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Energy-Saving Strategies by Extending Unavailability Interval Approach for Multiple Traffic Classes in IEEE 802.16e

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Abstract: IEEE 802.16e standard have been designed for both delay sensitive and delay tolerant applications. This paper presents energy-saving strategies by extending unavailability interval for multiple power saving classes simultaneously. The proposed model allows mobile stations to dynamically adopt multiple sleep mode operation or multiple partial sleep mode operation based on the buffer status of power saving class I and II. We set up partial sleep interrupt function which decides whether to stay in multiple partial sleep state or busy state to enhance the response time in real time traffic. Various performance indices of the system are presented. A cost model is formulated to determine the optimal values of various parameters at minimum cost using quadratic fit search method. It is shown numerically that the proposed model improves the system performance efficiently.

Key-Words: IEEE 802.16e, downlink, sleep mode, accessible batch, multiple power saving classes, unavailability interval.

1. Introduction

During the past decades, the development of multimedia services has created high demand for broadband access. Worldwide Interoperability for Microwave Access popularly known as WiMAX is cost effective among other broadband access technology [1]. The WiMAX and its gradual development have been well planned to meet the challenges and fulfilling the requirements of high data rate applications like interactive gaming, high definition television, video streaming as well as low intensity data rate application such as web browsing.

Recently developed IEEE 802.16e systems present scalability in both radio based communication network and network architecture [2]. It can offer full-mobility for WiMAX and supports seamless handoff which renders switching between base stations (BS) in vehicular speeds without interrupting the connection as depicted in Figure 1. The MSs are fully dependent on light weight batteries for maintaining the connections with the serving base stations. The IEEE 802.16 standard family adopt power saving mechanism by discontinuing connection for a pre negotiated time with the BS station. In this state, the down link traffic intended for MS cannot be transmitted as MS switch off with the BS for saving the energy, which is known as sleep state. The MS wakes up to check the buffer status and transfers messages with the BS between sleep states in a short interval, called listening window.

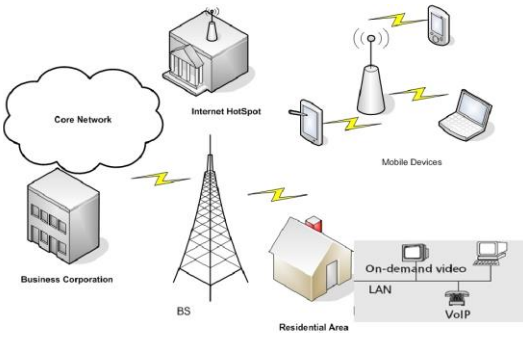

Figure 1. Network Infrastructure of IEEE 802.16.

If a mobile station has multiple data traffic connections with a BS, then in reality it may connecting with the BS and maintaining number of Power Saving Classes(PSC).

The three different Power Saving Classes are categorized based on sleep interval to enhance power saving and manage QoS for different type of applications. The primary difference in the power saving classes can be identified by the duration of the sleep window and its pattern. Type I class is recommended for best effort (BE) or non-real-time variable rate service. Here service connections with an exponential increase of the sleep window size. Type II class is recommended for the Real Time Variable Rate (RT-VR) or the Unsolicited Grant Service (UGS) and traffic with a constant sleep window size. Type III is recommended for multi-cast and management connections with the sleep window size controlled by the base station.

Most of the research works mainly focus on individual traffic separately but we observed that in real life scenarios the individual terminal receiving traffic of power saving class I and II at the same instance. There are two types of intervals are present in a multiclass scenario, that is, unavailability interval and availability interval, respectively. During the unavailability interval the MSs' switch off the transceiver and attention of BS is not required. In this interval, there will be no overlap of busy period or listening period of other active PSC and can carry out other functionality which do not need connection with the serving Base station. On the other hand the MS is capable of receiving transmissions during an availability interval, and executes all the normal operations [1]. One can note that lots of energy can be preserved by extending the unavailability interval in real life situation. But the BS, buffers the frames intended to the MS for a sleep period. It increases the delay of the traffic. The main objective is to maintain the needed QoS for multiple class traffic and to maximize the energy saving. To the best of our knowledge, there are no such results available for this general approach.

