to address the larger picture. In order to fully address the threats presented by mobile devices, a wider view of the mobile security ecosystem is necessary. This document discusses the *Mobile Threat Catalogue*, which describes, identifies, and structures the threats posed to mobile information systems.

Keywords

cellular security; enterprise mobility; mobility management; mobile; mobile device; mobile security; mobile device management; telecommunications

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Note to Readers

The development of this interagency report and the *Mobile Threat Catalogue* supports the *Study on Mobile Device Security*, as a part of the Cybersecurity Act of 2015 - Title IV, Section 401. Mobile threats and mitigations supporting the Congressional Study on Mobile Device Security and the *Mobile Threat Catalogue* may incorporate submissions from request for information (RFI) – Mobile Threats & Defenses from FedBizOps solicitation number: QTA00NS16SDI0003.

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1 Introduction

Mobile devices pose a unique set of threats to enterprises. Typical enterprise protections, such as isolated enterprise sandboxes and the ability to remote wipe a device, may fail to fully mitigate the security challenges associated with these complex mobile information systems. With this in mind, a set of security controls and countermeasures that address mobile threats in a holistic manner must be identified, necessitating a broader view of the entire mobile security ecosystem. This view must go beyond devices to include, as an example, the cellular networks and cloud infrastructure used to support mobile applications and native mobile services.

1.1 Purpose

This document outlines a catalogue of threats to mobile devices and associated mobile infrastructure to support development and implementation of mobile security capabilities, best practices, and security solutions to better protect enterprise information technology (IT). Threats are divided into broad categories, primarily focused upon mobile applications and software, the network stack and associated infrastructure, mobile device and software supply chain, and the greater mobile ecosystem. Each threat identified is catalogued alongside explanatory and vulnerability information where possible, and alongside applicable mitigation strategies. Background information on mobile systems and their attack surface is provided to assist readers in understanding threats contained within the Mobile Threat Catalogue (MTC). Readers are encouraged to take advantage of resources identified and referenced within the MTC for more detailed information, all of which are also referenced within Appendix C of this document.

The MTC is a separate document located at the Computer Security Resource Center (CSRC) [1].

1.2 Scope

NIST Special Publication (SP) 800-53 [10] defines a mobile device as:

> "A portable computing device that: (i) has a small form factor such that it can easily be carried by a single individual; (ii) is designed to operate without a physical connection (e.g., wirelessly transmit or receive information); (iii) possesses local, non-removable or removable data storage; and (iv) includes a self-contained power source. Mobile devices may also include voice communication capabilities, on-board sensors that allow the devices to capture information, and/or built-in features for synchronizing local data with remote locations. Examples include smart phones, tablets, and E-readers."

With this definition in mind, smart phones and tablets running modern mobile operating systems are the primary target of this analysis. Devices typically classified within the Internet of Things (IoT) category are excluded from the scope of this document. Although some devices contain capabilities to communicate via the auxiliary port and infrared, these are also excluded from the scope of this effort as they are not common methods of attack.

Cellular networks are prominently featured within the catalogue, and accordingly comprise a large portion of this document's information. However, although cellular networks are becoming increasingly intertwined with the internet and private packet switched networks, internet protocol (IP) network security is covered extensively by other resources and not within the scope of this work. Finally, threats specific to the Public Switched Telephone Network (PSTN) are also excluded.

1.3 Audience

Mobile security engineers and architects can leverage this document to inform risk assessments, build threat models, enumerate the attack surface of their mobile infrastructure, and identify mitigations for their mobile deployments. Other audiences for this document include mobile operating system (OS) developers, device manufacturers, mobile network operators (MNOs) (e.g., carriers), mobile application developers and information system security professionals who are responsible for managing the mobile devices in an enterprise environment.

This document may also be useful when developing enterprise-wide procurement and deployment strategies for mobile devices and when evaluating the risk mobile devices pose to otherwise secure parts of the enterprise. The material in this document is technically oriented, and it is assumed that readers have an understanding of system and network security.

1.4 Document Structure

The remainder of this document is organized into the following major sections:

- Section 2 provides a background on the attack surface of mobile devices and their associated infrastructure.
- Section 3 details the structure of the MTC and the methodology used to create it.

The document also contains appendices with supporting material:

- Appendix A defines selected acronyms and abbreviations used in this publication,
- Appendix B contains a list of references used in the development of this document, and
- Appendix C contains a list of references from the MTC.

1.5 Document Conventions

The following conventions are used throughout the Interagency Report:

- This work is not specific to a given mobile platform or operating system (OS). Most identified threats are agnostic to a specific platform; however, the catalogue specifically distinguishes any instance where that is not the case.
- All products and services mentioned are owned by their respective organizations.

