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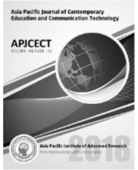

# EVOLUTION OF ANDROID OPERATING SYSTEM: A REVIEW

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## Abstract

In past mobile phones were used only to make calls but with the introduction of smartphone the mobile phone has evolved to a low powered hand-held processing system. This evolution was caused by the operating system for the mobile phones making them smart that have processing and storage of their own. Now the mobile provides numerous functionalities from calling to texting, multimedia sharing, emails, socializing applications, word processor, excel sheets to various multiplayer games and much more. The operating system for these hand held devices are iOS by Apple Inc., Windows by Windows Inc. and Android by Google. Among the competitors in smartphone operating system industry Android holds the largest market share in terms of units shipped worldwide and number of users. Android an open source operating system is based on linux kernel on which applications run on an application framework that controls the activities supported by the libraries and Dalvik virtual machine which compiles and converts all java class files into a single file. There can be number of virtual machines running simultaneously on a single device handling different applications or instances of an application. Android operating system provides memory management, process management to the applications and services running. Each release of android improved user experience and brought enhanced features. This paper presents a study of evolution that each release brought to the android operating system.

***Keywords:*** Android, Operating System, Google, Smartphone, Linux, Kernel, Dalvik Machine.

## 1. Introduction

Smart phones in today's world have become so popular that they have captured a big economical market along with a large number of users each using different types of smart phones with varying features. The most prominent thing that distinguish smartphones industry and their user base is the operating system being used among which popular are Android, iOS and Windows phone. With the statistical figures from International Data Corporation (IDC), the smartphone industry grew by 1.1% last year and by third quarter of the year more than 350 million units were shipped worldwide. Android has maintained its position on score board with market share of 86.8% [1-2].

With this increase in the demand of android phones trade, customers concern is to select and buy the phone that meets their requirement within affordable price. In the present era of Competition, different vendors are trying to make profit by using the Android OS because of its acceptance among the users. With each day the struggle and efforts been put to give an operating system that is compatible with most hardware and provide all the necessary features to the users in an efficient way Android production is growing. Every corporation desires to give best quality in their android phones and as well improving features to be its main objective. The immense usage of android lead in the direction of advance method about usability, multitasking, accessibility, protection of end user-private data and many more, in which each release is expected to cater the mentioned issues provide something new to the user [3-6].

The architecture of the android phones was first developed by Android Inc. now owned by Google and launched AOSP (Android Open Source Project) in 2007. That statement was taken by the foundation of the OHA (Open Handset Alliance). The software used in it launched under the Apache license as an open source. The Open Handset Alliance is a collection of many hardware, software and telecom Firms which may also include Intel, Google, NVIDIA, Qualcomm, Motorola, HTC and T-Mobile, in which Android is the adapted-able OS. Its core objective is to build up advance equipment according to its technology that may considerably less the time and cost as well and also enhance the services and provides best features to customer [7-10]. At present android version in use are kit Kat, Marshmallow and ginger bread. Table 1 below shows the history of Android operating system from initial release to the day. An Operating system that acts as a bridge between user and the hardware, is similar to Android OS. We talk about android Operating system, however, the latest version is Nougat this version upgraded up to 7.0-7.12 which is based on Linux 4.4.1 kernel that consist upon layers, the architecture of which is shown in figure 1. The application layer in an android operating system is the top layer that includes utilities like SMS, contacts, phone, browser, camera, media player, cleaner, etc. All of which are develop in Java programming language. The utilities or applications require application framework as a base to setup up and work. Application framework is large set of analysis used for developing an app with attractive GUI that may consist of check list, navigation menus, text box, but-ton, check box, and more likely an embedded and responsive web browser. A Resource Manager provides access to resource as well, but not access to source code like restricted String, GUI and design [11].

