Energy Consumption in Smartphones: An Investigation of Battery and Energy Consumption of Media Related Applications on Android Smartphones

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Abstract

Modern smartphones have become indispensable for many people around the world as they continue to evolve and introduce newer functions and operations. Battery capacity has however failed to keep up with the rate at which smartphones have evolved in recent years, which has led to rapid battery drain and the need for users to discard and replace them very frequently. This inevitably leads to increased greenhouse gas emissions and harmful consequences the world over due to poor disposal and reuse practices among users.

Using the Samsung Galaxy Note as an android platform for experimentation, the factors most responsible for energy consumption and battery drain in smartphones are identified as the network, the device specifications, the applications on the device, and the common practices by the smartphone user. Interviews conducted with varied respondents further reveal that user practices impact energy consumption in smartphones more significantly than perhaps all the other factors.

It is recommended that information be better conveyed to smartphone owners, while smartphone manufacturers should improve their design specifications in keeping with the Green Code. Further study is also suggested to distinctly clarify the impact of the stated factors on smartphone battery drain.

INTRODUCTION

Smart devices such as smartphones can interconnect to share data and functionality due to recent innovations which imbue them with computing capabilities comparable to artificial intelligence. Modern smartphones blend cellphone features with hypermedia proficiencies to do everything from basic phone calls and SMS, to data manipulation, multimedia playback, internet access, social media optimisation, and suchlike, atop state-of-the-art processing platforms (Gartner, 2016), made possible by batteries enabling portability. This portability represents the primary attraction to end-users; but batteries need periodic charging as they are frequently drained through power consumption, and must soon be discarded and replaced. (Newman, 2013)

Offhand disposal of smartphones has become commonplace so that they typically last an average of two years with a user before they are unceremoniously discarded to produce the unwelcome consequence of mountains of toxic waste added to the environment each year. Consequently, recognising and categorizing the factors that produce drain in smartphone batteries is important as the devices continue to evolve and improve, both for manufacturers to improve on design and for owners to improve on usage patterns, as this will contribute to longer lasting devices and reduced environmental fallout, in keeping with Green Computing ideals (Saha, 2014; Ferreira et al. ,2012).

To this end, this research aims to proffer supportive recommendations to the public regarding manufacturer specifications and common practices among smartphone owners that can potentially help lower greenhouse gas emissions the world over.

The following research objectives will benefit the accomplishment of this aim:

Research Objective 1 – Critically surveying known factors affecting smartphone battery drain and energy consumption;

Research Objective 2 – Developing a framework for the identified factors;

Research Objective 3 – Experimentally determining and analysing energy consumed by certain smartphone apps (software programs on smartphones);

Research Objective 4 – Conducting interviews to determine and document user behaviour and their impact on smartphone battery consumption;

Research Objective 5 – Developing targeted recommendations to improve smartphone battery performance based on identified factors.

REVIEW OF LITERATURE

Evolution of the Smartphone

Telephony used to occur with or without transmission cables and wires, merging development with deployment of electronic transmission. Nikola Tesla and Guglielmo Marconi founded wireless technology late in the 19th century through ship-to-shore radiotelegraphy. Soon there were radiophones and radiotelephony speech transmission, then broadcasting by 1900, soon two-way voice communication, and then television across the early to mid-1900s. Martin Cooper operated the first cell-phone system in 1973, and it was Motorola who 10 years later introduced actual cellular telephony (Clark, 2013).

The first generation (1G) of mobile phones employed the electromagnetic spectrum like a 2-way radio but were big, heavy, costly and ungainly, such as the 794g Motorola which required 10 hours to charge its battery for a 30-minute call. The second generation (2G) introduced digital technology and out-of-band signaling, with texting, ringtones, and digital content, ushering in GSM (Global System for Mobile) Communications in Finland 1991 (Clark, 2013). Examples were the Nokia 1100, 3310, 3410, and 6310 series; and the Motorola v60, v70, v600; and the Samsung SPH-V9900, which had slow data connectivity but were more affordable (Miyashita, 2012).