The rest of the paper is organized as follows. An overview of some related works are presented in Section 2. An analytical model of the proposed downlink resource management framework to improve the power efficiency is presented in Section 3. Section 4 evaluates the performance metrics of multiple power saving class of I and II simultaneously for the proposed model. Section 5 discusses cost analysis and numerical results. Section 6 concludes the paper.

2. Related Work

Most of the performance analysis of the IEEE 802.16e sleep mode considers from BS to MS. The energy consumption in IEEE 802.16e by assuming the message delivery in both direction has been proposed in [3]. Two power saving class (PSC) management schemes in real time traffic scenario has been presented in [4]. They demonstrated their results using simulation and shown that resource utilization in PSC II is better from PSC I. Their considerations consume lots of energy because of frequent wake up, so the given model is not suitable for moderate traffic. Performance evaluation of an energy saving model in the mobile WiMAX have been studied in [5, 6]. They considered listening interval as a part of sleep window, but in reality listening interval consumes lots of energy as it frequently checks up buffering status.

The sleep mode operation in mobile WiMAX for preserving the power of mobile station using M/GI/1/N queueing system with multiple vacations has been studied in [7]. The performance of PSC I under given traffic arrival patterns using a semi-Markov chain analysis is proposed in [8]. A simulation-based performance evaluation of the sleep mode with various traffic types for efficient energy saving has been implemented in [9]. An analytical model based on the generalized traffic process has been studied in [10]. The outcome shows that the arrival processes of different traffic generate discrepancy in delay of frame or energy consumption. Performance analysis of a renewal input bulk service queue with accessible and non-accessible batches in a continuous-time has been studied in [11]. Load based power saving scheme for power saving class III has been studied in [12]. They estimated the size of the sleep window for mobile subscriber station based on the traffic load at base stations. This scheme is not suitable for managing efficiently the RT-VR traffic.

An analytical model that shows the relationship between traffic load at BS and service rate of the traffic at MSs has been discussed [13]. They used an M/G/1 queueing model to determine the behavior of BS and MS, and also developed a cost model to optimize the cost. Most of the research work considered energy saving for non-real time traffic or traffic with constant bit rate traffic. A model consists of a BS and an MS with real time traffic has been proposed in [14]. They also considered both jitter and delay types of QoS in their research work. Their successive scheduling approach minimizes power consumption of the MS.

Sheu. et al. [15] proposes Listening interval spreading approach (LISA) where idle periods and the listening periods are redistributed for reducing the response time of interactive traffic. They have shown that the LISA scheme allows an energy saving solution for dealing with burst traffic, but this scheme is not suitable for handling light traffic. Chen et al. [16] presented energy saving strategy for power saving class II by extending the maximum unavailable interval. Performance analysis of power saving class I and class II individually have been carried out in [17]. Kong and Tsang [18] analyzed the selection mechanism where a single power saving class operates at a specific instance.

This paper proposes an analytical model to maximize the unavailability interval for multiple power saving classes operations of an MS terminal. The proposed model primarily designs the PSC -I traffic with multiple sleep state as it is tolerable to delay. In contrast to provide better response time to delay sensitive PSC of type II, we adopt multiple partial sleep state. In addition, to trade between delay and power saving more efficiently, we take up partial sleep interruption so that it can interrupt multiple partial sleep to switch over busy state to reduce response time for delay sensitive traffic and save the energy indirectly.

3. System Model

In this model, we consider base station as a queue with infinite buffer, and incoming traffic is accumulated by a first-come, first-served (FCFS) discipline in the downlink direction.

