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Energy Consumption in Mobile Phones

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Abstract—As the mobile devices are widely used in this world. With the increasing number of users, the numbers of customized applications are also introduced for these users according to their own requirements but on the other hand, there is a dire need of a system which must be energy conserved, estimated and maintained. A survey of energy consumption in mobile phones is presented in this paper with the factors at which the consumption of the energy depends on i.e. Energy consumed by OS, by hardware, by applications, by the user to interact with the applications, by wireless, by the sensor network. The energy management models and frameworks are also discussed in this paper.

Index Terms—Power consumption in mobile phones, Application level, hardware level, models, and frameworks.

I. Introduction

Mobile phones are a very pronounced invention. Nowadays it became a main accessory used in human life. It is an electronic device that is used to perform different operations, run the applications, connectivity of wireless networks and data sharing in a network and cloud computing environment. It needs a battery as energy source. These batteries are required 1 to 4 hours to charge that is not enough for few hours talk time [1] as maximum 14 hours. The mobile phone is used in social media, playing games, location-aware applications, video streaming and connectivity with the other devices. These requirements required a massive processing by the mobile device. A lot of power energy is consumed during processing. On the other hand, other different components of the device like memory, display screen etc also are also required a huge amount of energy for their working. As the demand for power of the system is increased rapidly, the solutions of this issue are not more frequently introduced according to the demand of device. 3D graphics are widely used in a new era. 3D applications like games, maps, and animated charts are now the demand of the every user but these applications consume a huge amount of the energy of device. So, there should be an ideal mobile system through which we get the better battery lifetime. Wifi and blue tooth are the platforms through which the different systems have to communicate with one another, these are also very power hungry features of the mobiles but are also most important features. Simply an efficient power consumption mobile battery is the main issue. In this paper, a survey on energy consumption and estimated in the domain of OS, hardware, frameworks, models, wireless and sensor network is presented.

II. Related Work

In the mobile world, there is a numeral error that arises in the system like in OS, applications, hardware, firmware or external devices. Now a day, another new bug is encountered that is e-bug or energy bug [2]. Energy is the main source for mobiles. An unexpected amount of energy is consumed during e-bug by the mobiles. But different techniques and tools are rapidly introduced on the demand of mobile users. Energy management system (EMS) is the system which is used to determine the power estimation, performance, and efficiency of a particular system whose power consumption is to be found [3]. According to the mobile phone manufacturer, the energy consumption is only based on two basic factors, an operating system, and applications. But there are some other energy consumption factors that are involved in energy consumption in user interaction, sensors, and wireless optimization [4] as shown in Fig 1.

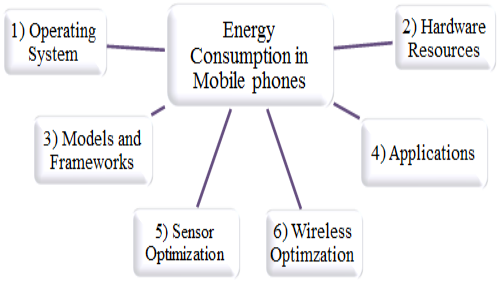

Fig.1. Energy Consumption in Mobile Phones

In this paper, these factors are discussed in a context of energy consumption in smartphones.

Because the Mobile equipment is widely used with cloud computing environment to formulate mobile cloud computing, in [5] and [6] researchers presented some methods for energy optimization in mobile cloud computing.

In [7] a scheduling algorithm for the energy-aware workload of different applications and software was developed to measure the impact of the workload of applications on energy consumption in mobile phones. In [8], the studied approach presented a relationship between the strength of the wireless signal and energy consumed during data transferring.

A new power model was suggested for WiFi and 3G that helped to measure the impact of signals strength/weakness on the power consumed in the smartphone by the embedded wireless components. The energy consumption of data transmission and connection over 802.11 wireless-based networks measured in [9]. In presented research, it was concluded that the devices context, handset, and the Operating Systems are also included among such factors which affect the optimal strategy of data transmission.

