LINEAGEOS ANDROID OPEN SOURCE MOBILE OPERATING SYSTEM : STRENGTHS AND CHALLENGES

by

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Abstract

The Android Open Source Project (AOSP) is a community-driven model for the development of mobile operating system platforms. Developers around the world distribute and share code, enabling others to use it and develop their own AOSP variants. This special study is aimed at identifying opportunities and challenges in developing a completely free and open source mobile operating system based on AOSP.

LineageOS, an active fork of the now-defunct CyanogenMod AOSP variant, has been ported to several different devices since its initial release. LineageOS ships with a complete set of binary firmware and shows the way for developers around the world to develop alternative platforms to Google Mobile Services.

In this special study, I describe the installation of LineageOS on a OnePlus One mobile device. I first describe the installation of a pre-built LineageOS image to the device, and then I explain how i compiled the available source to build my own LineageOS image for the device. Source compilation provides a more complete understanding of device-level OS builds.

I also discuss various alternatives to Google Mobile Services. All the available alternative services are in the development stage. A promising approach is the reverse engineering microG project, which is a free and open source re-implementation of Google Mobile Services. Such alternatives to Google's services, meaning client-side free and open source applications and libraries, provide an excellent base upon which can build completely free and open source background services as well as applications on mobile devices.

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Chapter 1

Introduction

This chapter provides information about the Background, Problem Statement and Objective of the study.

1.1 Background

The Android Operating System (OS) is a free and open source, fully customizable mobile OS platform. The Android Open Source Project (AOSP), which provides a framework for the development of Android, uses a community-driven model for the improvement of mobile operating system platforms. Developers around the world can distribute and share code. This helps others to use the shared code and develop their own AOSP variants. In November 2007, AOSP was announced. Since the initial release of the AOSP, many popular variants have been introduced. AOSP is led by Google and the Open Handset Alliance (OHA). Android source code is released under an open source license, but paradoxically, most Android devices ship with a combination of free and open source and proprietary firmware, especially the firmware required for accessing Google Play Services.

Google Play Services, generally referred to as Google Mobile Services (GMS), has system-level control over the mobile device. It is part of the Google Apps package and is proprietary. Developers having the intention to develop an open source application and publish it on the Play store need to agree upon Google's terms, which state that a few parts of the code are proprietary. This paradoxical situation of the impossibility of launching a complete free and open source application via the Play Store raises many privacy and security-related concerns.

AOSP has functioned as the baseline for all original equipment manufacturers (OEMs) and community-run packaged firmware such as CyanogenMod. Some of the apps inside AOSP have been abandoned and then released on Google Play with a closed-source model. Many apps only function when Google Play Services are available. Examples include Gmail, YouTube, and Google Maps.

There are many distributions of Android. CyanogenMod (CM) was a popular fork of AOSP developed by Cyanogen (Cyngn) Inc. that emphasized allowing its users to modify everything on the platform. In December 2016, Cyanogen Inc. announced the discontinuation of the CyanogenMod project. One-Plus' first phone, Oneplus One, was a popular smart phone featuring Cyanogen OS when it shipped in 2015. Builds builds are still available. Immediately after the discontinuation of CyanogenMod, LineageOS took up the effort to continue towards the goal. It is a fork of the now-defunct CyanogenMod version of Android. Similar to CM, the LineageOS project is being extended by many device-specific maintainers.

LineageOS emphasizes the delivery of a complete free and open source project. This is in contrast with the usual way to run Android hardware, in which source code is adapted by original equipment manufacturers (OEMs) that produce parts and equipment that were originally manufactured by another company.

1.2 Problem Statement

This section states various problems with the Android Open Source Project in practice.

1.2.1 Google Play Services API

Most Android application developers rely on the Application Programming Interfaces (APIs) of Google Play services. These services include the location API, which is needed for all map-related work on a mobile device. Google Play Services is a proprietary code base; hence, nobody knows precisely how applications using it work. There are many similar APIs for which we do not have access to the full source code.

1.2.2 Device Drivers

For years, Google has been adding functionality not only to the AOSP code base, but also to its own proprietary binary libraries and very specific GMS (Google Mobile Services). Manufacturers must pass a compatibility test to receive official GMS support from Google. Usually, the code being tested includes device drivers that are proprietary, meaning there is no hope of looking at the code to understand what happens inside. As a user of proprietary software is not allowed to control its execution (the vendor and other third parties control it), he or she cannot prevent tracking and selling his or her information to advertising companies, and he or she is prevented from doing all possible things on the device. At a high level, users are controlled and directed to do what vendors want them to do. On a practical level, users are continually told that their devices are obsolete just because vendors fail to upgrade the firmware. Specifically, even though AOSP is free and open source software in theory, in practice most devices use dozens of proprietary blobs to control the actual hardware.

1.2.3 Other cases

Most Android-based devices are manufactured with a chip-set named Qualcomm Snapdragon. This is a system on chip (SOC) semiconductor device designed and marketed by Qualcomm for mobile devices. Qualcomm develops a large number of proprietary device drivers for the SOC. Other device manufacturers have to buy the SOC and drivers from Qualcomm. For example, the H.264 video and audio codec library for the Snapdragon is actually developed by Qualcomm, who owns a patent on it. Being closed source, any flaws of the hardware-level implementation of the mobile phone are nearly impossible to fix.

