Impact of low temperature on smartphone battery consumption

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Abstract: Most smartphones employ Li-ion (or Li-polymer) batteries as their power sources. Though battery consumption significantly varies along with the cell temperature, which is severely affected by ambient temperature, many studies simply assume that the cell temperature is equal to room temperature. Furthermore, there has not been any study that has quantitatively analysed the impact of ambient temperature on battery consumption. In this paper, it can be shown that low ambient temperature significantly affects battery consumption of a smartphone. To show the impact of the cell temperature on battery consumption, the battery consumption at low ambient temperature (−20 ℃) is compared with that at room temperature. As a result, high power consumption results in more severe battery consumption at low ambient temperature. Real measurements show that the battery consumption increases by up to 113.1% at low ambient temperature in comparison with the same discharge condition at room temperature.

Key words: smartphone; battery; temperature

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Most smartphones use Li-ion (or Li-polymer) batteries as their power sources, since Li-ion battery is relatively cheaper, lighter and smaller than other rechargeable batteries. The total energy that a Li-ion battery can deliver varies depending on battery cell temperature, discharge power profile and the number of charge/discharge cycles.

Many battery-aware studies consider discharge power profile and the number of charge/discharge cycles to prolong battery life or to accurately estimate battery[1,2]. On the other hand, most of the studies do not consider the cell temperature[3-7]. They simply assume that the cell temperature is equal to room temperature (15 ℃ − 25 ℃). However, in reality, the cell temperature of a smartphone is significantly affected by the ambient temperature, which dramatically changes due to the high mobility of smartphones. Most importantly, the battery discharge behavior is dramatically influenced by the cell temperature. For example, even though the smartphone consumes the same energy, the battery loses more energy in case of low cell temperature.

Therefore, it is important to accurately analyse the battery discharge behavior considering battery cell temperature. In this paper, we analyse the impact of low temperature on the battery discharge behavior. Though there are several battery consumption estimation models[1,2], we only use real measurements to analyse the battery consumption. Note that it is not possible to use the models since the models do not consider low cell temperature[1,2]. The rest of this paper is organized as follows. In section 1, we explain the battery characteristics that significantly affect battery discharge behavior. In section 2, we depict our experimental environment. In section 3, we show our experimental results. Finally, in section 4, we conclude this paper.

1 Battery characteristics

When a smartphone consumes energy, a Li-ion battery loses as much energy as energy consumption of the smartphone. Simultaneously, the battery internally loses some more energy[1]. The energy consumed by a smartphone is called delivered energy, while the energy lost internally is called unavailable energy. In other words, battery loses energy as much as the sum of delivered energy and unavailable energy when a smartphone consumes battery.

While delivered energy is solely dependent on energy consumption of a smartphone, unavailable energy is dependent on various parameters: cell temperature, discharge power profile and the number

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of charge/discharge cycles[1].

Assume that a battery delivers energy E to a smartphone over a certain period of time. A battery loses energy as much as the sum of E and unavailable energy. When the cell temperature gets low, the battery loses more energy as unavailable energy. Similarly, a battery loses more energy as unavailable energy when the power consumption of a smartphone is higher. Finally, a battery becomes more sensitive to the cell temperature and the power consumption of a smartphone, as the number of charge/discharge cycle increases. Due to these characteristics, battery consumption (the total energy that a battery lost while energy delivery) varies, even when the delivered energy is the same.

2 Experimental environment

We perform our experiments on a brand new dual-core smartphone. The CPU of the smartphone executes application at one of the five frequencies, which are 200 MHz, 500 MHz, 800 MHz, 1 000 MHz and 1 200 MHz.

A Li-ion battery of which capacity is 6 108.5 mWh supplies energy to the smartphone. We obtain the capacity by fully discharging the battery with extremely low power (208.1 mW). Note that a battery does not lose much energy as unavailable energy when the load power is very low.

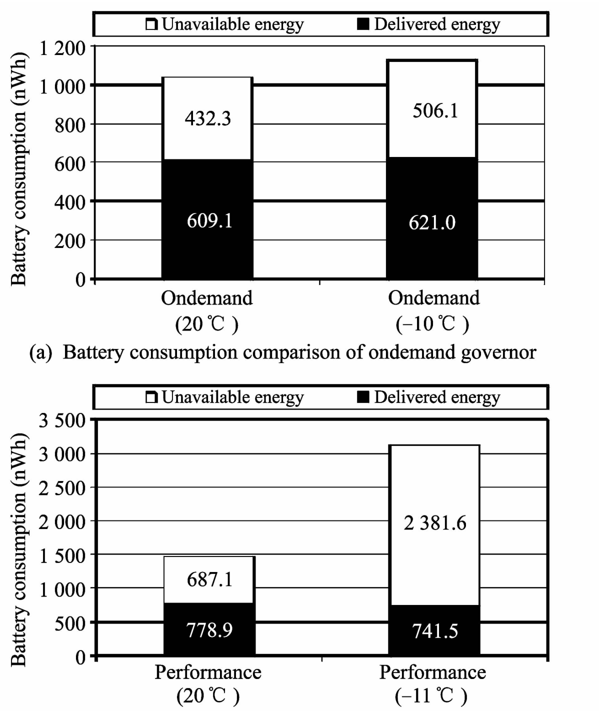
In the experiment, we first fully charge the battery at room temperature (18 ℃). Then, we take the battery and the smartphone to the condition where the ambient temperature is from − 11 ℃ to − 10 ℃. After a certain period of time in the condition, the cell temperature converges to − 9 ℃. At this moment, we play a video file with a media player application (MX Player).