2 Mobile Device & Infrastructure Attack Surface

The functionality provided by mobile devices has significantly evolved over the past two decades and continues to rapidly advance. When first introduced, mobile devices were basic cellular phones designed to make telephone calls. Although carriers were targeted by malicious actors wanting to make free phone calls, users and their data were rarely the target of criminals. Once modern mobile OSs were introduced over a decade later, the threat landscape drastically changed as users began trusting these devices with large quantities of sensitive personal information. Enterprises also started allowing employees to use mobile devices and applications to access enterprise email, contacts, and calendar functionality. Shortly after the wide scale adoption of modern smartphones, a large upscale in the use and deployment of cloud services occurred. While this reduced costs and simplified operations for businesses, it altered the threat landscape in its own unique way.

The following sections describe primary components of the mobile attack surface: mobile device technology stack, mobile and local network protocol stacks, supply chain, and the greater mobile ecosystem.

2.1 Mobile Technology Stack

Mobile devices share some architectural similarities with their desktop counterparts, but there are significant distinctions between personal computers and these portable information systems. In addition to cellular functionality, including a number of radios, modern smartphones and tablets typically include a full suite of environmental sensors, cryptographic processors, and multiple wireless and wired communication methods. They also include a touch screen, audio interface, one or more high definition (HD) video cameras, and in odd edge cases unusual capabilities like video projectors.

Figure 1 illustrates the mobile device technology stack, described in additional detail further below.

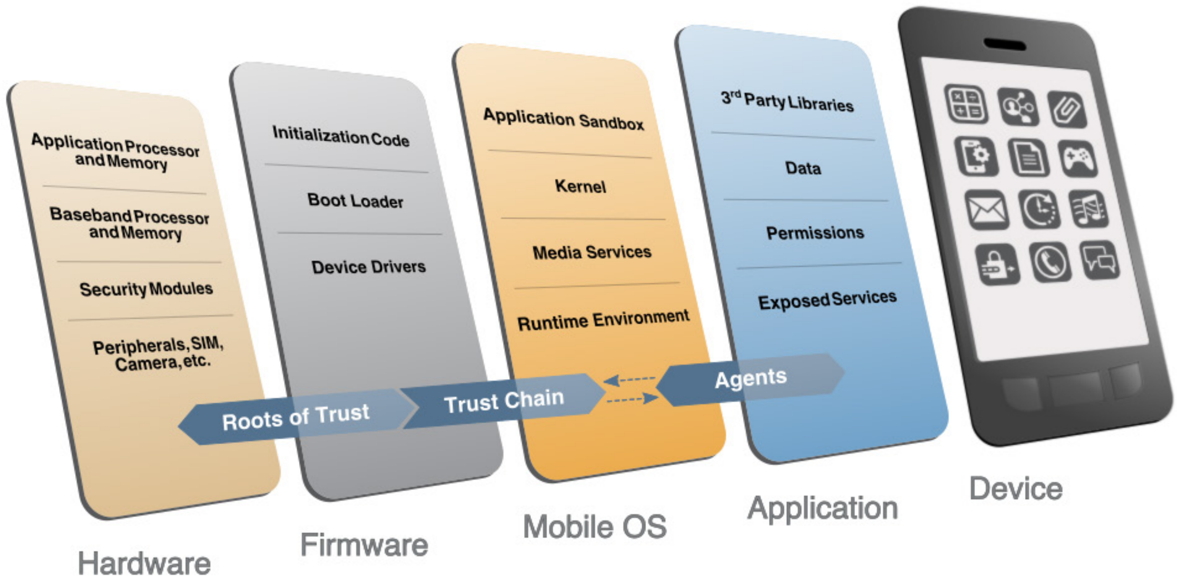

Figure 1 - Mobile Device Technology Stack

For smart phones and tablets with cellular capabilities, a separation exists between the hardware and firmware used to access cellular networks and the hardware and firmware used to operate the general purpose mobile OS. The hardware and firmware used to access the cellular network, often referred to as the telephony subsystem, typically runs a real-time operating system (RTOS). This telephony subsystem is colloquially named the *baseband processor*, and may be implemented on a dedicated System on a Chip (SoC), or included as part of the SoC containing the application processor also running the general purpose mobile OS.

The firmware necessary to boot the mobile OS (i.e., bootloader) may verify additional device initialization code, device drivers used for peripherals, and portions of the mobile OS – all before a user can use the device. If the initialization code is modified or tampered with in some manner, the device may not properly function. Many modern mobile devices contain an isolated execution environment, which are used specifically for security-critical functions [7]. For example, these environments may be used for sensitive cryptographic operations, to verify integrity, or to support Digital Rights Management. These environments typically have access to some amount of secure storage which is only accessible within that environment.