Documents released by Edward Snowden have revealed that the National Security Agency (NSA) and Global Surveillance joint programs, such as the program named PRISM, aims at collecting all possible information about people around the world by partnering with companies such as Microsoft, Facebook, Apple, and Google (MacAskill, 2013). LineageOS is aimed at community development that reaches the masses and provides a purely free and open source operating system. GMS is not

provided by default in LineageOS. Instead, users can decide themselves whether or not to load it. Alternatives to GMS are in the development phase. The LineageOS developer community is focused on better free and open source operating system software for users to have a complete functional OS in their hands.

1.3 Objectives

The objective of this study is to understand the implications of the AOSP on technology freedom, identifying weaknesses and opportunities for LineageOS, and to experiment with LineageOS on a real device.

To achieve these objectives, I have performed following steps:

- Write a literature survey to provide a good grasp of the background.
- Perform a technology review to know more about the AOSP and identify methods to continue LineageOS on different platforms.
- Install LineageOS on a device to check device-level performance.
- Identify gaps compared to other AOSP projects.
- Make a plan for possible contribution to LineageOS to help improve the AOSP.

1.4 Organisation of the report

Chapter 1 provides the background, problem statement, and objectives of the study. Chapter 2 provides a literature survey. Chapter 3 describes the methodology of my study. Chapter 4 discusses preliminary results. Discussion and conclusion are in Chapter 5.

Chapter 2

Literature Review

This chapter reviews mobile operating systems and Google Mobile Services (GMS) and compares alternatives to GMS such as independent email applications, alternative search engines, offline maps, and alternative application repositories. I also provide information regarding the previous work.

2.1 Mobile Operating Systems

In general, a mobile OS typically starts up when a device powers on, presenting a screen with icons or tiles that present information and provide application access. Mobile operating systems manage cellular and wireless network connectivity, as well as phone access. All of these tasks must be handled by an embedded system.

Around 1994, IBM launched the first smartphone, named IBM Simon, which only had a touchscreen, email, and PDA features. Slightly later, Symbian Ltd introduced Symbian OS, which was used by Nokia and then became the first modern mobile OS on a smartphone with the launch of the Ericsson R380 mobile phone. Around 2008, the Open Handset Alliance (OHA) released Android 1.0 based on the Linux kernel on the HTC Dream (T-Mobile G1) as the first Android phone. Android's first version had features including the GMS from the beginning.

AOSP, being an open source developer community spread around the world, enables introduction of different custom ROMs enabling users to modify the system. LineageOS, which is a recent fork of the defunct of CyanogenMod ROM, allows users to side-load GMS or leave it out.

2.2 Google Mobile Services and other alternative applications

Google Mobile Services (GMS) includes applications and services provided by Google that enhance the user's mobile experience. Applications such as Gmail, Chrome, Google Maps, YouTube, Google Docs, and the Play Store are pre-installed in stock Android versions. These are closed source applications. There are many privacy and data mining issues with GMS because they ship many proprietary blobs with unknown functions in the software and device drivers. Google Play Services has two major components: client library and external Android Package Kit (APK) files. The client library contains interfaces to the individual Google services and allows them to obtain authorization from users to gain access to Google Play Services with their credentials. It also contains APIs that allows resolving any issues at runtime, such as a missing, disabled, or out-of-date Google Play services APKs. The Google Play Services APK contains the individual Google services and runs as a background service in the OS. Figure 2.1 shows an overview of the Google Play Services and their operation.

Figure 2.1: Overview of Play Services

(<https://developers.google.com/android/guides/overview>)

Independent Email Applications such as K-9 Mail, Tutanota, and ProtonMail help developers to review and modify their source as intended under a free and open source model. K-9 Mail is the most popular alternative mail service has several features. Tutanota and Proton are also being the popular alternative mail services has the end-to-end encryption infrastructure. As GMS is unable to assuage user's privacy concerns, these kind of alternative email applications are necessary.

There are different search engines available as alternatives to Google search. All of these search engines are based on search engine optimization (SEO) techniques. DuckDuckGo (DDG) is a popular open source alternative to Google search. It emphasizes protecting searchers' privacy and avoiding personalized search results. DDG distinguishes itself from other search engines by claiming that it does not profile its users and deliberately shows all the users same search results for a given search term. It emphasizes returning the best results rather than the most results and generates those results from over 400 individual sources. It includes key crowdsourced sites such as Wikipedia and other search engines such as Bing, Yahoo!, Yandex, and Yummly.

DDG has an interesting feature, “!Bang” syntax, which allows searchers to use keywords from a menu list and directly search over different available sites. There is also the possibility of writing DDG tools on the “DDG hack” platform. Some parts of DDG's source code is free software is hosted at GitHub under the Apache 2.0 License, but the core is proprietary. It is used by a few corporations

as a default option in the provided list. On 18 September 2014, Apple included DDG in its Safari browser as an optional search engine (Schwartz, 2014). On 10 November 2014, Mozilla added DDG as a search option to Firefox 33.1 (Mozilla, 2014). On 30 May 2016, The Tor Project made DDG the default search engine for Tor Browser 6.0 (Johnson, 2016). DDG earns revenue by providing ads from the Yahoo-bing search alliance and also through partner relationship with Amazon and ebay.

For alternative Maps utilities, open street mapping is the popular model. The open street mapping (OSM) community has developed capabilities for offline maps. This had led to a great deal of growth in the community. OSM is a collaborative project to create a free editable map of world. The creation and growth of OSM has been motivated by restrictions on use or availability of map information across the world, and the advent of inexpensive portable satellite navigation devices. OSM is considered a prominent example of volunteered geographic information (Anderson, 2006).

