Mobile Devices - An Introduction to the Android Operating Environment

Design, Architecture, and Performance Implications

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1.0 Introduction

With the worldwide proliferation of mobile devices, reliability, availability, connectivity, as well as performance related concerns, similar to the once encountered on traditional IT server systems, became paramount. On the smartphone and internet tablet side, one of the fastest growing solutions are Android based products (source *digitimes 2010*). While Android based systems get a lot of exposure in the media, there is a lot of myth surrounding the actual implementation details. Some people label Android as a Linux solution, which really does not reflect the facts. Ergo, this report discusses the major components that comprise the Android operating environment, elaborating on the Android design and architecture (the building blocks), as well as addressing the Android verses Linux question.

2.0 Background & History

Android is described as a mobile operating system, initially developed by Android Inc. Android was sold to Google in 2005. Android is *based* on a *modified* Linux 2.6 kernel. Google, as well as other members of the Open Handset Alliance (OHA) collaborated on Android (design, development, distribution). Currently, the Android Open Source Project (AOSP) is governing the Android maintenance and development cycle [8].

To reiterate, the Android operating system is based on a *modified* Linux 2.6 kernel [6]. Compared to a Linux 2.6 environment though, several drivers and libraries have been either modified or newly developed to allow Android to run as efficiently and as effectively as possible on mobile devices (such as smart phones or internet tablets). Some of these libraries have their roots in open source projects. Due to some licensing issues, the Android community decided to implement their own *c* library (*Bionic*), and to develop an Android specific Java runtime engine (*Dalvik Virtual Machine* – DVM). With Android, the focus has always been on optimizing the infrastructure based on the limited resources available on mobile devices [2]. To complement the operating environment, an Android specific application framework was designed and implemented. Therefore, Android can best be described as a complete solution stack, incorporating the OS, middlewear components, and applications. In Android, the modified Linux 2.6 kernel acts as the hardware abstraction layer (HAL). To summarize, the Android operating environment can be labeled as:

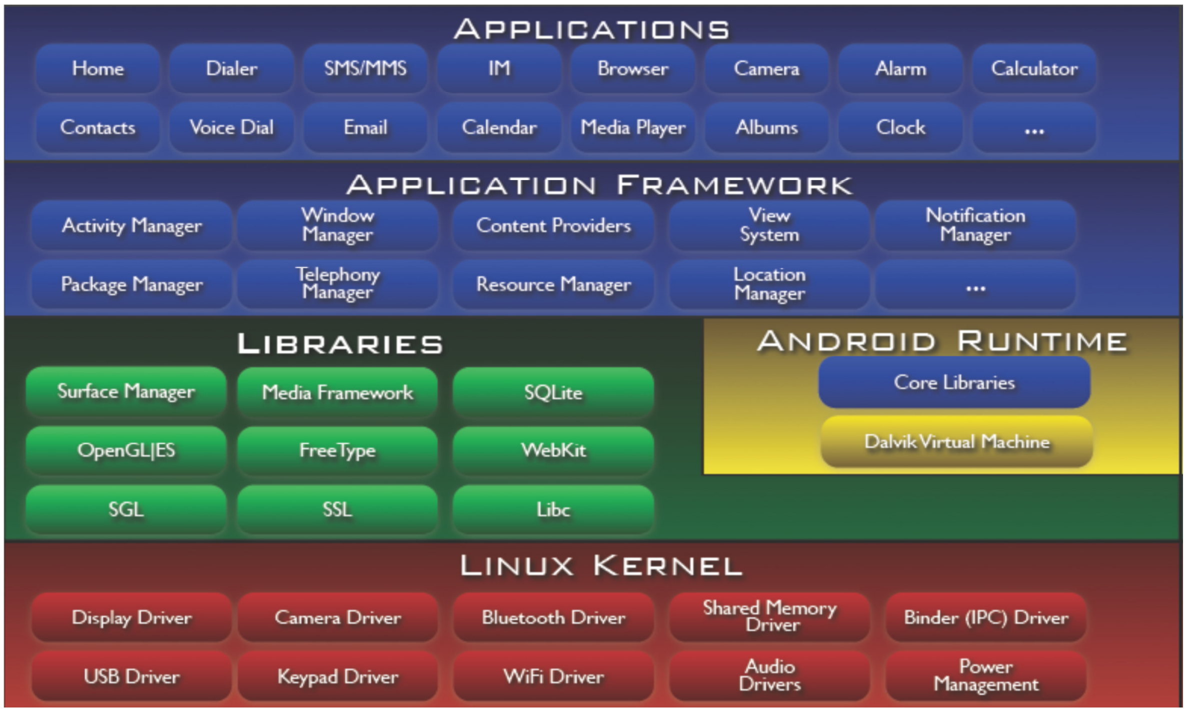
- An open platform for mobile development
- A hardware reference design for mobile devices