3G smartphones arrived in 2007 with improved connectivity and speed, pioneered by the Sony Xperia, Samsung Galaxy, and iPhone; and complimented by the BlackBerry, Windows Phone, BlackBerry, and LG G-Flex (Miyashita, 2012). 4G-LTE (Long Term Evolution) smartphones, which have been around since 2012, today possess higher diversity and adaptability, coupled with enhanced user experience. Interactive TV, mobile video blogging, advanced gaming, over 100 Mbps downlink peak connectivity, and less than 10ms RAN (Radio Access Network) round-trip time, are all features found in the fourth generation of smartphones, which continue still to evolve and improve (Kumaravel, 2011).

The Smartphone and Battery Capacity

The 'rapid development of wireless technologies' resulted in urgent need for portable power, while modern batteries were limited generally to 1500 mAh, which is unable to keep up with the functionality of contemporary smartphones (Ferreira, et al., 2011; Nawarathne, et al., 2014; Ta et al., 2014). Makers try to manage this demand by introducing standby states to keep batteries from draining too rapidly each day (Vallina-Rodriguez et al., 2010). In the meantime, clever protocols remain the best approach to energy-efficient design (Ta, et al., 2014). Vallina-Rodriguez, et al. (2010) blames poor battery capacity mostly on user behaviour, while Xia, et al. (2015) fault multiple network interfaces and processes running parallel for pushing processors to consume more energy.

Factors responsible for consumption and drain in smartphones are:

a) network
b) device
c) apps (applications/software), and
d) the user (Chen et al., 2015)

Amid others (Carroll & Heiser, 2010; Ta, et al., 2014; Xia, et al., 2015).

Chen, et al. (2015) added that battery drain varies with each generation of the device, as newer mobile phones are faster and stronger, but work and drain the battery more. Apps consume large amounts of energy in use, pointing to their culpability as well.

Moore's Law posits that technology evolves at a rapid measurable rate (Brock, 2006). Smartphones have become the world's most popular electronic devices. Sales are reaching unprecedented levels worldwide each year, to top 1.7 billion by 2014, and with up to 1.4 billion units shipped in 2017 alone (Wollenberg and Thuong, 2014; Molina and Cava, 2015). They generally last about two years until owners want the next new thing with enhanced functionality and sensor-applicability (Li, et al., 2012; Ta et al., 2014).

Smartphones and the environment

Discarded handsets often remain functional but harm the planet by seeping chemicals into the ecosystem. Makers seek raw materials, exploiting the planet. The damage done is difficult to quantify (Babatunde et al., 2014). According to Li et al., (2014) increasing smartphone lifespan through manufacturer dexterity is one potential remedy to this; but Lilius (2012) affirms that reuse and recycling will produce the desired outcome of controlled adverse effects on the environment. Li et al., (2014) opines that effective reuse trumps recycling, although challenged by indifferent demand for refurbished devices, hence used smartphones can be broken down into individual counterparts for later reuse.

Reuse options vary with functional counterparts having their key mechanisms still viable, notably, the processor, screen, storage units, and the battery (Li et al., 2014).

An unbroken screen is reusable in almost any other electronic appliance with user-interactive capacity. Processors can be degraded via hot-election effects or gate-oxide breakdown into basic transistor assemblages, with altered performance that last up to 7 years longer than the parent smartphone; and storage units can be outfitted into external storage and reused almost interminably. Smartphone batteries however degrade rapidly so that options for reusing them remain appallingly restricted (Li, et al., 2014).

Smartphone Batteries

Primary batteries can be used only once and must be discarded once depleted. They have high densities, weigh more, and their applicability is limited low-power-drain devices or portable gadgets not in constant use. 'Dry-Cell Batteries' like alkaline and zinc-carbon batteries fall in this category. They are different from secondary batteries (such as the lead-acid, nickel-cadmium, and lithium-ion batteries) which can be restored by recharging. A third category of batteries blend properties from the two previous types. Examples are the Nickel-Metal Hydride (NiMH) and the Nickel-Cadmium (Ni-Cd) battery (Linden and Reddy, 2002).