In the similar context and framework, a comprehensive study was made in [10] about efficient and resilience mobile cloud computing. In [11], the researchers proposed a new and efficient model that distributes tasks to certain applications and software that are executed on smart devices and directs to other tasks that are executed in a cloud environment.

III. Energy Aware Operating System

The operating system is a main and necessary component of any device. Power consumption by the operating system is also a main issue for the developers. There are a number of operating systems introduced for mobile phones. Operating systems are main cause sources of energy consumption [12]. The graph in Fig 2 shows a number of operating systems which are used in cell phones. The name and percentage of their energy consumption are:

Android 50.9%
Symbian 11.7%
OS 23.8%
RIM 8.8%
Bada 2.1%
Microsoft 1.9 %
Others are 0.8%.

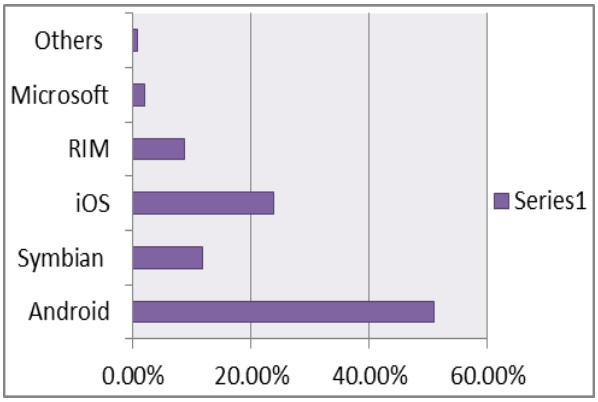

Fig.2. Energy Consumption by Operating Systems

In [13] the Android JAVA is compared with the Sun embedded operating system and their performances are examined. According to the author, the Android operating system works more efficiently as compared to Sun embedded operating system. Android, Symbian, IOs, Microsoft, TinyOS [94], and other operating systems are a platform for other energy-aware operating systems that are discussed in this paper.

ECO-system is another energy-aware operating system [14-16] that is to be worked on the Linux-based operating system. Its functionality is to distribute its power between application and trade-off efficiently to complete some specific tasks. The ECO-system encounters the energy conserved by service for the synchronous operation to get the best battery timings of the device. Cinder operating system [17-18] works for the managing the energy efficiency in the application by using three control mechanisms i.e. isolation, delegation, and subdivision. The prototype is tested on Android G1 which is normally worked on Mac, Android or Microsoft operating system.

Erdos operating system is user-centered that extends the lifetime of smartphones, security and manages the resources [19] Erdos consists of three main modules: Activity Manager (responsible to manage applications during their runtime and trigger the event when a special call occurs i.e. when the system is going to be shut down due to certain reasons or demand for the resources hardware etc.), Access Control Manager (control flow of data and errors when the data is transferred over network), and Erdos Manager (a central unit that controls all the resources locally).

Odyssey operating system [20] is a platform used to transfer data over a wireless connection in mobile phones [21] and is widely used in Grid computing on smartphones. It is a gateway to application and hardware resources. Odyssey OS provides the energy on demand to different components of the system. ContextOS [22] and CondOS [23] are context-aware operating systems that consume less power as compared to the application which is run independently.

Table 1. The Energy-Aware OS and their Descriptions

S.no	Proposed by	Year	Operating system	Platform	Description
1	H. Zeng, et al [24]	2002	ECO-system	Linux OS	Distribute the power between applications and trade-off
2	Chu, David C, et al [21]	2009	Odyssey OS	Microsoft, Mac OS	It works on wireless network, it fulfills the energy demand of resources and applications
3	Roy, Arjun, et al [18]	2011	Cinder OS	Mac OS, Microsoft Window	Work on 3 control mechanisms
4	Vallina-Rodriguez, et al [19]	2011	ErdOS	Android OS	User-centered, access control and security
5	Ariyapala, Kanishka, et al [20]	2013	ContextOS	____	Manage memory and energy, sensor privacy

IV. Hardware Resources

In a smartphone to reduce power consumption, first of all, one must have enough knowledge about factors and components which affect power efficiency of the system. Many tools and interfaces are introduced that are used for the mobile users to estimate the energy of each component. The screen is hardware component that consumes most of the battery that is approximately 35% [24]. For memory and bandwidth usage a special hardware is used in power consumption that is called rasterization hardware [25].

