IST-Africa 2017 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2017
ISBN: 978-1-905824-56-4

Investigating Battery Consumption in Low-End Smartphones: Preliminary Results

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Abstract: Due to lack of electricity in the rural communities of Africa, users often have to incur extra expense on recharging their mobile phones. The limited battery capacities of low-end smartphones, therefore, present a barrier to their positive integration with such communities because of their vast networking features that likely lead to their elevated usage, thus, causing faster battery depletion and in turn, escalating recharge costs. This paper presents preliminary results of ongoing investigations on battery consumptions in low-end smartphones in order to estimate their battery life under different usage scenarios, and estimate the surge in communication expense brought about from the frequent recharging. Voice call experiments over WiFi and 3G data, in different network mode combinations, were conducted using three brands of low-end smartphones. Results, compared using analysis of variance and Tukey methods for pairwise comparison, yielded Smart4Mini brand to be the least battery draining, along with Smart Kicka being second best and Galaxy Pocket Neo being least efficient. In addition, the investigations aided in building a platform for future experiments in order to precisely estimate communication costs under different usage scenarios. Dissemination of such information can assist rural users in making well-informed communication expenditure towards purchase and usage of low-end smartphones.

Keywords: rural areas, low-end smartphones, battery consumption; WiFi; 3G; voice call

1. Introduction

Charging the smartphones on regular basis can become a major concern, especially, for the 1.2 billion population of the world that are living without electricity, and of which 95% are in countries in sub-Saharan Africa and developing Asia, predominantly residing in the rural areas [1]. Though affordability of the smartphones by rural consumers has been addressed to a certain extent by the constantly dropping prices of smartphones and data services, battery life remains a major concern for rural users [2][3][4]. This research is focused on such an area, Mankosi located in the Eastern Province of South Africa.

Spread across 12 villages, Mankosi comprises of 564 households with families consisting of approximately 6 members. The monthly income of a household, including government grants and payments from family members who temporarily migrate for work, is approximately USD 125.31 and individual monthly income of approximately USD 26.55 [5]. The community, through partnership (ongoing) with the University of the Western Cape UWC), has built a wireless mesh network (WMN) that spreads across an area of 30 Km^2. The community WMN creation has also led to the formation of a locally owned telecommunication co-operative, Zenzeleni Networks (ZN) which manages the services provided by the network [6]. The WMN is powered using solar charged batteries due to absence of electricity in the community and consists of 12 mesh routers called Mesh Potato (MP-1). The MP-1s are pre-loaded with private branch exchange (PBX) system supporting Session Initiation Protocol (SIP) calls. The PBX system empowers community members to make free intra-community calls using analogue phones connected to the telephone port present on MP-1s. By subscribing to cheap Voice over Internet Protocol (VoIP) provider, ZN also offers breakout voice calls at costs lower than those of South African telecommunication operators. Additionally, the power generated by the solar-charged batteries is also used to provide mobile phone recharge facilities to community residents by ZN. Figure 1 shows solar panel and router on top of a thatched-roofed house (left) and mobile devices being charged at a recharge station (right).

Figure 1: Solar panel and mesh router unit (left) and charging station for mobile phones (right)

The current usage of mesh network is limited to only voice calls from the 12 stationary MP points. Therefore, community members have asked UWC to explore cost-effective and power-efficient ways to broaden the use of the mesh network such that members could make voice calls as well as access other data services using their personal mobile handsets. Given the barriers to access GSM spectrum and create a community cellular network as done elsewhere [7], the next phase of the project is considering the introduction of low-end smartphones in the community and upgrade the MP-1s to newer versions with better hardware specifications (specs), thus leading to entire upgrade of the mesh network.

