Survey on Energy Consumption Entities on the Smartphone Platform

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Abstract— *The full degree of freedom in mobile systems heavily depends on the energy provided by the mobile phone's batteries. Their capacity is in general limited and for sure not keeping pace as the mobile devices are crammed up with new functionalities. The discrepancy of Moore's law, offering twice the processing power at least each second year, and the development in batteries, which did not even double over the last decade, makes a shift in researchers' way of designing networks, protocols, and the mobile device itself. The bottleneck to take care of in the design process of mobile systems is not only the wireless data rate, but even more the energy limitation as the customers ask for new energy-hungry services, e.g., requiring faster connections or even multiple air interfaces, and longer standby or operational times of their mobile devices at the same time. In this survey, the energy consuming entities of a mobile device such as wireless air interfaces, display, mp3 player and others are measured and compared. The presented measurement results allow the reader to understand what the energy hungry parts of a mobile device are and use those findings for the design of future mobile protocols and applications. All results presented in this work and further results are made public on our web page [2].*

Index Terms—*Energy, power, smartphone*

1. INTRODUCTION

Mobile phones have been undergoing a breathtaking evolution over the last two decades, starting from simple devices with only voice services towards smartphones offering novel services such as mobile Internet, geo location and maps, multimedia services, high data rate connectivity and many more. Smartphones are battery driven to allow the highest degree of freedom for the user and the battery has to empower all the nice new features of a smartphone.

In the current state of the art, most smartphones are powered by lithium-ion batteries [4]. These batteries are popular because they can offer many times the energy of other types of batteries in a fraction of the space. At the moment, engineers cannot sufficiently increase the amount of energy created by the chemical reactions and the only way to create more powerful batteries seems to be making them larger. However this does not well match with the evolution of mobile terminals which tend to have less room available for the battery in order to accommodate additional components and technologies.

There are some new trends though. Some researchers at Stanford University are using nanotechnology [5] to make batteries able to produce ten times the amount of electricity of existing lithium-ion batteries. Other researchers try to exploit the movement of the user to recharge the battery of the phone [6], but are only initial research fields.

Nowadays batteries are energy and power limited. While the energy limitation has a direct impact on the time a mobile device is operational, the power limitation is related to the heating of the mobile device. Making the mobile devices smaller and smaller, the heat dissipation becomes a huge problem for the mobile handset vendors. In [10] it is shown that a mobile device is increasing its temperature significantly when parts of the wireless air interface are switched on. Handset vendors came up with a large number of tricks to distribute the heat of critical entities within the mobile device and let the heat dissipate in a moderate way without risk of the device or users.

Coming back to the energy limitation and the operational time, the handset vendors have also a huge interest to increase that time as consumers are looking for smartphones that offer the largest operational time. As the size of the battery is determined by the design of the mobile device, energy saving strategies becomes more important.

Excessive energy consumption is limiting the evolution of smartphones as the improvement of battery capacity is quite moderate [1] compared to the increase of the complexity due to new hardware and services. In fact, as batteries can store a fixed amount of energy, the operational time a user is able to use its phone within one charging cycle is limited as well. As the operational time is one of the most important factors for consumers when they buy a new phone, the smartphone industry is very keen in finding solutions to extend the operational time. Using batteries with more capacity could be a trivial solution, but unfortunately their technological evolution does not follow the trends dictated by Moore's law. While the computational complexity is doubled every two years according to Moore, the battery capacity is doubling only every decade.

Therefore this survey is looking into the energy consumption of different parts of the smartphone. Main focus is on the

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radio communication, but also other energy consumers are presented and measured. The survey will explain the energy measurement methodology shortly and then present the results. In [2] an energy model has been derived from the energy measurements in order to let engineers and developers design future mobile protocols and applications with respect to minimized energy consumption.

2. Energy Measurements Methodology

The smartphone used for the measurements is a Nokia N95 [7] which is running Symbian OS 9.2 as an operating system. When making the measurements, we used scripts to control the phone. This allowed us to measure the consumptions without interacting directly with the phone, avoiding to press any keys and to have the backlight of the display turned on, which could lead to misleading results. We used Python for S60 [9] as programming language to develop the scripts for testing. We observe that there is no significant penalty in terms of energy and performance by using the Python environment compared to standard Symbian/C++ for the energy levels we deal with throughout this paper.

