WiFi Centric Power Modeling of Smartphones

Jonghoe Koo
Department of ECE and INMC
Seoul National University
jhkoo@mwnl.snu.ac.kr

Wonbo Lee
Department of ECE and INMC
Seoul National University
wblee@mwnl.snu.ac.kr

Sunghyun Choi
Department of ECE and INMC
Seoul National University
schoi@snu.ac.kr

Yongseok Park
Digital Media &
Communications R&D Center
Samsung Electronics
yongseok.park@samsung.com

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C.4 [**Performance of System**]: [Modeling Techniques]

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1. MOTIVATION

Previous work of WiFi power modeling proposes the power-throughput curve [2], the power-transmission/reception air-time curve [1], or the state transition between high power level and low power level according to the packet rate [3]. These models cannot accurately estimate the energy consumption of the smartphone because they either do not take into account the power reduction from the power saving operation of the components in the smartphone or model the active power level too simplistically, thus resulting in larger estimation error. The smartphone, which is one of the battery sensitive devices, essentially has power saving algorithms in its components to reduce energy consumption by turning off the components when they are not in use.

In this sense, two types of traffic, which turn out to be the same average throughput, airtime, or packet rate, may result in different total energy consumption if one does not allow the smartphone to turn off its components but the other allows it. We propose a packet interval based power model which takes into account the power saving operations of the WiFi module so that it accurately estimates power level of the smartphone when the smartphone transmits/receives packets using its WiFi interface. Furthermore, we manage the power state of the smartphone with the Finite State Machine (FSM) to accurately estimate the power level of the smartphone considering other components in the smartphone, e.g., CPU and display.

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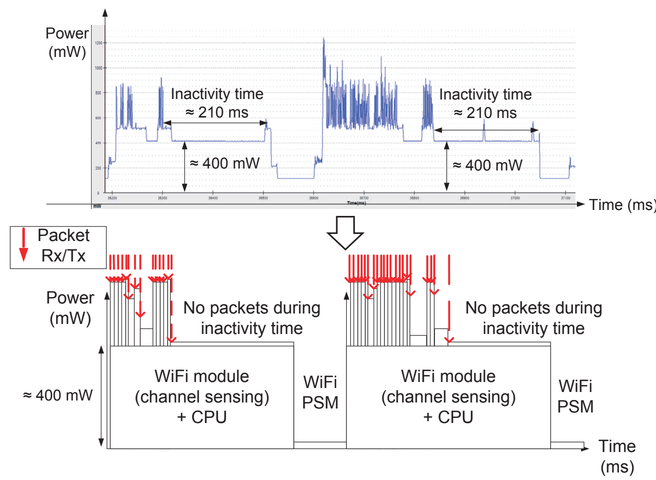

Figure 1: Overview of packet interval based power modeling.

Our proposed power modeling accurately estimates the energy consumption of the smartphone for all kinds of traffic pattern using the packet trace, CPU usage and clock frequency, and pixel RGB values and brightness level of the display.

2. POWER MODELING CURVE

To model the power level, we implement a simple android application on the smartphone with a socket programming. In the proposed power model, the energy consumption is calculated as the sum of the consumed energy during one packet interval, i.e., the average power level of the smartphone is updated every time a packet is transmitted/received. Assume that the smartphone receives (or transmits) N packets during the time T, the total energy consumption of the smartphone, denoted E_{total}, caused by N packets is calculated as follows:

$$E_{total} = \sum_{n=1}^{N} \big(P(i_n) \cdot \max(i_n, t_{tail}) + P_{bg}(i_n) \cdot u(i_n - t_{tail}) \cdot (i_n - t_{tail})\big), \quad (1)$$

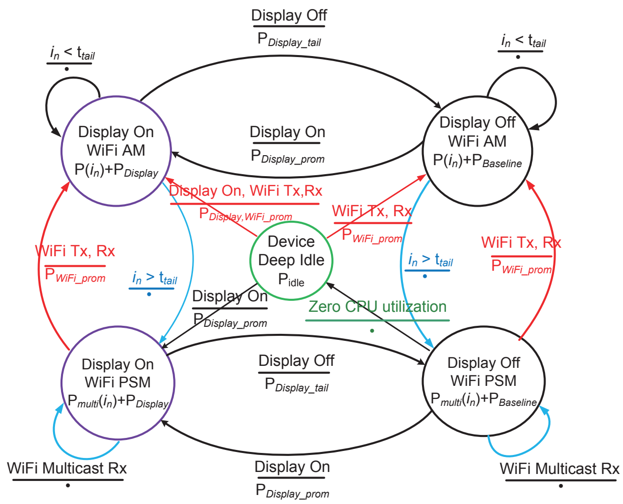

Figure 2: State transition diagram.