Most smartphones use lithium-ion batteries, well-known for being rechargeable and portable, their high-energy density. They self-discharge slowly when not in use and are easily manufactured to varied shapes, albeit expensively, while losing their capacity to hold charges over use. They tend to overheat or explode if short-circuited, with their terminal voltages (Valøen and Shoesmith, 2007; O'Farrell, 2014). It has been found that if a smartphone is connected to a network, Wi-Fi or cellular, there will be some battery discharge, which shortens battery life. The same is true for when the smartphone screen is on, as its level of brightness is directly proportional to energy consumed (Boyden, 2014).

The exponential rise in smartphone users has increased e-waste disposal, with 20 to 50 million metric tonnes produced annually in Nigeria alone. The UK is only marginally better, landfills laden with more than a billion primary batteries carelessly discarded yearly (Babatunde, et al., 2014). If Waste from Electronic and Electrical Equipment (WEEE) continues to grow at this pace, it will expand by more than 30% in a few short years and contribute to chemical substances harming the planet (Boyden, 2014).

Green computing attempts to protect the environment by laws regulating smartphone use and disposal. Smartphone makers, users, and governments imbibe these guidelines to better protect and preserve the environment (Babatunde et al., 2014).

METHODOLOGY

This study uses a quantitative research method of mathematical investigations applied to data collected from experiments, questionnaires or surveys, employing statistical models and computations to examine energy consumption features. The findings are applied to hypothesising submissions that potentially improve usage practices in keeping with green computing for preserving the planet.

Research Approach

An experiment is carried out in a controlled laboratory environment, where battery drain factors are regarded as variables while measuring consumption and other battery drain parameters of specified apps on an android smartphone by a Trepn Profiler – an app developed by Qualcomm Technologies to measure energy consumption by tracking the processor, network, screen resolution or brightness, set to its advance mode.

Experiment

The device elected for this study is the Samsung Galaxy Edge with the following specifications:

Network Technology	–	2G/3G/4G LTE
Body Dimension	–	151.3 x 82.4 x
CPU	–	Quad-Core

Operating System	–	Android
Display	–	Super AMOLED capacitive touchscreen
Resolution	–	1600 x 2560 pixels
Communication	–	Wi-Fi 802.11 a/b/g/n/ac, dual-band, Wi-Fi Direct, hotspot
Battery Capacity	–	3000mAh

The following well laid-out guidelines were observed to obtain accurate results:

1) Setup

i. Trepn application downloaded from Google play store to the device
ii. Smartphone charged to 100% and disconnected from mains to rely solely on battery power
iii. Smartphone app is profiled in preparation for measurement capture.

2) Software Tool profiling

i. Preset Trepn profiler to advance mode and adjust settings for researcher objectives
ii. Set baseline power measurement and reading unit to current (mA) or power (MW)
iii. Acquire wake lock icon to prevent CPU and the phone screen from ‘sleeping’.
iv. Set data point to power and CPU statistics. Ensure icon depicts desired readings for CPU loads 1,2,3,4, all checked.
v. Check network statistics to ensure Wi-Fi or cellular readings at any point in time
vi. Maintain thermal reading for battery and processor temperature statistics
vii. Check other statistical readings, viz., app state, screen brightness, and screen state.

3) Saving readings

i. Stop profiling at the end of each experiment
ii. Save reading on device memory in CSV format
iii. CSV file is converted to an excel format with all calculations.

Interview

Interviews were conducted to explore user awareness and practices with respect to their smartphones. Time constraints necessitated a semi-structured approach to draw the needed information from three carefully selected respondents in 15- to 20-minute sessions, ensuring quality facts were drawn regarding usage practices and subsequent effects on smartphone lifespan with a view to possible solutions that prolong battery life. Respondents were decided upon based on their perceived ownership and knowledge of smartphones. Interaction was direct and data collection took the primary approach.

Results obtained are reasonably construed as representative of the collective UK populace both in smartphone models and in common usage practices. Battery charging fluctuations are assumed to be even. Interpreting the data collected went through preparation, similarities, transcription, validation and representation as required (Denscombe, 2010).

Ethical Considerations

The research process adhered to research-standard conduct for academically empirical results, precluding data manipulation and ensuring acceptable behaviour without violating human rights where collaborative effort became necessary.