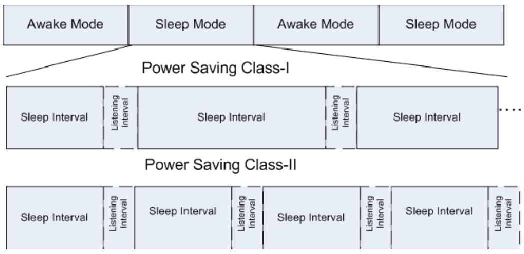

Figure 2.Awake and sleep mode in power saving class I and II

When the buffer is empty, the mobile station either begins a Multiple Sleep State (MSS) with probability p or takes a Multiple Partial Sleep State (MPSS) with probability 1-p, where p can be defined as the probability of incoming packets of PSC-I and 1-p represent the probability of incoming packets of PSC-II. If the buffer is non-empty at a service completion epoch in a MPSS, the server either ends the state and enters a regular busy period with probability 1-q, that is, Multiple Partial Sleep State Interruption (MPSSI), or continues the MPSS with probability q. Figure 2 depicts the awake and sleep mode in power saving class I and II.

The effect of proposed power saving approach for power saving class I and II is shown in Figure 3. The intended traffic for mobile station arrive one at a time according to a Poisson process with arrival rate λ. The sleep length in MSS is V and in MPSS is V1 is assumed to be exponentially distributed with parameters φ and Φ respectively. The service time is assumed to follow exponential distribution with mean 1/μ. The service times during MPSS are assumed to follow Poisson distributions with parameter η. During MPSS the service rate η is different and generally lower than the regular service rate μ. The inter-arrival times, sleep times during MSS, service times during regular service and during MPSS are mutually independent. That is, we consider a Markovian queueing system with

Bernoulli-schedule controlled vacation and vacation interruption [19].

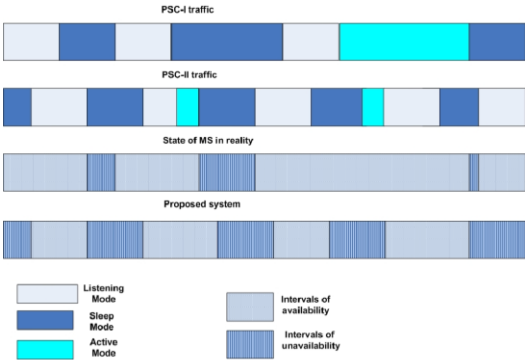

Figure 3.Effect of proposed power saving approach for power saving class I and II

Let at steady-state, $\Pi_{0,0}$ i ≥ 0 be the probability that there are i packets in the $\Pi_{i,1}$ system when the server is in MPSS state, i ≥ 0, be the probability that there are i packets in the system when the server is in MSS state, and $\Pi_{i,2}$, i ≥ 1 be the probability that there are i packets in the system when the server is in regular busy period. Using the Markov process theory, we obtain the following set of steady-state equations

$$\lambda\Pi_{0,0} = \eta\Pi_{1,0} + (1-\lambda)\mu\Pi_{1,2} \qquad (1)$$

$$(\lambda+\mu+\varphi)\Pi_{n,0} = \lambda\Pi_{n-1,0} + q\eta\Pi_{n+1,0},\ n \geq 1 \qquad (2)$$

$$\lambda\Pi_{0,1} = p\mu\Pi_{1,2} \qquad (3)$$

$$(\lambda+\Phi)\Pi_{n,1} = \lambda\Pi_{n-1,1},\ n \geq 1 \qquad (4)$$

$$(\lambda+\mu)\Pi_{1,2} = (1-q)\eta\Pi_{2,0} + \mu\Pi_{2,2} + \varphi\Pi_{1,0} + \Phi\Pi_{1,1} \qquad (5)$$

$$(\lambda+\mu)\Pi_{n,2} = \lambda\Pi_{n-1,2} + (1-q)\eta\Pi_{n-1,0} + \mu\Pi_{n+1,2} + \Phi\Pi_{n,1} + \varphi\Pi_{n,0} \quad n \geq 2 \qquad (6)$$

$$\Pi_{1,2} = \frac{\lambda}{p\mu}\Pi_{0,1} \qquad (7)$$

$$\Pi_{n,1} = \frac{\lambda^n}{(\lambda+\Phi)^n}\Pi_{0,1},\ n \geq 1 \qquad (8)$$

