Analysis of MS Power Saving Scheme to BS with Finite Buffer in IEEE 802.16e networks

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Abstract - **This paper analyzes effects of power saving of mobile station (MS) to Base Station with finite buffer in IEEE802.16e class type I network. IEEE802.16e standard accept MS to switch to sleep-mode to minimize power when MS processing load is reduced. However, when packets destined to MS appear into BS buffer, they should be stored until end of MS sleep window. Although the sleep-mode designed in effort to conserve environment but it risks loss of packets once BS buffer overloaded with accumulated packets. This paper designs numerical analytic model to measure risk of packet drop. Through asymptotic analysis the effect of packets destined to sleeping MS into BS finite buffer is measured and analysed.**

Keywords-IEEE802.16e, Power saving, sleep-mode, Base station, finite buffer, successive vacation.

I. INTRODUCTION

IEEE802.16e standard introduce an optional feature that allows MS to sleep if its processing load falls beyond threshold [1]. While MS sleep all of its packets are stored in BS buffer until expiration of sleep window.

As depicted in figure 1, IEEE802.16e sleeping mode is characterized by exponential growth of sleep-window when MS performs successive vacations. For instance, if MS undergoes 'n' successive vacations then the length of n^{th} vacation will be longer by factor of 2^n.

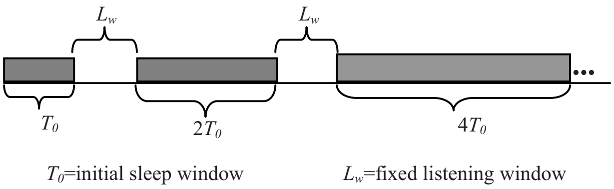

Figure 1. Exponential increase on MS sleep-window

In high-speed broadband IEEE802.16e networks, carrying multimedia or other delay-sensitive traffic, designers tend to maintain buffer relatively small to keep delay and jitter at an acceptable level [2]. This design characteristic imposes risk of packet loss when MS sleep-window becomes large due to exponential growth of successive vacations.

There have been many studies on the topic of effect of power saving scheme to IEEE802.16e operation. The studies in [3][4][5] analyze the effect by design analytical model as M/G/1 model. Kwanghun et al. in [3] consider MS sleep-mode states as semi-Markov chain. With four types of transition states the model consider delay *(D)* and power consumption *(P)* with trade-off relationship, implying to be difficult to minimize both D and P. Hyun-Ho et al. in [4] propose a hybrid energy-saving scheme that implements class type II during talk spurt but applies the truncated binary exponential algorithm of class type I during mutual silence periods of two-way VoIP traffic. The paper considers average delay-margin (D) as delay-threshold for an individual VoIP packet upon which the packet dropped from BS/MS buffer. Alouf S. et al in [5] consider M/G/1 queue model with repeated inhomogeneous vacations. The paper considers Poisson arrivals into buffer characterized with regeneration cycles. Based on regeneration cycles the study comment that a parameter that mostly affect the performance of power saving scheme is size of initial sleep window.

This study complements other studies to determine how exponential behavior of sleep window affects packet loss probability. Our study designs an analytical model which considers BS buffer operation as Turing machine's tape with two possible inputs of 0 and 1. Through the model, we develop hypothetical equations of packet loss ratio (PLR) due to accumulation of stored packets. The Laplace Stieltjes Transformation of time duration between appearances of first packet to end of sleeping window help to deduce impact of exponential growth.

The rest of the paper is organized such that in section II we design analytical model based on Turing machine tape to represent BS buffer operation when MS switches to sleep-mode. We also develop packet loss ratio (PLR) due to accumulation of stored packets destined to sleep MS. Section III analyzes BS buffer to determine time duration for packets to start discarded from BS queue. Asymptotic analysis is performed in section IV, and thereafter performs numerical analysis in section V and conclusion in section VI.