Applications such as Maps.Me and OsmAnd provide offline maps and free navigation utilities. They has been developed in the free and open source model. Maps.Me features includes, offline map data, GPS support, offline search, offline routes for cars and by foot, a Map Editor, Bookmark, Locations, bookmarks sharing, and KML import. The OsmAnd features includ, navigation, map viewing, using OSM and Wikipedia data, safety features, bicycle and pedestrian features, and directly contributing to OSM.

2.3 Application Repositories

Most of the apps in the Google Play Store are not open source, and many of them are loaded with proprietary blobs and many try to gather information about their users. There are a few independent app stores that allow open source software. One such implementation is F-Droid. F-Droid is a software repository (or app store) for Android applications, similar to the Google Play store. The main repository hosted by the project, contains apps that are free and open-source software. Applications can be browsed and installed from the F-Droid website or client app. There is no need to register for an account. Applications incorporating advertising, user tracking, or dependence on non-free software must inform users in the app descriptions. The website offers the source code of the applications it hosts, and the software running the F-Droid server is also open, allowing anyone to set up their own app repository. This software repository is licensed under GNU GPLv3+ (Nardi, 2012).

2.4 microG Project

The microG project is a free and open source re-implementation of Googles proprietary Android client side apps and libraries. Different free and open source applications require Googles proprietary libraries to be installed. To solve this problems, different scenarios led to the development of a free and open source software clone of Googles proprietary core libraries and applications. The main idea of this project was to build a free and open source replacement for all proprietary parts injected by Google into the Android ecosystem. The components of this project are shown below.

- **Service Core (GmsCore):** This is a library application that provides functionality to run Google Play Services or the Google Maps Android API.
- **Services Framework Proxy (GsfProxy):** This is a utility that allow apps developed for Google Cloud to Device Messaging (C2DM) to use the compatible Google Cloud Messaging service included with GmsCore.
- **Unified Network Location Provider (UnifiedNlp):** This is a library that provides Wi-Fi and cell-tower-based geolocation to applications that use Googles network location provider. It is included in GmsCore but can also run independently on most Android systems.
- **Maps API (mapsv1):** This is a system library which provides the same functionality as the now deprecated Google Maps API v1.
- **Store (Phonesky):** This is a front-end application providing access to the Google Play Store to download and update applications.

2.5 Related works on Android Open Source Project

There have been many projects building on the AOSP demonstrating tasks such as reverse engineering, exploring the Play Store, and privacy-and security-related aspects of the project. Table 2.4 shows this related works.

Table 2.1: Work plan for research

SL	Reference	Paper Discussion
1	(Viennot, Garcia, & Nieh, 2014)	Developed a method for crawling the Play Store applications and observing 3rd party application usage from users. The author also provide interesting methods for reverse engineering the Play Store.
2	(Erturk, 2013)	Discusses security and privacy related issues regrading Android adware. Also proposes developing an open source mobile application platform to reduce the security vulnerabilities.
3	(Khokhlov & Reznik, 2017)	Discusses data security evaluation for Android mobile devices. Provides useful information about sensor data manipulation determined through different evaluation metrics.

Chapter 3

Methodology

This chapter provides information about the implementation of LineageOS on the OnePlus One device. It mainly focuses on Device Partitioning, Custom ROMs, Android SDK Platform Tools, Bootloader and Recovery Mode, Wiping Partitions, Flashing LineageOS, and Open GApps.

3.1 Device Partitions

All Android devices follow a standard internal storage partition tree. As OnePlus One is an Android-based mobile device, it follows the same kind of partitioning. A partition tree usually consists of partitions such as boot, system, recovery, data, cache, and misc. In addition to these partitions, the device also has a sdcard partition. Following are some individual details about the above-mentioned partitions.

- **boot:** This partition is essential for a device to boot. It comprises of the kernel and the ramdisk.
- **system:** This partition stores the entire operating system, other than the kernel and the ramdisk. This includes the Android user interface in addition to all the applications that are pre-installed on the device.
- **recovery:** This is an alternative boot partition that lets users boot the device into a recovery console for advanced recovery and maintenance operations.
- **data:** This partition contains the user's data. All the contacts, messages, settings, and apps are installed by default on this partition.
- **cache:** This partition stores frequently-accessed data and app components.
- **misc:** This partition stores miscellaneous system settings. This includes, settings such as carrier or region ID (CID), USB configuration, and a few hardware settings. This partition changes from device to device.
- **sdcard:** Usually, this is not a partition on the internal memory storage device but a mounted separate SD card partition storing media, documents, and Custom ROMs.

3.2 Custom Roms

LineageOS, which continues the defunct CyanogenMod project, is a custom ROM. It gives different facilities to users to modify the system according to their interests. Currently, LineageOS has custom builds for 29 devices, each of which has different versions. LineageOS developers also provides a procedure to build LineageOS for specific user devices.

At present, OnePlus company has five different devices, and OnePlus One is the first version of their flagship product line. For each of these devices, LineageOS has different nightly builds, which are maintained regularly. OnePlus One's nightly builds are named under the codename "bacon". In order to proceed with the installation, users should download a nightly build.

At first, OnePlus One was pre-installed with CyanogenMod OS. By December 2016, there were no future stock updates from the company. During that period, the device had CyanogenMod 13.1 as the stock OS. Before installing LineageOS, it is recommended to flash the unofficial CyanogenMod 13.1.2 OS first, as it upgrades to the latest firmware. Before installing any custom ROM, it is suggested to have the latest firmware on the device. Android SDK platform tools help to interact with the device shell and further interact with wiping partitions, flashing the OS, and other tasks.

