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Battery-Life Management With An Efficient Sleep-Mode Power Saving Scheme (BM-ESPSS) In IEEE 802.16e Networks

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***ABSTRACT*—There have being advancement from the former standard of the IEEE known as worldwide interoperability for Microwave Access (WiMAX), with the 802.16e being explored by the research community for power savings; due to their economic and societal gains. Thus, a Battery-Life Management with an Efficient Sleep-Mode Power Saving Scheme (BM-ESPSS) is proposed which is an extended version of an Efficient Sleep-Window-Based Power saving Scheme (ESPSS). The proposed BM-ESPSS introduced a modified average based sleep mode to minimize the longer sleep interval; as well as introduced a modified minimum and maximum sleep interval to further enhance the variant sleep parameters of the existing ESPSS and improve the Quality of Service (QoS). The proposed BM-ESPSS was evaluated using a discrete event simulator and analytical theoretical model. The results revealed that the proposed BM-ESPSS achieves better performance significantly in terms of response delay and efficiency while improving the QoS accordingly.**

Keywords—Battery-Life, Efficiency, Response-Delay and QoS

I. INTRODUCTION

The IEEE 802.16 is designed for MS that are fixed [1] while subsequent version of the IEEE is an extension of the earlier standard with features that enables MS to be moveable [2][3]. The 802.16e Standard use three power saving classes (PSC) to improve the battery life of a MS. The PSC includes: PSC of type I, PSC of type II and PSC of type III.

PSC I is designed for Best effort (BE) and non-real-time variable rate (NRT-VR) traffics. While PSC II for unsolicited grant service (UGS) and real time variable rate (RT-VR) traffics and PSC of type III for managing operations and multicast operations. Hence, variant schemes was proposed in order to improve the efficiency of MS in [6] [7] [8][9]. However, the schemes in [6] [7] wastes energy due to their mode of parameter adjustments as well as the choice of sleep parameters [8][9] Utilizes half of it last sleep interval, to adjust the minimum sleep intervals (Tmin) when it exits from the previous sleep-mode operation, the initiate sleep interval in the next sleep-mode operation will reduce the listening operations of MS. However, the existing schemes traffic arrival where not appropriately captured due to their variant traffic arrival which is still an important problem with an effect in power savings. Which may result to performance degradation of a MS.

Thus, a Battery-Life Management with an Efficient Sleep-Mode Power Saving Scheme (BM-ESPSS) is proposed. The proposed scheme is an extension of the existing Efficient Sleep-Window-Based Power saving Scheme (ESPSS) in [11]. The Proposed BM-ESPSS introduced a modified average based sleep window that will enhance the parameters of the existing ESPSS. The proposed scheme also proposed a modified maximum and minimum sleep interval (Tmax and Tmin) that will minimize the rate of consumption and delay while improving QoS rightly.

A. Power saving class (psc) of type I, II and III

PSC of type I consists of listening window and sleep window. The length of the listening window in this power saving class is fixed and a MS with PSC I subsequently checks if there are some buffered traffics for the listening window [8] [10]. If there are traffics, the MS revert to normal operation to receive them Figure 1 and 2. Otherwise, the sleep window is activated in order to save energy. The procedure is repeated as the length of the sleep window is doubled until maximum length of the sleep window [9] which is activated only by a positive (+) MOB- TRF-IND-Message from the Base State (BS) to Mobile Station (MS).

PSC of Type II is for unsolicited grant service (UGS) and real time variable rate (RT-VR) traffics, similarly PSC of type II consisted of listening window and sleep window that is the sleep window is interleaved with a listening window. However, unlike type I, the length of listening and sleep windows are both fixed for PSC of type II and the sum of them is called, sleep cycle. PSC of type II is able to transmit data without returning to normal mode. Thus, the length of listening window is long enough to receive all packets arriving during a single sleep cycle in PSC II [7] [8] Figure 1.

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While PSC of type III is use for managing operations and multicast operations only. These three PSC varies from each other by their parameter sets, methods of activation/ deactivation, and the policies of MS availability for data transfer [10].

PSC of type III comprises of a single sleep window and is mainly used for multicast services (Figure 1). By activating this PSC, a single sleep window with defined length in WiMAX standard starts and subsequently returns to normal mode operation
[6].

