Comparative Study of Google Android, Apple iOS and Microsoft Windows Phone Mobile Operating Systems

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Abstract—**This paper focuses on a comparative study of the most used three operating systems for mobile devices: Google Android, Apple iOS and Microsoft Windows Phone. The article presents which are the most important features of this three operating systems. The paper also deals with the features that these operating systems have in common and analyzes some of their disadvantages.**

Keywords—Google Android; Apple iOS; Windows Phone Mobile; Mobile Operating Systems; software platforms;

I. INTRODUCTION

The operating system is a program that acts as an intermediary between a computer user and the computer hardware. We shall use both the abbreviation OS and the complete denomination operating system. An operating system has the following main objectives: first it has to execute user programs and facilitate troubleshooting for users; secondly it has to make the computing system easy to use; and third it has to use efficiently the hardware of the computing system [1], [2].

The operating system offers services to both users and developers who make possible the operation of a computer without the need of employing low-level hardware controls, which are difficult run. The operating system provides relatively uniform interfaces to access a wide range of devices the computer interacts with, from input/output devices, such as printers or digital cameras, to wire or wireless network components that ensure communication among computers. The operating system allows users to create, manage and organize different types of files [11]. Most modern operating systems provide graphical interfaces (GUI - Graphical User Interface) to ensure the relatively easy usage for customers [6], [9], [10], [18].

II. OPERATING SYSTEMS

Operating systems usually provided a set of APIs, named system calls. However safer operating systems have been adopted recently. Currently we have multithreading and multicore architectures integrated into our operating systems. Modern operating systems for mobile devices support many media formats: audio, video, image, and may use video cameras, touchscreens, GPS, accelerometers, accelerated 3D graphics and other types of sensors.

System calls have changed so dramatically in the past two years that they actually became irrelevant. This change may be attributed to two companies, Apple and Google, which are real innovation forces. With the launch of the iPhone by Apple a new paradigm has been introduced on the market, i.e. the one where the keywords are controlled user interfaces and application stores. Google followed this example with the introduction of the Android operating system, which was quickly adopted by both application developers and users. This caused a major change in the way we think about operating systems, [8], [12], [13], [14], [15].

III. Operating Systems for Mobile Devices

A. The Android Operating System

The Android operating system and its video call services show how this operating system is different from others: it is based on Linux and may be considered a variant of embedded Linux [3], [7].

It can be said that Android operating system is the leading mobile platform from Google; it brings a wealth of features to increase both speed and performance. The version 5 of the Android operating system, brings a wealth of features designed to improve the mobile experience.
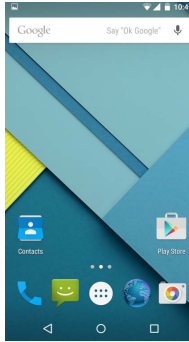

Fig. 1. The 5.0 Android (Lollipop) operating system [19]

Android is a platform and also an operating system for mobile phones and other devices. Android OS is designed especially for touch screen mobile devices but also for television (TV Android), cars (Android Auto) and watches (Android Wear). It can be said that there are many hardware products on which an Android OS is running [19], [20]. This OS can transform a mobile device into a personal computer with the size of a pocket calculator.

Google Play (formerly called Android Market) is a service of online stores selling songs, movies, books and apps/games for the Android operating system. Since January 2015 we have access to more than 1.43 million applications available in this shop. Android is first in terms of applications downloads. In the summer of 2013, 50 billion downloads were performed, but the main problem is represented by the quality of these applications as compared to applications developed on other modern mobile operating systems. Originally only free apps were accepted, but since 2009 payable applications are also available [19], [20], [21].

The Android OS is an open source software, which means that any user can bring improvements to the operating system, therefore one may benefit not only from Google developers' know-how, but also from that of third-party developers. Google opened the entire source code (including the network and telephony support) so producers are free to add extensions without making them available to the open source community. Android has been criticized for the fact that some parts of libraries and APIs are not fully open source [19], [20].