3.3 Android SDK Platform Tools

Android SDK Platform Tools are basic to developing Android applications. The toolset include tools that interface with the Android platform, such as adb, fastboot, and systrace. These tools help unlock the device boot-loader and allow flashing it with a new system image. Using fastboot, a device can be flashed with a recovery file, then adb can be used to flash a custom ROM through the recovery mode. adb also allows the device shell to be accessed.

3.4 Boot-loader and Recovery Mode

In general, the bootloader is a software program that activates an operating system. We can utilize the fastboot tool to switch to bootloader mode in order to flash a new version of the OS. This involves a complete format of the partition tree. To perform privileged shell-level activities, we must unlock the bootloader in order to give root access to the system partitions.

As mentioned earlier, the recovery partition is a separate partition on the system. It helps users to recover a damaged system with the help of tools. Besides the stock recovery mode, a device can be loaded with a custom recovery tool. Usually, custom recovery provides more functions than the stock recovery. There are many custom recoveries, among which ClockworkMod (CWM) and TeamWin (TWRP) are the most popular. CWM is a software company, whereas TWRP is an open source community project.

3.5 Wiping Partitions

In order to flash a custom ROM, the device's partitions should first be formatted. Partitions such as data, system, and cache must be wiped from the system. This is because most data is stored in those partitions. In many of the cases, normal wiping works, but if partitions are not wiped correctly, a hard wipe may be required; this means a full format of the device. OnePlus One uses the ext4 format for

the partition tree, and it requires a hard wipe to format the partition tree, because this requires several back and forth operations regarding the OS.

3.6 Flashing LineageOS

Flashing LineageOS on OnePlus One requires a few basic steps. As mentioned earlier, we should first upgrade to the stock version of CM 13.1.2 and follow by flashing an experimental migration build of LineageOS. This is because of the firmware included in the last stock version. LineageOS builds prior to that stock version are deprecated, and now version 14 nightly builds should be used for all devices.

We must make sure to have a full backup of the system, as data is not recovered after formatting the storage device. Also, the device needs a full charge before proceeding with the installation.

The XDA-developer community maintains the unofficial stock CM 13.1.2 version in the form of downloadable zip file. We must also make sure to download the Android SDK platform tools for Debian GNU/Linux (now it is only implemented in this environment). We must place the downloaded CM 13.1.2 zip in the SDK tools directory.

We enter fastboot mode and flash the zip file before connecting it to the laptop. TWRP is suggested on user forums. We must check the device information to make sure the flashed OS is as expected. Next, to flash LineageOS, we must make sure to download the experimental migration build from CM. Finally, by repeating the above steps, LineageOS can be successfully installed. Hereafter, nightly builds can be received as updates occur.

3.7 Open GApps

It is possible to install the bundled Google Apps package. This package depends on Google Mobile Services. LineageOS offers users a choice to side-load these bundled GApps.

3.8 Installing microG suite

To enable the services offered by the microG project, we have to install the microG-LineageOS build of the OS. To flash this version of LineageOS, we follow same steps previously described earlier to flash LineageOS. Utilizing the Android platforms tools, we can install the zip file from the TWRP recovery mode.

One issue in using microG is that we have to enable signature spoofing in the system application settings. Signature spoofing allows applications to behave as if they have been signed by a third party. This means that whenever one application asks the operating system for the certificate used to sign an installed package and that package uses signature spoofing, instead of the original certificate associated with the app, a spoofed certificate is returned. This certificate has to be announced in the AndroidManifest file, and the app is required to request the android-permission-FAKE-SIGNATURE file permission. These signatures are used to verify the integrity of a package and to ensure that the new version is from the same author when the system updates the app. The verification process normally relies on the fact that, only one author has access to the private key used to sign an app. A different author is not able to sign an app using the same key, because he does not have access to it, and thus cannot provide update to another authors application. Signatures are thus an essential part of the Android package management security system.

Besides the official Play store app, there are other application stores that providing utilities similar to the Play Store, and the Yalp store is one of them. Yalp Store lets us download apps from the Google Play Store as apk files. It can be installed as a system app to gain background package installation permission. It is independent from the Google Services framework. It uses the same remote API that the Play store app uses.

Chapter 4

Results

This chapter gives results for the work that was done in chapter 3. It has the two method results which are based on the pre-build installation and source code compilation.

4.1 Pre-build Installation

First, I attempted installation through the pre-build images from the official LineageOS website. This process utilizes the Android studio platform tools. As the process involves two upgrades, first the OnePlus One needs to be upgraded to the LineageOS experimental build, then we follow with the nightly update as they occur. The whole process took two hours on a 2.5 GHz CPU with 3GB RAM. Table 4.1 shows the specifications of the OnePlus One mobile phone.

4.2 Source Compilation

Next I fetched the source from the official LineageOS project page in Github. I did the build on a virtualbox with Ubuntu 16.04 as the host system. The process took nine hours to build the entire image on a 3.10GHz CPU-i5-4440 with RAM of 5GB. In order to build proprietary modules, I extracted those modules sources from existing LineageOS device. Here, I used the pre-build image for the OnePlus One device to extract the sources of the proprietary modules. The code is available in official LineageOS Github page. The Figures 4.1-4.4 show the post execution directories of the LineageOS source compilation.