- A system powered by a modified Linux 2.6 kernel
- A run time environment
- An application and user interface (UI) framework

3.0 Android Architecture

Figure 1 outlines the current (layered) Android Architecture. The modified Linux kernel operates as the HAL, and provides device driver, memory management, process management, as well as networking functionalities, respectively. The library layer is interfaced through Java (which deviates from the traditional Linux design). It is in this layer that the Android specific libc (*Bionic*) is located. The *surface manager* handles the user interface (UI) windows. The Android runtime layer holds the *Dalvik Virtual Machine* (DVM) and the core libraries (such as Java or IO). Most of the functionalities available in Android are provided via the core libraries.

Figure 1: Android Architecture



Note: Figure 1 courtesy of the OHA

The application framework houses the API interface. In this layer, the *activity manager* governs the application life cycle. The *content providers* enable applications to either access data from other applications or to share their own data. The *resource manager* provides access to non-code resources (such as graphics), while the *notification manager* enables applications to display custom alerts. On top of the application framework are the built-in, as well as the user applications, respectively. It has to be pointed out that a user application can replace a built-in application, and that each Android application runs in its own process space, within its own DVM instance. Most of these major Android components are further discussed (in more detail) in the next few sections of this report.

3.1 Dalvik Virtual Machine

Android based systems utilize their own virtual machine (VM), which is known as the Dalvik Virtual Machine (DVM) [4]. The DVM uses special byte-code, hence native Java byte-code cannot directly be executed on Android systems. The Android community provides a tool (*dx*) that allows converting Java class files into Dalvik executables (*dex*). The DVM implementation is highly optimized in order to perform as efficiently and as effectively as possible on mobile devices that are normally equipped with a rather slow (single) CPU, limited memory resources, no OS swap space, and limited battery capacity. The DVM has been implemented in a way that allows a device to execute multiple VM's in a rather efficient manner. It also has to be pointed out that the DVM relies on the modified Linux kernel for any potential threading and low-level memory management functionalities.

With Android 2.2, some major changes to the JVM infrastructure were implemented. Up to version 2.2, the JVM was an actual *interpreter*, similar to the original JVM solution deployed with Java 1.0. While the Android solution always reflected a very efficient interpreter, it was still an interpreter and hence, no native code was generated. With the release of Android 2.2, a just-in-time (JIT) compiler has been incorporated into the solution stack, which translates the Dalvik byte-code into much more efficient machine code (similar to a C compiler). Down the road, additional JIT and garbage collection (GC) features will be deployed with Android, further busting (potential) aggregate systems performance.

3.2 Target Platform - Instruction Set

To simplify the discussion, the statement made here is that most of the Linux 2.6 based devices are *x86* based systems, whereas most mobile phones are *ARM* based products. While ARM represents a 32-bit reduced instruction set computer (*RISC*) instruction set architecture, x86 systems are primarily based on the complicated instruction set computer (*CISC*) architecture. In general, the statement can be made that ARM (RISC) is executing simpler (but more) instructions compared to an x86 (CISC) system. As already discussed, memory is at a premium in mobile devices due to size, cost, and power constraints.

ARM addresses these issues by providing a 2nd 16-bit instruction set (labeled *thumb*) that can be interleaved with regular 32-bit ARM instructions. This additional instruction set can reduce the code size by up to 30% (at the expense of some performance limitations). Ergo, from an overall systems perspective, the incorporation of the *thumb* instruction set can be considered as an exercise in compromises. Compared to x86 processors, the ARM design reveals a strong focus on lower power consumption, which again makes it suitable for mobile devices [1].

3.3 Kernel and Startup Process

It is paramount to reiterate that while Android is based on Linux 2.6, Android does not utilize a standard Linux kernel [6],[7]. Hence, an Android device should not be labeled a Linux solution per se. Some of the Android specific kernel enhancements include:

- alarm driver (provides timers to wakeup devices)
- shared memory driver (ashmem)
- binder (for inter-process communication),
- power management (which takes a more aggressive approach than the Linux PM solution)
- low memory killer
- kernel debugger and logger

During the Android boot process, the Android Linux kernel component first calls the *init* process (compared to standard Linux, nothing unusual there). The *init* process accesses the files *init.rc* and *init.device.rc* (*init.device.rc* is device specific). Out of the *init.rc* file, a process labeled *zygote* is started. The *zygote* process loads the core Java classes, and performs the initial processing steps. These Java classes can be reused by Android applications and hence, this step expedites the overall startup process. After the initial load process, *zygote* idles on a socket and waits for further requests.