Table 1: Versions of Android Operating System

| Android version | API Level | Linux Kernel in (AOSP) | Release |
|---|---|---|---|
| Cupcake | 3 | 2.6.27 | 2009 |
| Donut | 4 | 2.6.29 | 2009 |
| Eclair | 5 | 2.6.29 | 2010 |
| Froyo | 8 | 2.6.32 | 2010 |
| Ginger-bread | 9 | 2.6.35 | 2011 |
| Honey-comb | 11 | 2.6.36 | 2011 |
| Ice cream-sandwich | 14 | 3.0.1 | 2011 |
| Jelly bean | 16 | 3.4.39 | 2012 |
| kitkat | 19 | 3.10 | 2013 |
| Lollipop | 21 | 3.16.1 | 2015 |
| Marsh-mallow | 23 | 3.18.10 | 2015 |
| Nougat | 25 | 4.4.1 update | 2016 |

The Notification Manager enables all apps to show routine alert on the screen [12-13]. The Activity Manager controls the lifecycle process of apps also offer an ordinary routing back stack. Beneath library layer consist a set of java library files applied by wide range of the Android Operating system processes and also offer maintenance to the Application framework. In Android, Runtime layer focus is on the set of core libraries and a Java Dalvik VM Dalvik virtual machine which can redevelop and adapted via Google to become suitable source for Android OS. Linux kernel is placed at the bottom layer of android OS to perform the task of the fastest layer among the hardware and software of Android. It may also provide major structure services of Operating System like protection/security, memory management, processes functions, network system, driver modules and supports of functions such as management of threads of Dalvik virtual machine included in the Linux kernel system [10-14].

Android operating system run in the Linux kernel, its application are developed in Java language so its task is to execute the applications on Java virtual machine called Dalvik VM. Dalvik has been redeveloped and optimized by Google as for the hardware aspect of smart phone devices. In smart phone operating system, a tool called .dx exists in the smart phone software development kit which convert Java files compile in a standard Java compiler into the .dex formats, that joins together all of the Java class files and remove unnecessary data in each Java class files. Characteristics of Dalvik virtual machine are as follows; Smart phone application run in a instance of a Dalvik virtual machine. There may exist various instances of Dalvik virtual machine instance on single machine, each instance runs in the form of chunks or separate Linux process. Dalvik virtual machine depend on the original OS Linux kernel for the execution, isolation memory manage process and threads supporting. Dalvik virtual machine is register based process [6].

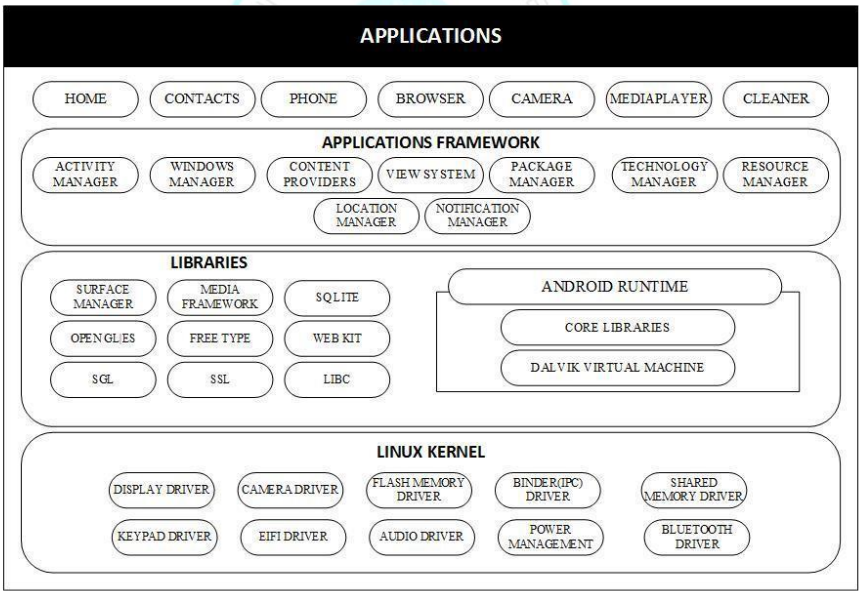

Fig 1. Architecture of Android Operating System

## 2. Material and Method

Each application in the android operating system is running separately of others and has memory spaces reserved for them making each one data inaccessible to others. For communication among applications message parsing is used. With the release of Android cupcake in 2009 API level 3 was used and the operating system supported widgets, search browsers, navigation applications that included free data of map to act as a navigation device. Content can be updated and synchronized over the internet without the need of a computer system [15-16]. Android Donut Operating System released the same year of cupcake used API level 4 that provided the features of phones screenshot capture and voice commands along with the features that were available in cupcake. To enhance user experience Android Éclair release used API Level 5 that enabled the operating system to support low density display screens from 320x240 to 854x480 high density screens. Instead of separate navigation centralized access was provided to the user by selecting a contact on which call, message and email can be made with a tap. Manage multiple email accounts with a universal account. Search and time based deletion of sms and mms. Camera, browser features were improved and virtual keyboard was introduced with intelligent auto correct feature. To accelerate the hardware graphics architecture was modified for better performance [17-20].

