Performance of Power Efficient Wake-Up Mechanisms for Mobile Multimedia Communication with Bursty Traffic

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Abstract: - The mobile communication handset system can be divided into three units of consuming battery power, which are data receiving, data processing, and the user interface units. Among other things, one of the power-efficient mechanisms is to make the data processing and the user interface units stay on the sleep state while the data receiving unit is waiting for packets from wireless network. We study two wake-up schemes: the threshold and the vacation schemes to conserve power. To take account of traffic burstiness, we consider three traffic models: the Poisson Process, the Interrupted Poisson Process (IPP), and the 2-state Markov Modulated Poisson Process (MMPP). Analytical models are considered to evaluate two wake-up schemes under three different traffic models. The performance measures of interest are the switch-on rate, the packet dropping probability, and the waiting time.

Key-Words: - Traffic burstiness, threshold, vacation, switch on rate, packet dropping probability, waiting time

1 Introduction

It is expected that a multitude of services, e.g., voice, still picture, high-speed data, short film clip, will be provided in the next generation of mobile communication systems. It implies that handsets and portable terminals will be used more frequently and/or much longer than ever. One of the ensuing consequences is that the power consumption of the handset is escalating rapidly. Since handsets and portable terminals are battery-powered, provision of power-efficient mechanisms to them has become more important than ever and has been under intensive study [1]-[4].

In this paper, we focus on how to switch off or on the mobile handset to reduce the power consumption as in [2]-[4]. As mentioned in [2], the mobile communication handset system can be divided into three units of consuming battery power, which are data receiving, data processing, and the user interface units, and these three units can be supplied with power separately. Among other things, one of the power-efficient mechanisms is to make the data processing and the user interface units stay on the sleep state while the data receiving unit is waiting for packets from wireless network. The wake-up (switch-on) action is performed while those two units, the data processing and the user interface units, change their state from the sleep state to the wake-up state. The data processing and the user interface units keep on working while switched on, and enter into sleep state if memory queue becomes empty again. The data receiving unit is always awake to receive packets, whether the data processing and the user interface units stay on the sleep state or not.

To switch on the data processing and the user interface units each time when the data receiving unit receives a packet could be power inefficient [3]. In order to overcome this defect, the data receiving unit can be made to wait for more packets to come before the other two units are switched on. However, some packets may be dropped if there is not enough space in the queue for the arriving packets. Furthermore, the more packets wait in the queue, the higher the waiting time a typical packet experiences. We study two wake-up schemes: the threshold and the vacation schemes to conserve power as proposed in [2]. Only Poisson packet arrivals are considered in [2]. In [4], the integer-valued threshold-based wake-up mechanism is extended to the fractional-valued, where the fractional threshold value shows the mean threshold value.

Although Poisson models have found many important applications in the wired telephony, they are inadequate in some important areas, e.g., Internet. It has been shown that the traffic in the Internet shows self-similarity [5] only. Furthermore, heavy-tailed ON/OFF models have been shown to present self-similarity [6] only. Since accessing Internet via mobile communications is a promising application, these non-Poisson traffic models have been studied in the design of wireless data transmission [7]. We also need to take into account the non-Poisson or bursty traffic models in designing the power efficient mechanisms for the multimedia handsets. Unfortunately, these traffic models are not suitable for queueing model analysis. Instead, to take account of the burstiness of packet arrival process, we consider three traffic models: the Poisson Process, the Interrupted Poisson Process (IPP), and the 2-state Markov Modulated Poisson Process (MMPP) [8]. The 2-state MMPP also has two states – state 1 and state 2. During state 1 (2), λ_1 (λ_2) packets per unit of time are generated. The transition probability rate, a (b), is the transition probability from state 1 (2) to state 2 (1) per unit of time. It is noted that both Poisson and IPP are special cases of MMPP.

The rest of the paper is organized as follows. In Section 2 we describe the system model, and analytical models are established to evaluate two wake-up schemes under three different traffic models. In Section 3 the numerical results and analysis are presented. Finally, Section 4 concludes the paper.