The mobile OS enables a rich set of functionality by supporting the use of mobile applications written by third-party developers. Accordingly, it is common for mobile applications to be sandboxed in some manner to prevent unexpected and unwanted interaction between the system, its applications, and those applications' respective data (including user data). Mobile applications may be written in native code running closely to the hardware, in interpreted languages, or in high-level web languages. The degree of functionality of mobile applications is highly dependent upon the application programming interfaces (APIs) exposed by the mobile OS.[1]

2.2 Communication Mechanisms

Contemporary mobile devices contain integrated hardware components to support a variety of I/O mechanisms. While some of the communication mechanisms are wireless (i.e., cellular, WiFi, Bluetooth, GPS, NFC), others require a physical connection (i.e., power and synchronization cable, SIM, external storage). As seen in Figure 2, each of these different wireless and wired device communication mechanisms exposes the device to a distinct set of threats and must be secured or the overall security of the device may be compromised.

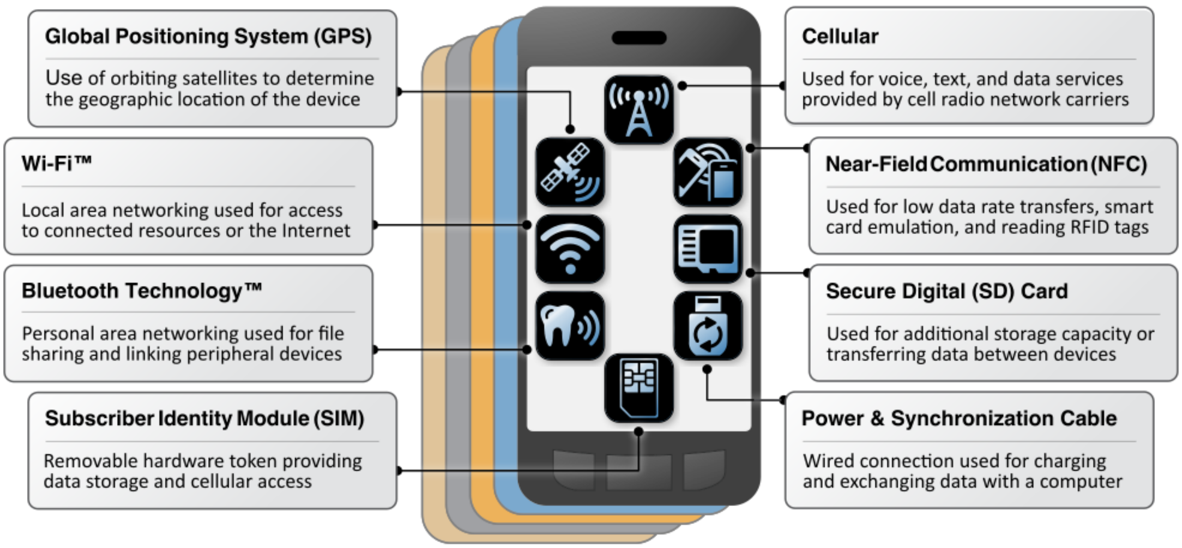

Figure 2 - Mobile Device Communication Mechanisms

The following sections provide a brief overview of each communication mechanism.

2.2.1 Subscriber Identity Module (SIM)

This removable hardware token is colloquially referred to as the Subscriber Identity Module (SIM) card, although current standards use the term Universal Integrated Circuit Card (UICC). This System on a Chip (SoC) houses the subscriber identity (i.e., International Mobile Subscriber Identity), pre-shared cryptographic keys, and configuration information needed to obtain access to cellular networks. The UICC is essentially a smartcard that runs a Java application known as the Universal Subscriber Identity Module (USIM), which is used to run a set of applications that control the phone's access and authentication with the MNO's cellular networks and roaming partners. It is possible to develop and run other applications on the Java Card platform, such as

[1] For additional information about mobile application security, see NIST SP 800-163 – Vetting the Security of Mobile Applications [5].

games and mobile payment applications.

As of the writing of this Interagency Report, a technology called Embedded SIM (eSIM) is being integrated into some mobile devices [4]. eSIMs will allow MNOs to remotely provision subscriber information during initial device setup, and allow the remote changing of subscription from one MNO to another. While this technology may radically change the way mobile devices are provisioned on the carrier network and therefore introduces a new set of threats.

2.2.2 Cellular Air Interface

The cellular air interface is arguably the defining networking interface for modern mobile devices. Initial cellular systems, such as second generation (2G) Global System for Mobile Communications (GSM) and third generation (3G) Universal Mobile Telecommunications System, were modeled after the traditional wireline circuit-switched telephone system. Each call was provided with a dedicated circuit providing a user making a telephone call with a baseline guarantee of service. In contrast, newer fourth generation (4G) Long Term Evolution (LTE) networks were designed to utilize a packet-switched model for both data and voice. An LTE network provides consistent IP connectivity between an end user's mobile device and IP-based services on the packet data network (PDN).