II. ANALYTICAL MODEL

Consider BS buffer which observe FIFO service discipline and buffer management policy. With exponential growth of MS sleep-window buffer risk to suffer rear dropping when a batch or single packet appears in BS buffer to find it full.

We model BS buffer as a tape of Turing-machine [6] with possible inputs of 0 to denote vacancy and 1 to denote

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presence of packet in buffer. For clarity, packets destined to sleep MS are denoted by 1_{MS}. As shown in figure 2, packet served by BS is located on right-most end and once served, the packet is removed from the tape and remaining packets shifted to the right to leave a vacancy at the leftmost space.

When packet arrives into the tape, it replaces the right-most zero (depicted by figure 2(a)). If the tape is full the new arrival is dropped (as depicted by figure 2(b)).

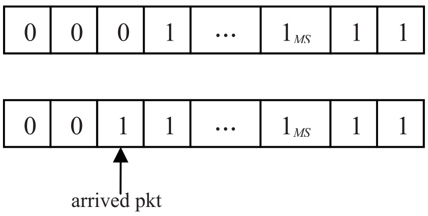

Figure 2(a). Tape with vacant space

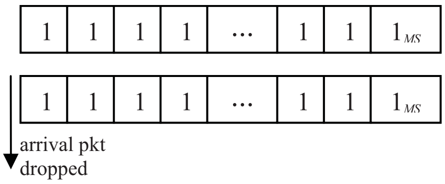

Figure 2(b). Tape without vacant space

However, if MS is in vacation then packet arrives into buffer is treated as summarized in pseudo-code below

Define:

- T = remaining time of n^{th} vacation since appearance of first 1_{MS}
- Q_m = current state of buffer with m ones
- b = maximum capacity of buffer
- *pkt* = packets
- 1_{MS} = packet in buffer destined to sleeping MS
- $E[T_R]$ = average waiting time for first 1_{MS}

```
BS (receive(pkt))
if (Q_m < b)
   if (pkt = = 1_MS)
      if(T > E[T_R])
      {
            Continue holding all 1_MS into buffer;
            insert(pkt into left of leftmost 1 in buffer);
      }
      else
            insert(pkt into left of leftmost 1 in buffer);
   else
         insert(pkt into left of leftmost 1 in buffer)
else
      drop(pkt)
```

Let Q_m denotes the states of tape with m number of 1s such that $m \geq 0$. We introduce a random sequences of α_m such that α_m is independent and identical distribution (i.i.d) sequence of serving m packets. Since among m's packets there 1_{MS} packets which are not served when MS slept then α_m is characterized with binomial probability mass function $P\{\alpha_m=1\}=p$ $(0<p\leq 1)$.

Assume BS serves packets in an arbitrary distribution with mean rate E[v] and variance σ_v^2. If the first 1_{MS} appears in BS tape while MS is in n^{th} vacation ($n \geq 1$), given there are 'z' number of packets (including currently served packet) ahead of 1_{MS}, then the conditional expectation of 1_{MS} to reach right-most end comprises waiting time for z-1 packets (T_{z-1}) plus remaining time of current served packet (T_c). The conditional expectation of T_c is derived such that

$$E[T_c \mid z] = \begin{cases} \dfrac{\sigma_v^2 + E[v]^2}{2E[v]} = \dfrac{\sigma_v^2}{2E[v]} + \dfrac{E[v]}{2}, & z \geq 1 \\ 0, & z = 0 \end{cases}$$

Applying law of total expectation and given P_z is probability of finding z packets waiting in buffer, we have

$$E[T_c] = \sum_z E[T_c \mid z] P_z = \sum_{z \geq 1} \left(\frac{\sigma_v^2}{2E[v]} + \frac{E[v]}{2} \right) P_z$$
$$= \left(\frac{\sigma_v^2}{2E[v]} + \frac{E[v]}{2} \right) \sum_{z \geq 1} P_z$$

