Reducing Power Consumption for Mobile Multimedia Handsets

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Abstract

This paper proposes three wake-up approaches to reduce the battery power consumption for a mobile multimedia handset. These approaches switch the system into the sleep mode when the memory queue for the arriving packets is empty. Depending on the approaches, various wake-up mechanisms are considered. The threshold approach switches on the system when the number of packets in the memory queue is above a threshold. The vacation approach wakes up the system when the vacation time expires. The hybrid approach turns on the system either when the memory queue length is above the threshold or when the vacation time expires.

Our study indicates that the threshold approach effectively reduces the switch-on rate, while the vacation approach has the lowest mean packet waiting time. To keep both the switch-on rate and the mean packet waiting time below some reasonable small values , the hybrid approach should be selected.

Key words: Packet-dropping probability, Power consumption, Sleep mode, Switch-on rate, Threshold, Vacation, Wake-up mechanism, Wireless multimedia

1. Introduction

Wireless multimedia becomes an important research area [9,10] due to the advance of the third generation wide-band wireless technologies [6,11]. To support wireless multimedia applications, a mobile multimedia device is designed to be portable, where any add-on feature needs to be power-cautious [2]. Operations of mobile multimedia handsets may significantly consume battery power. Since battery power is life-limited and should be used efficiently, power consumption is an important issue in mobile multimedia handsets design. A mobile multimedia handset system can be generally divided into three units that consume battery power. They are data receiving, data processing, and user interface units as illustrated in Figure 1. A data receiving unit is a fixed-size memory storage queue for packets received from wireless networks. A data processing unit is a CPU that processes received data. A user interface unit is in charge of passing processed data to mobile users. One approach to reduce power consumption is to design a mobile multimedia handset that supplies power separately to the three units [1,16]. With this design, the data processing and user interface units can be put in the sleep mode while the data receiving unit is waiting for data from the network. Those two units will not be woken up until the data receiving unit receives an incoming packet. A wake-up action is called a switch-on. The frequency R_s of switch-on actions performed is referred to as the switch-on rate. Once the data processing and user interface units are switched on, they work until the memory queue becomes empty. Then the two units enter the sleep mode to conserve power. In the sleep mode, only the data receiving unit is awake to receive packets. This handset architecture can be viewed as a single-server queueing system with finite capacity [3,4,13].

Immediately waking up the data processing and user interface units upon receipt of a packet may cause too many switch-on actions, and thus degrade the power efficiency

[15]. To avoid this problem, the data receiving unit is designed to wait for more packets to arrive before waking up the other two units. To be more specific, a switch-on action is performed only when there has been a certain number of packets in the memory queue. However, with the continuous arrival of packets, if we do not reserve enough space for the incoming packets, some packets may be dropped. Denote P_d as the packet-dropping probability or the probability that an arriving packet is dropped. In designing the power-saving mechanism for wireless multimedia handset, an important goal is to reduce the switch-on rate R_s without significantly increasing the packet-dropping probability P_d.

To achieve power saving by controlling the switch-on activities, we consider three wake-up mechanisms: threshold, vacation and hybrid. Suppose that the size of the memory queue in the data receiving unit is R. In the threshold approach, a threshold value r, where $1 \leqq r \leqq R$, is used to determine when to switch on the system. As soon as the number of packet arrivals reaches the threshold r, the data processing and the user interface units are woken up to start working. It is important to select the r value properly because the threshold value r affects the switch-on rate R_s and packet-dropping probability P_d at the same time.

The second mechanism adopts the concept of vacation, where a timer is utilized to count when to wake up. Every time when the memory queue becomes empty, the data receiving/processing units enter the sleep or vacation (switch-off) mode immediately, and the vacation timer starts counting down. The processing and the user interface units come back to work by a switch-on action as soon as the vacation time expires [5]. If there are packets waiting in the queue, then these packets will get served. After the data queue is empty, the data processing and the user interface units enter the sleep mode again.

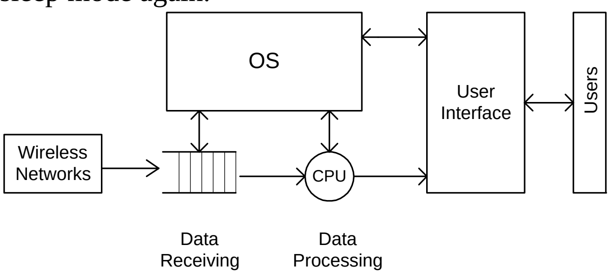


Figure 1. A mobile multimedia handset system

The hybrid approach combines both the threshold and the vacation mechanisms. In this approach, the data processing and the user interface units wake up either when the threshold r is reached or when the vacation time expires.