1) Interview respondents were accorded and informed of their absolute rights to participate or withdraw.
2) Absolute anonymity of all contributors was assured.
3) Participants were clearly informed of the study's aim and objectives even with respect to the data being collected.
4) A decent, courteous, and morally conscientious study atmosphere was maintained.
5) Contributors and data were sustained in a risk-free setting.
6) The questionnaire was painstakingly constituted to consider participants' disposition to violence.
7) Effort was made to ensure an independent, objective, and unbiased enquiry.

RESULTS AND ANALYSIS

The experiment carried out on the Samsung Galaxy Note smartphone with an Android platform included taking temperature, CPU load, and battery power readings while operating various apps on the device, produced the following findings:

Table 1 – Tabulation of Experiment Findings

			Power Consumption (µW)	Temperature (Heat Dissipated) (1/10C)	CPU load (%)
Audio Applications	Wi-Fi	Samsung music	12,296.5283		46
		Google music	502,736.4003		49
	Cellular	Samsung music			27
		Google music			46
Video Applications	Wi-Fi	YouTube Video	1,216,692	340	62
		Samsung video	568,572	321	49
		VLC Player	1,239,238	326	50
	Cellular	YouTube Video	800,212	326	60
		Samsung video	547,904	322	43
		VLC Player	10,449,609	334	55
Social Media Chat	Wi-Fi	Viber	490,769	319	41
		WhatsApp	463,569	345	42
	Cellular	Viber	290,102	358	32
		WhatsApp	620,256	344	34

Audio Applications

Two audio player apps were tested and results graphically illustrated in Fig. 4.1.

The same song was played ten times on the two apps, first over Wi-Fi and then the other cellular (mobile) network. The temperature generated was recorded, and it was observed that the Samsung music app consistently generated lower temperatures than the Google music app. Lower temperatures naturally translates into less energy consumed and vice-versa. Evidently, some apps generate higher temperatures when they run, hence consuming more energy and draining the battery faster.

Fig. 4.1b illustrates battery power consumption when operating audio apps on the Samsung Galaxy Note. Here, consumption under Wi-Fi appears heavier than on the cellular network, indicating that higher battery power consumes more energy over the same task.

From Fig. 4.1c, a 46% CPU load was realised for the Samsung music app over the Wi-Fi network, compared to a 49% load by the Google music app. On the cellular network, the Samsung app pulled 27% while Google music pulled a 46% CPU load. Evidently, CPU load is higher on the Google music app than on the Samsung music app; and playing music on Wi-Fi consumed more energy/power than when music was played on the cellular network, as higher CPU load implies higher power consumption and subsequent battery drain.