Since p is a probability mass function of serving tapes content other than 1_{MS} then we have

$$E[T_c] = \left(\frac{\sigma_v^2}{2E[v]} + \frac{E[v]}{2} \right) p \qquad (1)$$

On the other hand, the conditional expectation of T_{z-1} is derived such that

$$E[T_{z-1} \mid z] = \begin{cases} (z-1)E[v], & z \geq 1 \\ 0, & z = 0 \end{cases}$$

Applying the law of total expectation we get

$$E[T_{z-1}] = \sum_z E[T_{z-1} \mid z] P_z$$
$$= \sum_{z \geq 1} (z-1) E[v] P_z$$
$$= E[v] \sum_{z \geq 1} z P_z - E[v] \sum_{z \geq 1} P_z$$

Likewise, consider Q_m and p then we get

$$E[T_{z-1}] = E[v] Q_m - E[v] p \qquad (2)$$

From equation (1) and (2), the average remaining time of first 1_{MS} upon its arrival until it reaches end of tape is

$$E[T_R] = E[v] Q_m + \left(\frac{\sigma_v^2}{2E[v]} - \frac{E[v]}{2} \right) p \qquad (3)$$

Now, let T and λ denote duration of time since first appearance of 1_{MS} and packet arrival rate. If T>E[T_R] and λ>E[v] then in FIFO service discipline the possibility of packet drop due to accumulation of stored 1_{MS} is obvious. Therefore, the packet loss ratio (PLR) due to accumulation of 1_{MS} out of all arriving packets is given as

$$PLR = \frac{1}{1 + \frac{E[T_R]}{T}\lambda} \quad (4)$$

III. BUFFER ANALYSIS

Let 'q' denote number of newly 1_{MS} which is accepted in buffer during n^{th} vacation and 'j' denotes generic random variables of other arrivals. If at any arbitrary moment ($Q_m + q + j) \leq b$ then newly arrivals are accepted. Otherwise some fraction of j is dropped until BS creates vacancy in buffer.

Let T_n denotes tagged slot of time when first 1_{MS} arrive into BS buffer during n^{th} vacation and 'c' denotes remaining capacity of tape. We introduce a random variable $\eta_{n,m}$ to denotes number of packets dropped after T_n as a result of stored 1_{MS}, defined such that

$$\eta_{m,n} = \begin{cases} [(j+q)/(b-Q_m)]\lambda - b, & \text{if } j > c \text{ or} \\ & T > \lceil ((b-Q_m)/(j+q))E[T_R] \rceil \\ 0, & \text{if } j \leq c \end{cases} \quad (5)$$

where $\lceil x \rceil$ means an integer round-off of x. This implies that when $j \leq c$ there would be no drop. However, if $j > c$ then $\eta_{n,m}$ denotes a fraction of packets loss. For the time bound, unless the length T of the n^{th} vacation is bounded to $[(b - Q_n)/(j+q)]$E[T_R], new arrivals face rear drop.

Let $F(z)$ be a probability generating function (PGF) of stationary distributed Markov chain $\eta_{m,n}$. Based on the Wiener–Hopf method [7], when $0 < j \leq c$ and $1 - p < |z|^{j+q}$ then

$$E[z^{\eta_{n,m} - TQ_m} \mid j \leq c] = E[z^{-TQ_m}]E[z^{\eta_{n,m}} \mid j \leq c]$$
$$= E[z^{-TQ_m}]\sum_{i=1}^{\infty}(1-p)^{i-1} p z^{(j+q)i}$$

Since z is indicator variable then we remain with

$$E[z^{\eta_{n,m} - T_n Q_m} \mid j \leq c] = E[z^{-T_n Q_m}]\frac{p z^{j+q_m}}{(1-p)z^{j+q_m}} \quad (6)$$

On the other hand, when $j > c$, we have

$$E[z^{\eta_{n,m} - TQ_m} \mid j > c]$$
$$= E[z^{-TQ_m}]\sum_{i=0}^{\infty}(1-p)^{i-1} p z^{(j+q)\lceil b - Q_m)/(c+q)\rceil} \quad (7)$$

Thus, the PGF $F(z)$ is obtained by summing up equation (6) and (7).