In this paper, we propose both analytic and simulation models to evaluate the three wake-up approaches by investigating the switch-on rate and the packet dropping probability. In Section 2, we describe the assumptions made in the analytic models. Section 3 describes the analytic models. Finally, Section 4 presents the analytic and simulation results.

2. Assumptions

This section describes the assumptions made for modeling the three wake-up approaches.

Let random variable t be the inter-arrival time of two consecutive packets. We assume that t is exponentially distributed with the arrival rate λ. Let random variable N_{0T} denote the number of packet arrivals in the time interval (0, T). Then { N_{0T} | T >= 0 } is considered as a Poisson process [8].

Every arriving packet is stored in the memory queue of the data receiving unit if there is still room in that queue. On the other hand, the arriving packet is dropped if the memory queue is full.

Let random variable S denote the service time for each packet, which has an exponential distribution with the service rate μ. Furthermore, the first-come first-served queueing discipline is assumed.

In the vacation method, the data processing and the user interface units enter a vacation when the memory queue is empty, and wake up again when the vacation time expires. Let random variable V be the vacation period, which has an exponential distribution with mean vacation time $1/\eta$. The input parameters of our model are summarized as follows:

r the threshold value (used in the threshold approach)
R the size of the memory queue
λ the packet arrival rate
μ the packet service (processing) rate
η the vacation rate (used in the vacation approach)

Two output measures are investigated in our model:

R_s the switch-on rate
P_d the packet-dropping probability

Our modeling effort investigates the appropriate r (for the threshold approach) and η (for the vacation approach) values such that by maintaining an acceptable packet-dropping probability P_d, the switch-on rate R_s can be reduced.

For the threshold approach, it is intuitive that the larger the threshold r, the less battery power a handset consumes. The reason is that a larger r value causes a smaller switch-on rate R_s, so the system consumes less battery power for the switch-on actions. However, since the packet-dropping probability P_d increases when the threshold r becomes larger, the threshold r cannot be enlarged infinitely and should be carefully selected.

For the vacation approach, the longer the vacation period is, the more battery energy can be saved. However, a longer vacation time period leads to an increased packet-dropping probability. Thus, selecting an appropriate η value is essential to the vacation approach.

3. The Analytic Models

This section describes the analytic models for the threshold, the vacation, and the hybrid approaches. Based on these models, we derive the switch-on rate R_s and the packet-dropping probability P_d.

3.1 The threshold approach

In the threshold approach, a switch-on action is performed when the number of the packets accumulated in the memory queue is more above the threshold r. For the special case where r = 1, the handset switches on as soon as a packet arrives, and switches off when the queue becomes empty. In this case, the threshold approach can be modeled directly by an M/M/1/R queue where the state transition diagram is shown in Figure 2. In this figure, a state s(i) represents that there are i packets in the memory queue.

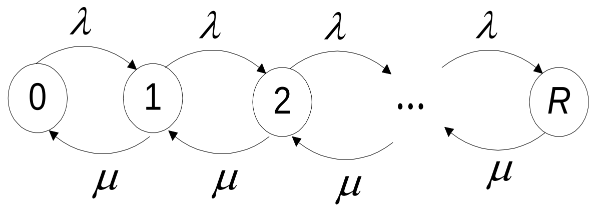


Figure 2. M/M/1/R queueing system

When r >1, the state transition diagram is shown in Figure 3, which consists of two groups of states.

In the stochastic process under study, a state s(i*) represents that there are i packets in the memory queue when the system is in the sleep mode, where $0 \leqq i < r$. A state s(j) represents that there are j packets in the queue when the system is in the active (wake-up) mode, where $0<j\leqq R$. When the system is in the sleep mode, the stochastic process moves from state s(i*) to state s((i+1)*) with rate λ for $0\leqq i< r-1$. When the system is in the active mode, the process moves from state s(i) to state s((i+1)) with rate λ for $1\leqq i<R$, and moves from state s(i) to state s((i-1)) with rate μ for $1\leqq i\leqq R$. A switch-on action occurs when the process moves from state s((r-1)*) to state s(r).