The version 5.1 of the Android mobile operating system is an operating system known as "Lollipop Android" ("Android L"), developed by Google and released at the end of 2014 [22]. The list of Android OS versions begins with the introduction of Android 1.0. in November 2007 and there is a large number of updates from this original release. These updates eliminate bugs and add new features. Since April 2009, each version of Android developed a code name based on desserts. These versions have been launched in alphabetical order [25]:

- Alpha (1.0)
- Beta (1.1)
- Cupcake (1.5)
- Donut (1.6)
- Éclair (2.0-2.1)
- Frozen Yogurt "Froyo" (2.2-2.2.3)
- Gingerbread (2.3-2.3.7)
- Honeycomb (3.0-3.2.6)
- Ice Cream Sandwich (4.0-4.0.4)
- Jelly Bean (4.1-4.3.1)
- KitKat (4.4-4.4.4, 4.4W-4.4W.2)
- Lollipop (5.0-5.1)

From the beginning to version 5.0, the Android platform used a virtual machine called Dalvik as a just-in-time process (JIT) for compiling the code obtained from Java byte code. Dalvik compiles the application each time it is launched, [19]. The Android OS architecture is shown in Figure 2, which also indicates how this OS is different from other sub-Linux OS.
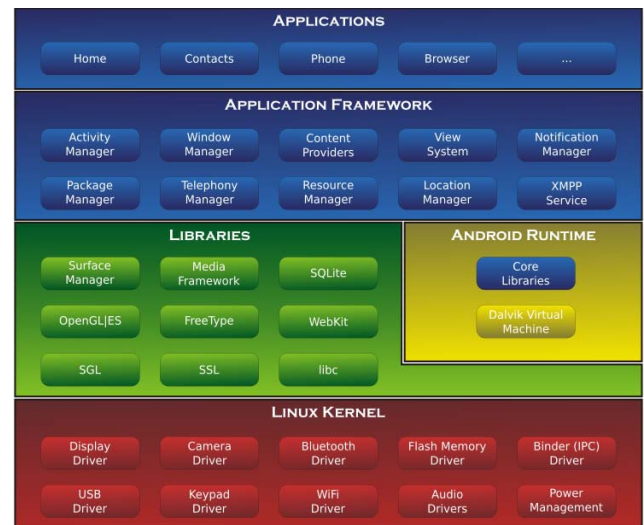

Fig. 2. The architecture of the Android operating system with Dalvik virtual machine [19]

As shown in Figure 2, Linux is just part of this architecture, and is placed at the lowest level. As in the case of the OS from Apple, we do not see the Android OS as a Linux operating system, and thus most developers do not have access at this level.

From the point of view of its developer, the Android OS has a Kinux kernel, based on Java (with Eclipse plugin); it has

its own Google virtual machine, called Dalvik, and the Linux features are not accessible to users [5].

Application Framework domain and the Applications domain, are marked in blue in Figure 2, and are all written in Java language. Application developers are limited to the upper part of the architecture while device manufacturers must optimize and execute their code at all levels of this architecture [7].

The new method of running Android Runtime (ART) applications compiles the bytecode at installing the software. After Android 4.4, ART has become the option of running in the next major release of Android 5.0, [19]. Figure 3 presents the architecture of 5.0 Android OS.
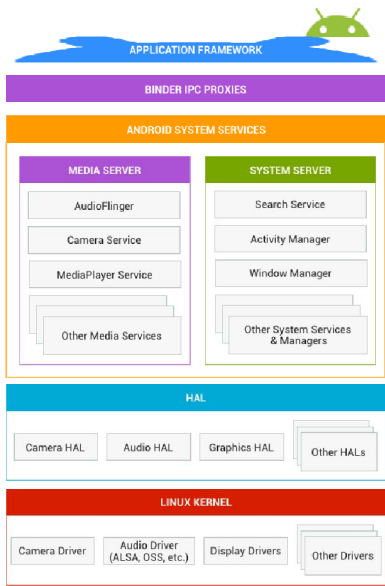

Fig. 3. The architecture of Android 5.0 OS [24]

Figure 4 shows the hardware abstraction layer (HAL).