4.2.1 Main tree of build files

```
root@ubuntu:~/android/system# ls -lrt
total 148
drwxr-xr-x  3 root root 4096 Nov 15 13:58 abi
drwxr-xr-x  4 root root 4096 Nov 15 13:58 android
drwxr-xr-x 21 root root 4096 Nov 15 13:59 art
drwxr-xr-x 12 root root 4096 Nov 15 13:59 bionic
drwxr-xr-x  3 root root 4096 Nov 15 13:59 bootable
-r--r--r--  1 root root   87 Nov 15 13:59 Makefile
drwxr-xr-x 10 root root 4096 Nov 15 13:59 build
lrwxrwxrwx  1 root root   26 Nov 15 13:59 bootstrap.bash -> build/soong/bootstrap.bash
lrwxrwxrwx  1 root root   19 Nov 15 13:59 Android.bp -> build/soong/root.bp
drwxr-xr-x 12 root root 4096 Nov 15 14:01 cts
drwxr-xr-x 10 root root 4096 Nov 15 14:01 dalvik
drwxr-xr-x  3 root root 4096 Nov 15 14:01 developers
drwxr-xr-x 21 root root 4096 Nov 15 14:01 development
drwxr-xr-x 283 root root 12288 Nov 15 14:08 external
drwxr-xr-x 17 root root 4096 Nov 15 14:10 frameworks
drwxr-xr-x 15 root root 4096 Nov 15 14:10 hardware
drwxr-xr-x 18 root root 4096 Nov 15 14:11 libcore
drwxr-xr-x  5 root root 4096 Nov 15 14:11 libnativehelper
drwxr-xr-x 14 root root 4096 Nov 15 14:11 lineage
drwxr-xr-x  8 root root 4096 Nov 15 14:11 ndk
drwxr-xr-x  6 root root 4096 Nov 15 14:12 pdk
drwxr-xr-x  7 root root 4096 Nov 15 14:12 platform_testing
drwxr-xr-x 21 root root 4096 Nov 15 14:17 prebuilts
drwxr-xr-x 25 root root 4096 Nov 15 14:18 sdk
drwxr-xr-x 23 root root 4096 Nov 15 14:18 system
drwxr-xr-x  3 root root 4096 Nov 15 14:18 toolchain
drwxr-xr-x  4 root root 4096 Nov 15 14:20 tools
drwxr-xr-x  9 root root 4096 Nov 15 14:33 device
drwxr-xr-x  3 root root 4096 Nov 15 14:33 kernel
drwxr-xr-x 10 root root 4096 Nov 15 14:33 packages
drwxr-xr-x  7 root root 4096 Nov 15 14:50 vendor
drwxr-xr-x  4 root root 4096 Nov 15 15:16 out
drwxr-xr-x  2 root root 4096 Nov 15 20:26 autoloader
drwxr-xr-x  2 root root 4096 Nov 15 20:26 colors
drwxr-xr-x  2 root root 4096 Nov 15 20:26 doc
drwxr-xr-x  2 root root 4096 Nov 15 20:27 plugin
drwxr-xr-x  2 root root 4096 Nov 15 20:27 syntax
```

Figure 4.1: Main build tree.

4.2.2 Output build files

```
root@ubuntu:~/android/system/out/target/product/bacon# ls -lrt
total 1606864
-rw-r--r-- 1 root root 68922 Nov 15 15:15 clean_steps.mk
-rw-r--r-- 1 root root 832 Nov 15 15:15 previous_build_config.mk
-rw-r--r-- 1 root root 64 Nov 15 15:16 build_fingerprint.txt
-rwxr-xr-x 1 root root 6210392 Nov 15 15:43 kernel
drwxr-xr-x 4 root root 4096 Nov 15 16:14 data
drwxr-xr-x 3 root root 4096 Nov 15 16:16 install
drwxr-xr-x 2 root root 4096 Nov 15 16:16 fake_packages
drwxr-xr-x 2 root root 4096 Nov 15 16:16 persist
-rw-r--r-- 1 root root 4776108 Nov 15 16:16 persist.img
-rw-r--r-- 1 root root 231424 Nov 15 16:16 dt.img
drwxr-xr-x 3 root root 4096 Nov 15 16:17 recovery
-rw-r--r-- 1 root root 64 Nov 15 16:18 android-info.txt
drwxr-xr-x 6 root root 4096 Nov 15 16:19 symbols
drwxr-xr-x 16 root root 4096 Nov 15 16:19 root
drwxr-xr-x 6 root root 4096 Nov 15 18:52 gen
-rw-r--r-- 1 root root 1458569 Nov 15 19:01 ramdisk.img
-rw-r--r-- 1 root root 7905280 Nov 15 19:01 boot.img
-rw-r--r-- 1 root root 10377728 Nov 15 19:02 ramdisk-recovery.cpio
-rw-r--r-- 1 root root 7199136 Nov 15 19:02 ramdisk-recovery.img
-rw-r--r-- 1 root root 13645824 Nov 15 19:02 recovery.img
-rw-r--r-- 1 root root 67 Nov 15 19:02 recovery.id
-rw-r--r-- 1 root root 146459748 Nov 15 20:27 userdata.img
drwxr-xr-x 16 root root 4096 Nov 15 20:27 system
-rw-r--r-- 1 root root 150457712 Nov 15 20:27 userdata_64G.img
drwxr-xr-x 2 root root 4096 Nov 15 20:27 cache
-rw-r--r-- 1 root root 10682684 Nov 15 20:27 cache.img
drwxr-xr-x 17 root root 4096 Nov 15 20:27 obj
-rw-r--r-- 1 root root 326244 Nov 15 20:28 installed-files.json
-rw-r--r-- 1 root root 100264 Nov 15 20:29 installed-files.txt
-rw-r--r-- 1 root root 620710392 Nov 15 20:30 system.img
-rw-r--r-- 1 root root 49 Nov 15 20:35 ota_script_path
-rw-r--r-- 2 root root 332353417 Nov 15 20:40 lineage_bacon-ota-8d73391d04.zip
-rw-r--r-- 2 root root 332353417 Nov 15 20:40 lineage-14.1-20171115_231421-UNOFFICIAL-bacon.zip
-rw-r--r-- 1 root root 84 Nov 15 20:40 lineage-14.1-20171115_231421-UNOFFICIAL-bacon.zip.md5sum
```

Figure 4.2: Final build files.