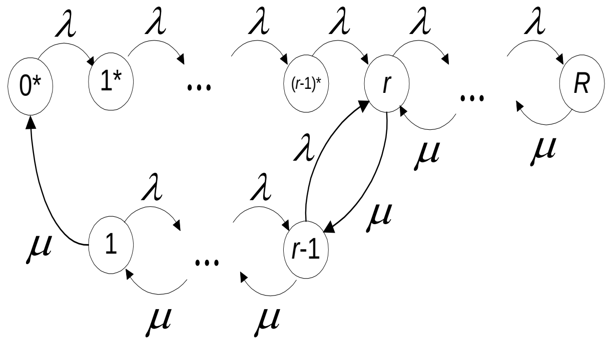


Figure 3. The threshold model

The switch-on rate R_s is computed as

$$R_s = \lambda P_{(r-1)*}$$

where P_i denotes the stationary probability of state s(i). An arriving packet is dropped when the memory queue is full, i.e., when the process is at state s(R). Thus, the packet-dropping probability P_d is expressed as

$$P_d = P_R$$

Based on the state transition diagram in Figure 3, when the system is in a steady state, the following equilibrium equations hold.

$$\lambda P_{0*} = \mu P_1$$

$P_{i*} = P_{(i-1)*}$ for $1 \leqq i \leqq r-1$
$(\lambda + \mu) P_1 = \mu P_2$
$(\lambda + \mu) P_i = \lambda P_{i-1} + \mu P_{i+1}$ for $2 \leqq i \leqq r-1$ or $r+1 \leqq i \leqq R-1$
$(\lambda + \mu) P_r = \lambda P_{(r-1)*} + \lambda P_{r-1} + \mu P_{r+1}$
$\mu P_R = \lambda P_{R-1}$

After rearranging the above equations, the steady state probabilities for the states of the threshold approach are expressed as follows.

$$P_{i*} = \begin{cases} \mu/\lambda \, P_1 & \text{if } i = 0 \\ P_{(i-1)*} & \text{if } 1 \le i \le r-1 \end{cases}$$

and

$$P_i = \begin{cases} \mu/(\lambda+\mu) P_2 & \text{if } i=1 \\ \lambda/(\lambda+\mu) P_{i-1} + \mu/(\lambda+\mu) P_{i+1} & \text{if } 2 \le i \le r-1 \text{ or } r+1 \le i \le R-1 \\ \lambda/(\lambda+\mu)(P_{(r-1)*} + P_{r-1}) + \mu/(\lambda+\mu) P_{r+1} & \text{if } i=r \\ \lambda/\mu P_{R-1} & \text{if } i=R \end{cases}$$

With the constraint that $\sum P_{i*} + \sum P_j = 1$ (where i = 0, 1, 2, …, r-1 and j = 1, 2, …, r-1, r, …, R), we can solve the above equations using the Gauss-Seidel method [7] by initializing $P_{0*} = P_{1*} = P_{2*} = \ldots = P_1 = P_2 = \ldots = P_r = \ldots = P_R = 1/(R+r)$. Then both the packet-dropping probability P_d and the switch-on rate R_s can be obtained.

3.2 The vacation approach

The vacation approach utilizes a vacation timer to control power switching activities. Once the memory queue becomes empty, the system sets the vacation timer and goes for a vacation. The system comes back as soon as the vacation time expires.

The state transition diagram for the vacation approach is shown in Figure 4.

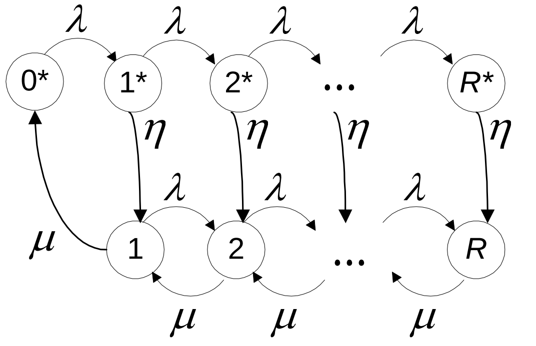


Figure 4. The vacation model

Like the threshold model, those states with '*' represent that the system is in the sleep mode. The stochastic process moves from state s(i*) to state s((i+1)*) (and from state s(i) to state s((i+1))) with rate λ for $0 \leqq i < R$. The packets are processed when the system is in the active mode and the process moves from state s(i*) to s(i-1) with rate μ for $0 < i \leqq R$. A switch-on action is performed only when the system comes back from its vacation. Thus the process moves from state s(i*) to s(i) with rate η for $0 < i \leqq R$.

Consequently, the switch-on rate R_s can be obtained by the following equation.

$$R_s = \eta (P_{1*} + \ldots + P_{R*})$$

Furthermore, the packet-dropping probability P_d can be computed as

$$P_d = P_{R*} + P_R$$

Based on the state transition diagram shown in Figure 4, in the steady state, the following equilibrium equations hold.