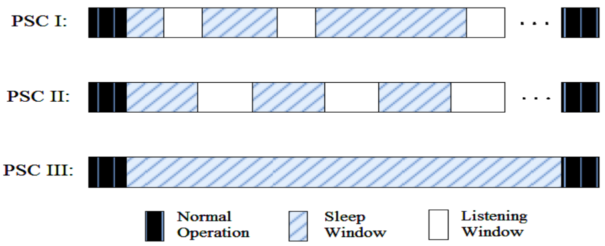

Figure1: Types of Power Saving Classes

These PSCs use three parameter to improve on power savings, namely, idle-threshold, initial sleep-window and final sleep-window [6][7][11]. The idle-threshold is the time interval in which the MS is in a waiting state, it has no messages to send or receive before moving to inactive state. The MS before moving to inactive state negotiates with is BS for approval in order to switch to a period of inactivity. The BS allocates the sleep parameters namely: initial sleep-window (Tmin), listening window (L) and final sleep-window (Tmax) to the MS, the MS transmits to it period of inactivity after is receives these parameters [7][8]. The Tmin is the range of the first-sleep session (T) that an MS will go to sleep. And then wakes up for the first T to listen to the traffic indication messages from the BS within the duration of the L. When the traffic indication messages indicate negative, the MS continues in sleep mode after the L duration. Else, the traffic indication message is positive (+), and the MS return to an active session. The T together with it L is called the sleep cycle [7][10][11].

So long as MS continue in a period of inactivity, the next sleep cycle start and the T doubles. The procedure continues until the Tmax is reached. When the Tmax is reached the MS remains in sleep until a positive (+) MOB-TRF-IND is sent from BS to MS (Figure 2) where the MS then wakes up to transmit/receive intending Traffics.

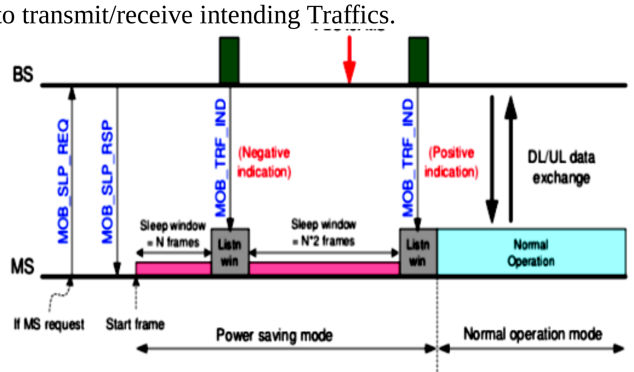

Figure2: IEEE 802.16e Sleep Mode

The rest of this paper is organized as follows: Section II Present Related Works, Section III Presents Proposed Algorithm, Section IV Presents the Performance Evaluation and Section V highlight the Conclusion of the study.

II. Related Works

This section presents related work on power saving schemes. The schemes are reviewed as follows: [5][10] Presented a survey on power-saving schemes, with the aim of understanding some of the most relevant sources of inefficiency in energy savings and how some of these challenges were solved by the existing schemes. The survey further presented comparative analysis on these schemes with the aim of identifying current challenges that are yet to be addressed by the research community as well as presented future directions towards efficient power savings. Hence, a Delay-Aware Power Saving Scheme (DAPSS) Base on load in traffic was proposed in [6] to minimize the longer sleep intervals of the existing Scheme. The scheme successfully minimized the longer sleep intervals of MS; thereby, minimizing the average response delay of the scheme while maintaining power savings.

However, it has an average increase in power consumption for response delay and also ignores in-cooperating real time services, which may further improve on the overall performance of the MS. Thus, an Enhanced Power Saving scheme (EPSS) was proposed in [7] to minimize the consumption and improve the QoS. The proposed scheme was an improvement of the existing DAPSS Scheme. Hence, an Improved Battery-Life Power Saving Scheme (IBPSS) in IEEE 802.16e Networks was also proposed in [8], address the former challenge mentioned, The Scheme in-cooperates real time services and successfully extends the battery life performance at the expense of an average increase in consumption rate, due to the real time services as UGS in PSC of type II that requires a dedicated bandwidth for data packets transmission. Therefore, a Quality of Service (QoS) Aware Power Saving Scheme was proposed in [9] to improve the QoS. The scheme introduced a Modified minimum (Tmin) and Maximum (Tmax) sleep intervals in order to enhance the parameters of the variant schemes. In addition, the scheme also introduced a modified sleep window as well as QoS Aware algorithm that enable the adjustments of the sleep Parameters more appropriately in order to minimize frequent Transition to listening mode while improving efficiency. Finally, a state transition diagram was also developed. However, the scheme suffers little increase in frequent sleep wake mode which may results to waste of energy under low traffic arrival.