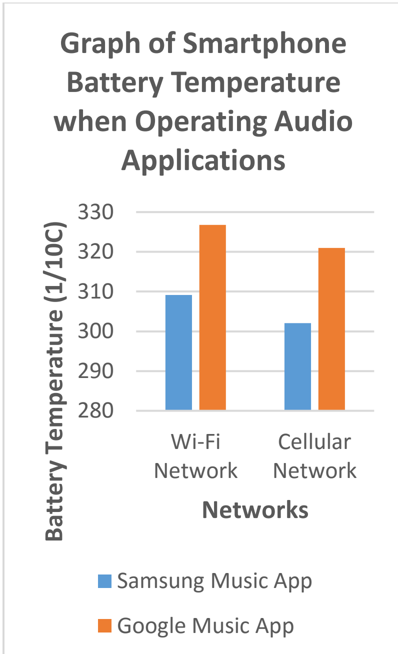


Fig. 4.1a Smartphone Battery Temperature when Operating Audio Applications

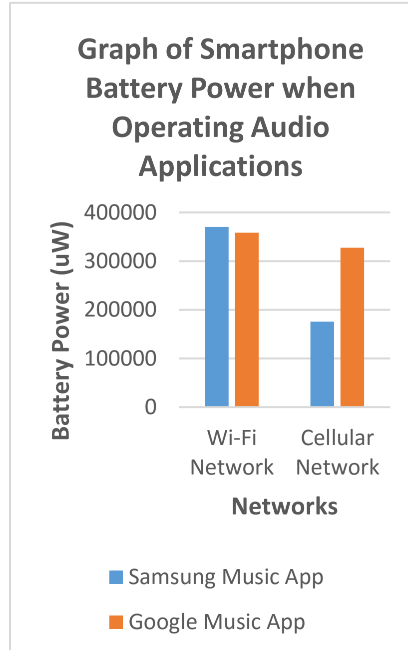


Fig. 4.1b Smartphone Battery Power when Operating Audio Applications

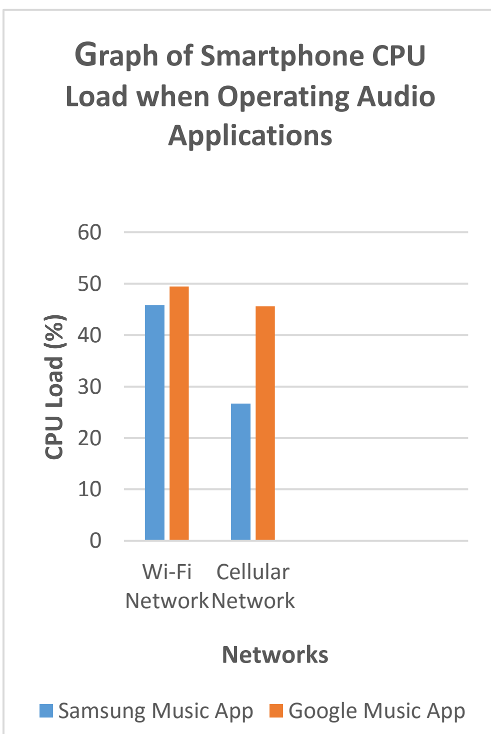


Fig. 4.1c Smartphone CPU Load when Operating Audio Applications

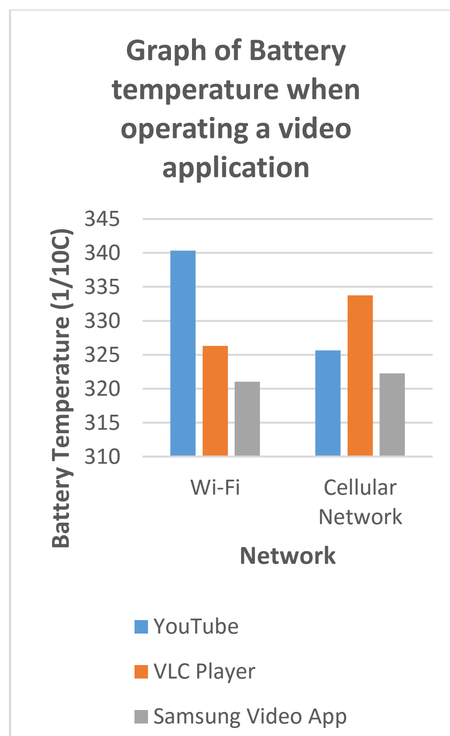
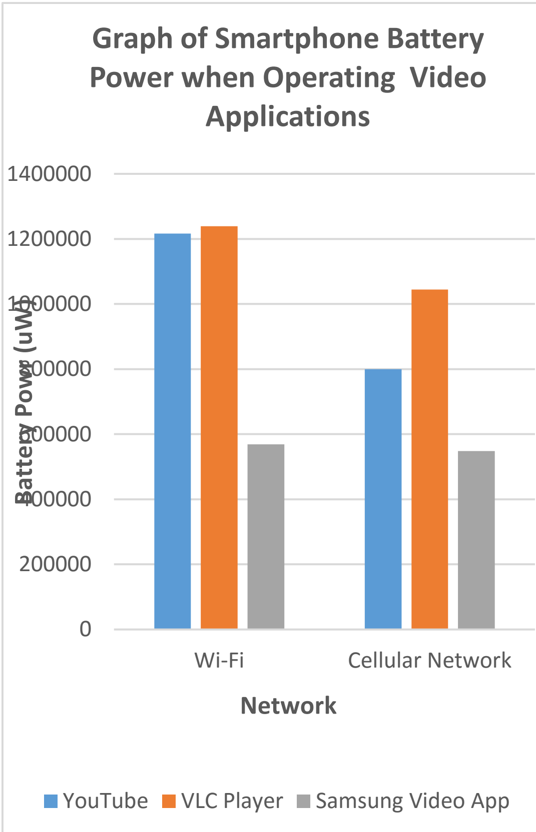