$\lambda P_{0*} = \mu P_1$
$(\lambda + \eta) P_{i*} = \lambda P_{(i-1)*}$ $1 \leqq i \leqq R-1$
$\eta P_{R*} = \lambda P_{(R-1)*}$
$(\lambda + \mu) P_1 = \eta P_{1*} + \mu P_2$
$(\lambda + \mu) P_i = \lambda P_{i-1} + \mu P_{i+1} + \eta P_{i*}$ $2 \leqq i \leqq R-1$
$\mu P_R = \lambda P_{R-1} + \eta P_{R*}$

After rearrangement, we have

$$P_{i*} = \begin{cases} \mu/\lambda \, P_1 & \text{if } i = 0 \\ \lambda/(\lambda+\eta) P_{(i-1)*} & \text{if } 1 \le i \le R-1 \\ \lambda/\eta \, P_{(R-1)*} & \text{if } i = R \end{cases}$$

and

$$P_i = \begin{cases} \eta/(\lambda+\mu) P_{1*} + \mu/(\lambda+\mu) P_2 & \text{if } i=1 \\ \lambda/(\lambda+\mu) P_{i-1} + \mu/(\lambda+\mu) P_{i+1} + \eta/(\lambda+\mu) P_{i*} & \text{if } 2 \le i \le R-1 \\ \lambda/\mu \, P_{R-1} + \eta/\mu \, P_{R*} & \text{if } i = R \end{cases}$$

With the constraint $\sum P_{i*} + \sum P_j = 1$ (where i = 0, 1, 2, …, R and j = 1, 2, …, R), we solve those equations by applying the Gauss-Seidel method.

3.3 The hybrid approach

In the hybrid approach, there are two indicators to wake up the system. More precisely, the system enters the active mode either when the threshold r is reached or when a vacation time period is finished.

The state transition diagram of the hybrid approach is shown in Figure 5. Basically, this state transition diagram combines the diagrams for both the threshold and the vacation approaches. Again, the states marked ‘*’ represent the states when the system is in the sleep mode and the states without ‘*’ marks, the active mode.

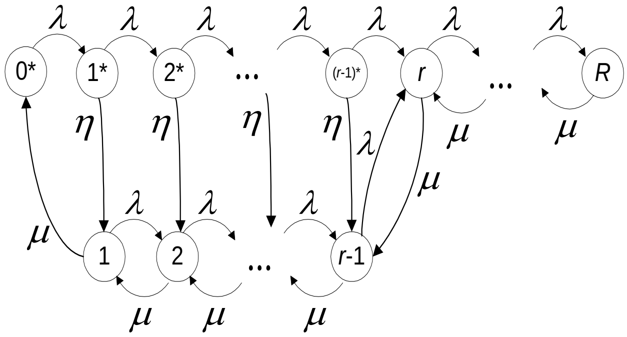


Figure 5. The hybrid model

Then the switch-on rate R_s and packet-dropping probability P_d are expressed as follows.

$$R_s = \eta\,(P_{1*} + P_{2*} + \ldots + P_{(r-1)*}) + \lambda P_{(r-1)*}$$

$$P_d = P_R$$

From the state transition diagram, we obtain the following equilibrium equations at the steady states:

$$\lambda P_{0*} = \mu P_1$$
$$(\lambda+\eta) P_{i*} = \lambda P_{(i-1)*} \qquad 1 \leqq i \leqq r-1$$
$$(\lambda+\mu) P_1 = \eta P_{1*} + \mu P_2$$
$$(\lambda+\mu) P_i = \eta P_{i*} + \lambda P_{i-1} + \mu P_{i+1} \qquad 2 \leqq i \leqq r-1$$
$$(\lambda+\mu) P_r = \lambda P_{(r-1)*} + \lambda P_{r-1} + \mu P_{r+1}$$
$$(\lambda+\mu) P_i = \lambda P_{i-1} + \mu P_{i+1} \qquad r+1 \leqq i \leqq R-1$$
$$\mu P_R = \lambda P_{R-1}$$

We rewrite the equations in the following form.