3G is the fastest wireless network platform through which secure data is transferred with a small energy consumption but the special management hardware unit [26] is used in mobile devices. The following are subsystem hardware units which consumed most of the battery in wireless smartphones:

Multimedia 39.5%
Modem operations 21.5%
Memory 19.4%
LCD 17.6%

Others hardware unit consumes 2% of the smartphone's battery as shown in Fig 3.

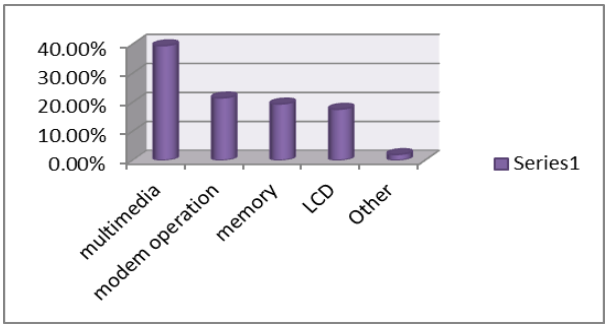

Fig.3. Energy Consumption by Different Components

V. Energy Management Models And Frameworks

Energy management models are used to estimate the power. To manage power allocation of different components of a system, authors proposed energy estimation models which give correct energy estimation and automatic battery performance based on power model generation for mobile phones [27-29]. Multicore mobile phones are widely used by the mobile users because they are work on the parallelism. These multi-core mobile phones are not powered efficient [30].

Cellular network models [31] are presented but in [32] it is presented that the energy-aware models are not only sufficient for the mobile devices but for gaining best result energy based models and their measurement should work together in the same system. A demand-side management (DSM) [33] strategy is used to reduce the usage of energy when multiple users used a single energy source to maintain the energy. The author Murmurs first time divides measurement of a system into sub-systems and present a model that divides the power consumption and estimation of the system that is the sum of power consumption by each sub-system i.e. CPU, display, graphics, audio, wifi etc [34].

Total power used by the application = cpu + display + graphics + gps + audio + mic +-----+ wifi. For the Android operating system, dynamic voltage and frequency scaling (DVFS) algorithm [35] is proposed that is used for energy saving by regulating the frequency of the CPU. Memory access rate and critical speed for the minimum energy consumption (MAR-CSE) equation is used to find the critical speed which minimizes the energy consumption in the system. A Micro-Blog [36] scheme is used for efficient localization in wifi and GSM.

A monitoring system is also introduced for an Android operating system whose name is smart energy metering operating (SEMO) [37] system. It has a central unit that is called as energy monitoring and analyzer. It has three parts: the first part is for analyzing the information, secondly is for monitoring the battery status, and third part record the battery and application information that what application consume how much amount of energy as shown in Fig 4.

ELens [38] is an approach which is used to estimate the energy and tracking the path during execution of each instruction. This approach doesn't require some special type of operating system or some special type of hardware resource. An energy-aware framework [39] is introduced especially for Android smartphones. In this framework, a number of models are combined in working state these models are battery energy model, service quality model and system level power model. For

taking the experimental result, global positioning system (GPS) application is considered as a case study to maximize the QoS for checking energy life of a system. Communication subsystem energy consumption model (CSECM) [40] works on wireless sensor networks. It is used to measures the estimated amount of power that is consumed in each transmission of data. The author in [41] presented the Mica architecture that is used in an embedded system for providing a wireless platform. It is also used to consume energy when the system is in standby mode.