Every Android application runs in its own process environment. A special driver labeled the *binder* allows for (efficient) inter-process communications (IPC). Actual objects are stored in shared memory. By utilizing shared memory, IPC is being optimized, as less data has to be transferred. Compared to most Linux or UNIX environments, Android does not provide any swap space. Hence, the amount of virtual memory is governed by the amount of physical memory available on the device [7].

3.4 The Bionic Library

Compared to Linux, Androids incorporates its own *c* library *(Bionic*) [3]. The *Bionic* library is not compatible with the Linux *glibc*. Compared to *glibc*, the *Bionic* library has a smaller memory footprint. To illustrate, the Bionic library contains a special thread implementation that 1st, optimizes the memory consumption of each thread and 2nd, reduces the startup time of a new thread. Android provides run-time access to kernel primitives [2]. Hence, user-space components can dynamically alter the kernel behavior. Only processes/threads though that do have the appropriate permissions are allowed to modify these settings.

Security is maintained by assigning a unique user ID (*UID)* and group ID (*GID)* pair to each application. As mobile devices are normally intended to be used by a single user only (compared to most Linux systems), the UNIX/Linux */etc/passwd* and */etc/group* settings have been removed. In addition (to boost security), */etc/services* was replaced by a list of services (maintained inside the executable itself). To summarize, the Android *c* library is especially suited to operate under the limited CPU and memory conditions common to the target Android platforms [2]. Further, special security provisions were designed and implemented to ensure the integrity of the system.

3.5 Storage Media & File System

When it comes to configuring and setting-up mobile devices, traditional hard drives are in general too big (size), too fragile, and consume too much power to be useful. In contrast, flash memory devices normally provide a (relative) fast read access behavior as well as better (kinetic) shock resistance compared to hard drives. Fundamentally, two different types of flash memory devices are common, labeled as *NAND* and *NOR* based solutions [5]. While in general, *NOR* based solutions provide low density, they are characterized as (relative) slow write and fast read components. On the other hand, *NAND* based solutions offer low cost, high density, and are labeled as (relative) fast write and slow read IO solutions. Some embedded systems are utilizing *NAND* flash devices for data storage, and *NOR* based components for the code (the execution environment).

From a file system perspective, as of Android version 2.3, the (well-known) Linux *ext4* file system is being used [9]. Prior to the *ext4* file system, Android normally used *YAFFS* (yet another flash file system). The *YAFFS* solution is known as the first *NAND* optimized Linux flash file system. Some Android product providers (such as Archos with *ext3* in Android 2.2) replaced the *standard* Archos file system with another file system solution of their choice. As of the writing of this report, the maximum size of any Android application equals to a *low 2-digit MB* number, which compared to actual Linux based systems has to be considered as being very small. This implies that the memory and file system requirements (from a *size* perspective – not from a *data integrity* perspective) are vastly different for Android based devices compared to most Linux systems.

3.6 Power Management

In the mobile device arena, power management is obviously paramount. That does not imply though that power management should be neglected on any other system. Hence, power management in any IT system, with any operating system, is considered a necessity due to the ever increasing power demand of today's computer systems. To illustrate, to reduce and manage power consumption, Linux based systems provide power-saving features such as *clock gating*, *voltage scaling*, activating *sleep modes*, or *disabling memory cache*. Each of these features reduces the system's power consumption (normally at the expense of an increased latency behavior) [9]. Most Linux based systems manage power consumption via the Advanced Configuration and Power Interface (*ACPI*).

Android based systems provide their own power management infrastructure (labeled *PowerManager*) that was designed based on the premise that a processor should not consume any power if no applications or services actually require power. Android demands that applications and services request CPU resources via *wake locks* through the Android application framework and native Linux libraries. If there are no active *wake locks*, Android will shutdown the processor.