There are many cellular network types, each with its own air interface standards. The cellular air interface is the technical term for the radio connection between a mobile device and the cellular tower. This air interface can generally communicate with many types of base stations (e.g., cellular towers) which come in many sizes and types — cellular repeater / relay nodes, and even other handsets.

MNOs strive to run high availability “carrier grade” services that operate over the air interface at the network level, and can integrate with other systems they operate. These services may include circuit switched calling, VoLTE (Voice over LTE), Unstructured Supplementary Service Data (USSD), integrated voicemail with notifications, and messaging (e.g., Short Messaging Service (SMS)). Carrier-grade messaging services are commonly referred to as text messages, but include SMS, the extension to SMS known as Multimedia Messaging Service (MMS), and the new Rich Communication Services (RCS). USSD is an aging method for establishing a real-time session with a service or application to quickly share short messages. Although not common within the United States, USSD is used in emerging markets for a number of services, including mobile banking.

For additional discussion of LTE security architecture see NISTIR 8071 – LTE Architecture Overview and Security Analysis [16].

2.2.3 WiFi

WiFi is a wireless local area network (WLAN) technology based on the IEEE 802.11 series of standards. WiFi is used by most mobile devices as an alternative to cellular data channels, or even the primary data egress point in WiFi-only mobile devies. WLANs typically consist of a group of wireless devices within a contained physical area, such as an apartment, office, or coffee shop, but more expansive enterprise or campus deployments are also common. While not guaranteed, campus or enterprise deployments are more likely to implement security features such as WPA2 encryption. Smartphones, laptops, and other devices utilizing WiFi often need to connect back to a central wireless access point (APs), but may work in a device-to-device *ad hoc* mode.

Readers looking for additional guidance for the installation, configuration, deployment, and security of WiFi can see NIST SP 800-153 – Guidelines for Securing Wireless Local Area Networks [14] or SP 800-97 – Establishing Wireless Robust Security Networks: A Guide to IEEE 802.11i [15].

2.2.4 Global Navigation Satellite System (GNSS)

A GNSS provides worldwide geo-spatial positioning via the global positioning system (GPS), which uses line of sight communication with a satellite constellation in orbit to help a handset determine its location. These systems run independently of cellular networks. The US Federal Government operates a GPS constellation, although mobile devices may use other systems (e.g., GLONASS, Galileo). It should be noted that the GPS system is not the only way for a mobile device to identify its location. Other techniques include Wi-Fi assisted positioning, which leverages databases of known service set identifiers (SSIDs) and geolocation of IP addresses.

2.2.5 Bluetooth

Bluetooth is a short-range wireless communication technology. Bluetooth technology is used primarily to establish wireless personal area networks (PANs). Bluetooth technology has been integrated into many types of business and consumer devices including cell phones, laptops, automobiles, medical devices, printers, keyboards, mice, headphones, and headsets. This allows users to form *ad hoc* networks between a wide variety of devices to transfer data.

For additional information about Bluetooth security, see NIST SP 800-121 Revision 1 – Guide to Bluetooth Security [13].

2.2.6 Near Field Communication (NFC)

NFC uses radio frequency emissions to establish low throughput, short-range communication between NFC-enabled devices. It is typically optimized for distances of less than 4 inches, but can potentially operate at and pose a threat at much greater distances. NFC is based on the radio frequency identification (RFID) set of standards. Mobile payment technology relies on NFC, which has led to NFC's increasing visibility in recent years as newer mobile wallet technologies are being deployed on a large scale. The use of NFC for financial transactions make it attractive to criminal attackers with the goal of financial gain.

For additional information on the security challenges associated with RFID, refer to NIST SP 800-98 – Guidelines for Securing Radio Frequency Identification (RFID) Systems [12].

2.2.7 Secure Digital (SD) Card

The SD card standard comprises various form factors that offer different performance ratings and storage capacities. SD cards are typically used to expand the storage capacity of mobile devices to store data such as photos, videos, music, and application data. SD cards are not integrated into every mobile device, although the use of SD cards is particularly popular in developing nations where built-in storage may be uncommon.

2.2.8 Power & Synchronization Port

The power and synchronization port on a mobile device is most often used to charge a mobile device, and may take the form of Universal Serial Bus (USB) Type-C, Micro-USB, Apple Lightning, or Apple 30 pin. The cable is also used to carry data to, or access the device from, another information system. Use cases include data synchronization with or backup to a PC, or provisioning into an Enterprise Mobility Management system. This cable may also be used to charge another device in some circumstances. Because of this dual use of power *and data*, this interface is used as a vector for a number of attacks.