With access to network services on personal mobile devices, it is likely that general device usage will escalate leading to quicker depletion of batteries and surge in device recharge costs. With 58% of the community members preferring battery life as the primary desired attribute in mobile phones, faster depletion of phone batteries and increase in the current cost of recharging them i.e., 2.67% of the monthly income, could hinder the successful introduction of the low-end smartphones in the community [8]. This paper presents preliminary results of ongoing experiments aimed at evaluating battery consumption in low-end smartphones under different usage scenarios before their introduction into Mankosi and other similar communities. We believe that the results obtained from the experiments will aid in estimating affordability costs of the low-end smartphones.

The paper is organized as follows: Section 2 presents related work on battery consumption in mobile phones and establishes research gap. Section 3 describes the experiment framework. Section 5 presents a summary of results, and discussions. Conclusion is presented in Section 6, with future works in Section 7.

2. Related Works

Wireless radios in mobile devices account for the major portion of the final energy consumption (up to 70% of total power consumed in active mode) [9][10][11]. The smartphones today are equipped with multiple wireless technologies e.g., 3rd generation (3G), Global System for Mobile Communications (GSM), Wi-Fi, and Bluetooth. So which one consumes the least battery?

Balasubramanian et al. concluded that between 3G, GSM and WiFi 802.11b technologies, for a transfer size of 10 Kilobytes (Kb), WiFi consumed one-sixth of 3G's energy and one-third of GSM's energy once connected to an access point, with efficiency increasing dramatically with increasing data sizes. However, the authors also reported that when the cost of scan and transfer is included, WiFi becomes less efficient than GSM for small sized transfers, yet still remained more efficient than 3G [12].

Another study by Xiao et al. assessed the energy consumption between 3G and WiFi 802.11g communication technologies during video streaming using YouTube app [13]. The results for progressive download and playback of a 9284 Kb video showed that 3G consumed 1.45 times more energy than WiFi.

The relationship between battery consumed and throughput achieved by Bluetooth and WiFi 802.11g in smartphones was investigated by Friedman *et al.* [14]. Results of User Datagram Protocol (UDP) and Transmission Control Protocol (TCP) traffic sent through the WiFi interface and RFCOMM traffic sent through the Bluetooth interface, at first using *iperf* network management tool, and then actual files sent using File Transfer Protocol (FTP) between the mobile devices showed WiFi to consume more battery than Bluetooth in both scenarios. Friedman *et al.* concluded that higher the throughput achieved by the interface, higher the battery consumed, and that Bluetooth would become more power consuming than WiFi if it were to achieve the throughput levels of WiFi.

Therefore the analyses and measurement of battery consumption by wireless technologies in smartphones show WiFi to be the most efficient mode of data transfer.

2.1 The Research Gap

Whereas some use of wireless technologies can be controlled by users such as automatic upgrades, communication using social networking apps (SNAs) has become a necessity especially because of their lower costs and vast features. Reports are being published frequently about the most battery draining SNAs for smartphones so that consumers can select the app that best fits their requirements and lifestyle [15]. However, these reports focus on devices in general and reports targeted specifically towards battery consumption in low-end smartphones are non-existent, thus, recognizing the need of a comprehensive study of battery consumption in low-end smartphones. Results from such a study can be used to promote the adoption of low-end smartphones in rural communities.

3. The Experimental Framework

This section presents the blueprint of experiments. The high level diagram (HLD) in Figure 3 shows the flow of decision making with their descriptions following in the subsequent sections.

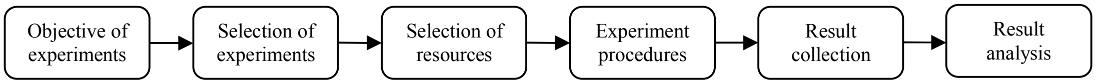


Figure 2: HLD of the experiment

4.1 Objective of Experiments

The following objectives were emphasized for this research:

1. Build preliminary understanding of battery life of low-end smartphones under different usage scenarios.
2. Form a hierarchy of low-end smartphones based on the results.
3. A framework for further experiments involving such smartphones.