We define the displacement operator

$E^j\Pi_{n,0} = \Pi_{n+j,0}$ and rewrite the equation as (2) as

$$[\lambda E^{-1} - (\lambda+\varphi+\eta) + q\eta E]\Pi_{n,0} = 0 \qquad (9)$$

The characteristics equation associated with (9) is

$$g(z) = \lambda - (\lambda+\varphi+\eta)z + q\eta z^2 = 0$$

By using Rouch 's theorem it can be shown that only one zero of g(z) falls inside the unit circle and, this root is real and unique, we denote this root by r ($0 < r < 1$). Thus, r satisfies the equation

$$\lambda - (\lambda+\varphi+\eta)r + q\eta r^2 = 0 \qquad (10)$$

Now the solution of (2) can be written as

$$\Pi_{n,0} = r^n\Pi_{0,0},\quad n \geq 0. \qquad (11)$$

Using (1), we get

$$\Pi_{0,0} = \frac{\lambda(1-p)}{p(\lambda-\eta r)}\Pi_{0,1} \qquad (12)$$

Solving the equation (5), we obtain

$$\Pi_{i,2} = h_i\ \Pi_{0,1}$$

Where

$h_1 = \frac{\lambda}{p\mu}$ and

$$h_2 = \frac{1}{\mu}\left[\frac{\lambda(\lambda+\mu)}{p\mu} - (\varphi+(1-q)\eta r)\frac{\lambda r(1-p)}{p(\lambda-\eta r)} - \frac{\Phi\lambda}{\lambda+\Phi}\right],$$

$$h_i = \frac{1}{\mu}\left[(\lambda+\mu)h_{i-1} - \lambda h_{i-2} - \Phi\left(\frac{\lambda}{\lambda+\Phi}\right)^{i-1} - (\varphi+(1-q)\eta r))\quad)\frac{\lambda r^{i-1}(1-p)}{p(\lambda-\eta r)}\right] \quad i \geq 3.$$

Using normalization condition we get

$$\Pi_{0,1} = \left[\sum_{i=0}^{\infty}\Pi_{i,0} + \sum_{i=1}^{\infty}\Pi_{i,1} + \sum_{i=1}^{\infty}\Pi_{i,2}\right]^{-1}$$

3. Performance and cost metrics

In this section, we discuss the various performance indices discussed in the previous section. The impact of power saving mode, access delay and costs due to reception of packets and wireless transmission are the key factors of performance measures. Then we derive the parametric expressions for cost and power saving at both PSC I and PSC II.

Let P(B), P(V) and P(W) be the probability that the system is in a regular busy period, multiple sleep state and a multiple partial sleep state, respectively. Then, we have

$$\mathrm{P(B)} = \sum_{\mathrm{i}=1}^{\infty} \Pi_{\mathrm{i},2}, P(V) = \sum_{i=0}^{\infty} \Pi_{\mathrm{i},1}$$

and $P(W) = \sum_{i=0}^{\infty} \Pi_{\mathrm{i},0}$

The average number of packets in the system Ls, the average number of packets in the buffer (L_q), are given by

$$L_s = \sum_{i=1}^{\infty} i\left(\Pi_{\mathrm{i},0} + \Pi_{\mathrm{i},1} + \Pi_{\mathrm{i},2}\right)$$

And

$$L_q = \sum_{i=1}^{\infty}(i-1)\,\Pi_{\mathrm{i},0} + \sum_{\mathrm{i}=1}^{\infty} \mathrm{i}\,\Pi_{\mathrm{i},1} + \sum_{\mathrm{i}=1}^{\infty}(\mathrm{i}-1)\Pi_{\mathrm{i},2}$$

Using Little's rule, the mean delay in the system (W_s) and the mean delay in the buffer (W_q) are given by $W_s = L_s/\lambda$ and $W_q = L_q/\lambda$, respectively.

4. Cost analysis and optimization investigation

The performance indices computed may be utilize to optimize the system performances.

We formulate the total expected cost function per unit time for the given system. The decision variables are assumed as μ and η.

C_h=holding cost per unit time for each packet in the system.

C_1=cost incurred per unit time for service during the busy period.

C_2=cost incurred per unit time for service during multiple partial sleep mode.

C_3=fixed cost incurred per unit time during a multiple sleep mode.

C_4=fixed cost incurred per unit time during multiple partial sleep period.