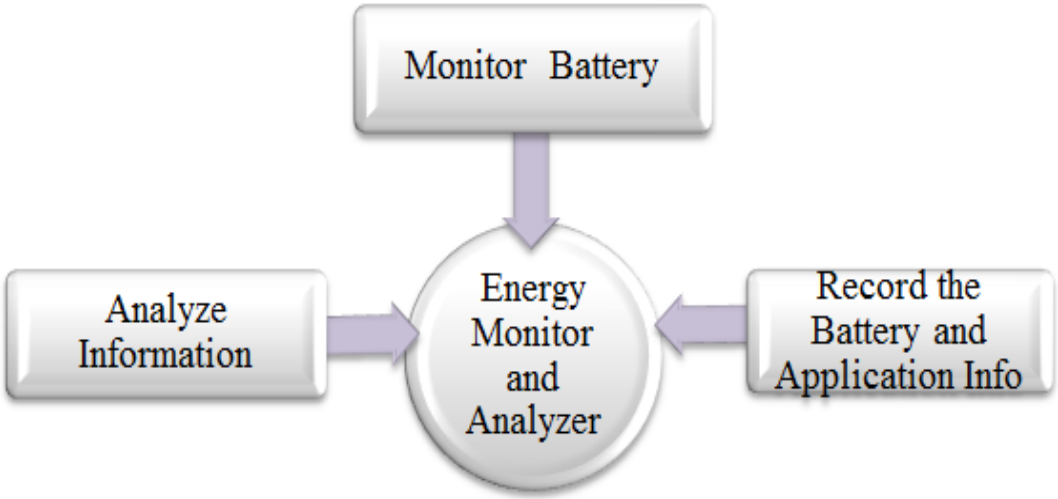

Fig.4. The SEMO Structure [37]

Table 2. Energy Aware Frameworks and Models

Author	**Model / framework**	***Description***
Fangwei Ding, et al [37]	**SEMO**	*Monitor the system which works on Android OS.*
Shuai Hao, et al [38]	**ELens**	*Estimate the track and estimate energy on each instruction.*
Wen-Yew Liang, et al [35]	**DVFS**	*Regulate the frequency of the CPU*
Qin Wang, et al [40]	**CSECM**	*Work on WSN, power consumption during data transmission.*
Jason L. Hill, et al [41]	**MICA**	*Consume energy when system is in standby mode*
Amir-Hamed Mohsenian-Rad, et al [33]	**DSM**	*Fulfill the demand of the energy resource when multiple users use the single source.*
Shravan Gaonkar, et al [36]	**Micro-Blog**	*A phone switch between multiple locations, It conserved power during that localization.*

VI. Energy Consumption In Applications

It is most important to have knowledge about energy requirements of an application and how this energy is managed? Energy consumption in mobile applications is estimated by special tools. By using these tools, estimated results are obtained that how much energy is consumed by each application? Energy/power efficiency debugging tool is introduced to investigate the performance of the software in a certainly changed scenario and compared to some techniques which are already implemented to reduce the power consumption in mobile phones [42]. Here are some applications which are commonly used by each smartphone like browsers (Mozilla, Opera, and Google Chrome), social media (Facebook, skype, Flicker, YouTube) and games (angry birds, temple run, hill climb racing) as shown in Fig 5.

Fig.5. Different Applications of Mobile Phones [42]

YouTube is a website which is mostly visited by the mobile users. As it is a continuous flow of packets, wireless networks International (WNI) should be inactive for receiving these packets. In [43] an Estreamer is presented. The function of the Estreamer is to save a

large amount of energy during video streaming. Generally, more energy is consumed in these mobile applications that consume more network resources [44]. Now a day's browser is also one of the most important applications for cell phones. In surfing web pages a great amount of battery is consumed [45]. The experimental results show that JPEG for image format and JavaScript are best in web paging according to efficient power consumption. The 3D applications are the one of the main cause of energy consumption of a system but by using of DVFS [46] based techniques; approximately 50% energy is saved as shown in Fig 6. In [47] some mobile applications of cell phones and their power consumption are predicted. In graph Fig 6, the browser application is used 0.35% battery when its run time is 30 sec. Angry birds game application is used 0.28% battery when its run time is 28sec, NY times applications are used 0.75% battery when its run time is 41 second and so on. These applications are services and tools that are used by humans to interact with any electronic device. In [48] the results are presented which are obtaining from the users of smartphones that how they use the mobile phones to conserve energy/battery. The mobile devices are the combination of hardware and software [49], the energy-aware scales down techniques are used to fulfill the requirement of a user to manage power intelligently. Now day's user interface is provided a way to save the power at some extents like the brightness of the screen, wifi and Bluetooth on/off mode etc. [50].