4.2 Selection of Experiments

The results of an airtime usage survey of 213 Mankosi residents showed that 79.5% of residents used airtime for calling relatives, friends and other people [8]. Therefore, experiments to evaluate battery consumption by voice calls were assigned top priority. In addition, the presence of a functional mesh network in the community, and low costs of VoIP calling provided further motivation to test battery consumption during WiFi voice calls first.

In the absence of a WiFi hotspot, voice calls using 3G or 2G data are the next cheap option. Therefore, further voice call experiments using 3G or 2G cellular data were considered. Due to the low transmission rates leading to poor call quality of the old 2G technology, selection decision went in favor of 3G [16][17].

4.2 Selection of Resources

The section describes the decision making process behind selection of the appropriate software, and the hardware resources for the voice call tests.

4.2.1 Software – Voice Call Apps

CSIPSimple (CSIP), a SIP client recommended by the router manufacturers, and available for free from the Google Play repository was selected for the free intra-network voice calls using the smartphones [18]. Breakout voice call using CSIP can also be configured, but by subscribing to a VoIP service provider. However to minimize experiment costs, we decided to use a SNA with calling feature to emulate breakout voice calls. Data usage and battery consumption reports showed that Viber received low app cost rankings, that highlighted impact of an app on battery drain and data plan consumption, as compared to other widely used SNAs e.g., WhatsApp, Facebook Messenger, Blackberry Mesenger, and Skype [15][19]. Therefore, Viber was chosen as the second app. Viber can also be used for intra-network voice calls, but unlike CSIP, it cannot function without Internet connection.

4.2.2 Hardware – Low-End Smartphones

A market survey concluded that most low-end smartphones in the South African market started with prices above USD 30, exceeding the reported individual monthly income of Mankosi resident. Therefore, the average household income figure of USD 126.55 was used to narrow the selection of the low-end devices. In addition to income figures, the technical specs of the CSIP app, which restricts installation on Android mobile devices only, permitted preference to Android smartphones only.

Before acquisition of the devices, a quantity of 20 each for at least 3 brands of devices was considered as a good sample size for this research. Acquisition of the following low-end devices; Samsung Galaxy Pocket Neo (Brand 1), Vodafone SmartKicka (Brand 2), and Vodacom Smart4Mini (Brand 3), was completed through financial assistance from the Department of Computer Science's Center of Excellence at UWC. Table 1 presents the out-of-box specifications of the smartphones. In the rest of the paper, the smartphones are referred using Brand 1, Brand 2 and Brand 3 instead of their exact names.

Table 1: Smartphone specifications

	Brand 1	**Brand 2**	**Brand 3**
Battery (mAh)	1200	1400	1400
Wireless technologies	GSM, 3G, WiFi 802.11 b/g/n	GSM, 3G, WiFi 802.11 b/g/n	GSM, 3G, WiFi 802.11 b/g/n
Claimed talk time	6 hours	8.5 hours	8 hours
Claimed stand-by time	600 hours	403 hours	600 hours
Android OS	4.4.2	4.4.2	4.2.2
Memory (MB)	512	512	512
Processor	850 MHz single-core	1 GHz dual-core	1.3 GHz dual-core
Display/ Resolution	3.0 inches, 240X320 pixels	3.5 inches, 320X480 pixels	4.0 inches, 480X800 pixels
Cost (USD)	44.47	37.62	51.32

4.2.3 Hardware – Mesh Routers

Preference was given to use of the newer version of mesh routers for the experiments called Mesh Potato 2 (MP-2). Table 1 shows a comparison between MP-2 and MP-1.

We configured an MP-2 to operate in single-radio mode to emulate WiFi voice calls. SIP call support was possible by simply enabling SIP settings in the router settings. For Viber to work, the router was configured for Wide Area Network (WAN) access. The router access point (AP) mode was left in default mixed mode, which was 802.11 b/g/n letting the phone autoselect the rate. The preinstalled G.711 voice codec was used for CSIP calls. Viber on the other hand is packed with proprietary voice codecs whose details remain undisclosed [20].