Android Runtime (ART) is used by the mobile Android operating system, which was first present in Android 4.4 KitKat; in Android 5.0, the Dalvik virtual machine is replaced completely. ART replaces Dalvik virtual machine, which carries out the turning of the application bytecode into native instructions every time the respective application starts (just-in-time). ART introduces a new method called ahead-of time (AOT), compilation, which is performed at installing the application.
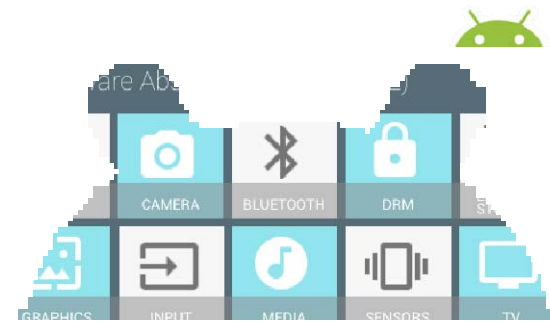

Fig. 4. Hardware Abstraction Layer (HAL) [24]

This technique eliminates JIT-associated processing techniques to improve system performance and optimize battery usage (Volta Project). Installation may take longer and requires more storage space for the compiled bytecode site, but at running applications it reduces the cost of resources and CPU usage, so battery life increases. Other advantages are: improving the waste collector, debugging applications and performance measurement. We can thus argue that overall efficiency is improved while energy consumption is reduced. In order to maintain compatibility with previous applications versions, ART uses the same bytecode format as the Dalvik virtual machine for the generated code. ART is cross-platform on 32-bits or 64-bits and accepts x86, ARM, MIPS and MIPS64, x86-64 [22], [23]. The company Samsung contributed with Knox, a security framework that provides the separation of personal data and is oriented towards work for any device, being accompanied with APIs for environmental management. The devices can also be configured so as customers do not have to use PINs or other security methods, if the user is in a physical location preset as a reliable one, or is close to an Android Wear device. At the same time, the device has data encryption implicitly enabled [22].

There are other mobile phone manufacturers who have introduced this OS (Samsung Electronics HTC, Sony, LG Electronics, etc.) because Android operating system offers increased speed and performance and allows us to turn the mobile device into a portable modern PC.

B. The Windows Phone Operating System

The template Windows Phone is also an OS designed for smart mobile devices. This OS was developed by Microsoft. Windows Phone OS is the successor of Windows Mobile platform, which was based on Windows CE kernel, starting with the operating system Pocket PC 2000 [4], [26]. Windows Phone 7 OS was announced on February 15, 2010 and was released on November 8, 2010 [16]. This OS was preceded by Windows Mobile 6.x version. In chronological order, the Windows Phone versions are [26]: Windows Phone 7, Windows Phone 7.5, Windows Phone 7.8, Windows Phone 8 (GDR1, CDR2, GDR3), Windows Phone 8.1 (GDR1, CDR2) and Windows 10 (mobile).

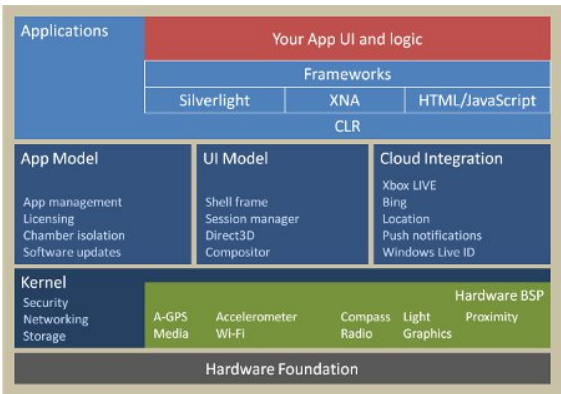The architecture of Windows Phone 7 is swown in figure 5.

Fig. 5. The architecture of Windows Phone 7 operating system [7].

Analyzing the architectures in Figures 2 and 5, it may be argued that one can almost map the architecture of Windows Phone 7 OS on the old architecture of Android OS.