2.3 Supply Chain

Mobile devices are designed, manufactured, distributed, used, and disposed of in a manner similar to other commercial electronics. Unique threats to mobile devices exist at every part of this lifecycle. Supply chain threats are particularly difficult to mitigate because mobile device components are under constant development and are sourced from tens of thousands of original equipment manufacturers (OEMs). Some subcomponents of mobile devices (e.g., baseband processors) require matched firmware developed by the OEM. This firmware can itself contain software vulnerabilities and can increase the overall attack surface of the mobile device.

Of the layers presented in the mobile device technology stack featured in Figure 1, a variety of different organizations own or control different parts. In the case of Apple's highly vertically integrated iOS devices, Apple develops the mobile operating system, as well as the majority of the specialized firmware and hardware components. In contrast, Google's Android ecosystem is almost completely vertically sliced with both hardware and software components being supplied by tens of thousands of vendors. Google does not manufacture any hardware components, although they do form partnerships to create the Google-branded Nexus series of Android reference devices. An independent handset manufacturer may design a majority of the hardware and firmware to operate an Android device, and even customize the Android user interface; however, they still need Google's core Android OS to be part of the massive Android application ecosystem. This entire design and manufacturing process has the potential to markedly influence the security architecture of the resulting mobile device.

2.4 Mobile Ecosystem

Mobile devices do not exist in a vacuum - a series networks and interconnected systems exist to support modern mobility. The utility of modern mobile devices is greatly enhanced by software applications and their supporting cloud services. Mobile OSs provide dedicated application stores for end users offering a convenient and customized means of adding functionality. Application stores pose an additional threat vector for attackers to distribute malware or other harmful software to end users. This is especially true of third-party application stores not directly supervised by mobile OS vendors.

Mobile applications may traverse many networks and interact with systems owned and operated by many parties to accomplish their intended goals. This mobile ecosystem is depicted in the Figure 3.

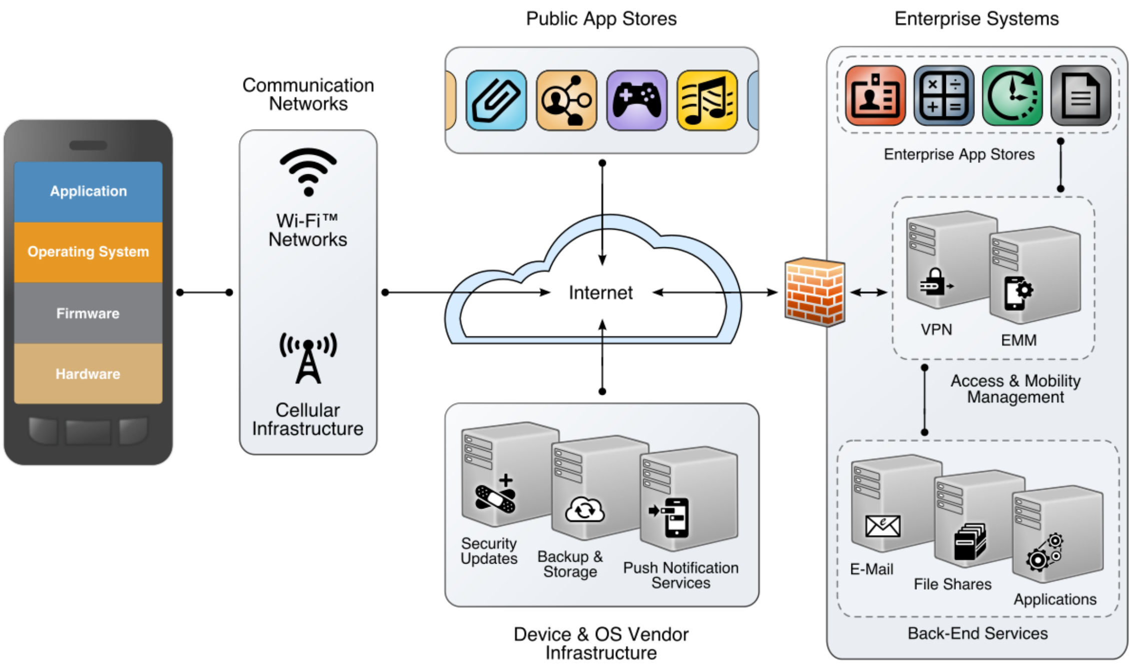

Figure 3 - Mobile Ecosystem

2.4.1 Cellular Infrastructure

MNOs build out cellular base stations over a large geographic area. These base stations modulate and demodulate radio signals to communicate with mobile devices. Base stations forward mobile device information, such as calls, messages, and other data, to other base stations and a cellular network core. The cellular network core contains anchor points to communicate with other networks, such as other MNO's cellular networks, WiFi networks, the Internet, and the PSTN. Cellular network cores also rely upon authentication servers to use and store customer authentication information.