To observe the battery consumption of different power consumptions in the cold environment, we repeat the experiment two times with different CPU scaling governors[8]. One of the governors is called performance governor, which executes every application at the highest CPU frequency. The other one is called ondemand governor, which dynamically scales the CPU frequency according to the workload. As a result, performance governor usually consumes higher power than ondemand governor since CPU dynamic power is proportional to frequency and voltage squared.

During the experiment, we measure the battery consumption by using a battery gauge[9], which is included in the smartphone. The accuracy of the battery gauge (higher than 95%) is high enough to be used in our experiment. To analyse the battery consumption, we isolate unavailable energy by subtracting delivered energy from the battery consumption. For example, when battery consumption is 1 000 mWh and delivered energy is 800 mWh, unavailable energy is 200 mWh. Note that delivered energy is easily obtained from a power measurement device.

3 Results and analysis

In this section, we analyse the impact of cold ambient temperature on battery consumption by comparing the battery consumption of the governors at room temperature and at cold ambient temperature. Since delivered energy is equal to the energy consumption of a smartphone, it is not affected by the ambient temperature, as shown in Figs. 1(a) and (b). For example, the difference of delivered energy between room temperature and low ambient temperature (− 10 ℃) under ondemand governor is only 1.9%.



(a) Battery consumption comparison of ondemand governor

(b) Battery consumption comparison of performance governor

Fig. 1 Battery comsumption comparison with different governors and at different temperatures

Unlike delivered energy, unavailable energy is significantly affected by the temperature. For performance governor, unavailable energy at room temperature is 687.1 mWh, as shown in Fig. 1(b). However, at low ambient temperature, it becomes 2 381.6 mWh, which increases by 246.7%, compared to the unavailable energy at room temperature. Similarly, for ondemand governor unavailable energy at low ambient temperature is 17.1% larger than that at room temperature. In the perspective of total battery consumption, performance and ondemand governor consumes 113.1% and 8.2% more battery at low ambient temperature, respectively.

As shown in Fig.1(a) and (b), unavailable energy increases more extensively under performance governor than under ondemand governor. Such a huge difference is caused by the difference in power consumption of the governors. In Fig.2, the power consumption of ondemand governor is 2 224.5 mW while that of performance governor is 3 118.8 mW. In other words, performance governor consumes 40.2% higher power than ondemand governor while playing the video. Since unavailable energy increases under higher power consumption, unavailable energy of performance governor is larger than that of ondemand governor at the same temperature. Furthermore, when ambient temperature is low, higher power consumption causes more severe unavailable energy[10].

Since high power consumption heats up the battery cell, it may alleviate the impact of low ambient temperature. Hence, we analyse the battery cell temperature along with the battery consumption. As shown in Fig. 2, the cell temperature of the both governor is − 9 ℃ in the beginning. At the end of the execution, the cell temperature of performance governor goes up to − 3 ℃, while that of ondemand governor stays low at − 8 ℃. Though cell temperature of performance governor is 5 ℃ higher than that of ondemand governor, unavailable energy of performance governor is 246.7% larger than that of ondemand governor, as shown in Fig.1(b). Therefore, heating up the battery cell by using higher power is not an effective method to reduce battery consumption under low ambient temperature.

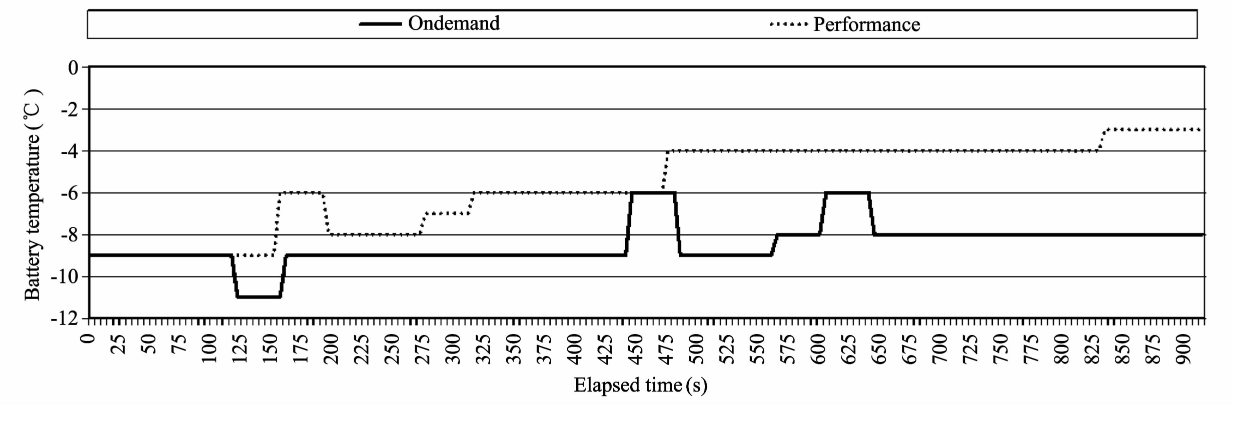


Fig.2 Battery cell temperature of ondemand and performance governors

4 Conclusion

Low ambient temperature causes low battery cell temperature, which in turn leads to increased battery consumption. In this paper, it can be found that the impact of low ambient temperature becomes substantial when the power consumption of a smartphone gets higher. As shown in our analysis results, battery consumption increases up to 113.1% under cold condition. In addition, it is not effective to heat up battery cell by using higher power consumption to alleviate the impact of low ambient temperature because such strategy causes significantly larger battery consumption since higher power consumption causes much larger unavailable energy (up to 246.7% more) under low ambient temperature.

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