With the next release of froyo by Google, it was claimed to have the fastest browser than any other smartphone would have in 2010 that used API level 8 with an improved performance rate of 2.5 times then all the previous versions released. To improve the security of the devices alpha numeral and numeral options were added in password and remote access to reset device data in case of theft or robbery to protect the privacy and integrity of the users. Before the release of froyo android operating system only allowed installation of the applications to be done on the device memory, whereas with froyo users can now install the applications on the external media as well. Among improved camera features and remote access through android cloud APIs for gesture detection for multi touch and OpenGL 2 for ETC1 text compression, YUV images was also supported by the operating system [21-22].

As the android operating system was initially developed by Android Inc. which was based on Linux kernels so Google did not do the things from scratch and focused on providing better user experience by continuing the work of Android Inc. Platform was initially developed by Android Inc. So, with the release of Android gingerbread with API level 9 Linux kernel was upgraded to 2.6.35 due to which the operating system was now able to manage power more efficiently with refined user interface. New devices were becoming popular in the market that have large displays, and need for communication over internet. With android gingerbread near field communication (NFC) was added that could have high frequency communication within the radius of 10 cm. To meet the market demand gingerbread supported SIP: Session Initiation Protocol for audio and video calling if the device has a 3g or Wi-Fi connection of internet. The introduction of SIP broke the traditional barriers of communication and the worry for billing for its users. Other features included audio encoding, video playback, multi touch virtual keyboard and gyroscope sensor which in extension to accelerometer that sense the alignment of phone calculates the rotation rate around x, y and z axis which can also be termed as twists. Accelerometer measured the linear and gyroscope measured the angular movement of the device this addition paved way in support of virtual reality [23-24].

With the second big release of honeycomb in 2011, Google also introduced its first smartphone Nexus S in liaison with Samsung. Honeycomb revolutionized the android operating system by the support of multicore processor environment with symmetric multiprocessing due to which multitasking was possible with all screens active at the moment. This update to the operating system was a major advancement among other updates that include enhanced web browsing experience, Google talk, 3d effects in Google map and multiple home screens to let the user customize the interface as per their wish [25-26]. The last release of 2011 was ice cream sandwich API level 14; the ice-cream sandwich release was compatible with both low and high resolution devices. Multitasking ability of operating system was further enhanced in which the opened applications can be switched in between by seeing the list of running applications. Notifications appearance was enhanced by removing the pop-ups and showing them in the top of the screen where a certain a notification will show its detail on tap. Ice cream sandwich operating system was improved to open microphone voice command for which the system is always ready to receive voice commands and process them instead of first starting the service before use. While the device is lock previously all applications are stopped and cannot be accessed whereas in ice cream sandwich operating system lets user answer the incoming calls, move among the playing media, and for authorization of user in addition to alpha numerals and numerals face lock feature is introduced to verify the authenticity of the user. Pertaining to the users demand, camera features were refined that included increased snap shot speed, continuous focus, zero shutter, panorama for image and at the same time recording videos of high definition. Ice cream sandwich release paved the way for future in which innovative, interesting, customized applications and features can be provided to users. An Example of which is the Android Beem based on NFC that would allow the users to share the content at a much higher speed which was not possible before [27-28].

Jellybean release came in 2012 with API level 16 that revamped all predecessors not in terms of speed and performance but user experience in which all core features of Ice cream sandwich were intact with widgets being intelligent to replace themselves based on the addition or deletion of any widget instead of lying still. For smooth user experience, user interface design had a refresh rate of 60 frame per second to make it more responsive. Other enhancements included support for five languages with right to left languages support, digital rights management, security measures, low energy Bluetooth for audio, video calling and remote access. A drawback in the schema was operating system does not prevent acquisition of device location even though Wi-Fi is turned off [29-30]. Kitkat operating system was released in 2012 with API level 19 in which the along with user interface focus was equally put on speed and performance as well that was achieved with improved multiple sensors feedback, use of tri-core cpu, improved battery usage for long lasting battery time, resolution up to four thousand and updated schema for user interface. With kitkat operating system applications installed in devices can be exchanged with other device and all previous versions of android were upgradeable to the kitkat. The edge to edge technology enabled the users to not only remotely access their device but also to perform activities like cloud printing, managing resources and many more [31-32].