The choice of the mentioned commercial device is due to several reasons. First of all it is equipped with several air interfaces, such as Bluetooth, WLAN, UMTS and secondly it is able to run the in-built energy profiler [8] developed by Nokia.

The Nokia Energy Profiler is an application running on the mobile device that allows making measurements without any external hardware. It provides the values for power, current, temperature, signal strength and CPU usage.

To further check the correctness of the data measured by the energy profiler on the phone, the complete setup includes the AGILENT 66319D used as multimeter. It is connected to a PC which is running the Agilent 14565B device characterization software, a tool designed for evaluation of portable battery powered device current profiles. We have compared results obtained with the energy profiler with the ones obtained with the Agilent 66319D and found no significant difference between those two [2].

3. Energy Measurements Results

In this section the measurements results of the energy consumption mainly for data communication and other services are presented using the testbed described in the previous section. The goal is always to retrieve the energy consumption or power values of one dedicated technology. In order to get this, all other elements that might consume energy and are not vital to run the phone are switched off. The values for energy and power levels reported in this paper have been obtained by running the same experiments several times and then averaging the results.

3.1. Data Communication

The data communication measurements are focusing on Bluetooth, WiFi and cellular communication with 2G and 3G technology. As the cellular technologies are straight forward (they are used or switched off), we are focusing more on the short range technologies such as Bluetooth and WiFi as there are different communication states.

Table 1: Energy consumption for different parts of the mobile phone.

Technology		Action	Power [mW]	Energy [J]
Wireless data	Bluetooth	BT off	12	
		BT on	15	
		BT connected and idle	67	
		BT discovery	223	
		BT receiving	425	
		BT sending	432	
	WiFi IEEE802.11 (infrastruct ure mode)	In connection	868	8.2
		In disconnection	135	0.4
		Idle	58	
		Idle in power save mode	26	
		Downloading@4.5Mbps	1450	
	WiFi IEEE802.11 (ad hoc)	Sending @ 700 kB/s	1629	
		Receiving	1375	
		Idle	979	
	2G	Downloading@44Kbps	500	
		Handover 2G->3G	1389	2.4
	3G	Downloading@1Mbps	1400	
		Handover 3G->2G	591	2.5
Miscellaneous	*CPU usage*	2%	55	
		25%	310	
		50%	462	
		75%	561	
		100%	612	
	Mobile TV	Watching Mobile TV with DVB-H	790	
	Display	Black background 20% intensity	63.0	
		Black background 60%	98.65	
		Black background 100%	259.65	
		White background 20%	196.56	
		White background 60%	254.16	
		White background 100%	527.05	
		Screensaver mode	13.86	
	Memory	Saving 1 Mb on drive C	587.7	56.2
		Saving 1 Mb on drive E	612.8	36.4
		Saving 1 Mb on drive D	560.0	2.2
Mobile	*Voice*	Making a voice call (3G)	1265.7	
		Receiving a voice call (3G)	1224.3	
		Idle (3G)	25.3	
		Making a voice call (2G)	683.6	
		Receiving a voice call (2G	612.7	
		Idle (2G)	15.1	
	Video	Making a video call (3G)	2210	
		Receiving a video call (3G)	2145	
	SMS	100 bytes length (2G)		1.72
		150 bytes length (2G)		2.35
		200 bytes length (2G)		2.52
		250 bytes length (2G)		2.64
		300 bytes length (2G)		3.15
		100 bytes length (3G)		2.24
		150 bytes length (3G)		3.22
		200 bytes length (3G)		3.42
		250 bytes length (3G)		3.56
		300 bytes length (3G)		4.22

3.1.1 Bluetooth (different states)

Bluetooth is a widely spread short range communication technology implemented on most smartphones nowadays. When Bluetooth was introduced, it was intended to be used as a cable replacement to connect devices wirelessly. In contrast to many other wireless technologies, Bluetooth comes with an embedded services discovery mechanisms to support different services. In the following we distinguish the different communication states for Bluetooth:

- **BT off:** This is the power value of the phone with Bluetooth off. Since all the other air interfaces are off and the backlight of the display as well, this represents the minimum consumption of the phone when is idle. All other values in the following contain this overhead power value.
- **BT on:** We have measured the power of the phone when Bluetooth is switched on and everything else inactive.
- **BT connected and idle:** This is the power of the phone connected to another Bluetooth entity but not sending nor receiving data.
- **BT discovery:** This is the power used when a mobile phone is performing a device discovery. This procedure can take a longer time according to the number of the devices in the range, but the power levels remains constant and is not a function of the number of Bluetooth devices around. Therefore the energy consumption only depends on the time duration of the discovery. In [3] we have presented some typical values for the time needed to perform a full service discovery in dependency of the number of neighboring phones.
- **BT receiving:** This is the power consumption of a phone receiving data using the RFCOMM protocol.
- **BT sending**: This is the power consumption of a phone sending data using the RFCOMM protocol.

In Table 1 the power consumption values for different Bluetooth states are given. By comparing the power values for Bluetooth when it is switched off and when it is turned on, it is important to note that having Bluetooth on will increase the power consumption only by 3 mW. This stands in total contrast with the generally accepted opinion that Bluetooth has a very high power usage when turned on.

3.1.2 WiFi

In this section, we investigate WiFi technology IEEE802.11 for infrastructure and ad hoc mode.

3.1.2.1 Infrastructure mode

For these measurements a Nokia N95 has been used for connecting to a WLAN Access Point (AP) using IEEE 802.11b/g in infrastructure mode. The distance between the AP and the phone is in the range of 3 to 5 meters. When the phone is receiving data from the Access Point, TCP/IP socket communication has been used.

Table 1 shows the power values of WiFi when used in Infrastructure mode for 5 different states, namely:

- **Connection:** Turn on WiFi on the phone and connect it to the Access Point
- **Disconnection:** Disconnecting from the AP and turning WiFi off
- **Idle:** Being connected to the AP and in idle mode
- **Idle power saving mode:** Being connected to the AP without transmitting nor receiving data and being in energy saving mode
- **Receiving:** Data is received from the access point

3.1.2.2 Ad-hoc mode

In tests for ad hoc mode, two Nokia N95s were used; one acting as server and one as client. The phones communicated using the internal IEEE 802.11b/g card, over which an amount of 2MB was transferred from the server to the client using TCP. Other factors affecting data rate such as interference is not considered in this measurement. However, to reduce the effect of temporal changes, the tests were reproduced during different times of the day e.g. at night where the building were vacated and a normal working day. The test was conducted by selecting random locations for both server and clients. At each random location devices were oriented randomly to represent an actual use of a device. The random orientation also reduced the advantage for any antenna gain with respect to a particular orientation. There were three energy values we were interested in, namely when the phone is in sending phase, receiving phase, and idle phase. The values are presented in Table 1 and they are comparable to those of the infrastructure mode. Note, that the idle power values are relatively high. The reason for this is that our idle phase where quite small and there was no change for the mobile phone to switch to a lower sleeping mode. But here we were interested in short idle values.

3.1.3 Data download for different wireless technologies

In Figure 1 the energy per bit spent when downloading 500 KB with different technologies, namely HSDPA, GPRS, WLAN, and Bluetooth, is shown. The energy is plotted against the data rate. When downloading with WLAN, the connection was set in infrastructure mode. The distance from the AP is approximately 3-5 meters.

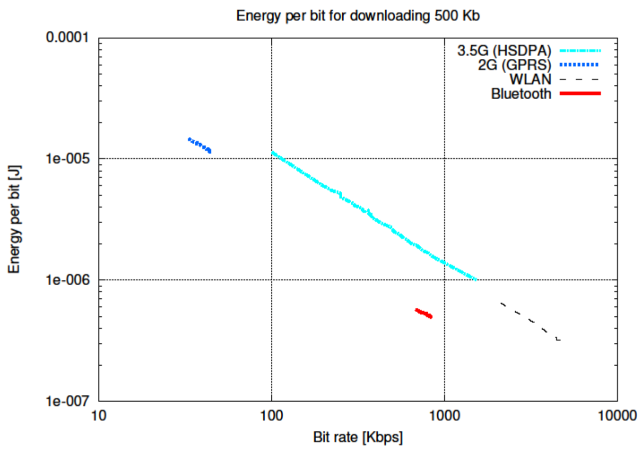

Figure 1: Energy per bit for downloading 500 KB using different wireless technologies.