4.2.3 Extracting proprietary files

Here I show the proprietary files shipping in the existing LineageOS pre-built image for the OnePlus One. All the files are categorized under different processes. Following are the details about the proprietary files.

- ADSP is the Application DSP (digital signal processor), which allows the device to process simple sets of data on low power, without having to wake up the Application processor (AP). It can run custom applications to perform simple tasks, such as word detection for voice recognition, sensor data aggregation from the accelerometer and gyroscope, and is also utilized for low power music playback. In the device it include different files are as follows:
 - bin/adsprpcd
 - vendor/lib/libadsprpc.so
 - vendor/lib/libfastcvadspstub.so
 - vendor/lib/libfastcvopt.so
- Bluetooth uses different libraries, as follows:
 - bin/btnvtool
 - bin/hciqcomminit
 - vendor/lib/libbbtnv.so
- Audio libraries include the following:
 - vendor/lib/libacdbloader.so
 - vendor/lib/libacdbrtac.so
 - vendor/lib/libadiertac.so
 - vendor/lib/libaudcal.so
 - vendor/lib/soundfx/libqcbassboost.so
 - vendor/lib/soundfx/libqcreverb.so
 - vendor/lib/soundfx/libqcvirt.so
- DRM libraries are as follows:
 - bin/qseecomd
 - lib/libdrmdecrypt.so
 - vendor/lib/libQSEECOMAPI.so
 - vendor/lib/libdrmfs.so
 - vendor/lib/libdrmtime.so
 - vendor/lib/librpmbs.so
 - vendor/lib/libssd.so
 - vendor/lib/libwvdrmL3.so

- vendor/lib/libwvm.so
- vendor/lib/libWVStreamControlAPIL3.so
- vendor/lib/drm/libdrmwmplugin.so
- vendor/lib/mediadrmlibwvdrmengine.so
- Graphic libraries and firmwares files are as follows:
 - etc/firmware/a330pfp.fw
 - etc/firmware/a330pm4.fw
 - vendor/lib/egl/eglsubAndroid.so
 - vendor/lib/egl/libEGLadreno.so
 - vendor/lib/egl/libGLESv1CMadreno.so
 - vendor/lib/egl/libGLESv2adreno.so
 - vendor/lib/egl/libq3dtoolsadreno.so
 - vendor/lib/libadrenoutils.so
 - vendor/lib/libbccQTI.so
 - vendor/lib/libC2D2.so
 - vendor/lib/libCB.so
 - vendor/lib/libc2d30-a3xx.so
 - vendor/lib/libgsl.so
 - vendor/lib/libllvm-qcom.so
 - vendor/lib/libOpenCL.so
 - vendor/lib/libsc-a3xx.so
 - vendor/lib/libRSDriveradreno.so
 - vendor/lib/librsadreno.so
 - vendor/lib/librsadrenosha1.so
 - vendor/lib/libscale.so
 - vendor/lib/libuiblur.so
- The listen service files are as follows:
 - vendor/lib/liblistenhardware.so
 - vendor/lib/liblistenjni.so
 - vendor/lib/liblisten.so
 - vendor/lib/liblistensoundmodel.so
- Media libraries on the device include files, are as follows:
 - vendor/lib/libDivxDrm.so
 - vendor/lib/libmm-color-convertor.so