Fig. 4.2a Battery Temperature when Operating a Video Application



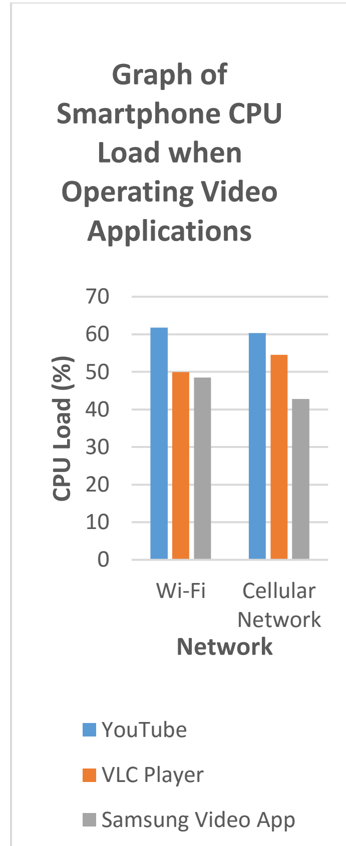


Fig. 4.2b **Smartphone Battery Power when Operating Video Applications**

Fig. 4.2c **Smartphone CPU Load when Operating Video Applications**

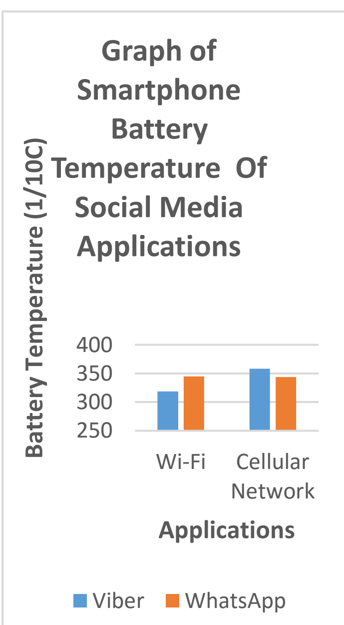


Fig. 4.3a Battery Temperature

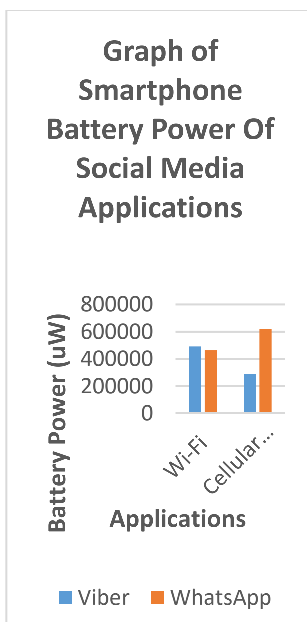


Fig. 4.3b Battery Power

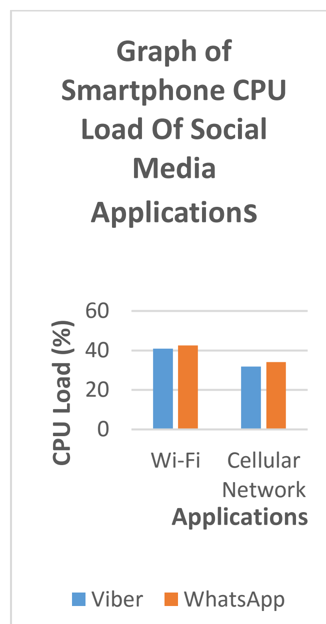


Fig. 4.3c CPU Load

Fig. 4.3 **Smartphones and Social Media Applications**

Video Applications

Readings were again taken when three different video apps were run on the device, namely the Samsung video app, VLC player, and YouTube video streaming. As with the audio apps, they were run both on Wi-Fi and on the mobile network.

The smartphone battery temperature reading was 340 (1/10C) for YouTube streaming, 326 (1/10C) for the VLC player, and 321 (1/10C) for the Samsung video app, all on Wi-Fi. On the cellular network, the readings were correspondingly 326 (1/10C) for YouTube Streaming, 334 (1/10C) for VLC player, and 322 (1/10C) for the Samsung video app, illustrated in Fig. 4.2a.