Table 2: Specifications of MP-1 and MP-2

Router	Processor	Flash Storage	RAM	WiFi	Frequency	Firmware	Routing Protocol
MP-1	Atheros AR2317 180MHz	4 MB	16 MB	802.11 b/g	2.4 GHz	v 1.1	batman-adv version 2011.2
MP-2	Atheros AR9331 400MHz	16 MB	64 MB	802.11 b/g/n	2.4 GHz w/ USB extension for extra radio	v 2.0	batman-adv version 2013.4

4.3 Experiment Procedures

Before commencing the voice call experiments, we conducted a few preliminary tests to assure normal functionality of devices; explored the possible WiFi and 3G call modes possible with the smartphones; devised a stepwise procedure to making voice calls; and established experiment controls to assure collection of relevant data. This section presents a description of the outcome of the process.

4.3.1 WiFi and 3G Voice Calls Network Mode Combinations

Table 2 presents the the different network modes combinations possible with the low-end smartphones for WiFi and 3G SNA voice calls experiments.

Table 3: WiFi/Cellular radio combinations

Call Type	App	Description
W-AUTO	CSIP and Viber	WiFi calls with devices in 2G/3G mode
W-2G	CSIP and Viber	WiFi calls with devices in GSM mode
W-3G	CSIP and Viber	WiFi calls with devices in 3G mode
W-PLAIN	CSIP and Viber	WiFi calls with cellular radio turned off , hence achieving partial Airplane mode
3G-X	Viber only	Voice calls using 3G data with WiFi radio ON but disconnected from access points
3G	Viber only	Voice calls using 3G data with WiFi radio OFF

4.3.2 Plans for Making Calls

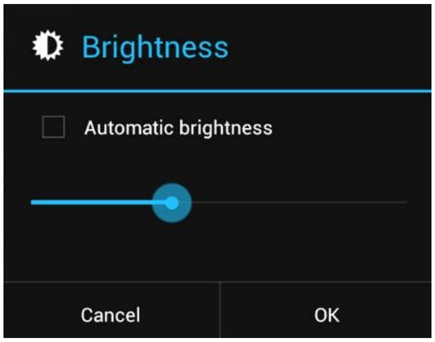
1. Conduct single cycle of 1-hour voice calls in both screen ON and OFF states between a pair of smartphones, therefore, equalling 30 pairs and 20 tests all together. Repeat dropped calls in order to provide 1-hour of undisrupted voice call data.
2. Stream Youtube media of speech type with lengths more than 1-hour through speakers in order to attain 1-hour of voice. Place call initiating smartphones close to the speakers with their mic end facing the speakers. Place call receiving devices at random distances apart from the calling devices. Use a separate timer to keep track of call time.
3. Purchase data bundles to emulate 3G voice calls using Viber.

4.3.3 Experimental Controls

Before beginning any experiments, a few preparatory control steps had to be taken in order to assure validity of data collected at the end of experiments. Table 4 presents the control measures applied for the experiments in this research and their description.

Table 4: Control measures

Control	Description
Apply firmware update	Updates bring along bug fixes and driver updates aimed at improving overall performance of device.
Disable auto-updates	Avoid background execution of processes during tests.
App versions	Make sure same version of CSIP and Viber is installed across all smartphones
Display	Ensure similar brightness settings across all smartphones.
Volume	System volume and app volume are two different settings. Make sure they are same across all phones.



☐ Automatic brightness

Figure 2: Brightness setting in the low-end smartphones.

The Android OS installed on the smartphones had a brightness bar, as shown in Figure 2 to set the brightness levels. In order to set brightness at 75% brightness, we first moved the indicator to the mid-point of the brightness bar representing approximately 50% and then moved the indicator towards right to the mid-point of 50% and 100% mark. For screen OFF tests, each phone screen was manually turned off by pressing their respective power buttons after five seconds of reception of a call because the screens would not turn OFF unless brought close to human ears and in case of Brand 1, not turn off at all but just dim.