The total expected cost F per unit time is given by

$F = C_h L_s + C_1 P(B) + C_2 \eta P(W) + C_3 \Phi\, P(W) + C_4 \varphi\, P(V).$

To minimize the cost function the quadratic fit search method is used. According to the quadratic fit search [20] the unique optimum agreeing with f(x) at 3-point pattern $f(x_0, x_1, x_2)$ occurs at

$$x = \frac{1 f(x_0)(x_1^2 - x_2^2) + f(x_1)(x_2^2 - x_0^2) + f(x_2)(x_0^2 - x_1^2)}{2 f(x_0)(x_1 - x_2) + f(x_1)(x_2 - x_0) + f(x_2)(x_0 - x_1)}$$

In this method, we use the quadratic fit search to enhance the present 3-point pattern by replacing one of its point which give the minimized value. We put the stopping tolerance limit as 10^{-4}.

5. Numerical results

We present some numerical analysis to investigate the performance analysis of download traffic for power saving class I and II at the same instance. Moreover, the design of our model can provide priority to the different power saving classes differently as per requirement in the real time situations. A variety of numerical results are presented to show the performance for increasing the priority of different power saving classes.

Table 1. The optimal values F and Lq for various values of p and q

q	P=0.3		P=0.7		P=0.9	
	Lq	F	Lq	F	Lq	F
0.3	5.66432	679.445	9.70905	1087.35	10.9121	1208.68
0.5	5.51706	663.882	9.59580	1075.74	10.8943	1206.86
0.7	5.33008	643.855	9.41577	1057.23	10.8645	1203.81
0.9	5.11403	619.613	9.06076	1020.50	10.7990	1197.06

Table 2. Sensitivity analysis of MSS, MPSS and MPSSI System

η,μ	L_q					
	λ=2.0, Φ=0.2, φ=0.1			λ=3.0, Φ=0.2, φ=0.1		
	MSS	MPSS	MPSSI	MSS	MPSS	MPSSI

(1, 4)	10.4651	2.83720	5.94375	12.2815	5.53350	9.68385
(1,5)	10.2497	2.54003	5.69121	11.5329	4.16130	8.67924
(1,6)	10.1397	2.39479	5.57018	11.2527	3.69927	8.32604
(1,7)	10.0730	2.30910	5.49985	11.075	3.47115	8.15049
(2,4)	10.4655	2.05164	3.15574	12.2833	4.41591	7.52850
(2,5)	10.2496	1.77535	2.96884	11.5345	3.06384	6.45417
(2,6)	10.1393	1.64176	2.88394	11.2540	2.61851	6.10827
(2,7)	10.0723	1.56347	2.83617	11.1085	2.40052	5.94501
(3,4)	10.4644	1.69903	1.72216	12.2842	3.92855	4.94947
(3,5)	10.2479	1.44094	1.59746	11.5351	2.60881	3.96714
(3,6)	10.1373	1.31719	1.54205	11.2543	2.17903	3.68318
(3,7)	10.0701	1.24504	1.51122	11.1086	1.96979	3.55578

Table 3. The quadratic fit search method in searching the optimum solution.

n	η_0	η_1	η_2	$F(\eta_0)$	$F(\eta_1)$	$F(\eta_2)$	η	$F(\eta)$	Tolerance
1	0.9000	1.1000	1.3000	1301.3275	1300.6833	1301.1629	1.1146	1300.6909	.01466
2	1.1000	1.1146	1.3000	1300.6833	1300.6910	1301.1629	1.08144	1300.6832	.01856
3	1.08144	1.10000	1.11466	1300.6832	1300.6833	1300.6910	1.09049	1300.6823	.00906
4	1.09049	1.08144	1.10000	1300.6823	1300.6832	1300.6833	1.09040	1300.6823	.00010
5	1.09040	1.09049	1.08144	1300.6823	1300.6823	1300.6823	1.09045	1300.6823	.00005

Table 1 shows the average number of packets in the buffer and cost for different values of p and q. When q is constant, the L_q and F increase with the increase of p, because the probability of switching to MSS state increases with the increase of p. As the probability of switching to busy period from state of MPSS increases, one can see that for fixed value of p, with increase of q the L_q and F decreases. Table 2 represents sensitivity analysis of L_q for (i) the multiple sleep state (ii) multiple partial sleep state (iii) multiple partial sleep state interruption. It is observed that as λ increases L_q increases because number of packets in the buffer increases with the increase of arrival rate.Increase of arrival rate. As expected, the number of packets in the buffer is less in MPSS state from other two states. At partial sleep state when service rate (η) is constant, with increase of regular service As expected, the number of data frames in the buffer is less in MPSS from other two states. At the partial sleep state when service rate (η) is constant, with increase of μ the L_q decreases for all the cases.