Observably, battery temperature with the Samsung video app varied only minimally from Wi-Fi to cellular network, but rather significantly with the other two apps. Taking battery power readings, we obtained 1216692µW for YouTube video, 1239238µW for VLC player, and a paltry 568572µW while running the Samsung video app on Wi-Fi; while the readings were 800212µW on YouTube, 10449609µW on VLC, and 547904µW on the cellular network.

Respectively, CPU load readings were 62% and 60% for YouTube video streaming first on Wi-Fi and then on the mobile network. For the VLC player they were 50% and 55% respectively; and for the Samsung video app they were 49% and 43% on Wi-Fi and the cellular network, as depicted in Table 1 and illustrated graphically in Fig. 4.2c.

Social Media

Whereas there is a myriad of social media apps that can be employed for this study, two of the most common ones were chosen – Viber and WhatsApp – experimented upon using both cellular and Wi-Fi networks, and illustrated in Figs. 4.3a-c. Fig 4.3a depicts battery power consumption, while Fig. 3.3b illustrates battery temperature readings, both on Wi-Fi and cellular. Viber brought in a 319 (1/10C) reading on Wi-Fi compared to WhatsApp readings of 345 (1/10C). On the mobile network, Viber chat raised the battery temperature to 358(1/10C), and WhatsApp made it 344(1/10C). Evidently, Viber at higher temperatures drained the phone battery faster than WhatsApp did.

When it came to CPU load, both apps had more impact on the smartphone under Wi-Fi than they did with the cellular network.

Viber chat brought about a CPU load of 41% on Wi-Fi compared to WhatsApp's 42%, showing a higher CPU load on the battery. On the cellular network, CPU load was 32% for Viber on cellular, and 34% for WhatsApp, indicating that WhatsApp drained more energy than Viber.

The following points were observed from the experiment:

a) Batteries function best at room temperature

b) The app in use significantly affects power consumption/battery drain
c) Different apps produce different power drain characteristics on the battery
d) Higher CPU loads drain battery power faster
e) Higher processing capacity lowers temperature and reduces battery drain
f) There is notable difference in battery drain between Wi-Fi and cellular network connectivity.

Interview Findings

Interview questions carefully selected to divulge usage patterns with respect to battery drain features in smartphones reveal markedly different practices among smartphone owners/users, justifiably resulting in significantly dissimilar results based on these patterns of usage. Due to time and spatial constraints, the interview respondents are limited to merely three (3) in number, with the responses presented in Table 2 below. Two of the respondents are female and both make use of the iOS platform yet with markedly different usage practices and subsequently different battery drain results, as taken from how frequently they must charge their smartphones in a day.

Table 2 Interview Questions: Responses

S/N	QUESTIONS	RESPONDENT 1	RESPONDENT 2	RESPONDENT 3
1	Age	29	A bit above 40	37
2	Gender	Female	Male	Female
3	Do you own a smartphone?	Yes	Yes	Yes
4	Smartphone platform?	iPhone 6s	Android	iPhone
5	Functions performed on smartphone	Basically – Everything	Browsing and watching movies	Videos, calls, messaging, chatting; planning, alarm, GPS, etc.
6	Any noted (battery) challenge with using the smartphone?	No	Battery runs down fast when watching videos	Yes. Battery runs down the faster it is used
7	Audio applications?	Not really	No	Yes
8	Time spent on audio app daily			About 1-2 hours
9	Video applications?	Minimally	A lot	Yes
10	Time spent on video apps daily	5-10 minutes	Usually over 3 hours	Less than 1 hour
11	Social media applications?	Yes: Facebook; Facetime; WhatsApp; Glider	Facebook and WhatsApp	Yes: Facebook; WhatsApp
12	Time spent on Social Media Apps daily	About 1 hour	About 1 hour	4-5 hours
13	Other frequently used applications	Google; calendar; (looking for a flat)	Photo editing	Instagram; SatNav; calculator; Facebook