- vendor/lib/libmmosal.so
- vendor/lib/libSHIMDivxDrm.so
- Sensors libraries on the device include the following:
 - bin/sensors.qcom
 - vendor/lib/hw/activityrecognition.msm8974.so
 - vendor/lib/hw/sensors.msm8974.so
 - vendor/lib/libsensor1.so
 - vendor/lib/libsensorreg.so
- Time services on the device include:
 - bin/timed daemon
 - vendor/lib/libtimegenoff.so
 - vendor/lib/libTimeService.so
 - app/TimeService/TimeService.apk
- WiFi firmwares files are as follows:
 - lib/libwpaqmieaproxy.so
 - lib/libwcnssqmi.so

```

root@ubuntu:~/android/system/device/oneplus/bacon# ./extract-files.sh
Cleaning output directory (../../../../../vendor/oneplus/bacon/proprietary)..
Extracting 127 files in ./proprietary-files-qc.txt from adb:
- /system/bin/adsprpcd .. 126 KB/s (13944 bytes in 0.107s)
- /system/bin/btnvtool .. 183 KB/s (18148 bytes in 0.096s)
- /system/bin/hci_qcomm_init .. 455 KB/s (137616 bytes in 0.294s)
- /system/bin/irsc_util .. 171 KB/s (17988 bytes in 0.102s)
- /system/bin/loc_launcher .. 427 KB/s (63236 bytes in 0.144s)
- /system/bin/mpdecision .. 376 KB/s (78696 bytes in 0.203s)
- /system/bin/netmgrd .. 490 KB/s (438144 bytes in 0.871s)
- /system/bin/qmuxd .. 457 KB/s (121968 bytes in 0.260s)
- /system/bin/qseecomd .. 175 KB/s (18176 bytes in 0.100s)
- /system/bin/radish .. 355 KB/s (42672 bytes in 0.117s)
- /system/bin/rfs_access .. 254 KB/s (26992 bytes in 0.103s)
- /system/bin/rmt_storage .. 335 KB/s (37240 bytes in 0.108s)
- /system/bin/sensors.qcom .. 603 KB/s (423392 bytes in 0.684s)
- /system/bin/time_daemon .. 275 KB/s (30332 bytes in 0.107s)
- /system/etc/data/dsi_config.xml .. 189 KB/s (21453 bytes in 0.110s)
- /system/etc/data/netmgr_config.xml .. 509 KB/s (56195 bytes in 0.107s)
- /system/etc/firmware/a330_pfp.fw .. 40 KB/s (2212 bytes in 0.054s)
- /system/etc/firmware/a330_pm4.fw .. 91 KB/s (9220 bytes in 0.098s)
- /system/etc/firmware/venus.b00 .. 3 KB/s (212 bytes in 0.054s)
- /system/etc/firmware/venus.b01 .. 3 KB/s (200 bytes in 0.055s)
- /system/etc/firmware/venus.b02 .. 661 KB/s (982928 bytes in 1.450s)
- /system/etc/firmware/venus.b03 .. 95 KB/s (5568 bytes in 0.056s)
- /system/etc/firmware/venus.b04 .. 0 KB/s (32 bytes in 0.055s)
- /system/etc/firmware/venus.mbn .. 618 KB/s (996720 bytes in 1.572s)
- /system/etc/firmware/venus.mdt .. 7 KB/s (412 bytes in 0.050s)
- /system/etc/permissions/qcnvitems.xml .. 3 KB/s (159 bytes in 0.050s)
- /system/etc/permissions/qcrilhook.xml .. 1 KB/s (159 bytes in 0.093s)
- /system/framework/qcnvitems.jar .. 366 KB/s (40201 bytes in 0.107s)