2 System Model

In this section we describe the analytical models for the threshold and the vacation schemes with three kinds of packet arrival processes: Poisson, IPP, and 2-state MMPP. Since Poisson and IPP are special cases of MMPP, only the derivation for MMPP is shown. Assume that the size of memory queue in the data receiving unit is R. In the following, the considered system is described as a three-dimensional Markov chain, where state (i,j,k) implies that there are i packets in the memory queue, system is in mode j (j=1(2) implies in the sleep (wake-up) mode), and arrival process in state k (k=1 or 2). Based on these models, we derive three performance measures of interest: the switch on rate R_s packet dropping probability P_d , and the average waiting time W_q .

2.1 The Threshold Scheme with MMPP Arrivals

In this scheme, a switch-on action is performed when the number of the packets accumulated in the memory queue reaches the threshold r, and a switch-off is performed when the queue becomes empty.

The state transition diagram is shown in Figure 1. Based on the state transition diagram in Figure 1, the associated equilibrium equations can be derived. We can solve those equations for the steady state probabilities iteratively. After the steady state probabilities are found, the performance measures of interest can be obtained as follows.

The switch on rate R_s is given by

$$R_s = \left[\lambda_1\left(\frac{b}{a+b}\right)+\lambda_2\left(\frac{a}{a+b}\right)\right]\left[\frac{\lambda_1 P_{(r-1),1,1}+\lambda_2 P_{(r-1),1,2}}{\sum_{i=0}^{r-1}\sum_{k=1}^{2}\lambda_k P_{i1k}+\sum_{i=1}^{R}\sum_{k=1}^{2}\lambda_k P_{i2k}}\right] \quad (1)$$

An arriving packet is dropped when the memory queue is full. Thus, the packet dropping probability P_d is given by

$$P_d = \frac{\lambda_1 P_{R,2,1}+\lambda_2 P_{R,2,2}}{\sum_{i=0}^{r-1}\sum_{k=1}^{2}\lambda_k P_{i1k}+\sum_{i=1}^{R}\sum_{k=1}^{2}\lambda_k P_{i2k}} \quad (2)$$

The average waiting time W_q is given by

$$\overline{W_{qT}} = \frac{\dfrac{\sum_{i=1}^{R}\sum_{k=1}^{2}(k-1)\lambda_k P_{i1k}+\sum_{i=1}^{R}\sum_{k=1}^{2}(k-1)\lambda_k P_{i2k}}{\sum_{i=0}^{r-1}\sum_{k=1}^{2}\lambda_k P_{i1k}+\sum_{i=1}^{R}\sum_{k=1}^{2}\lambda_k P_{i2k}}}{\left[\lambda_1\left(\frac{b}{a+b}\right)+\lambda_2\left(\frac{a}{a+b}\right)\right]\left[1-P_d\right]} \quad (3)$$

2.2 The Vacation Scheme with MMPP Arrivals

The vacation scheme 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 is shown in Figure 2. Based on the state transition diagram in Figure 2, the associated equilibrium equations can be derived. Similarly, the above equations are solved iteratively. Then, the switch on rate R_s is given by

$$R_s = \eta\left[\frac{\sum_{i=1}^{R}\sum_{k=1}^{2}\lambda_k P_{i1k}}{\sum_{i=0}^{R}\sum_{k=1}^{2}\lambda_k P_{i1k}+\sum_{i=1}^{R}\sum_{k=1}^{2}\lambda_k P_{i2k}}\right] \quad (4)$$

Also, the packet dropping probability P_d can be computed as follows.

$$P_d = \frac{\sum_{j=1}^{2}\sum_{k=1}^{2}\lambda_k P_{Rjk}}{\sum_{i=0}^{R}\sum_{k=1}^{2}\lambda_k P_{i1k}+\sum_{i=1}^{R}\sum_{k=1}^{2}\lambda_k P_{i2k}} \quad (5)$$

The waiting time W_q is expressed as follows.

$$\overline{W_{qV}} = \frac{\dfrac{\sum_{i=1}^{R}\sum_{k=1}^{2}(k-1)\lambda_k P_{i1k}+\sum_{i=1}^{R}\sum_{k=1}^{2}(k-1)\lambda_k P_{i2k}}{\sum_{i=0}^{R}\sum_{k=1}^{2}\lambda_k P_{i1k}+\sum_{i=1}^{R}\sum_{k=1}^{2}\lambda_k P_{i2k}}}{\left[\lambda_1\left(\frac{b}{a+b}\right)+\lambda_2\left(\frac{a}{a+b}\right)\right]\left[1-P_d\right]} \quad (6).$$

3 Numerical Results

The analytical results for the aforesaid models are presented in this section. The size of the memory queue R is fixed at 100. The packet service rate, μ , is fixed at 30/sec. For the MMPP process, the transition rate from state 1 to state 2, a, is 1/200 1/sec, and the transition rate from state 2 to state 1, b, is 1/100 1/sec.