To obtain several data rates for the different technologies, we have repeated the tests several times. We have noticed that there is no significant correlation between the data rate/energy and the received signal strength (e.g. cellular connection).

3.1.4 Data download/Upload with a combined use of wireless air interfaces

We have conducted several tests for a combined use of technologies and results are shown in Figure 2. The question was whether the single power values will simply add up or if different values will come up. Bluetooth communication is using RFCOMM as communication protocol, whereas cellular and WLAN are using TCP/IP as transport and network protocol.

- **WLAN+ UMTS + Bluetooth:** In the tests for this scenario we measured the power values when sending and receiving data using Bluetooth, while downloading data using both UMTS and WLAN at the same time.
- **UMTS + Bluetooth:** In tests for this scenario we measured the power values when sending and receiving data using Bluetooth, while downloading a file with UMTS. WLAN card is switched off.
- **WLAN + Bluetooth:** In the tests for this scenario we measured the power values when sending and receiving data using Bluetooth, while downloading a file with WLAN. The phone was in offline mode. Therefore the cellular air interface is switched off.
- **GPRS + Bluetooth:** In tests for this scenario we measured the combined power value when sending and receiving data using Bluetooth, while downloading a file with GPRS. WLAN card is switched off for this setup.

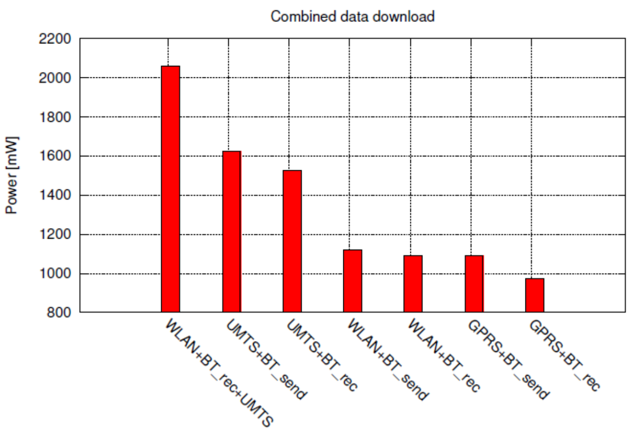

Figure 2: Power consumption for exchange data using different wireless technologies.

Figure 2 shows that the individual energy values can simply be summed up if a combination of technologies is used. E.g. GPRS and Bluetooth have individual values of 500 mW and 425 mW, respectively and the combined value is 950 mW. But as soon as Bluetooth and WiFi are used in a combined way, we need to be careful. The combined energy value of those two technologies is below 1200mW, but if we sum up the individual values from Table 1 we would expect something around 1800mW. The reason is that parts of Bluetooth and WiFi are used the same hardware parts such as the antenna. This results in inference (we measured significant data rate decrease for both technologies) which in turn ends up in fewer transmissions for both. Even though we have no evidence at this stage we assume that either one or the other technology is active. This would explain the smaller data rates and also the lower energy values.

3.2 Cellular link services

3.2.1 Handoff

In Table 1 power and energy values for making a handoff from 2G networks to 3G and vice versa are shown. The measurements have been taken in Aalborg, Denmark using a Sonofon SIM card. The results show that power values are larger for switching from 2G networks to 3G ones than the other way around. However, as it can be derived from Table 1 the time need to perform a handover is much shorter, leading to energy consumption very similar for both scenarios.

3.2.1 Voice call

The power values for the calls have been obtained by making a phone call of five minutes duration between two phones for each test. Then the average of the power consumption of the two phones for all the tests has been calculated. The power values during the idle time have been calculating averaging the power levels over eight hours of idle mode. Results in Table 1 show that making a call using GSM costs 46% and that receiving a call costs 50% less energy than using UMTS. Being idle and connected to a GSM network costs 41% less than being connected to UMTS. This is the main reason why 3G users with only interest in phone calls and no data connection should switch off the 3G technology.

3.2.2 Video call

In each test the power values for video calls have been obtained by making and receiving a video call of one minute duration and calculating the average of the power levels. Results of the average values are shown in Table 1. It can be seen that there is no significant difference between receiving and initiating a video call. This is expected as the traffic conveyed and video coding performed is the same on both sides. The slight larger power value for initiating the video call is caused by extra overhead maintaining the session.