Android lollipop with API level 21 was released in 2015 to enhance users' experience with 3D views now elements can be viewed in real time with shadows as the object moves. With shared visual elements transition of elements from one state to another is done smoothly and seamlessly. With the new design threads are rendered for smooth execution of animations even though there comes a delay in the user interface main thread. The lollipop version does not compromise on the performance of system for which it runs on new ahead of time just in time and Android Run Time codes built from scratch to meet the needs that supports 64-bit MIPS and ARM architecture. This update fulfilled the need to efficiently reduce garbage and keeping the applications responsive without affecting their performance. To strengthen the claim of high performance android kitkat offers enhance audio, video synchronization by the use of pipelining for smooth output. For productivity, new sensors were introduced that included sensor for heart rate, to detect interactions such as flick, swipe, pinch etc. interaction sensors and for activity recognition tilt sensor. The new added APIs improved battery performance, accessibility, web view, screen capture and camera features [33-35]. Android marshmallow API Level 23 was released same year of kitkat in which finger print detection was introduced with which number tasks can be performed such as unlocking the device, answering incoming call and holding up outgoing calls, browsing images in gallery, capturing and recording in camera and many more, but as per security authenticity and integrity of users' device and data operating system was able to provide an extra added layer by fingerprint sensor. Previously when an application was installed it was mandatory to grant all the permissions asked at the time of installation and it cannot be altered later on. With marshmallow, it lets the user change the application permissions to empower the user. For fast charging type C cable was introduced and doze mode enables operating system to save more power and can almost double the battery time. Notifications and camera can also be accessed while the screen is lock [36-37]. The most recent release of android operating system is Android Nougat with API level 25 in 2016. In nougat operating system, the most prominent feature is of multitasking of applications in split screen. With marshmallow performance, look feel and performance was delivered to the best and nougat focus was to improve the existing features provided by marshmallow [38]. Given below in Table 2 is categorization of each android operating system release with the features they have;

Table 2: Features of Android Operating System

| **Android version** | **API Level** | **Release** | **Features** |
|---|---|---|---|
| Cupcake | 3 | 2009 | Support widgets, search browsers navigation apps, |
| Donut | 4 | 2009 | Screen capture, voice commands |
| Eclair | 5 | 2010 | Battery savor, enable in low resolution 320*240<br>Keyboard auto-correct |
| Froyo | 8 | 2010 | High security, cloud API, gesture detection. |
| Ginger-bread | 9 | 2011 | NFC range in 10 cm, audio video calls, 3g supported, gyroscope sensors |
| Honey-comb | 11 | 2011 | Symmetric multiprocessor, multitasking, google talk, 3d effects |
| Ice cream-sandwich | 14 | 2011 | Notification pop up on lock screens, fast image capture, NFC enable. |
| Jelly bean | 16 | 2012 | Speedy, audio & video calling, remote access |
| Kit-kat | 19 | 2013 | Responsive, tri core cpu, cloud response |
| Lollipop | 21 | 2015 | 3D views, 64 bit MIPS,<br>Sensors, heart rate, swipe pinch. Screen capture. |

| | | | |
|---|---|---|---|
| Marsh-mallow | 23 | 2015 | Finger Print detection, gesture & voice sensors in camera, high resolution, backup in cloud, power saving mode |
| Nougat | 25 | 2016 | Finger print, gestures voice sensors, palm detection. Power saving modes, cloud |