The performance measures of interest are the switch on rate R_s, the packet dropping probability P_d, and the average waiting time W_q.

3.1 Effect of Offered Load, Threshold, Vacation Time

MMPP packet arrival process is assumed in this subsection. The performance measures of threshold scheme versus the threshold value for three different offered loads ρ, 0.30, 0.45, and 0.65, are shown in Figures 3 to 5, respectively. According to Figure 3, R_s remains at almost zero as $r \geq 20$, and increases rapidly as $r \leq 10$. This is because most of the time the queue occupancy remains at smaller values for $\rho \leq 0.65$. On the other hand, ρ has little effect on R_s. According to Figure 4, P_d increases rapidly only when $r \geq 80$ and $\rho \geq 0.65$. For $\rho \leq 0.45$, p_d remains at about zero for all values of r and ρ has little effect on R_s. According to Figure 5, W_q increases linearly as r increases. Interestingly, for the same r, the average waiting time increases as ρ decreases. This is because besides queueing delay which is caused by the service time of the packets ahead of the packet in question, there is accumulation delay until the system can wake up to process the packets in the queue. Obviously, for the values of ρ considered, the accumulation delay dominates the queueing delay.

The performance measures of vacation scheme versus the expected vacation time for three different offered loads ρ, 0.30, 0.45, and 0.65, are shown in Figures 6 to 8, respectively. According to Figure 6, R_s decreases as $1/\eta$ increases and remains at low values as $1/\eta \geq 1.0$, and increases rapidly as $1/\eta \leq 0.2$. This is because the longer the expected vacation time, the less frequently the system will wake up or return from the vacation. On the other hand, ρ has little effect on R_s except for $\rho = 0.65$. According to Figure 7, P_d increases as $1/\eta$ increases, and becomes noticeable only when $1/\eta \geq 1.0$. Further, P_d increases as ρ increases as expected. According to Figure 8, W_q increases almost linearly as $1/\eta$ increases. This is because the longer the expected vacation time, the more time the system spends in waiting for waking up and the greater the average waiting time. Interestingly, there is a crossover between the curves for $\rho = 0.65$ and $\rho = 0.45$. It is because that as $1/\eta$ increases, once the system becomes empty, it will spend more time on vacation, i.e., the system will not start processing packets and thus the waiting time increases. On the other hand, as ρ increases, it is less likely that the system becomes empty and thus the waiting time due to vacation decreases. Obviously, when $1/\eta \geq 1.4$, the waiting time due to vacation dominates the waiting time due to packet service time ahead of the packet in question.

3.2 Comparison of Two Wake-up Schemes

The comparison among the two wake-up schemes with MMPP arrival process is considered. Given ρ =0.65 and MMPP arrival process, Figure 9 shows the switch-on rates R_s versus the packet-dropping probability P_d for the two schemes. For $P_d \leq 10^{-3}$, the vacation scheme results in the highest switch-on rate, whereas the threshold scheme leads to the lowest R_s. Furthermore, Figure 10 shows the waiting time W_q versus the packet-dropping probability P_d for the two schemes. The threshold scheme results in the highest waiting time, whereas the vacation scheme leads to the lowest. It is noted that for $P_d > 10^{-3}$, the vacation scheme may lead to lower R_s and higher waiting time than the hybrid scheme.