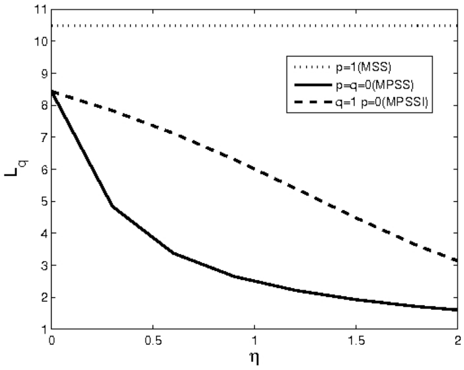

Figure 4.Impact of η on L_q

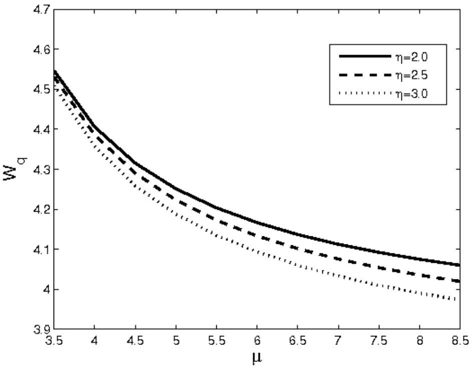

Figure 5.Effect of μ on W_q

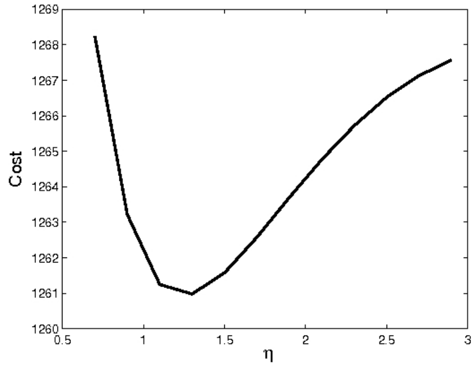

Figure 6.Effect of service rate at multiple partial sleep state (η) on cost.

In Figure 4, we compare the number of packets in the buffer L_q for three different policies: the multiple sleep state (MSS), multiple partial sleep state (MPSS) and multiple partial sleep state interruption (MPSSI). The parameters are taken as $\lambda = 2.0$, $\mu = 4.0$, $\Phi = 0.2$ and $\varphi = 0.1$.