For simplicity, consider Laplace-Stieltjes transform of $F(z)$ relative to T

$$f^* = \int_0^{\infty} e^{-sT} dF(z)$$

Given that the limit into F(z) doesn't exist pathwise it is then possible to apply Wiener-Hopf method into the integral version of stochastic differential part of $F(z)$, which is not differentiable. Implementing Wiener-Hopf decomposition method we have

$$f^* = e^{-sT} \lim_{T \to \infty} F(z) - \lim_{T \to \infty} \int_0^T F(z) de^{-eT} \quad (8)$$

Note that the second term in right hand side of equation (8) is improper integral which doesn't converge and so shall diminish. Therefore remain with

$$f^* = e^{-sT} \lim_{T \to \infty} F(z)$$

Replacing F(z) with PGF obtained before we get

$$f^* = e^{-sT} \lim_{b \to \infty}\left[E[z^{-TQ_m}](\frac{p z^{j+q}}{(1-p)z^{j+q}} + \sum_{i=0}^{\infty}(1-p)^{i-1} p z^{(j+q)\lfloor b - Q_m)/(c+q)\rfloor} \right] \quad (9)$$

Applying limit as T approach to infinity and mean probability of serving sequence of contents of tape p [8], the second term of equation (9) becomes infinity series that cannot converge and we remain with

$$f^* = e^{-sT} E[z^{-TQ_m}](\frac{p z^{j+q}}{(1-p)z^{j+q}})$$

But, since z is an indicator variable that takes only integer values and converge then $E[z^{-TQ_m}] = \frac{1}{s^{1-T}}$. Therefore, above equation is reduced to

$$f^* = s^{T-1}\left(\frac{p}{1-p}\right)e^{-sT} \quad (10)$$

Equation (10) is reduced to Gamma distribution with variable S, scale parameter p and shaping parameter T. Since the Laplace Stieltjes Transform is based on PGF of $\eta_{m,n}$ then this equation suggest that packet drop as a result of accumulation of 1MS follows Gamma distribution.

IV. ASYMPTOTIC ANALYSIS

With asymptotic analysis the study intends to evaluate the complexity of performance measure of buffer relative to newly arrivals when MS goes to sleep.

Recall that the duration of vacation intervals for IEEE802.16e sleep mode (class type I) is characterized with exponential increase of factor 2. This means if the initial sleep window is set to T_0 the duration of n successive vacations are $2T_0$, $4T_0$, exponentially grow up to 2^nT_0. As depicted in figure 3, the length of n^{th} vacation comes after n-1 asymptotic jumps of $2^n(\cdot)$ function provided the initial state of n^{th} vacation is tightly equivalent to previous n-1 vacations.

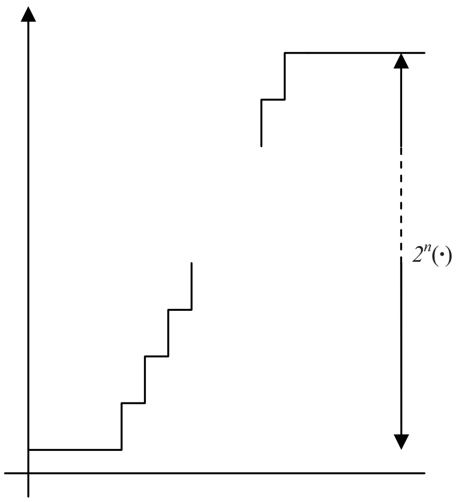

Figure 3. Asymptotic jumps of sleep window

Note in IEEE802.16e each vacations is interleaved with fixed length of listening intervals [1]. Asymptotically, this mean the length of n^{th} vacation is of order $O(2^n)$ interleaved with fixed listening interval of order $O(n)$. Based on the fact that $O(2^n)$ dominates the $O(n)$ term, we consider $O(2^n)$ as the asymptotic upper bound of n^{th} vacation. It implies that the length of n^{th} vacation grow proportionally to number of successive vacation of MS during sleeping mode regardless of listening intervals.