3.2.3 SMS

Text messages sent by using SMS can be encoded in different ways: the default GSM 7-bit alphabet, the 8-bit data alphabet, and the 16-bit UTF-16/UCS-2 alphabet. Depending on which alphabet the text is coded with, the maximum size per SMS is 160 7-bit characters, 140 8-bit characters, or 70 16-bit characters. It is possible to send longer texts by concatenating more messages with each other.

Figure 3 shows the results of measurements done by sending messages of different sizes to evaluate how energy consumption is related to the length of the text. The messages were sent using both GSM and UMTS with a SIM card from TeliaSonera in Oulu, Finland.

We have sent 50 messages for each size and then plotted the average value of the energy spent. The phone was in the same

position for all the measurements to have the smallest variation possible in the received signal strength.
The plot clearly shows that the energy consumption increases linearly with the length of the message.

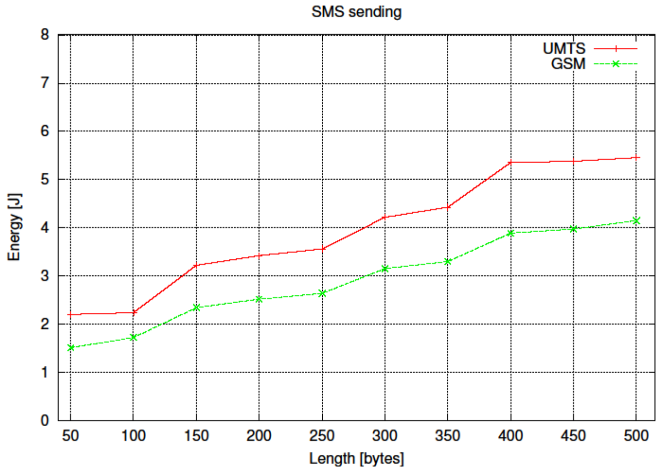

Figure 3: Energy spent for sending text messages with different length.

The messages sent were 8-bit encoded, therefore it is possible to see some jumps up in the energy consumption when two messages are concatenated, namely between 100-150, 250-300, and 400-450. It is interesting to notice that given a fixed length, sending an SMS using 3G is always more energy consuming than using GSM. The gap varies from 0.6 to 1.4 Joules.

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3.3 Miscellaneous

In this section, measurements of miscellaneous energy consumer are reported.

3.3.1 Display

Figure 4 shows the values of power consumption of the backlight of the display for different light levels and different background colors. The tests consist of drawing the canvas of the display with one of the colors (white or black) and then switching the backlight on. The test has been repeated 10 times for each intensity level of the backlight (in fact the Nokia N95 provides 5 different levels) for both white and black canvas of the screen.

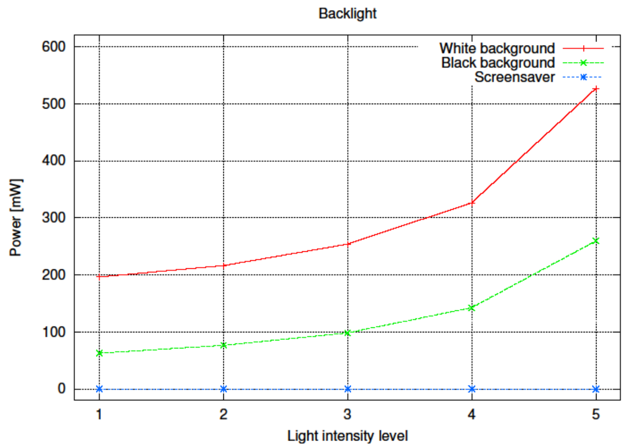

Figure 4: Power consumption of the backlight of the display for different light levels and different background colors.

3.3.2 Screen update

Figure 5 shows values of power consumption of the backlight of the display for different light levels for a black and white background respectively. During the tests, the screen is being repainted with different speed: from 1 to 10 frame updates per second.