$$P_{i*} = \begin{cases} \mu/\lambda\ P_1 & \text{if } i = 0 \\ \lambda/(\lambda+\eta)\,P_{(i-1)*} & \text{if } 1 \le i \le r-1 \end{cases}$$

and

$$P_i = \begin{cases} \eta/(\lambda+\mu)P_{1*} + \mu/(\lambda+\mu)P_2 & \text{if } i=1 \\ \eta/(\lambda+\mu)P_{i*} + \lambda/(\lambda+\mu)P_{i-1} + \mu/(\lambda+\mu)P_{i+1} & \text{if } 2 \le i \le r-1 \\ \lambda/(\lambda+\mu)(P_{(r-1)*} + P_{r-1}) + \mu/(\lambda+\mu)P_{r+1} & \text{if } i=r \\ \lambda/(\lambda+\mu)P_{i-1} + \mu/(\lambda+\mu)P_{i+1} & \text{if } r+1 \le i \le R-1 \\ \lambda/\mu\,P_{R-1} & \text{if } i=R \end{cases}$$

With the constraint $\sum P_{i*} + \sum P_j = 1$ (where i = 0, 1, 2, …, r-1 and j = 1, 2, …, R), the above equations are solved again by the Gauss-Seidel method.

4. Numerical Results

Based on the analytic models described in the previous section, we use numerical examples to illustrate how to select the input parameters (such as r and η) to reduce the battery power consumption. In our examples, a memory queue of fixed size R = 100 is used. Let the system workload $\rho = \lambda/\mu$. Three ρ different values 0.5, 0.76, and 0.91 are considered in the experiments.

Figure 6 shows both the switch-on rate R_s and packet-dropping probability P_d as functions of the threshold r for the threshold approach. The figure indicates that R_s is a decreasing function of r. Furthermore, when r < 30, R_s is dramatically reduced as r increases. On the other hand, when r > 30, R_s is insignificantly affected by r. For P_d, Figure 6 indicates that P_d is an increasing function of r . Furthermore, when r > 40, P_d is dramatically increased as r increases. On the other hand, when, r < 40, P_d is insignificantly affected by r. Thus, we conclude that for this particular workload ρ =0.91, 30 < r < 40 should be selected. We note that as ρ decreases, the range for selecting r becomes larger. For example, 25 < r < 80 is appropriate for ρ = 0.76, and 15 < r < 90 is appropriate for ρ = 0.5. Our example indicates that even if the system is in the heavy load situation (i.e., ρ =0.91), we can still find an appropriate r range.

Figure 7 shows both the switch-on rate R_s and packet-dropping probability P_d as functions of the vacation time $1/\eta$ for the vacation approach. Similar to the threshold approach, this figure indicates that R_s is a decreasing function of $1/\eta$ and P_d is an increasing function of $1/\eta$. Furthermore, when $1/\eta < 0.10$, R_s is significantly affected by $1/\eta$. On the other hand, P_d is significantly affected by $1/\eta$ when $1/\eta > 0.40$. This result implies that it is difficult to find an appropriate η range that keeps both R_s and P_d in small values.

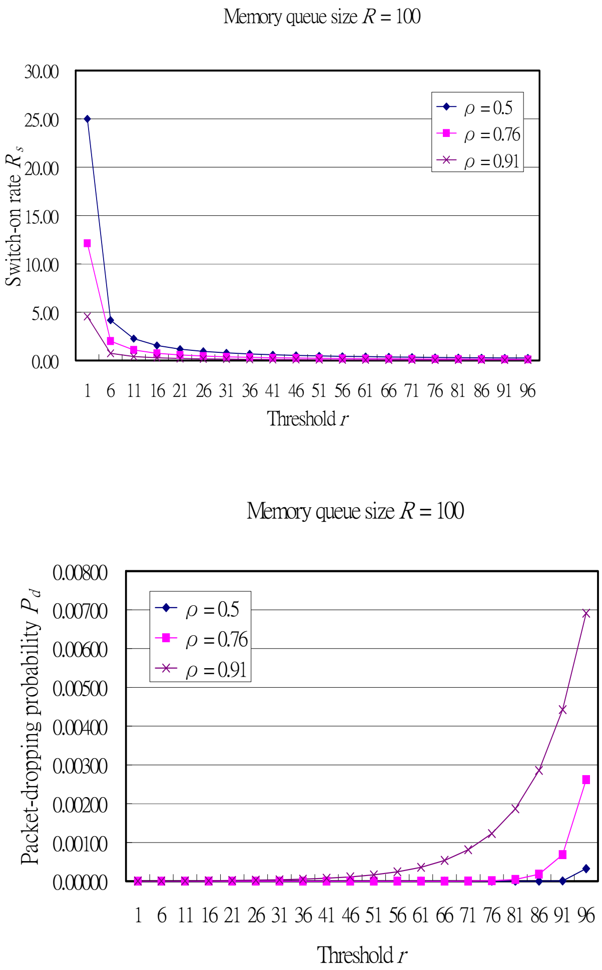


Figure 6. Performance of the threshold approach

Figure 8 shows both the switch-on rate R_s and packet-dropping probability P_d as functions of the threshold r for the hybrid approach. The results are similar to that of the threshold approach.