As with the Android OS, Windows Phone OS is projected for multiple hardware platforms and chipsets, so that application developers must be able to "compile" in real time. Microsoft chose to use C# language as the main development language and everything is compiled on the CLR, which is its own virtual machine, similar to the Dalvik virtual machine of the Android OS. In 2011, Microsoft launched Windows Phone 7.5 Mango OS. Another minor change was launched in 2012 and is known as "Tango". On October 29, 2012, Microsoft released Windows Phone 8, a new generation of the operating system. Windows Phone 7 could not be upgraded to Windows Phone 8 due to hardware limitations [26].

Windows Phone 8.1 is a version of the operating system released in April, 2014. New features added to it include a notification center, Internet Explorer 11, the possibility of synchronization with other devices, separate volume control etc. Windows Phone 8.1 OS added "Cortana", which is a voice assistant similar to Siri and Google Now [26].

Fig. 7. Windows 10 operating system interface (mobile) [27].

An element of novelty is represented by the fact that notifications can be synchronized among devices. Another advantage is the improved interface and its application, as well as its use with one hand. Microsoft introduces a new web browser project called "Spartan", which will replace Internet Explorer Mobile browser [27].

The main criticism brought to Windows Phone OS is the absence of apps compared to iOS and Android operating systems. Windows Phone Store is a digital distribution platform developed by Microsoft for its Windows Phone platform. Microsoft has confirmed that there are over 200,000 apps in Windows Store, and that there are over 585 000 apps in Windows Store and Windows Phone Store combined. This means that there are over 385,000 apps in Windows Phone Store. Even if Windows Store platform has far fewer apps, however, most of the top 50 downloaded apps are available in Windows Phone Store. As application platform installed on smartphones, Windows Store platform is on the third place, behind the platforms from Android OS and iOS OS [28].
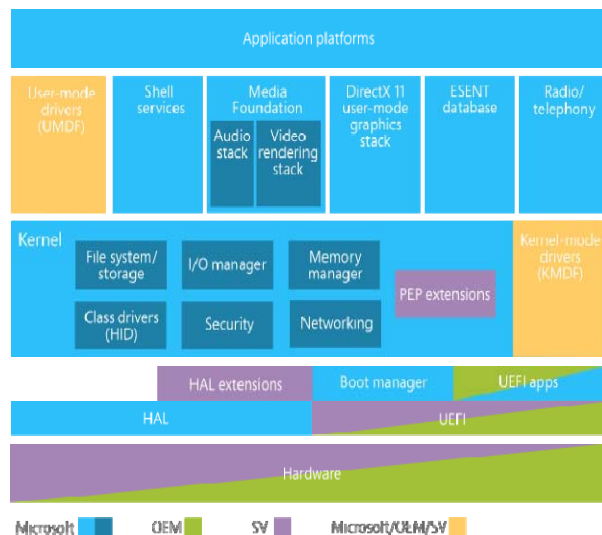

Fig. 6. The architecture of Windows Phone 8.1 operating system, [29].

Windows Phone OS was withdrawn in 2015, due to the new Microsoft strategy. In 2015 Windows 10 OS (mobile) was launched, which was designed to provide a universal experience about the PC version of Windows 10, [26], [27].

Windows 10 (mobile) was announced on January 21, 2015 and was released on February 12, 2015 as a mobile operating system for smartphones and tablets. Its main objective is the unification of applications and services. To provide an example in this respect, Microsoft Store refers to smartphones by "Windows 10 ready" and not by "Windows Phone 10". Microsoft downplayed reference to brand Windows Phone; however, we can state that Windows 10 OS is a continuation Windows Phone OS given the similarity of functioning for the two operating systems [26], [27]. Windows 10 (mobile) OS supports ARM and Intel x86 systems and uses Hybrid Windows NT kernel [27].