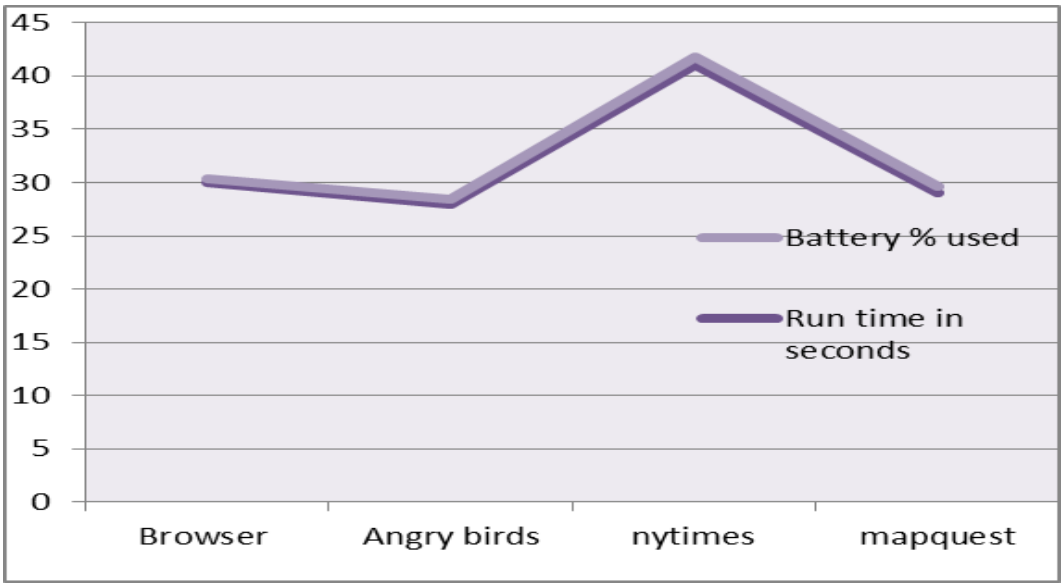

Fig.6. Estimated Power Consumption by Applications

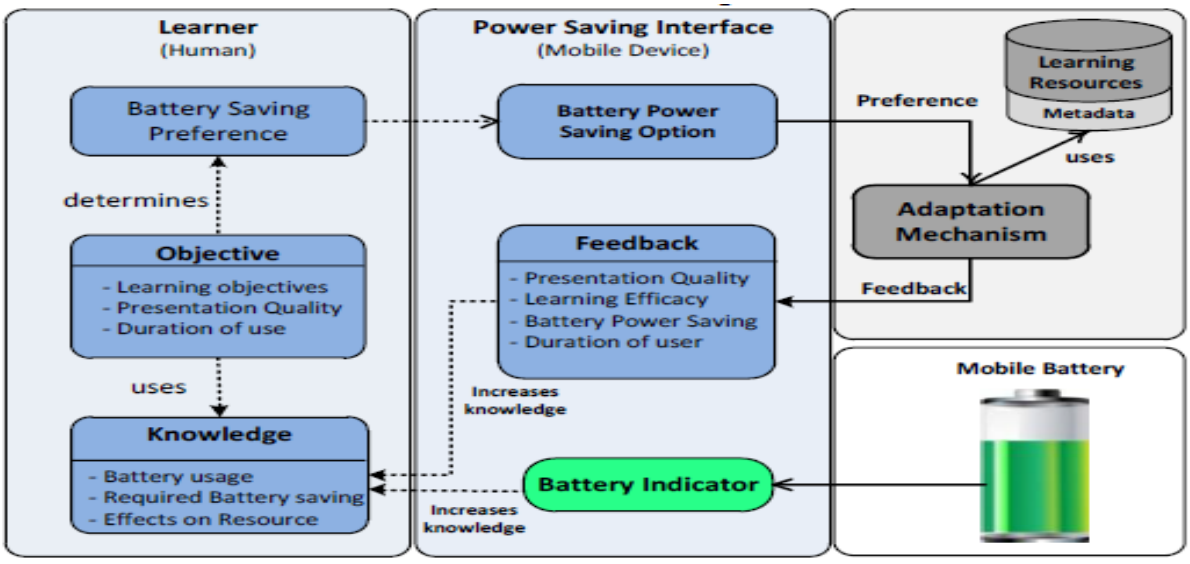

Fig.7. User Learner Battery Interaction [51]

In Fig 7 [51] an interface is explained that is called power saving interface. With this interface, a user interacts gets knowledge and uses options to save power. In short applications and user interaction with the

application are also very important factor in energy consumption in a mobile system.

VII. Sensor Energy Optimization

Another factor of energy consumption is sensor network, GPS in many smartphones is power hungry but it is still used in sensor network because it detects the location of the sensor node more accurately and efficiently. The mobile users demand a more accurate and efficient system which is less energy consuming and more reliable according to sensor localization [52]. The Bluetooth-based sensor network is used to provide an efficient system in term of cost and energy. So Vtrack [53] system is introduced for sensor optimization. Smartphones are widely used to fulfill the demand of the user, embedded sensor are used like camera [54] (barcode reader), microphones, digital compass etc. These sensors provide a new direction to the mobile devices. The mobile phones are now used in transportation [55-57] like discovering direction, monitoring environment [58] [51] like the temperature of the environment and social network [59] like Facebook, Skype etc.

Movement of the human and surveillance by using wireless sensor networks [95] is examined by the mobile phones because mobile phones are used Accelerometer and a human motion detection application is used in this technique [60]. Another energy attack consumption control technique is used for sensor nodes. As the sensor networks work on the nodes and if the size of the cell is decreased, energy usage is also reduced. In short size of the cell affects the consumption of the battery in a system. In [61] the size of the cell is fixed between two well-defined values. The experimental result shows that battery consumption is reduced approximately 40%. Sensor nodes are of three types used in indoor localization i.e. localization without Beacons, with moving Beacons, with Beacons etc. [62].