3.3 Comparison of Three Arrival Processes

Comparison among three arrival processes is performed as well. It is noted that in terms of traffic burstiness, IPP is the largest, MMPP is the second largest, and Poisson is the smallest. With ρ =0.65 and the threshold method, Figure 11 shows the switch on rates R_s versus the packet-dropping probability P_d for three arrival processes. It is noted that the IPP traffic results in the lowest switch-on rate for $P_d > 10^{-3}$ and the highest one for $P_d < 10^{-3}$. Furthermore, Figure 12 shows the waiting time W_q versus the packet-dropping probability P_d for the three traffics. It is noted that the IPP traffic results in the highest waiting time for $P_d > 10^{-3}$ and the lowest one for $P_d < 10^{-3}$. With ρ =0.65 and the vacation method, Figure 13 shows the switch-on rates R_s versus the packet-dropping probability P_d for three arrival processes. The IPP results in the highest switch on rate for $P_d < 10^{-2.7}$ and the lowest one for $P_d > 10^{-2.7}$. Furthermore, Figure 14 shows the waiting time W_q versus the packet-dropping probability P_d for the three traffics. It is noted that the IPP traffic results in the highest waiting time, whereas the Poisson traffic leads to the lowest. Apparently, the traffic burstiness could lead to significant change of performance measures. To summarize, if the major concern is the power consumption, under the same packet dropping probability, the threshold scheme seems to provide the lowest switch on rate and thus the lowest power consumption, at the expense of maybe highest waiting time. On the other hand, if the waiting time is the major concern, e.g., for real-time traffic, the vacation scheme may be the best choice. Furthermore, as the traffic load increases, the differences among the three wake-up schemes become smaller. Furthermore, for the threshold scheme, IPP could result in lower switch on rate and higher waiting time than Poisson process with larger packet dropping probability. The associated differences are more pronounced as the load increases.

4 Conclusion

We study two wake-up schemes: the threshold and the vacation schemes, and three traffic models: the Poisson, IPP, and 2-state MMPP. Analytical models are established for comparison among these wake-up schemes and traffic models. The performance measures of interest are the switch on rate, the packet dropping probability, and the waiting time. If the major concern is the power consumption, under the same packet dropping probability, the threshold scheme seems to provide the lowest switch on rate and thus the lowest power consumption, at the expense of maybe highest waiting time. On the other hand, if the waiting time is the major concern, the vacation scheme may be the best choice. Furthermore, as the traffic load increases, the differences among two wake-up schemes become smaller. It is also observed that for the threshold scheme, IPP could result in lower switch on rate and higher waiting time than Poisson process with larger packet dropping probability. The associated differences are more pronounced as the load increases.

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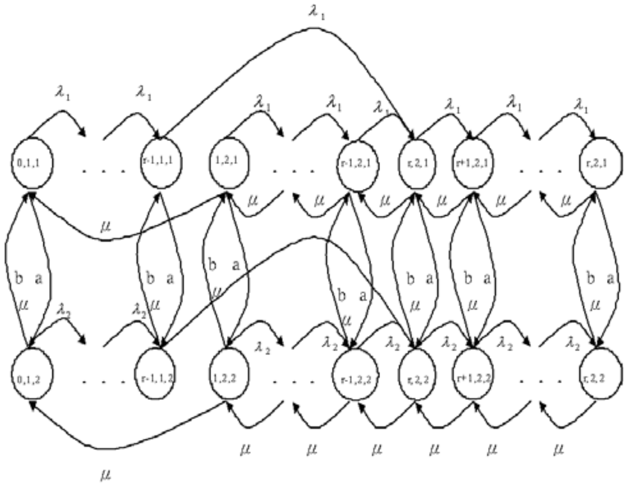

Figure 1: The state transition diagram for the threshold scheme.

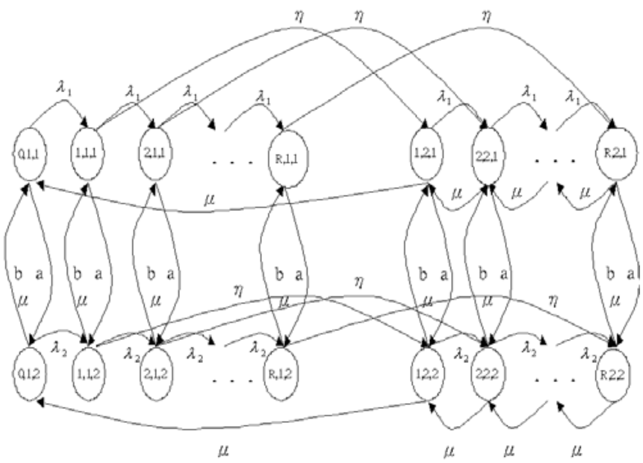

Figure 2: The state transition diagram for the vacation scheme.