## 3. Discussion

Android cupcake API level 3 was the first version released in 2009 which was the evolution of android OS. The advantage in cupcake version I increased speed and performance but not up to required level, the drawback of cupcake version is not much Responsive and lack of multitasking [15-16]. Donut API level 4 launched in 2009 the main purpose of Donut was to focus on the issues faced in previous version cupcake, in Donut provides the power savor option and keyboard auto correct option also provided, fast web browsing Experience, but typing is quite slower [17-20]. Éclair API level 5 introduced in 2010, the features were not introduced in previous version of Androids. Éclair Improve typing speed on virtual keyboard with smarter dictionary but No Adobe Flash Media Supported [17-20]. After Éclair, Froyo API level 8 launched Focus on Privacy protection also support Adobe flash Media supported but drawback in Froyo lags while Multiprocessing [21-22]. Ginger-bread API level 9 release in 2011(NFC) was added that could have high frequency communication within the radius of10cm and supported (SIP) Session Initiation Protocol for audio and video calling if the device has a 3g or Wi-Fi for internet connection, Multiprocessing and faster than Froyo. The disadvantage in ginger-bread is automatically close applications [23-24].

After Ginger-bread, Honey-comb take place API level 11 released in 2011, the main purpose of Honey-comb focus on applications which can closed automatically in Ginger-bread, and Honeycomb won't close the applications until the user won't close applications. In honeycomb Enhanced web browsing experience, Google talk, 3d effects in Google map and multiple home screens to let the user customize the interface as per their wish, issue in honey-comb is battery drain in some applications [25-26]. (Ice-cream sandwich) launched in 2011 API Level 14, ice-cream android version is far faster than honey-comb and cannot drain battery like honey-comb, Multitasking ability of operating system was further enhanced in which the opened applications can be switched in between by seeing the list of running applications, main problem in ice-cream sandwich was device is lock previously all applications are stopped and cannot be accessed [27-28]. Jelly bean API level 16 release in 2012 jelly is responsive then all previous versions of Android's the main purpose of jelly bean is to provides Security measures, a drawback in jelly bean the schema was operating system does not prevent acquisition of device location even though Wi-Fi is turned off [29-30]. After jelly bean Kitkat, API level 19 launched in 2013 consist of edge to edge technology and enabled the users to not only remotely access their device but also to perform activities like cloud printing, managing resources and many more, kitkat provides a location address when Wi-Fi is turned off in previous jelly bean was face that problem. A drawback in kitkat is cannot write Messages and E-mail enable in Power saving mode [31-32].

Lollipop API level 21 launched in 2015 lollipop is likely kitkat, but lollipop have some new features like new sensors were introduced that included sensor for heart rate, to detect interactions such as flick, swipe. Interaction sensors and for activity recognition tilt sensor, problem in Lollipop is background apps were not close that will be cause of battery drain faster [33-35]. After successful completion of Lollipop, Marshmallow API level 23 launched in 2015 in Marshmallow added layers by fingerprint sensor, Grant all the permissions while enables application fast charging type C cable was introduced and sleep mode enables operating system to save more power and can almost double the battery time. Notifications and camera can also be accessed while the screen is lock. Gesture and voice commands in camera while taking pictures, Marshmallow focus on the drawbacks of lollipop and kitkat, in lollipop application were not close in background process in Marshmallow focus on this problem, and write messages and email in power saving mode which is the drawback of kitkat, disadvantage in Marshmallow is both Wi-Fi and hotspot not working at same time [36-37]. Today more successful version of android is launched in 2016 API level 25 named as Nougat. It is more likely Marshmallow and all the features of Marshmallow included in Nougat version also Split screen option and both Wi-Fi and hotspot enables in Nougat version which is the drawback of Marshmallow [38].

## Conclusion and Future Work

The demand of smartphones is increasing each day with android being the most popular among its users and holding the largest market share for usage and number of units shipped worldwide which is 350 million units and market share of 86.8%. With features provided in each release that increased user adaptability and fulfilled their needs the focus of google in developing android operating system should equally be security and privacy that is a major threat to operating system and vulnerabilities attract intruders to benefit from it and exploit the users by gaining access to the content on their device. By doing so side by side with enhancing user experience android operating system would gain the trust of its users and would further strengthen its market share and will hold the users. Until now, Google has effectively presented android operating system as an open source and available for multiple devices by different manufacturers. Now the time has come for Google to lay quality bench marks on the device manufacturers who are using android operating system to ensure user experience and upheld the operating system standards that would also guarantee security protocols to be followed. By doing so, android operating system can overcome the loopholes and criticism faced by the competitors and would emerge as a user friendly platform that cares for its users.

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