4.4 Results Collection

We decided to use the default battery monitoring app supplied with the Android OS on the devices for the experiments instead of third-party apps or multimeter. The following explain our reasons behind doing so:

1. Time: There are numerous free battery monitoring apps in the Google Play repository e.g 3C Battery Monitor Widget, GSam Battery Monitor, CurrentWidget, Battery Monitor, PowerTutor, etc, with each claiming to provide users with accurate and detailed battery consumption data for smartphones. Use of such an app would have meant performing a benchmarking process amongst the apps, emphasizing their data calculation methods, error rate and battery profile. With the objective of building preliminary understanding of battery consumption, the benchmarking of the third-party apps would have likely elongated the completion time of experiments.
2. Breach of warranty: The use of multimeter required physical modifications to the phones in order to measure voltage and current readings accurately. At the time of experiments, the devices were still under warranty. Any physical modifications to so many devices, and considering the fact of devices malfunctioning due to modifications, would have led to breach of warranty terms, and extra unplanned expenses to get the devices repaired.

The default app displayed the value for remaining battery capacity in a percentage form and could be obtained from the settings menu in the smartphones.

4.5 Results Analysis

The statistical procedure Analysis of variance (ANOVA) was chosen to compare the mean of battery percentage drops obtained from the experiments. Conducted using Statistical Analysis System (SAS) software, using the results of ANOVA, conclusions can be made whether there is statistically significant difference in means of the groups [21]. In our experiments, we have a factor i.e., the smartphones, with three levels, Brand 1, Brand 2 and Brand 3, which are all independent of each other. Therefore, a one-way ANOVA procedure was performed to determine the differences between the means of three levels for each test. The following four steps describe the approach to ANOVA of the data obtained from the smartphone experiments to make conclusions about the means [22]:

1. Setup hypothesis and determine level of significance (α). The null and alternative hyothesis that are generally used in ANOVA are:
   $$H_0 : \mu_1 = \mu_1 = \mu_2 = _{...} = \mu_n \text{; all means, } \mu\text{, are equal} \quad (1)$$
   $$H_1 : \text{not all } \mu \text{ are equal} \quad (2)$$
   The significance level, α was decided as 0.05.
2. Decide an appropriate test statistic. One-way ANOVA uses the F statistic. The SAS software computes the F-ratio.
3. A P-value associated with the F statistic will be determined by SAS. If $p \leq \alpha$, the null hypothesis is rejected and H_1 is true.
4. Based on results from step (3), make conclusions such as H_1 or H_0.

However, the one-way ANOVA does not distinguish which specific means are significantly different from each other. A *post-hoc* analysis is usually conducted to determine which means are significantly different. The result of such an analysis, in our case, can be used to differentiate the smartphones. Tukey’s Honest Significance Difference (HSD) test was selected for *post-hoc* analysis. Tukey's HSD test used in ANOVA creates confidence intervals for all pairwise differences between factor level means while controlling the family error rate to α level [23].

5. Results and Discussion

5.1 Presentation of Results

The significance of results of brand comparison relies on the 95% confidence interval. If the confidence limit (CL) for the brand comparison ranges between negative and positive values, thus including zero, that result is considered insignificant because it could mean that the two brands might have the same consumption. The significant results obtained from the analysis are summarized in tables with the following column headings:

The column headings in the tables represent the following:

- Call type - the particular test conducted using the app. Refer to Table 2.
- Brand match - represents the pair of devices being compared.
- DBM - difference between the means of two brands of smartphones used for comparison.
- 95% CL - shows the 95 % confidence limits of the DBM.

CSIP and Viber screen ON voice call tests are presented in Tables 5 and 6 respectively. Tables 7 and 8 show the significant results for CSIP and Viber screen OFF voice call tests respectively. The insignificant results are not presented in the tables for simplification of comparison. Table 9 and 10 show the CSIP and Viber DBM, and the 95% CL of screen ON and screen OFF modes respectively.