The self-organization is the most important and crucial feature of the wireless sensor network. In [63] a self-organization mechanism is presented for sensor nodes with very small amount of power consumption. A sensor is used for speaker sensing [64] and to sense the audio signals. With an audio signal, a low-power processor has attached that work simultaneously with the main processor. It decreases work of power processor of audio speaker sensor.

Table 3. Energy Consumption of Different Sensors [65]

S. #	Sensors	Approximate Battery Life (hrs)	*Average Power Consumption (mW)*
1	Video Camera	**3.5**	*1258*
2	IEEE 802.11	**6.7**	*661*
3	GPS(outdoor)	**7.1**	*623*
4	GPS (indoor)	**11.6**	*383*
5	Microphone	**13.6**	*329*
6	Bluetooth	**21.0**	*211*
7	Accelerometer	**45.9**	*96*
8	All sensors Turned off	**170.6**	*26*

VIII. Wireless Energy Optimization

Wireless connection is based on wireless transmission of data. Wi-Fi, Bluetooth or 3G is commonly used for this purpose. Although during transferring of data over the network security and privacy are basic issues of the wireless network. On the other hand, energy consumed by the smartphones based on Wi-Fi [66] and 3G [67] is another burning issue. To find the energy consumption by the wireless network by estimating the energy at each step is expressed in [68]. The Bluetooth [69] is the one of the wireless based networking technique which doesn't require a high bandwidth and power for data transmission. In [70] an energy-efficient mobile radio network is described. In the wireless network, the nodes forward the data packets to its neighboring nodes. In [71-72] routing algorithms are considered that provide blocking. These algorithms first calculate the best possible path according to the energy constraint and then start transmission that is called the global energy-aware routing (GEAR) and then a local energy-aware routing (LEAR) is presented. Due to LEAR, the destination node doesn't wait or block. For a wireless network, a distributed optimized protocol (DOP) [73] that support peer to peer communication is worked by that mechanism of configuring itself and maintain the consumption of energy.