2.4.2 Public Application Stores

Major mobile operating vendors own and operate their own native mobile application stores, which host mobile applications for users to download and install. These stores also provide music, movies, video games, and more. Access to these stores is natively installed and configured into mobile devices. Third-party mobile application stores also exist for most mobile operating systems. These third-party application stores may be explicitly built into the mobile OS, or they may be added as additional functionality for jailbroken or rooted devices.[2] Third-

[2] Jailbreaking or rooting a mobile device bypasses built-in restrictions on security. While this may provide the user more freedom to control their device, at the same time may compromise the security architecture of the mobile device.

party application stores may be completely legitimate, but may also host applications that commit substantial copyright violations or “cracked” versions of applications that allow users to install and use paid applications for free.

The native application stores are hosted and operated by their respective mobile OS developers.

2.4.3 Private Application Stores

Many enterprises and other organizations host their own mobile application stores. These stores either host, or link to, a set of applications for an organization’s users to access. These applications may be privately developed applications that organizations do not wish to be made public, or they may be publicly available applications that have been specifically approved for enterprise use. The servers used to host these applications may be privately hosted and operated by the enterprise, or hosted and operated by a third-party cloud provider.

2.4.4 Device & OS Vendor Infrastructure

Mobile OS developers often host infrastructure to provide updates and patches to a mobile device’s OS and native applications. Other cloud-based applications may be provided as well, including functionality to locate, lock, or wipe a missing device or to store user data (e.g., pictures, notes, music).

2.4.5 Enterprise Mobility Management Systems

Enterprise Mobility Management (EMM) systems are a common way of managing mobile devices in an enterprise. Although EMMs are not directly classified as a security technology, they can help to deploy policies to an enterprise’s device pool and to monitor a device’s state. Mobile OS developers provide APIs for EMM systems to deliver mobile policies, such as only allowing a whitelisted set of applications to run; ensuring a lock screen security policy is met; and disabling certain device peripherals (e.g., camera). EMMs can also use APIs to gather data about various aspects of a mobile device’s state.

For more information about the management and security of EMMs, see NIST SP 800-124 – Guidelines for Managing the Security of Mobile Devices in the Enterprise [2].

2.4.6 Enterprise Mobile Services

Email, contacts, and calendars are common workforce drivers, and are the cornerstone applications in mobile devices that are deployed by enterprises. Directory services are also deployed in an enterprise and used by mobile devices. Enterprises may also make other services available to mobile devices depending on their specific mission needs and requirements..

3 Mobile Threat Catalogue

The MTC captures a broad range of the threats posed to mobile devices and their associated infrastructure. The following section describes the structure of the catalogue and the methodology used to create it.

3.1 Methodology

NCCoE's mobile security engineers performed a foundational review of mobile security literature in order to identify major categories of mobile threats. Building upon this knowledge, threats were identified using a modified NIST SP 800-30 risk assessment process [6]. One of the primary drivers for change was the lack of a specific information system under review. A single mobile deployment was not under review – instead the threats posed to foundational mobile technologies were analyzed. Therefore, key risk information necessitated by NIST SP 800-30 such as likelihood, impact, and overall risk was unavailable and not included. Threats were identified in communication mechanisms, the mobile supply chain, and at each level of the mobile device technology stack. These threats were then placed into threat categories alongside information pertaining to specific instantiations of these threats.

During the threat identification process, it was necessary to identify which associated systems would be included and applicable mitigation capabilities. The mitigation capabilities are inclusive of a mobile security literature review and submissions resulting from the request for information on mobile threats and defenses[3], which support the congressional study on mobile device security. A broad scope was used in an effort to be comprehensive. The threats listed in the catalogue are sector-agnostic. For instance, threats pertaining to the use of mobile devices in a medical setting are not included. The exception to this is the inclusion of threats pertaining to the telecommunications industry, since this includes threats to cellular networks and infrastructure by definition.

3.2 Catalogue Structure

Threats are presented in categories and subcategories within the catalogue. NIST 800-30 Revision 1 defines a threat as "any circumstance or event with the potential to adversely impact organizational operations and assets, individuals, other organizations, or the Nation through an information system via unauthorized access, destruction, disclosure, or modification of information, and/or denial of service" [6]. For each threat identified within our analysis, the following information is provided:

- **Threat Category:** The major topic area pertaining to this threat. Topic areas are further divided when necessary, and are discussed in section 3.3.
- **Threat Identifier (ID)**: The Threat ID is a unique identifier for referencing a specific threat. The broad identifier categories used within the MTC are:

[3] FedBizOps solicitation number: QTA00NSTS16SDI0003

- *APP*: Application
- *STA*: Stack
- *CEL*: Cellular
- *GPS*: Global Positioning System
- *LPN*: Local Area Network & Personal Area Network
- *AUT*: Authentication
- *SPC*: Supply Chain
- *PHY*: Physical
- *ECO*: Ecosystem
- *EMM*: Enterprise Mobility Management
- *PAY*: Payment

- **Threat Origin**: Reference to the source material used to initially identify the threat.
- **Exploit Example**: A reference to the vulnerability's origin or examples of specific instances of this threat.
- **Common Vulnerability and Exposure (CVE) Reference**: A specific vulnerability located within the National Vulnerability Database (NVD) [10]. A vulnerability origin may describe a specific vulnerability, which may, or may not, be associated with a CVE.
- **Possible Countermeasure**: Security controls or mitigations that could reduce the impact of a particular threat. If a countermeasure is not present, it may be an area for future research.