```

Figure 4.3: Proprietary files -1.


```

Extracting 61 files in ./proprietary-files.txt from adb:
- /system/bin/mm-qcamera-daemon .. 88 KB/s (9436 bytes in 0.104s)
- /system/etc/firmware/cpp_firmware_v1_1_1.fw .. 144 KB/s (16128 bytes in 0.108s)
- /system/etc/firmware/cpp_firmware_v1_1_6.fw .. 144 KB/s (16384 bytes in 0.110s)
- /system/etc/firmware/cpp_firmware_v1_2_0.fw .. 147 KB/s (16384 bytes in 0.108s)
- /system/etc/sensor_def_qcomdev.conf .. 190 KB/s (20870 bytes in 0.107s)
- /system/lib/hw/camera.vendor.bacon.so .. 680 KB/s (7328964 bytes in 10.510s)
- /system/lib/libmmcamera_interface.so .. 330 KB/s (38100 bytes in 0.112s)
- /system/lib/libmmjpeg_interface.so .. 348 KB/s (42084 bytes in 0.118s)
- /system/lib/libqomx_core.so .. 156 KB/s (17992 bytes in 0.112s)
- /system/vendor/firmware/libbn547_fw.so .. 326 KB/s (36722 bytes in 0.109s)
- /system/vendor/lib/libAKM8963.so .. + (keeping pinned file with hash 741eb7ee64bffd54d53ff6a7ed17c4baf0d2c7b8)
- /system/vendor/lib/libchromatix_imx214_common.so .. 335 KB/s (47120 bytes in 0.136s)
- /system/vendor/lib/libchromatix_imx214_default_video.so .. 238 KB/s (26392 bytes in 0.108s)
- /system/vendor/lib/libchromatix_imx214_hfr_120.so .. 237 KB/s (26392 bytes in 0.108s)
- /system/vendor/lib/libchromatix_imx214_hfr_60.so .. 244 KB/s (26392 bytes in 0.105s)
- /system/vendor/lib/libchromatix_imx214_liveshot.so .. 242 KB/s (26392 bytes in 0.106s)
- /system/vendor/lib/libchromatix_imx214_preview.so .. 243 KB/s (26392 bytes in 0.105s)
- /system/vendor/lib/libchromatix_imx214_preview_binning.so .. 243 KB/s (26392 bytes in 0.105s)
- /system/vendor/lib/libchromatix_imx214_snapshot.so .. 238 KB/s (26392 bytes in 0.107s)
- /system/vendor/lib/libchromatix_imx214_snapshot_hdr.so .. 246 KB/s (26392 bytes in 0.104s)
- /system/vendor/lib/libchromatix_imx214_video_binning.so .. 239 KB/s (26392 bytes in 0.107s)
- /system/vendor/lib/libchromatix_imx214_video_cmcc.so .. 236 KB/s (26392 bytes in 0.109s)
- /system/vendor/lib/libchromatix_imx214_video_hdr.so .. 240 KB/s (26392 bytes in 0.107s)
- /system/vendor/lib/libchromatix_ov5648_common.so .. 248 KB/s (47120 bytes in 0.184s)
- /system/vendor/lib/libchromatix_ov5648_default_video.so .. 242 KB/s (26392 bytes in 0.106s)
- /system/vendor/lib/libchromatix_ov5648_preview.so .. 245 KB/s (26392 bytes in 0.104s)
- /system/vendor/lib/libchromatix_ov5648_preview_fb.so .. 233 KB/s (26392 bytes in 0.110s)
- /system/vendor/lib/libchromatix_ov5648_video_cmcc.so .. 219 KB/s (26392 bytes in 0.117s)
- /system/vendor/lib/libchromatix_ov5648_zsl.so .. 250 KB/s (26392 bytes in 0.102s)
- /system/vendor/lib/libchromatix_ov5648_zsl_fb.so .. 236 KB/s (26392 bytes in 0.109s)
- /system/vendor/lib/libjpegdhw.so .. 210 KB/s (21648 bytes in 0.100s)
- /system/vendor/lib/libjpegehw.so .. 172 KB/s (18476 bytes in 0.104s)
- /system/vendor/lib/libmmcamera2_c2d_module.so .. 345 KB/s (42104 bytes in 0.119s)
- /system/vendor/lib/libmmcamera2_cpp_module.so .. 437 KB/s (62520 bytes in 0.139s)
- /system/vendor/lib/libmmcamera2_frame_algorithm.so .. 83 KB/s (5216 bytes in 0.061s)
- /system/vendor/lib/libmmcamera2_iface_modules.so .. 240 KB/s (25700 bytes in 0.104s)
- /system/vendor/lib/libmmcamera2_inglb_modules.so .. 653 KB/s (784744 bytes in 1.172s)
- /system/vendor/lib/libmmcamera2_isp_modules.so .. 623 KB/s (419948 bytes in 0.657s)
- /system/vendor/lib/libmmcamera2_pproc_modules.so .. 278 KB/s (29796 bytes in 0.104s)
- /system/vendor/lib/libmmcamera2_sensor_modules.so .. 436 KB/s (93032 bytes in 0.208s)
- /system/vendor/lib/libmmcamera2_stats_algorithm.so .. 551 KB/s (272700 bytes in 0.482s)
- /system/vendor/lib/libmmcamera2_stats_modules.so .. 372 KB/s (79000 bytes in 0.206s)
- /system/vendor/lib/libmmcamera2_vpe_module.so .. 356 KB/s (43108 bytes in 0.118s)
- /system/vendor/lib/libmmcamera2_wnr_module.so .. 81 KB/s (5076 bytes in 0.061s)
- /system/vendor/lib/libmmcamera_faceproc.so .. 702 KB/s (1234160 bytes in 1.716s)
- /system/vendor/lib/libmmcamera_hdr_gb_lib.so .. 449 KB/s (71092 bytes in 0.154s)
- /system/vendor/lib/libmmcamera_hdr_lib.so .. 323 KB/s (38220 bytes in 0.115s)
- /system/vendor/lib/libmmcamera_inglb.so .. 377 KB/s (80012 bytes in 0.206s)
- /system/vendor/lib/libmmcamera_imx214.so .. 137 KB/s (17208 bytes in 0.121s)
- /system/vendor/lib/libmmcamera_ov5648.so .. 77 KB/s (8404 bytes in 0.105s)
- /system/vendor/lib/libmmcamera_sony_imx214_eeprom.so .. 78 KB/s (5200 bytes in 0.064s)
- /system/vendor/lib/libmmcamera_tintless_algo.so .. 173 KB/s (17552 bytes in 0.098s)
- /system/vendor/lib/libmmcamera_tintless_bg_pca_algo.so .. 124 KB/s (13508 bytes in 0.105s)
- /system/vendor/lib/libmmcamera_tuning.so .. 648 KB/s (549948 bytes in 0.827s)
- /system/vendor/lib/libmmcamera_wavelet_lib.so .. 317 KB/s (34208 bytes in 0.105s)
- /system/vendor/lib/libmmipl.so .. 625 KB/s (514872 bytes in 0.803s)
- /system/vendor/lib/libmmjpeg.so .. 458 KB/s (145728 bytes in 0.310s)
- /system/vendor/lib/libmmjpeg_codec.so .. 537 KB/s (161408 bytes in 0.293s)
- /system/vendor/lib/liboemcamera.so .. 338 KB/s (37988 bytes in 0.109s)
- /system/vendor/lib/libqomx_jpegdec.so .. 435 KB/s (63104 bytes in 0.141s)
- /system/vendor/lib/libqomx_jpegenc.so .. 453 KB/s (112256 bytes in 0.241s)

```

Figure 4.4: Proprietary files (listing 2).

Table 4.1: OnePlus One mobile specifications.

Parameter	Description
Codename	Bacon
Screen	5.5" IPS-LCD
Resolution	1080x1920
Soc	Qualcomm MSM8974AC Snapdragon 801
CPU	Quad-core 2.5 GHz Krait 400
GPU	Adreno 330
RAM	3GB
Storage	64GB
Rear Camera	13MP
Front Camera	5MP
Battery	3000mAh

Chapter 5

Discussion and Conclusion

5.1 Discussion

In this special study, I observe that the challenges for LineageOS are increasing compared to the stock Google Android variants. Although the alternative Google Play Services and client applications compared to the official Play services, primarily due to the user experience, which could be improved. I also observe that Google proprietary policy on different devices has led to security vulnerabilities and violation of users' privacy. By installing and contributing to the development of alternatives to the Google Play Services such as the microG project, we can support reverse engineering of certain Google services such as back-end location service, push notification and messaging service, and network-based location services utilizing the Mozilla location service for geolocation.

5.2 Conclusion

This special study explores opportunities for contributing to the development of LineageOS as a fully open mobile operating system. I show how to build LineageOS, and the same procedure should be applicable to many different devices. I describe alternatives to the Google Play services. From previous work, I conclude that data privacy and security vulnerabilities from the Play Store have violated users' privacy, that closed-source models are unable to solve those issues, making it important to invest in open source alternatives to improve user experience and make them a truly viable alternatives.

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