In [74] statistical report is described after examining the NTT DoCoM (It is the mobile company in Japan) that 3G feature is the most power consuming part of a mobile system because it works on the radio signals [75-76] and compares a number of routing protocols on the basis of energy consumption: one is Ad Hoc on-demand distance vector routing (AODV) [77-79] which can be used for different detection techniques in wireless Ad Hoc networks [96]. This protocol works on when a node is used to transfer data. Simply AODC routing protocol works only on demand. By using this technique power consumption is decreased. The second one is dynamic source routing (DSR) protocol [80] that is used to maintain the list of the nodes through which the packets have to be transferred from its source to destination while temporally ordered routing algorithm (TORA) protocol [81-82]and route-lifetime assessment based

routing (RABR) protocol are used for lifetime estimation [83].

The WiMAX is the fastest broadband technique. The 802.16 and 802.16d are worked on the fixed wireless access but the 802.16e [84] is worked on mobile wireless access. There are a number of advantages in WiMAX that are low energy consumption, high data rate over a large distance with great speed etc. While for getting more advantages [85] Wifi and WiMAX are combined together that are used in its applications for optimization.

The video is the main type of data that is transferred over the wireless network in the form video conferencing, skype etc [86]. So the system should manage the resources (energy and hardware) in a better way.

Table 4. Comparison of the Wireless Techniques

Wireless technique	Stands for	Standard	Version	Speed	Operated by	Limitations
Wi-Fi	Wireless Fidelity	IEEE 802.11	802.11n, 802.11b, 802.11g	100mbit/s	Mobile phone, tablets, online games	Modem is required
3G	3rd Generation of mobile telecom technology	3G	3.5 G, 3.75G	384 Kbit/s	Smartphone organizations	Required base station to be close to getting clear radio signal
WiMax	Worldwide Interoperabi-lity for Microwave Access	IEEE 802.16	802.16, 802.16d, 802.16e	70mbit/s	Mobile phones, tablets, online games	Big installation and maintenance cost, modem is required

IX. Discussion And Future Direction

In this paper, the energy consumption in mobile phones is discussed in different components of a cell phone. The cell phones are worked on hardware as well as software. In this paper, the energy consumption at the operating system level is discussed while platforms are Microsoft, Android, Symbian, iOS, RIM or any other OS. The energy consumption operating systems are ECO-system, Odyssey [87-88] OS, Cinder OS, Erdos and Context OS. At the hardware level, some energy-hungry components are mentioned that how much energy is consumed at computing level by CPU etc? Many models and frameworks are designed for measuring the power consumption. Some of them are given for example SEMO, ELens, DVFS, CSECM, MICA, DSM, and Micro-Blog. Some applications are also mentioned that are widely used throughout the world and also energy-hungry applications. Sensor and wireless networks are main networks which are also the main feature of mobile phones and need of users is increasing day by day. These networks are also energy consuming but there will be an optimal solution for these networks.

Although above-described methods or approaches are good in their performance a more work is needed on the battery with pools of network bytes, which can improve the battery life according to network aspects. The mobile phones can help to motivate the scientists to present the most optimized tools that may be used for minimizing the less energy dissipation in mobile devices during processing, less energy consumption by memory, reduce the power usage during transmission of data on any network or any cloud computing environment [89-91].

X. Conclusion

In this paper the survey on power consumption by the mobile phones is presented, in which the factors which are energy-hungry and badly affect the battery life are discussed with the models and the frameworks by different authors. These are used for power estimation, managing it or fine distribution of energy to all the applications. Then the resources which consume most of the energy and the tools used to manage the power are also discussed. It indicates that the CPU and wireless techniques consume most of the energy of the system.

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