			Christian message apps	
14	How many times do you charge you phone in a day?	Once a day (nightly)	Twice daily	Twice daily
15	Do you think there is a need to conserve energy in smartphones?	Don’t really think about it.	A heavy user, would love makers to produce phones with longer lasting batteries.	Yes – to conserve battery for the apps that will be used. Would take much discipline otherwise

Results obtained from the interviews appear to be in keeping with the experiments’ findings, notably that certain apps – such as video apps – appear to drain smartphone batteries more heavily than others, such as audio applications, while heavy use of social media apps tend to produce the same effect. Both female respondents (Respondent 1 and Respondent 3) report that they do ‘everything’ with their smartphones, however, it is obvious that Respondent 3 spends more time on audio and video applications, and a lot more time on social media apps such as Facebook, WhatsApp, and Instagram. Even though neither seems particularly aware of how this drains their device battery, Respondent 3 reports having to recharge this smartphone’s battery twice in a day whereas Respondent 1 does this only the one time.

The report from Interview Subject 2 is markedly like that of Respondent 3, indicating a relatively heavy user. This user however appears to be more aware of the implications of comparative substantial use on the device battery, stating that ‘a heavy user would want smartphone manufacturers to produce phones with longer lasting batteries’, while also establishing that he must charge his device twice in a day.

A closer look at the replies from Respondent 2 reveals that this is a relative heavy user of the video app on his android smartphone, indicating the assertion that video apps perhaps contribute meaningfully to battery drain features in smartphones. Respondent 3 is contrarily a heavy social media app user, depicting as found earlier that weighty and consistent use of social media apps on a smartphone contributes profoundly to the draining of the battery.

Within reason, smartphone owners who report heavier usage of the software applications (apps) on their devices appear to require charging for their devices more frequently than users who do not employ their smartphones so exhaustively. As a matter of fact, the interviews reveal that users who are more conscious of the effects of heavy use on their smartphones appear to be more careful with how they make use of their devices. The implication of this is that these latter class of users do not require frequent charging for their smartphones because they do not drain their batteries with incessantly heavy usage.

Observably, users who are more conscious of energy consumption and battery drain features on their smartphones and other electronic devices tend to expect smartphone manufacturers to produce better devices with longer lasting batteries. As such, it can be inferred that awareness or education concerning the factors and implications of battery drain among smartphone users can contribute conspicuously to improved design features in smartphones, in addition to improved usage and disposal practices amongst end users the world over. The small number of respondents however make it impossible to decisively conclude that these results are universal.

These findings, while agreeing in some way with previous observations from the experiment results, are in themselves inconclusive due to the small number of subjects interviewed.

CONCLUSION AND RECOMMENDATION

Conclusion

Smartphones indeed are rapidly proliferating but battery drain and energy consumption as consequences of four primary factors limits their use and increase the risk of harmful effects on the environment. With respect to the specific objectives of this research, these factors have been determined to be the network, the device specifications, apps on the device and habits of the smartphone user.

Developing a framework for the identified factors has been accomplished as well and laid out in the study. It centers around user awareness and manufacturer astuteness with respect to improved design features and specifications during production. These were determined experimentally in keeping with Research Objectives 3 and 4, targeted to analyze energy consumption (and consequent battery drain) by respective smartphone apps; augmented by interviews conducted to determine and document user behaviours and their impact.

Based on these, the user is determined to be the biggest determinant of battery drain/consumption in smartphones based on how much time they spend on their devices and what they do with them. The only way to completely stop battery drain is if the device is turned off because ongoing background processes still contribute to energy consumption. Drained batteries are largely discarded, which brings about the release of carbon dioxide and other greenhouse gas emissions that are harmful to the planet. The manufacturer however bears some responsibility in that they need to work more levelheadedly to design better smartphones, while also communicating better to their consumers the recommended usage practices for optimal use and improved preservation of the planet.

Recommendation

It is recommended that further study be carried out with more attention given to hardware and software functionalities to lower drain features. In addition, effort can be made as stated above, to more effectively communicate to smartphone users how best to preserve their batteries and protect the environment through improved usage practices. Smartphone manufacturers will also do well to employ the Green Code in design considerations to further lower power consumption in batteries. A further recommendation is for deliberation to be given to keeping battery evolution at pace with the rate of development of general smartphone technology as this has been shown to be lacking in recent years.

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