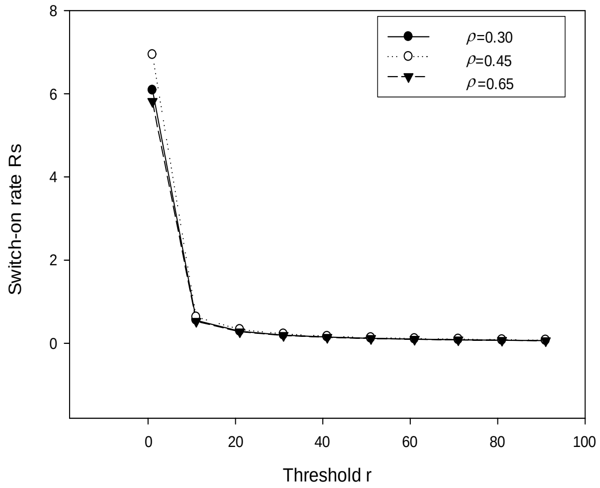

Figure 3: Switch on rate of threshold scheme with MMPP process

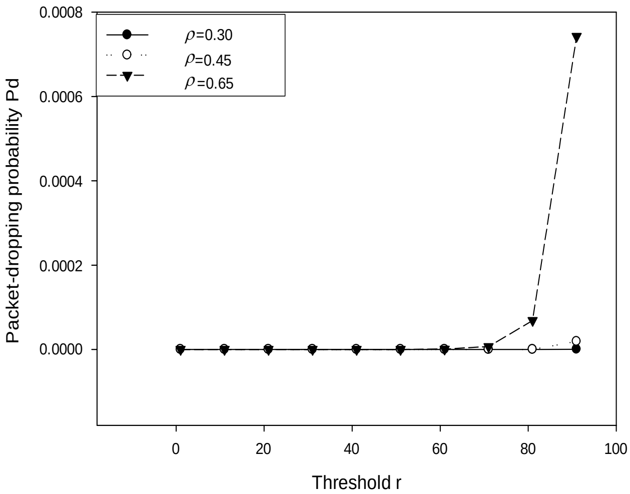

Figure 4: Packet-dropping probability of threshold scheme with MMPP process

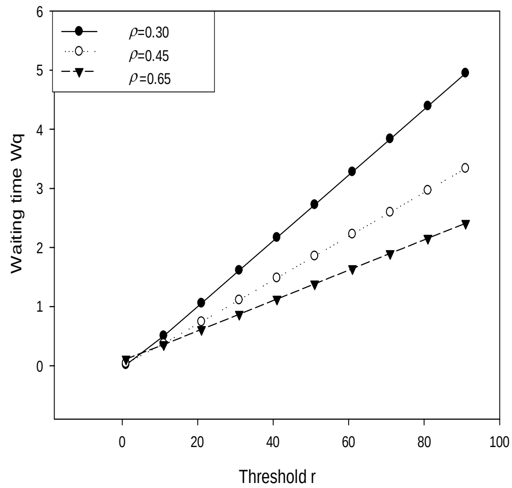

Figure 5: Waiting time of threshold scheme with MMPP process

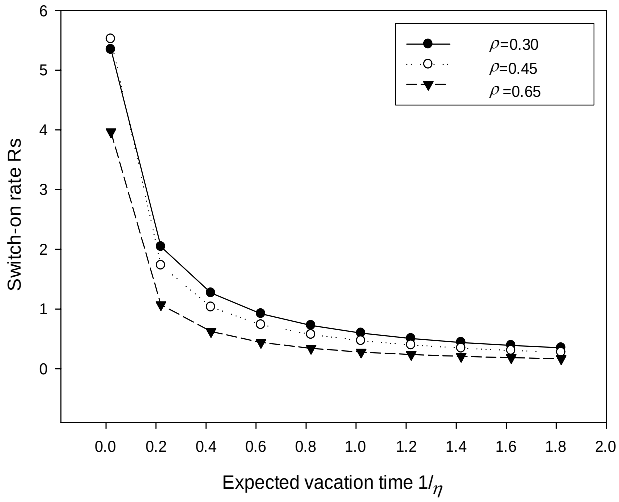

Figure 6: Switch-on rate of vacation scheme with MMPP process