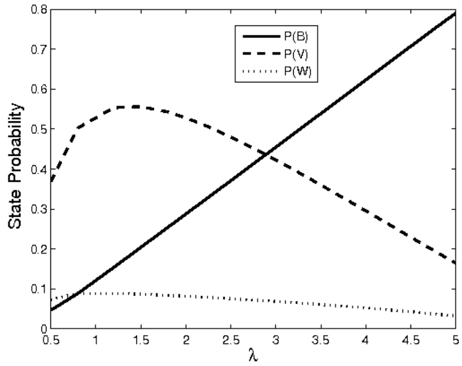

Figure 7. Impact of λ on different probability

The average number of packets in the buffer reduces with the increase of service rate η in MPSS as the buffered downlink packets are in partial sleep state because the packets can be served at the rate η during the MPSS. As expected, we can find that L_q decreases with an increasing value of η. In case of MPSSI, L_q decreases monotonically as η increases. It is seen that with the increase of ηthe average number of packets in the buffer L_q decreases evidently. Multiple partial sleep state interruption policy performs better than other two policies. Figure 5 depicts the impact of μ on the mean delay of the packets intended for downloading the buffered traffic. It can be seen that as μ increases the mean delay of the system W_q decreases. For fixed μ as η increases mean delay of the system reduces. Hence, we can set up μ and η in such a way so that the delay should be less. Figure 6 shows the impact of cost function with the change of η. It is evident that the cost is minimum when the range of η is in between 0.9 and 1.3. When $\eta > 1.3$, the cost function F increases exponentially with the increase of η. With this information from the Figure 6, we select the initial 3-point as $\eta_0 = 0.9$, $\eta_1 = 1.1$ and $\eta_2 = 1.3$. Using the quadratic fit search method, after five iterations, Table 3 shows that the minimum average cost per unit time converges to the solution $\eta = 1.09045$ with a value of 1300.6832.

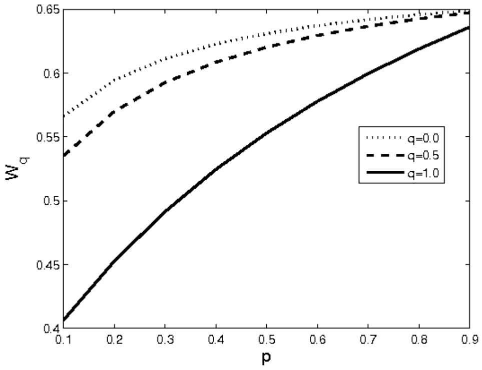

Figure 8. Effect of p on W_q.

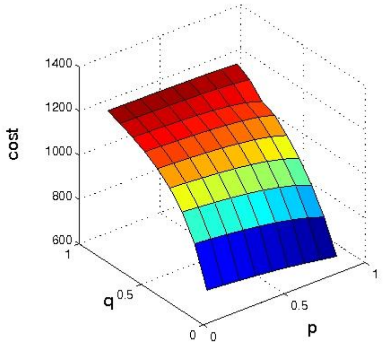

Figure 9. Impact of p and q on cost.

The effect of incoming packets arrival rate λ on the different state probabilities are given in Figure 7. It can be seen that that as the incoming packet arrival rate λ increases, the probability of switching over to busy period increases. But as λ increases, the probability that the system is in multiple sleep state and a multiple partial sleep state decrease. As expected, the problem that the system is in MPSS is least with the increase of incoming packets. We further observe that, due to increase of incoming packets arrival rate the probability of busy period increases proportionately.

Figure 8 depicts the impact of probability of incoming packets of PSC-I type on the mean delay in the buffer (W_q) for various values of q. The parameters are taken as

λ=2.0, μ=3.0, η=2.0, Φ= 0.2 and φ= 0.1. As probability of incoming packets of PSC-I type increases the probability that the system is in MSS increases for all values of q so the mean delay in the buffer also increases. It is also seen that as q increases, the probability that the system is in MPSS increases and correspondingly the mean delay in the buffer W_q decreases.

Figure 9 illustrates dependence of the cost on the value of q and p. It is observed that for fixed values of p, cost value decreases with increase of q. Further, with fixed q cost increases with the increase of p. Hence to minimize the cost we can setup an admissible value of p in between $0 \leq p < 0.5$ and q in between $0.5 \leq q \leq 1$. Hence, by varying the value of p and q a better performance result can be achieved.

6. Conclusion

In this paper, we have designed a realtime system that can handle multiple class of traffic and can adaptively save the energy and maintained the required Quality of Service (QoS) of IEEE 802.16e standard. In this work, we have extended unavailability interval by taking into account multiple power saving classes simultaneously at the same terminal. We have carried out an analytical analysis by considering a Markovian single server queue with Bernoulli-schedule controlled vacation and vacation interruption. The performance of downlink traffic intended for mobile stations of IEEE 802.16e networks are calculated with respect to the packet or frame.

Various performance indices such as probability that the system is in a regular busy period, multiple sleep state, multiple partial sleep state, average number of packets in the system, the average number of packets in the buffer, average delay time, etc are carried out. Some numerical results are also presented.

A cost model is calculated with respect to determine the optimal values of service rate at a minimum cost using quadratic fit search method. The results obtained in this paper are useful and significant for power saving prospect for handling real time and non-real time traffic at the same time.

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