Let f, g and h be the functions in time which represent the distributions of tagged slot T, $E[T_R]$ and upper bound $O(2^n)$ respectively. Obviously

$$f_{(T)} \leq g_{E[T_R]} \leq h_{O(2^n(\cdot))}$$

As $q \rightarrow$ b this can be written as

$$\lim_{q\to b} f_{(T)} \leq \lim_{q\to b} g_{E[T_R]} \leq \lim_{q\to b} h_{O(2^n(\cdot))} \quad (11)$$

According to [9], in order to reduce risks of packet loss then

$$\lim_{q\to b} f_{(T_n)} = \lim_{q\to b} h_{O(2^n(\cdot))} = L \quad (12)$$

where L is the upper bound of n^{th} vacation.

Applying squeezing theory [10] into equation (11) and (12), we obtain

$$\lim_{q\to b} g_{E[T_R]} = L \quad (13)$$

Equation (13) suggest that in order to reduce risk of packet loss due to appearance of first 1_{MS} the n^{th} vacation should end immediately after 1_{MS} reach right-most end of the tape ($T = E[T_R]$).

V. NUMERICAL EXAMPLES

In this part we consider IEEE802.16e operational parameters and relate them to statistical variables. We assume BS transmission power ranging between 40 to 43dBm in order to get an average service rate of $2 \leq E[v] \leq 4$ for 128-bytes packet size. We also assume BS antenna gain is 15dBi with a path loss between BS and MS in dB set to $128.1+37.6\log_{10}(d_m)$, which imitates a normal broadband packet arrival rate of up to 1.5 Mb/s per channel.

For the case of T and T_n we consider MS sleep window parameter of IEEE802.16e sleep mode as defined in [1]. To simplify reference to those parameters we show them in table 1.

TABLE 1: IEEE802.16E SLEEP-MODE PARAMETERS

Parameter	Descriptions	Value
T_0	Initial sleep window	2 frames
L_w	Listening window	64 frames
T_f	Final sleep window base	1024 frames
F_{length}	Frame length for IEEE802.16e MAC	5ms.

In figure 4, a cumulative distribution function based on equation (10) is depicted. We set service rate parameter p (here treated as scale parameter) to be fixed value of 2. T_n is set to be second frame of n^{th} vacation with length of T vary between 64 to 512 frames (implies n to be an integer value such that $4 \leq n \leq 7$, based on parameter shown in table 1). As a result, a reader may notice from the area underneath corresponding curve that when T increases the probability of packet loss increases. Note that the curves are drawn from equation (10) where T is an exponent of variables e and S.

This result correspond to the observation made in asymptotic analysis which suggests that in order to reduce risk of packet drop T should be less or equal to $E[T_R]$.

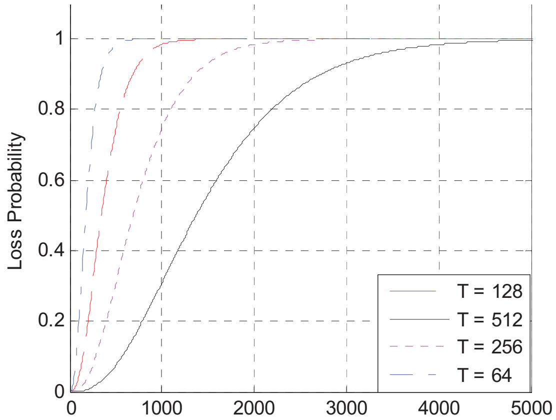

Figure 4. CDF of Varied *T* with constant *p*.