Table 5: Results for CSIP WiFi voice calls with screen ON

Call type	**Brand match**	**DBM**	**95% CI**	
			Lower	Upper
W-2G	2 – 1	6.25	4.78	7.72
	3 – 1	5.45	3.98	6.92
W-AUTO	1 – 2	1.40	0.34	2.46
	1 – 3	1.55	0.49	2.61
W-3G	2 – 1	2.30	0.25	4.35
W-PLAIN	3 – 1	2.15	1.19	3.11

Table 6: Results for Viber voice calls with screen ON

Call type	**Brand match**	**DBM**	**95% CI**	
			Lower	Upper
W-AUTO	2 – 3	2.25	0.64	3.86
	1 – 3	2.20	0.59	3.81
W-PLAIN	3 – 1	1.25	0.17	2.33
3G-X	2 – 1	2.05	0.61	3.49
	2 – 3	2.10	0.66	3.54
3G	2 – 3	1.55	0.17	2.93
	2 – 1	2.60	1.22	3.98

Table 7: Results for CSIP WiFi voice calls with screen OFF

Call type	Brand match	DBM	95% CI	
			Lower	Upper
W-2G	1 – 2	1.40	0.79	2.01
	1 – 3	4.15	3.54	4.76
	2 – 3	2.75	2.14	3.36
W-AUTO	1 – 2	2.25	0.91	3.59
	1 – 3	5.15	3.81	6.49
	2 – 3	2.90	1.56	4.24
W-3G	1 – 2	3.95	3.15	4.75
	1 – 3	4.15	3.35	4.95
W-PLAIN	1 – 3	4.80	4.26	5.34

Table 8: Results for Viber voice calls with screen OFF

Call type	Brand match	DBM	95% CI	
			Lower	Upper
W-2G	1 – 2	3.55	2.69	4.41
	1 – 3	4.15	3.29	5.01
W-AUTO	1 – 2	3.20	2.34	4.06
	1 – 3	5.15	4.29	6.01
	2 – 3	1.95	1.09	2.81
W-3G	1 – 2	2.10	1.14	3.06
	1 – 3	3.75	2.79	4.71
	2 – 3	1.65	0.69	2.61
W-PLAIN	1 – 3	4.10	3.71	4.49
3G-X	1 – 2	1.85	0.15	3.55
	1 – 3	5.00	3.73	6.27
3G	1 – 2	3.15	1.88	4.42
	1 – 3	5.00	3.73	6.27
	2 - 3	1.85	0.58	3.12

Table 9: CSIP voice call DBM of screen ON and OFF modes with the 95% confidence limits

	Brand 1			Brand 2			Brand 3		
	DBM	95% CL		DBM	95% CL		DBM	95% CL	
		Lower	Upper		Lower	Upper		Lower	Upper
W-AUTO	8.40	8.04	9.25	9.25	8.08	10.42	12.00	10.74	13.26
W-2G	2.85	1.78	10.50	10.50	9.76	11.24	12.45	11.37	13.53
W-3G	7.00	5.57	13.25	13.25	12.43	14.07	12.90	11.34	14.46
W-PLAIN	5.80	5.40	6.20	Not Possible			12.75	11.72	13.77

Table 10: Viber voice call DBM of screen ON and OFF modes with the 95% confidence limits

	Brand 1			Brand 2			Brand 3		
	DBM	95% CL		DBM	95% CL		DBM	95% CL	
		Lower	Upper		Lower	Upper		Lower	Upper
W-AUTO	8.20	7.00	9.40	11.45	10.51	12.39	11.15	10.05	12.25
W-2G	6.95	5.80	8.10	11.10	10.45	11.75	10.50	9.22	11.78
W-3G	7.25	6.30	8.20	9.60	8.87	10.33	11.35	9.80	12.90
W-PLAIN	5.15	4.13	6.17	Not possible			10.50	9.98	11.02
3G-X	5.65	4.16	7.14	9.55	8.48	10.62	10.60	9.15	12.05
3G	7.70	6.32	9.08	13.45	12.64	14.26	10.80	9.82	11.78

5.2 Discussion of Results

The experiments evaluated battery consumption in three low-end smartphones during voice calls over WiFi, using CSIP and 3G data, using Viber. We present a discussion on the performance of the devices based on the results presented in Tables 5-10.