4.0 Android Applications

Android applications are bundled into an Android package (*.apk*) via the Android Asset Packaging Tool (*AAPT*). To streamline the development process, Google provides the Android Development Tools (*ADT*). The ADT streamlines the conversion from class to *dex* files, and creates the *.apk* during deployment. In a very simplified manner, Android applications are in general composed of:

- *Activities* (needed to create a screen for a user application – classes with a UI)
- *Intents* (used to transfer control from one activity to another)
- *Services* (classes without a UI, so they can be executed in the background)
- *Content Providers* (allows the application to share information with other applications)

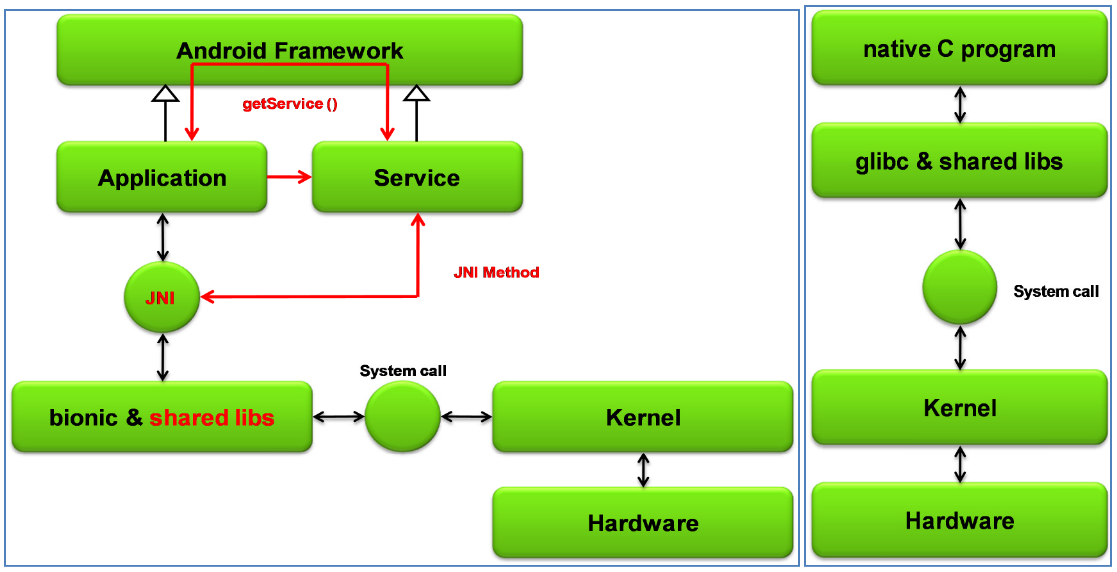
5.0 Android and Linux – Comparison

Figure 2 discloses the major differences between the Android and the Linux 2.6 operating environment. First of all, the Android kernel was derived from Linux, but has been significantly altered outside the mainline Linux kernel distribution. To further illustrate that point, Android is neither equipped with a native X-Windows setup, nor does it support the full set of standard GNU libraries. Hence, it is a daunting task to port any existing GNU/Linux application or library to Android (*support* for X-Windows would be possible in Android though).

The biggest difference between Linux and Android revolves around the ***Java*** abstraction layer embedded into Android. As depicted in Figure 2, the Android design is based on a deeper *implementation stack* than Linux. In other words, the Android applications are farther removed from the actual kernel than in Linux (have a longer code path down into the OS layer). The core of Linux applications are developed in *c* and *c++,* hence *c* and *c++* code represents the predominant Linux application environment. In Linux, the user applications (via the libraries and the system call subsystem) have direct kernel access, not so with Android (see Figure 2) [7]. In Android, the kernel is almost *hidden* deep inside the Android operating environment. Under Linux, the *make* process for (*c, c++*) applications can directly be optimized via special compiler flags, further boosting application performance [7]. Further, the Linux operating setup natively incorporates a very rich infrastructure of libraries, debuggers, and development tools that are not accessible by Android.

While the Android design is based on a *deeper implementation* stack, and hence the applications are farther removed from the kernel compared to Linux, Android kernel performance is still important and has to be quantified and understood. As in Linux, aggregate application performance is still impacted by the efficiency of the implemented kernel primitives. Compared to Linux, only a few Android performance, stress-testing, and benchmarking tools (such as *DHTDroid*) are available today. Based on the rapid development and deployment cycle of Android based systems, the need for actual Android application and kernel-level performance tools will increase rather significantly over the near future.

Figure 2: The Android vs. the Linux 2.6 Environment



Note: Figure 2 courtesy of OHA. The Java Native Interface (JNI) represents the interface between the Java code (running in a JVM) and the native code running outside the JVM.

Summary

Elaborating on the major components that comprise the Android operating environment, this report focused on providing a comprehensive overview of the status quo. The very impressive, rapid evolution of Android resembles the great work done by the Linux community over the years. As discussed in this report, Android is not a Linux solution per se, but does utilize a modified Linux 2.6 kernel that is incorporated into the Android operating environment.

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