The CVE is a dictionary of publicly known information security vulnerabilities and exposures [11].

3.3 Category Descriptions

There are 12 tabs within the MTC, each acting as general threat categories with subcategories defined as necessary.

3.3.1 Mobile Device Technology Stack

As discussed in Section 2.1, the mobile device technology stack consists of the hardware, firmware, and software used to host and operate the mobile device.

- Mobile Applications: The Applications tab contains threats related to software application developed for a mobile device, or more specifically a mobile operating system. *Note: The Applications category was separated into its own tab to enhance the usability of the catalogue. All of the other items are listed under the Stack tab.*

- Vulnerable Applications: This subcategory contains threats related to discrete software vulnerabilities residing within mobile applications running on top the mobile operating system. *Note: Some vulnerabilities may be specific to a particular mobile OS, while others may be generally applicable.*
- Malicious or Privacy-Invasive Applications: This subcategory identifies mobile malware based threats, based in part on Google's mobile classification taxonomy [3]. There are no specific software vulnerabilities within this subcategory, and accordingly no CVEs are cited. Additional malware categories are included within subcategory to augment Google's classification taxonomy.

- Mobile Operating System: Operating system specifically designed for a mobile device and running mobile applications.
- Device Drivers: Plug-ins used to interact with device hardware and other peripherals (e.g., camera, accelerometer).
- Isolated Execution Environments: Hardware or firmware-based environment built into the mobile device that may provide many capabilities such as trusted key storage, code verification, code integrity, and trusted execution for security relevant processes.
- SD Card: SD cards are removable memory used to expand the storage capacity of mobile devices to store data such as photos, videos, music, and application data.
- Boot Firmware: The firmware necessary to boot the mobile OS (i.e., bootloader). Firmware may verify additional device initialization code, device drivers used for peripherals, and portions of the mobile OS – all before a user can use the device.
- Baseband Subsystem: The collection of hardware and firmware used to communicate with the cellular network via the cellular radio.
- SIM Card: This removable hardware token is a SoC housing the IMSI, pre-shared cryptographic keys, and configuration information needed to obtain access to cellular networks.

3.3.2 Network Protocols, Technologies, and Infrastructure

Although divided into multiple sections within the mobile threat catalogue, this category includes wireless protocols and technologies used by mobile devices.

- Cellular: Threats exist to a number of cellular systems, broken into the following subcategories:
    - Air Interface: The cellular air interface is the radio connection between a handset

and a base station. There are many cellular network types each with its own air interface standards which as a total set are extremely flexible and primarily communicate with base stations. *Note: While a number of general threats to the cellular air interface are listed, specific threats to particular cellular protocols (e.g., GSM, CDMA, LTE) are also included.*

- Consumer grade small cell: Small cells are often used to extend cellular network coverage into homes, offices, and other locations lacking service.

- Carrier-grade Messaging Services: Messaging services (i.e., SMS, MMS, RCS) allow text, photos, and more to be sent from one device to another. Although third-party messaging services exist, carrier-grade messaging services are pre-installed on nearly every mobile phone, and are interoperable with most MNOs' networks.

- USSD: A method for establishing real-time sessions with a service or application to quickly share short messages. Although USSD messages may travel over SMS, the protocol itself is distinct.

- Carrier Infrastructure: This category includes threats to the base stations, backhaul and cellular network cores.

- Carrier Interoperability: This subcategory is primarily reserved for signaling threats associated with the Signaling System No. 7 (SS7) network.

- VoLTE: The packet switched network application used for making voice calls within LTE. Although not supported in all MNO networks, large-scale rollouts are underway throughout the world.

- LAN & PAN: This threat category consists of local and personal area wireless network technologies.

  - WiFi: WiFi is a WLAN technology based on the IEEE 802.11 series of standards.

  - Bluetooth: Bluetooth is a medium-range, lower power, wireless communication technology.

  - NFC: NFC is a short range wireless communication technology commonly used for mobile wallet technologies and peripheral configuration, although a number of other applications exist.

- GPS: A network of orbiting satellites used to help a device determine its location.