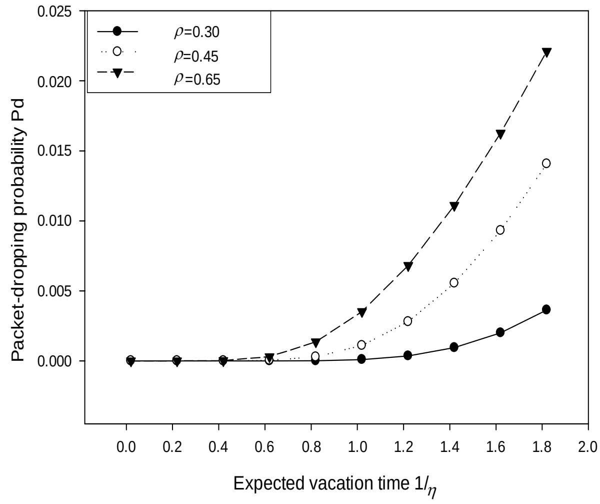

Figure 7: Packet-dropping probability of vacation scheme with MMPP process

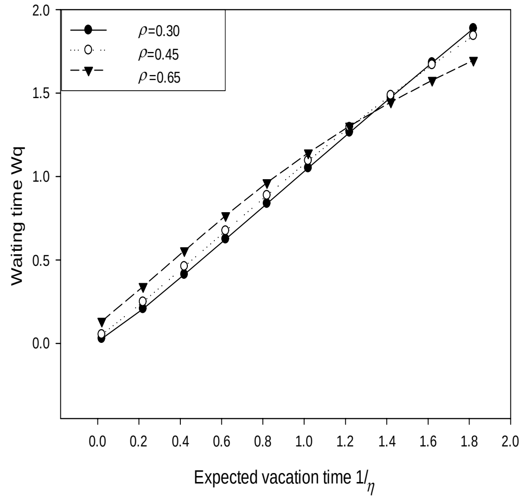

Figure 8: Waiting time of vacation scheme with MMPP process

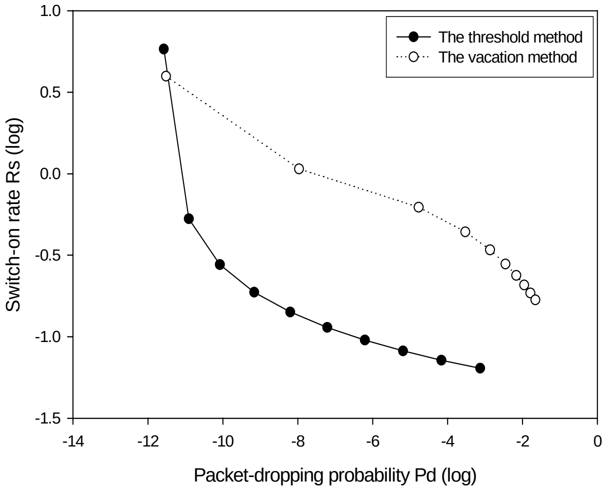

Figure 9: Switch-on rate with MMPP process and ρ =0.65

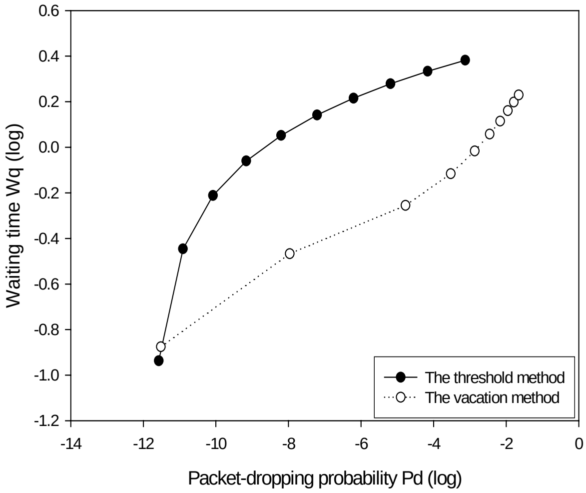

Figure 10: Waiting time with MMPP process and ρ =0.65

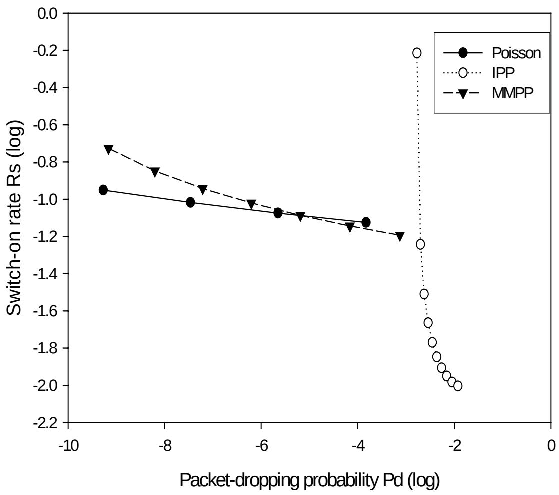