where i_n is the packet interval, $P_{bg}(i_n)$ is the average background power level during i_n, $u(\cdot)$ is the unit step function, and t_{tail} is the WiFi inactivity timer timeout value of the smartphone. $P(i_n)$ is the average power level during the packet interval, i_n, which is given by the following:

$$P(i_n) = \begin{cases} \alpha \cdot {i_n}^{\beta}, & \text{if } i_n < t_{tail}, \\ \alpha \cdot {i_n}^{t_{tail}}, & \text{otherwise.} \end{cases} \quad (2)$$

Through the intensive measurement, we validate that power curve $P(i_n)$ is well fitted to an exponential function with respect to the packet interval where it is defined only up to t_{tail} after which the smartphone turns off its WiFi module to enter the power save mode (PSM). It consists of the CPU power for processing the packet, channel sensing power at the WiFi module and transmission/reception power of the packet at the WiFi module. The coefficients of Eq. (2), α and β, are determined by the airtime of the packet because the long packet or the lower transmission rate of the packet causes the large airtime, i.e., it requires much more time to transmit/receive the packet consuming more energy than the short airtime case. The effect of the airtime to the coefficients α and β is still negligible because the CPU power and channel sensing power take the dominant portion of the total power level.

3. STATE TRANSITION DIAGRAM OF FSM

In conjunction with the power level curve, the proposed power modeling system manages the power state of the smartphone with the proposed FSM. In this paper, we model the display power in addition to the power of the network interfaces and CPU. The state transition diagram of the FSM is shown in Fig. 2 with the five states, where AM and PSM stand for active mode and power save mode, respectively. Packet interval which is larger than the WiFi inactivity timer timeout value, t_{tail}, makes the WiFi module turn off until the next packet to be transmitted/received is generated. Hence, the power model considers the power reduction by turning off the WiFi module when the smartphone operates on the PSM. The FSM also reflects the background power, P_{bg}, which may have different value according to the state of the smartphone. P_{bg} may contains the CPU power, which is needed to operate a fundamental processing. We model the CPU power in terms of the CPU usage and clock frequency and the display power in terms of the RGB value of the pixels and brightness. We refer to [3] to measure the AMOLED display power which has non-linear characteristics with the RGB pixel value.

We also consider the promotion and tail power of the component when the component turns on or off to further enhance the accuracy of the estimated power. When the WiFi module turns on, it brings out the additional power and delay for promotion whereas the tail power of the WiFi module is negligibly small. The display also causes both the promotion and tail power. The power estimator reflects the promotion and tail power of the components in the smartphone using the system call information given by the OS when one of the components changes its state.

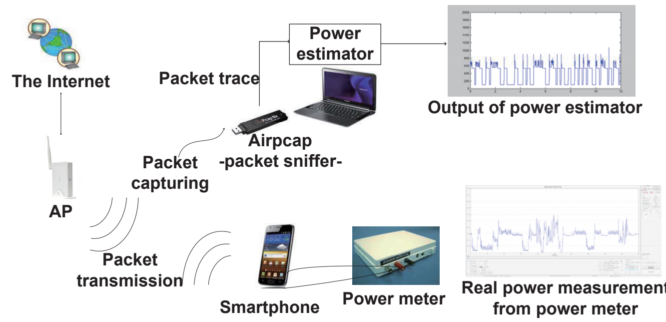

Figure 3: Application 2): The packet sniffer estimates the average power of the smartphone by capturing the packet trace of the smartphone.

4. APPLICATION

The applications of the proposed power model are as follows: 1) a smartphone estimates total energy consumption and instant power level of the smartphone for a user who wants to know how much energy is consumed for running a target application. 2) A packet sniffer captures packets from/to the smartphone and estimates the energy consumption of the smartphone by using the packet trace. The demo setup for the packet sniffer application is illustrated in Fig. 3. 3) A network simulator, e.g., NS-3, estimates the energy consumption of wireless nodes assuming that the nodes are smartphones following the proposed power model.

5. ACKNOWLEGEMENTS

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