5.2.1 Brand 1 (Samsung Galaxy Pocket Neo)

1. CSIP: Analyzing the results presented in Tables 5, with screen ON, Brand 1 displayed lower battery consumption than both Brand 2 and 3 for W-2G voice calls. Individually, Brand 1 achieved less battery consumption than Brand 2 for W-3G and Brand 3 for PLAIN screen ON calls. However, for W-AUTO screen ON calls, Brand 1 showed higher drains than Brand 2 and 3. With screen OFF, Brand 1 could not outperform the drops achieved by Brand 2 and 3. Even though the battery consumption was minimized for with screen OFF, the drops were lower than those of Brand 2 and 3.
2. Viber: While screen ON, Brand 1 displayed lower battery consumption than Brand 2 for 3G and 3G-X calls, and Brand 3 for PLAIN mode calls. With screen OFF, Brand 1 once again could not outperform the drops of Brand 2 and 3.

The results show that Brand 1 consumed less battery than Brand 2 and 3, mostly, during screen ON calls. On the other hand, with the setting W-AUTO, which keeps the devices in auto select (2G/3G) cellular network mode, Brand 1 is shown to drain more battery than both Brand 2 and 3 when using CSIP, and Brand 3 when using Viber. This shows that the Brand 1 are more energy efficient in a 2G network mode setting for screen ON calls, than in auto-select network mode. With screen OFF, though Brand 1 consume less battery, the drops in Brand 2 and 3 are higher. Debunking the reason for such results is a trivial affair because factors such as physical dimensions of the phones and battery, and processing speed of data can be at play. Plans of experiments to precisely differentiate the reason for such result are underway.

5.2.2 Brand 2 (Vodafone SmartKicka)

We would like to start off this section by mentioning that the WiFi radio in Brand 2 could not be turned active after setting the phone to Airplane mode due to which PLAIN mode tests could not be conducted. The significant results of the conducted tests reveal the following:

1. CSIP: As shown in Table 5, with screen ON, Brand 2 showed lower battery consumption than Brand 1 during W-AUTO voice calls. This was the only instance amongst screen ON CSIP tests where Brand 2 outperformed Brand 1 and 3. With screen OFF, results in Tables 7 show that Brand 2 consumed less battery than Brand 1 for W-2G, W-AUTO, and W-3G mode voice calls.
2. Viber: As shown in Table 6, with screen ON, Brand 2 showed higher battery consumption than Brand 1 and 3 amongst all the significant test results. However, as shown in Table 8, with screen OFF, Brand 2 Viber results displayed similar results to that of CSIP results and consumed less battery than Brand 1 amongst all the results.

As shown in Tables 9 and 10, the drops in battery consumption by turning screen OFF in Brand 2 are significantly higher than those of Brand 1 devices. The result patterns show Brand 2 to be a better option than Brand 1 for voice calls in screen OFF mode. Also, as shown in Tables 9 and 10, Brand 2 registered bigger drops in battery consumption than Brand 3 for CSIP W-3G, and Viber W-AUTO, W-2G, 3G-X and 3G voice calls when screen turned OFF but still registered high overall battery consumption than Brand 3.