3.3.3 Authentication

Authentication mechanisms are grouped within the three subcategories listed below. Individual credential and token types are not broken into their own categories and are instead included within one of these three broad categories.

- User to Device: Mechanisms used to authenticate with a mobile device, such as passwords, fingerprints, or voice recognition. This is most often local authentication to a device's lock screen.
- User or Device to Remote Service: Mechanisms a user or a distinct non-person entity (NPE) uses to remotely authenticate to an external process, service, or device.
- User or Device to Network: Mechanisms a user, mobile device, or peripheral uses to authenticate to a network (e.g., Wi-Fi, cellular). This commonly includes proving possession of a cryptographic token.

3.3.4 Supply Chain

This category includes threats related to the device and component supply chain. To the extent that they are included, software supply chain related threats are noted within the Exploitation of Vulnerabilities in Applications category.

3.3.5 Physical Access

This category includes general threats originating from outside of the device, such as device loss and malicious charging stations.

3.3.6 Ecosystem

This category includes threats related to the greater mobile ecosystem includes a number of items, including EMMs, mobile OS vendor infrastructure, and mobile enterprise services such as email, contacts, and calendar.

- Mobile OS Vendor Infrastructure: Infrastructure provided by the OS developer to provide OS and application updates, alongside auxiliary services such as cloud storage.
- Native Public Stores: Major mobile operating system vendors own and operate their own native mobile application stores, which host mobile applications alongside music, movies, games, etc. for users to download and install.
- Private Enterprise Stores: Application stores may be owned and operated by private enterprises to host applications not meant for public distribution, such as applications developed and used solely within the organization.
- Third-Party Stores: Other legitimate, and illegitimate, application stores may be owned and operated by organizations external to the major mobile operating system vendors.

3.3.7 Enterprise Mobility

This threat category comprises enterprise mobility management systems and threats to enterprises services.

3.3.8 Payment

Threats related to mobile payments are included within this category, including a variety of mobile payment technologies such as USSD, NFC-based payments, and credit card tokenization. Although general threats relating to USSD and NFC are included elsewhere, threats relating to payment specific use cases are captured here.

3.4 Next Steps

The NCCoE aims to construct a series of mobile security projects to address the threats listed in the MTC. A subset of the threats listed in the MTC may be identified for each project. Example projects could include mobile application vetting, mobile security for public safety handsets, and cellular security for the LTE air interface. Additionally, the NCCoE has partnered with the Cyber Security Division at the DHS Science & Technology Directorate in mobile security research for future research and development to spur innovation. The list of mobile threats lacking mitigation capabilities will be considered primary areas for future research and development projects in mobile security.

The NCCoE is interested in receiving comments on the Mobile Threat Catalogue, ideas for future mobile security projects, and mobile security architectures operating and/or managing enterprise mobile deployments. The NCCoE is also interested in feedback from mobile technology vendors who may wish to work in collaboration to solve mobile security challenges. Please connect with the NCCoE's mobile security team at mobile-nccoe@nist.gov.

If you have specific comments on this document, please email us at nistir8144@nist.gov.

Appendix A—Acronyms

Selected acronyms and abbreviations used in this paper are defined below.

2G	2nd Generation
3G	3rd Generation
4G	4th Generation
AP	Access Point
API	Application Programming Interface
BYOD	Bring Your Own Device
COPE	Corporately Owned Personally Enabled
COTS	Commercially Available off the Shelf
CSRC	Computer Security Resource Center
CVE	Common Vulnerabilities & Exposures
DoS	Denial of Service
EMM	Enterprise Mobility Management
GNSS	Global Navigation Satellite System
GSM	Global System for Mobile Communications
FIPS	Federal Information Processing Standard
HD	High Definition
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
LTE	Long Term Evolution
MDM	Mobile Device Management
MNO	Mobile Network Operator
MMS	Multimedia Messaging Service

MTC	Mobile Threat Catalogue
NCCoE	National Cybersecurity Center of Excellence
NFC	Near Field Communication
NIST	National Institute of Standards and Technology
NISTIR	NIST Interagency Report
NPE	Non-Person Entity
OS	Operating System
PAN	Personal Area network
PSTN	Public Switched Telephone Networks
RCS	Rich Communication Services
RFID	Radio Frequency Identification
SD	Secure Digital
SIG	Special Interest Group
SIM	Subscriber Identity Module
SMS	Short Message Service
SoC	System on a Chip
SP	Special Publication
SS7	Signaling System No. 7
SSID	Service Set Identifier
UICC	Universal Integrated Circuit Card
UMTS	Universal Mobile Telecommunications System
USIM	Universal Subscriber Identity Module
USSD	Unstructured Supplementary Service Data
VPN	Virtual Private Network
WLAN	Wireless Local Area Network

Appendix B—References

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Appendix C— Mobile Threat Catalogue References

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