C. The iOS Operating System

The iOS OS (originally called iPhone OS) is the mobile operating system developed by Apple Inc. for mobile devices manufactured by Apple. Originally this operating system was developed for iPhone, and later it was extended to be implemented on other Apple devices, such as iPod touch (MP3 player), iPad, Apple TV (set-top box type of device). These devices are much more expensive, but also stable as compared to other devices and systems produced by competing manufacturers [17], [33].

iOS is a Unix-like operating system, which contained, since its first version, several elements of Mac OS X operating system (Unix-like operating system from Apple Inc.). One of

the main advantages of iOS OS is that Apple allows the updating of the operating system for older tablets, but this support is declining. Apple provides updates to iOS operating system through over-the-air (OTA) interface. For product policy reasons, iOS OS does not support the Flash multimedia application of Adobe American company [17], [33].

iOS 8 OS is the successor to iOS 7 OS, launched on September 17, 2014. iOS 8 is based on the redesign of iOS7 OS with improvements on the interface as well. As a novelty this OS provides for example the functionality of a personal Internet access point (hotspot) [33], [38]. The latest update is iOS 8.2 OS, which was launched on March 9, 2015. This new version has solved many problems and bugs and introduced support for the upcoming Apple Watch. Currently, there is another version of iOS 8 OS, which is still in a beta stage, namely iOS 8.3 Beta3 OS, launched on March 12, 2015. With this new version, Apple continues to limit the support for older devices such as iPhone 4, [30], [31], [33].
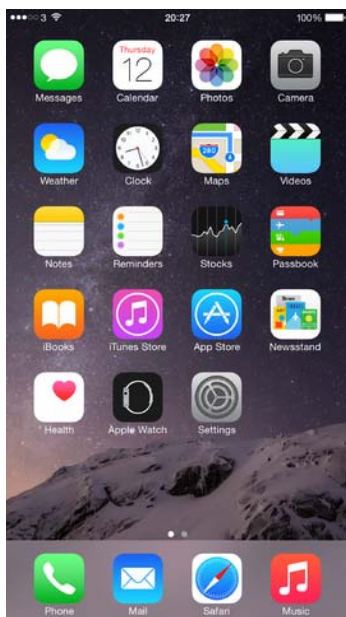

Fig. 8. The iOS 8 operating system [30].

App Store is a digital distribution platform for mobile applications developed and maintained by Apple for iOS OS. With App Store, users can browse and download applications that are developed with the SDK of Apple iOS OS. Applications can be downloaded directly to a device with an iOS OS, or to a personal computer. App Store includes many quality applications, which most often are worth their price. On February 1, 2015, App Store has reached over 1.4 million apps and over 75 billion downloads [32].

Given its functionality, iOS OS is one of the success factors of iPhones in the world market. A competitor of iOS is the Android operating system from Google [33]. iOS operating system is different from previous operating systems (Android and Windows Phone), mainly because both the operating system and the final products are maintained and developed by the same company. You can't get an iOS OS to run on a different machine because there is no license to install an iOS

operating system on hardware that has not been manufactured by Apple. Today there are only simulators on the market for iOS OS. With iOS, there are four levels of abstraction: the operating system kernel, the core services level, the media level and the user interface [33].

Unfortunately even if much information is available for iOS OS, there is no chart that would represent the architecture of this operating system. Figure 9 shows the mapping of Cocoa Touch interface in iOS operating systems.
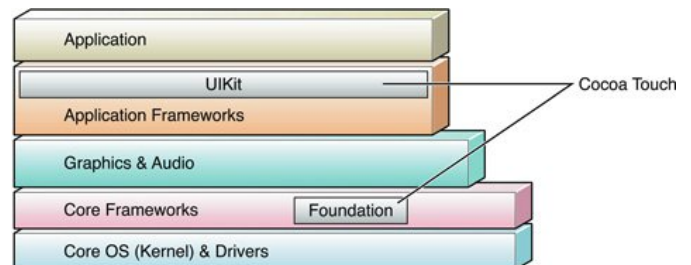

Fig. 9. Mapping the Cocoa Touch interface in iOS OS architecture, [7].