5.2.3 Brand 3 (Vodacom Smart4Mini)

Brand 3 smartphones were the most expensive of the three costing USD 51.32 each, approximately 41% of the monthly income of a household in Mankosi. With the higher price tag, Brand 3 came with faster processor and bigger screen than Brand 1 and 2, yet same battery capacity as Brand 2. The results for Brand 3 reveal the following:

1. CSIP: As shown in Table 5, with screen ON, Brand 3 consumed less battery than Brand 1 during W-AUTO voice calls. Infact this was the only sceen ON voice call test where Brand 3 consumed less battery than any other brand. As shown in Table 7, with screen OFF, Brand 3 showed lower battery consumption than Brand 1 for W-3G, and W-PLAIN, and both Brand 1 and Brand 2 for W-2G, and W-AUTO voice call types.
2. Viber: Results in Table 6 show that with screen ON, Brand 3 consumed less battery than both Brand 1 and Brand 2 for W-AUTO. In addition, Brand 3 also outperformed Brand 2 in screen ON 3G-X and 3G type calls. Results for tests with screen OFF in Table 8 show that Brand 3 consumed less battery than Brand 1 during W-2G and PLAIN voice calls; Brand 2 during 3G-X voice calls; and both Brand 1 and Brand 2 during W-AUTO, W-3G and 3G voice calls.

Analysis of results resented in Tables 5-8 reveals that with the phone screens turned off, Brand 3 exhibit the lowest battery consumption of the three low-end smartphones.

6. Conclusion

This paper presents the preliminary results of ongoing investigations on battery consumption in low-end smartphones under different usage scenarios. Voice calls using WiFi and 3G using three different brands of phones and different network mode combination were conducted. Results revealed Brand 3 as the least battery consuming low-end smartphones during the more efficient screen OFF mode. In addition, the second best low-end smartphones were Brand 2 which consumed less battery than Brand 1 for screen OFF voice calls. In addition, the screen ON and OFF results in our opinion, have revealed new insight into battery consumption by display screen, other than the well understood fact of screen OFF mode being more battery efficient than screen ON. The drop in consumption screen ON and OFF for each brand was different for each network mode. In the opinion of the researchers, further study is required to precisely explain such behavior.

Before we end this section, we would like to reflect back on the objectives meant to be achieved from the experiments in this paper. We believe that the preliminary experiments successfully provided an insight into the battery consumption of low-end smartphones, a hierarchy of low-end smartphones using the results obtained, and a framework for future tests. However, it is of utmost importance to mention that no matter what the end results are, choosing a low-cost smartphone is a very personal decision and it is influenced by values that go beyond the technical factors presented in this paper. In addition, in the event of deciding to buy a low-end smartphone, it is surprising how little information is present to assist the users from economically disadvantaged communities to make a choice that best fits their financial position.

7. Future Work

The list below presents plans of future experiments for a comprehensive study of battery consumption in low-end smartphones.

1. Stand by tests: a very complicated because the stand-by time of phones is affetced by factors such as the distance to the closest cell tower, and moving the phone (driving or walking) in and out of different cell tower cover area.
2. Social networking: Battery consumption by commonly used apps e.g., WhatsApp, Facebook, Skype, and Viber (more tests). The tests will also include media sharing because photos and videos are shared heavily through these app isn recent dates.
3. Video streaming: We have decided to perform this test using the famous YouTube app.
4. Web browsing: measure battery consumption during use of default browser provided with the low-end smartphones. Plans are underway on how to specifically conduct web browsing test to match the real world usage.
5. Audio/video playback: playback of stored media on the local phone storage by users also add to the battery consumption. In fact, the ability for a phone to play music was the third most preferred feature by Mankosi users.
6. FM radio: battery consumption when listening to radio broadcasts on FM frequency by radio apps in low-end smartphones can also be very insightful.

The option of use of a battery profiling app to measure the battery consumption preferably in units such as Watts, Ampere or Ampere-hour is being explored. Plans to collect smartphone usage statistics of Mankosi residents are underway. The usage data, when combined with the experiment results, will assist in estimating the real world battery life of the low-end smartphones and in turn lead to estimation of affordability costs of the devices.

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