More precise comparison among the three wake-up approaches where ρ = 0.76 is considered. Figure 9 (a) illustrates the switch-on rates R_s as the functions of the packet-dropping probability P_d for the three approaches. The threshold approach results in the smallest switch-on rate, while the vacation approach winds up with the highest. Figure 9 (b) illustrates the mean packet waiting times (the waiting time is defined as the period between a packet arrives and when it is processed) as the functions of the packet-dropping probability P_d for the three approaches. The figure indicates that the vacation approach has the lowest mean packet waiting time. We conclude from the above results that if the system designer cares more about the mean packet waiting time, the vacation approach may be adopted regardless of its high switch-on rate. On the contrary, the threshold approach is a better choice if the switch-on rate is a big concern. If keeping both the switch-on rate and the mean packet waiting time below some reasonable small values is important, then the hybrid approach should be selected.

To validate our analytic results, simulation experiments are conducted. Figures 10-12 plots the switch-on rates R_s and the packet-dropping probability P_d based on analytic and simulation results, where ρ = 0.5 is assumed. These figures indicate that the analytic results are consistent with the simulation experiments.

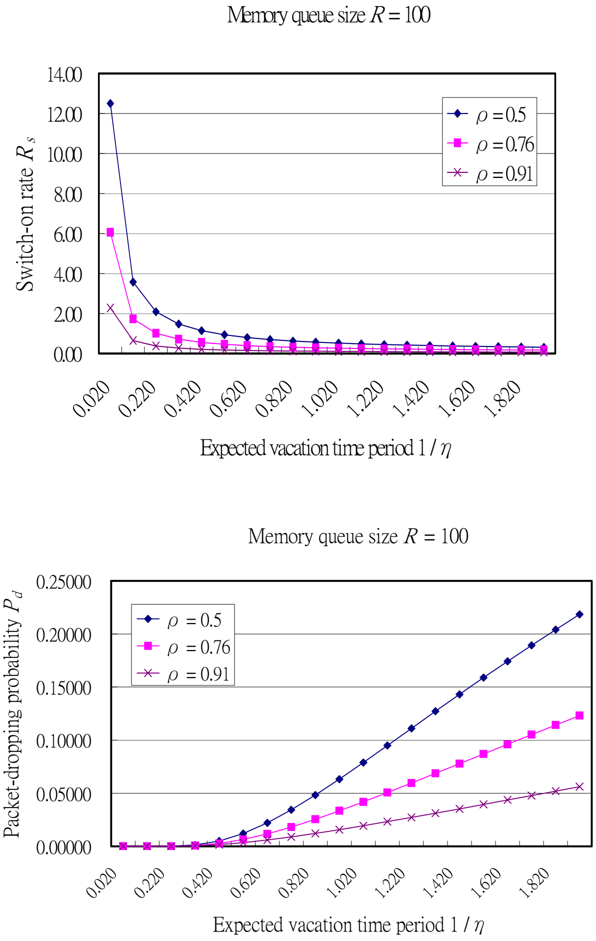
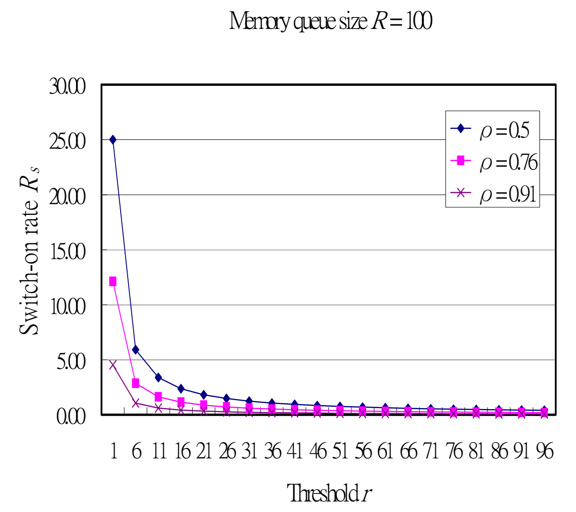