Figure 11: Switch-on rate of threshold method with three processes and $\rho = 0.65$

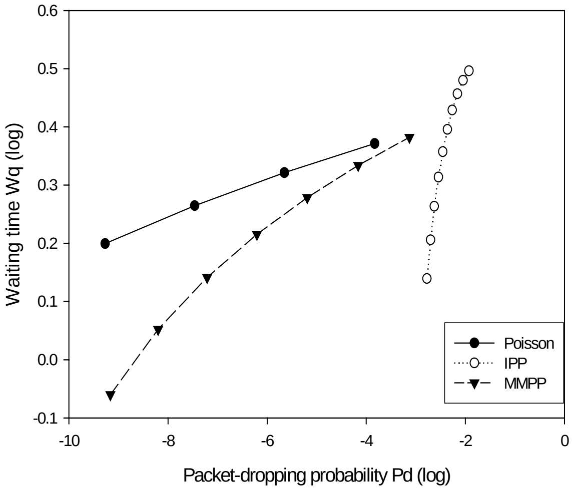

Figure 12:Waiting time of threshold method with three processes and ρ =0.65

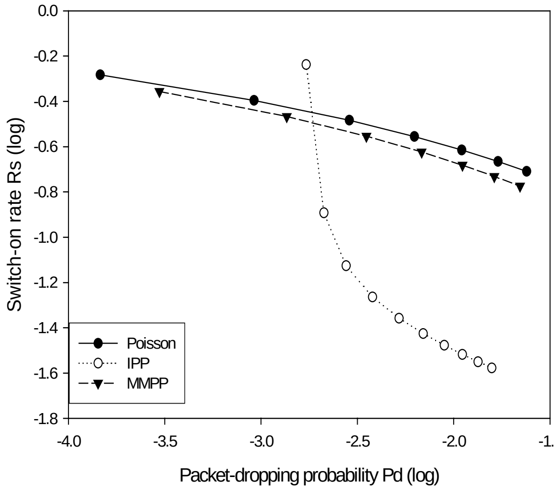

Figure 13: Switch-on rate of vacation method with three processes and ρ =0.65

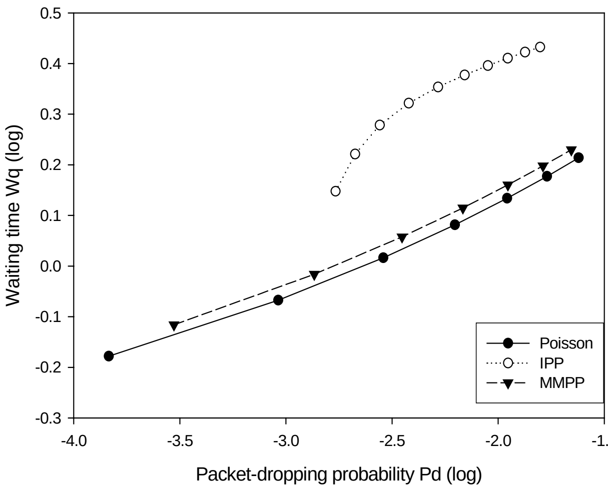

Figure 14: Waiting time of vacation method with three processes and ρ =0.65