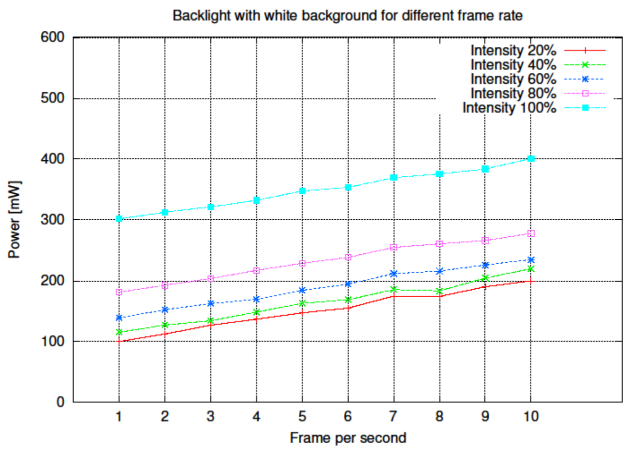

Figure 5: Power consumption of the backlight of a white display for different light levels and screen update speed.

3.3.3 Mobile TV

The test has been performed in Finland. It consisted in displaying MTV3 channel for 5 minutes. The power consumption is quite stable in the range of 0.79 W. The phone used for this measurement is a Nokia N96.

3.3.4 CPU

This experiment consisted in loading the CPU from 0% to 100% with various tasks and measuring the power levels. During the measurements, the displays as well as all air interfaces are off.

3.3.5 Memory access

In this section consumption of memory access is measured by saving a file of one MB on different drives of the phone:

- **D**: It is the drive used to store temporary files
- **E**: Memory card (micro SD)
- **C**: This drive is a flash memory also called phone memory

Table 1 shows the values of power and data rate for saving the file. As expected time, and therefore energy, is smaller when using the "D" drive.

4 Energy Models

From the energy and power measurements we have also derived some simple models. E.g. the measurements for sending an SMS when using 2G and 3G networks are resulting in the following model for energy consumed:

$$E\,(J) = A + B * L + C * Q(L,140),$$

where the values for A, B and C can be found in Table 2, L is the length of the SMS in bytes (note that in many countries each character is encoded with 7 bits), and Q(x,y) represents the integer portion of x divided by y.

Table 2:Values for the energy model.

	A	B	C
GSM 2G	1.4	0.003	0.5
UMTS 3G	2.0	0.002	1.0

For example, to send an SMS of 250 bytes using 2G, the energy in Joules is given by the following equation:

$$\begin{aligned} E(J) &= 1.4+0.003*250+0.5*Q(250,140) \\ &= 1.4+0.75+0.5*1 \\ &= 2.65 \text{ Joule} \end{aligned}$$

The obtained value matches the one in the Figure 3, as expected. More energy models are presented in [2] and are not discussed in detail here due to space limitations.

4. Conclusion

In this work we gave a detailed survey on the energy consumption of smartphones. This work should give the reader a feeling where energy is used and help to design energy aware protocols to reduce the overall energy consumption. Due to the space limitation not all values have been presented here, but can be found in [2], a web page that has been created to list all potential energy consumers on a smartphone. The page will be maintained and updated in the future in case new technologies are available.

In this work we have shown that the most energy hungry parts of a mobile phone are the wireless technologies and not the display or the CPU as this is the case for laptops.

In Figure 6 the top six energy consumers compared to HSDPA downloading is shown.

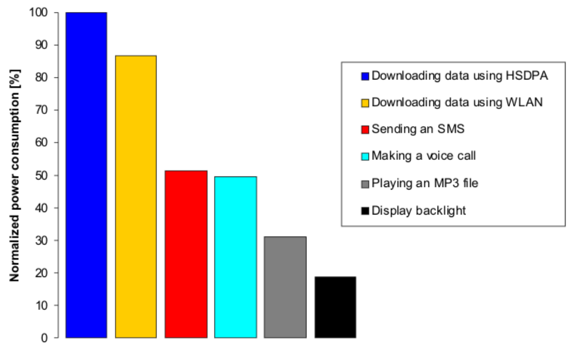

Figure 6: Top 6 energy consumers on a Nokia N95 mobile phone when switched on.

One of the findings is that voice calls should be done by using the 2G network, while data connections should be realized by 3G technology in order to achieve the lowest possible energy consumption. For the short range communication Bluetooth should be used in case only a few data needs to be exchanged. If more data needs to be transmitted, WiFi should be used. It does not cost much to have BT always on. This creates opportunities for new services which combine the local communication with cellular communications.

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