Figure 7. Performance of the vacation approach



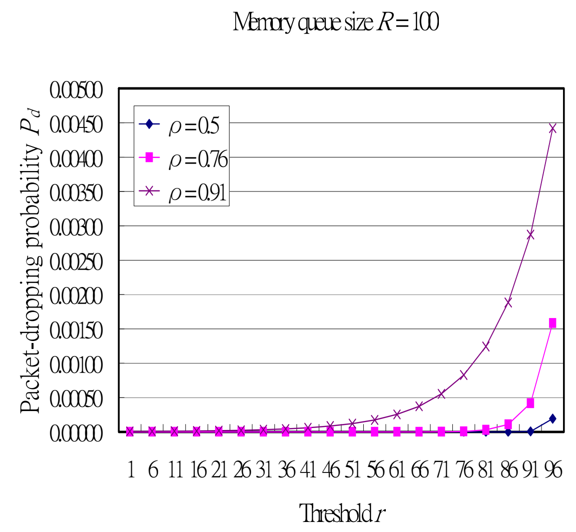
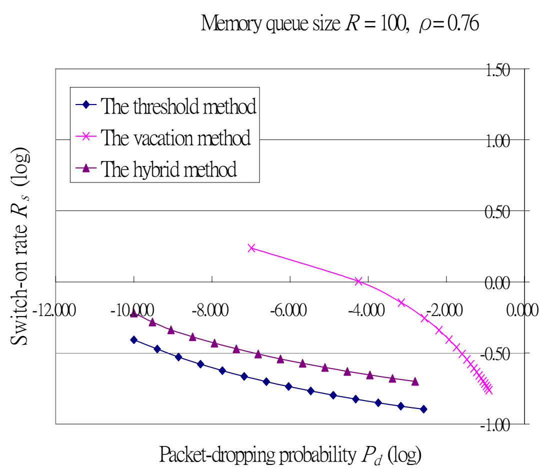
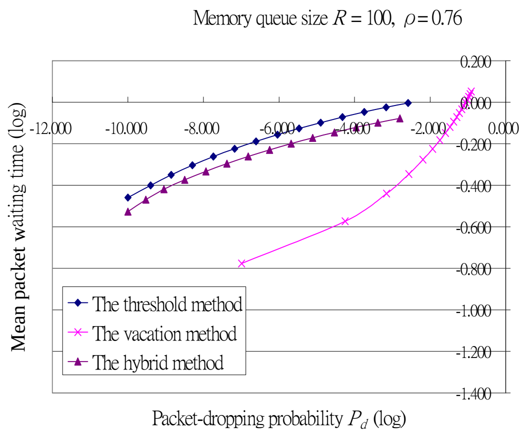


Figure 8. Performance of the hybrid approach

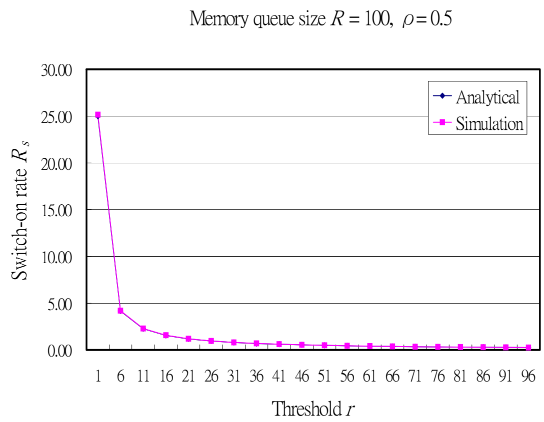


(a) Switch-on rate



(b) Mean packet waiting time

Figure 9. Comparison of the three wake-up approaches



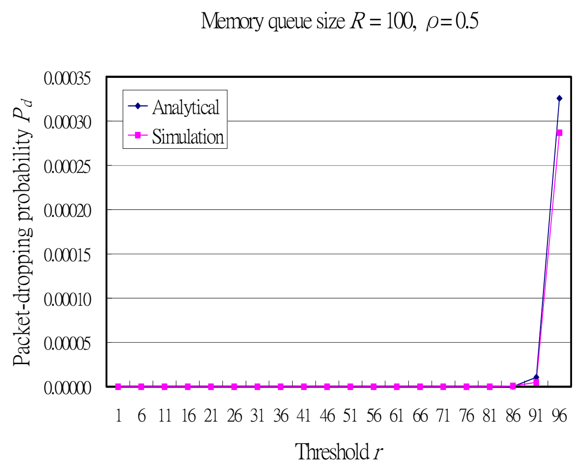


Figure 10. Comparison of the analytic and the simulation results (the threshold approach)