On the other hand, in figure 5, we draw cumulative distribution function based on same equation (10) but with service rate parameter *p* set to range between 2 to 4 while *T* is fixed at 128 frames (implies *n* to be an integer value such that $n = 5$, based on parameter shown in table 1). This figure clearly shows that with increase service rate there is less chance of packet drop. The behaviour of this figure matches with the result drawn from equation (4) that to reduce packet loss ratio then BS service rate should be good enough to cause $E[T_R]$ to outperform T and reduce value of PLR due to newly arrivals.

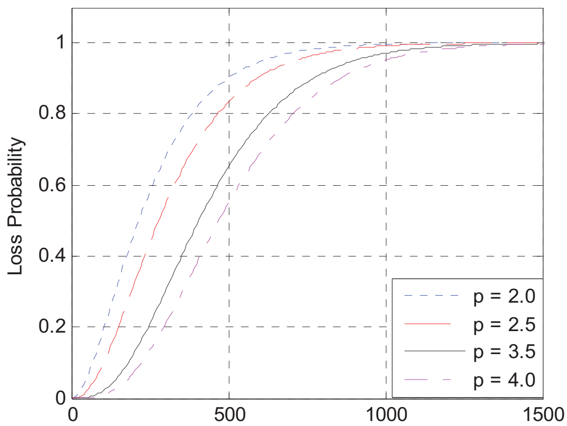

Figure 5. CDF of Varied *p* with constant *T*.

Finally, in figure 6, the relation between packet loss ratio (PLR) and arrival rate given duration *T* is shown based on equation (4). The figure depicts PLR in a logarithmic scale as a function of fraction of packets arrived after expiration of $E[T_R]$ given $T > E[T_R]$.

As it can be clearly deduced from figure 6, the packet loss ratio (PLR) increases with increase of incoming load as well as increasing length of T. For high load, regardless of T, most of the newly arrival will find no space in buffer and get lost. As the trend of the graph predict, for $T \rightarrow \infty$ and high load all curves will converge to PLR = 1, and therefore get lost.

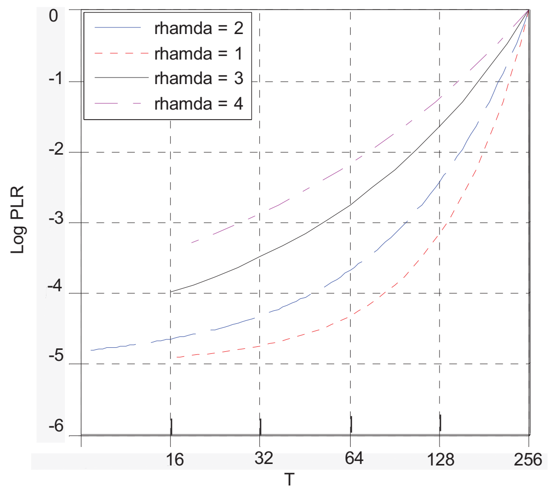

Figure 6. PRL with varied *T* for different λ.

VI. CONCLUSION

This study focused on impact of MS sleeping mode mechanism to base station (BS) with finite buffer size. Most of previous researches on effect of sleeping mode to QoS requirements of IEEE802.16e have concentrated on the impact of the power saving scheme to MS operation, assuming BS as an entity with infinity buffer. However, since buffer of intermediate BSs should be relatively small to keep delay and jitter at favourable level for broadband high-speed networks to perform better, then any event that risks healthy performance of BS buffer should better investigated.

This study develops mathematical equations of packet loss ratio (PLR) due to accumulation of stored packets destined to sleeping MS. The study further deduces Laplace Stieltjes Transformation of time duration between appearances of first packet destined to sleeping MS to end of vacation period. The result of numerical analysis and asymptotic analysis proves that the effect of MS sleep mode to BS with finite buffer is not negligible because the possibility of packet loss due to accumulated packet destined to sleeping MS is exist.

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