Core OS level contains a kernel system, the file manager, a safety system and a series of device drivers, etc. Core OS is the closest to hardware with a UNIX multitasking kernel. Here are APIs written in C language, and not Object Oriented, [34]. The kernel of iOS OS is called XNU and is a core of Darwin. Versions starting with iPhone OS (1.0) and up to iPhone OS 3.1.3 have used the 9.0.0d1 version of Darwin and Darwin's current version is 14.0.0, [33]. The Core Services level is located above the base layer of the operating system and in this place we have Object Oriented APIs. This layer is object oriented offering basic functionality also covering Core OS [34]. Core Services provides basic services such as handling with lines, collections administration, interaction with network, the management of contact and options. These services give the possibility to use the hardware features of the device (GPS, compass, accelerometer or gyroscope) [37]. The Media Level is the next level used for multimedia transfer [34], [37].

Cocoa Touch is the user interface of the iOS operating system, being an interface whereby developers interact at the rate of 90% when developing an application. This interface is fully object-oriented [34]. Cocoa Touch contains the framework that enables one write an app on iOS OS and these frameworks define the aspect of the application. They also provide the basic application infrastructure and support for multitasking, touch, notifications etc. [36]. Although the Cocoa Touch interface of iOS OS is similar to the Cocoa interface of Mac OS X, there are some essential differences between the two interfaces [37]. The main development language used is either Objective-C or Swift. Swift is a compiled programming language, created and introduced by Apple in 2014 for iOS OS. Swift is projected to interact with Cocoa and Cocoa Touch frameworks and with the existing code written in Objective-C for Apple products. Swift is designed to be more resistant to erroneous codes ('safer') than Objective-C, and also more concise. Swift is built with the help of LLVM compiler, included in Xcode 6, and it uses runtime Objective-C, which enables the use of C, Objective-C, C ++ and Swift languages

[35]. Developers receive 70% from the sale of applications, and 30% go to Apple. App Store is one of the largest online stores in the world for applications of mobile operating systems, used only for Apple devices [34]. In the case of iOS operating system, it is not necessary to use a virtual machine since Apple controls the entire environment: chip applications and the end device.

	Android 5.0	Windows Phone 8.1	iOS 8.2
App store	Google Play	Windows Phone Store	AppStore
User interface	Material design / v17 Leanback	Silverlight / XAML	Cocoa Touch
Web Browser	Chromium WebView	Internet Explorer 11	Webkit2
3D Graphics	OpenGL ED3.1	DirectX	Metal
Main programming language	Java	C#	Objective-C/Swift
Virtual machine	None	CLR	None

IV. CONCLUSIONS

The mobile operating systems evaluated here offer several advantages. A first advantage is that these operating systems have a built-in browser. Another advantage is that all three operating systems have a user interface. that comes together with an application frameworks. All three mobile operating systems have a paradigm for application development, in other words there is a coupling of the OS at its own applications store. These mobile OS allow Over The Air (OTA) updates, through which the operating system upgrades and which perform the update of certain applications.

We may point out here that there are three major operating systems for smartphones on the market: iOS, Android and Windows Phone. All three operating systems offer advanced multitasking, but the operation system is different. iOS and Android operating systems are two mature operating systems, each borrowing from the other numerous functions, therefore it is difficult to say which one is better. In addition, Microsoft WP OS is coming to the fore through a different brand, and when it will benefit from a number of applications that come close to the iOS offer, Android will become a real threat. The three app stores, namely: App Store for iOS, Google Play for Android and Windows Store for Widows Phone are very similar in terms of usage. Applications are grouped by categories and are installed after a similar process that includes presentation of screenshots and of main features. Android OS has the majority of the market share, around 70% globally, while Apple has the largest share of the profit. Therefore the operating system from Apple is the first in the chain of Android vs iOS vs WP profitability. Other important aspects are the number, respectively the quality applications from official stores. Windows Phone OS is the lack of apps compared to iOS OS and Android OS. iOs is different from Android and Windows Phone mainly in that both the operating system and the final product are produced and controlled by the same company, Apple and you can't get an iOS operating system to work on a different device since there is no license for the installation of iOS operating system on hardware devices that are not produced by Apple. This is a disadvantage since this OS is not portable on mobile devices produced by other companies.

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