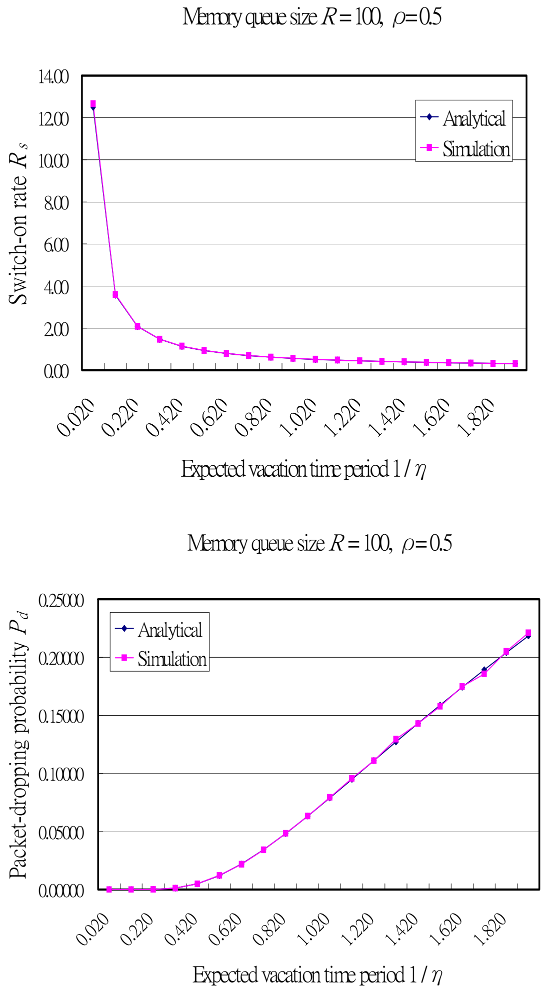
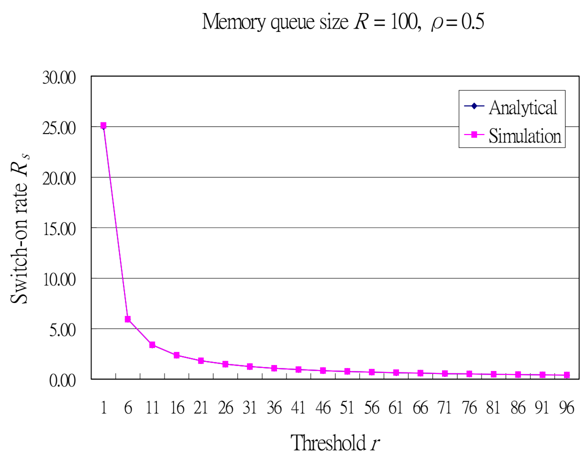


Figure 11. Comparison of the analytic and the simulation results (the vacation approach)



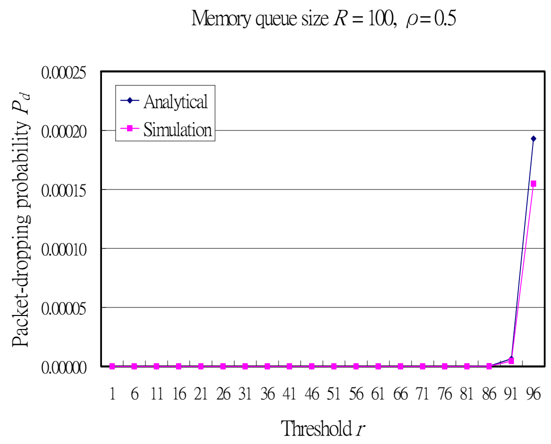


Figure 12. Comparison of the analytic and the simulation results (the hybrid approach)

5. Conclusion

This paper proposes three approaches to reduce the power consumption in a mobile multimedia handset. These approaches switch the system into the sleep mode when the memory queue for the arriving packets is empty. Depending on the approaches, various wake-up mechanisms are considered. The threshold approach switches on the system when the number of packets in the memory queue is above a threshold. The vacation approach wakes up the system when a vacation time expires. The hybrid approach turns on the system either when the memory queue length is above the threshold or when the vacation time expires. Our study indicates that it is possible to find a range of the threshold values to achieve small switch-on rate and packet dropping probability for the threshold approach. On the other hand, such a range for vacation time may not exist for the vacation approach.

Our study further indicates that the threshold approach effectively reduces the switch-on rate, while the vacation approach has the lowest mean packet waiting time. To keep both the switch-on rate and the mean packet waiting time below some reasonable small values, the hybrid approach should be selected

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