Hence, an Efficient Sleep-Window-Based Power Saving Scheme (ESPSS) in IEEE 802.16e Networks was also proposed in [10], the scheme extend the battery life of MS by enhancing the parameters of the existing scheme. However, the actual variant traffic characteristics of the existing ESPSS were not appropriately captured due to the various traffic arrival patterns which may results to poor QoS. Thus, a Battery-Life Management with an Efficient Sleep-Mode Power Saving Scheme (BM-ESPSS) is proposed which is an extended version of the existing ESPSS [11] the proposed scheme tries to improve the QoS accordingly in order to extend mobile device performance before recharging exercise is conducted.

III. Proposed BM-ESPSS Scheme

In this section, a Battery-Life Management with an Efficient Sleep-Mode Power Saving Scheme (BM-ESPSS) in IEEE 802.16e networks for mobile broadband network services (MBNS) is propose, which is an extended version of the existing Efficient Sleep-Window-Based Power Saving Scheme (ESPSS).

The Proposed BM-ESPSS dynamically tunes the sleep parameters in order to minimize the power consumption of MS; as well as reduce the frequent transition of MS to sleep mode while improving the Quality of service (QoS).

The parameters of the proposed BM-ESPSS were analytically modified by way of adjustment at the simulation time as well as analytically modeled. The main sleep parameters are idle threshold, initial sleep window and final sleep as follows:

First, the idle threshold (Tt) is adaptively updated based on the DL traffic arrival pattern in order to predict the best duration for the next idle check time. This best duration provides better idle time (s) that considerably minimize response delay of MS obtained as follows:

$$T_{th} = \min(\max(\lceil \lambda.dft \rceil, T_{th}\_\min), \max\left(\left|\left\lceil\left(\frac{\sigma_n}{T_{average}}\right)dft)\right\rceil T_{th\_\min}\right)\right) \quad (1)$$

Where Tth is the idle threshold, Tt-dft is the default idle threshold and the default idle threshold is set to be (1) in this paper.

Then, the modified minimum sleep interval (Tmin) is obtained as follows:

$$T_{\min} = \max\left(\left\lceil T_{average} - k\sigma_n \right\rceil, 1\right) \quad (2)$$

Where k is a positive integers given as 0<k<1 and then the modified Tmin is dynamically adjusted base on the DL traffic load arrival in order to transmit/process frames appropriately within their lifetime. More-so, the appropriate adjustment of the Tmin value (s) will help predicts the next actual arrival of the DL traffics which may significantly reduce the average number of listening intervals that usually results to waste of energy.

Thus, the possible duration (Pr) of a sequence of sleep cycle is dynamically calculated as follows:

$$Pr[j] = \sum_{k=1}^{\infty} \Pr(j = k) \quad (3)$$

$$T_D = \frac{N_{FTMS}}{n * cbt} * (1 + R) \quad (4)$$

Where N_{FTMS} is the total number of MS, n is the sampling factor, Cbt is the channel bandwidth, and R is the ration of cyclic prefix time to useful time [12]

$$L = Length\,(DL - MAP) + 3T_s \quad (5)$$

Where L is the listening period, DL is the downlink frames, Ts is the Orthogonal Frequency Division multiplexing (OFDM) symbol duration computed in Equation (4) with frame control header (FCH) all located at the listening intervals that helps enable MS receive DL burst.

$$T_{sleep} = \min(T_{\max, N_c} * frameDuration - L \quad (6)$$

Where *N*c is the number of successive sleep cycles, Tsleep is the sleep intervals, L is the listening intervals and Tmax is the threshold value.
The scheme introduces an average based sleep mode (Tj) given in Equation (7) to reduce the longer sleep intervals adopted from [11].

$$T_j = \begin{cases} \left(1+\frac{k}{\lambda}\right)2^{j-1}T_{\min,} & if \quad \left(1+\frac{k}{\lambda}\right)2^{j-1}T_{\min} < T_{\max},\ \lambda \neq 0 \\ \frac{T_{j-1}+T_{\max}}{4}, & \text{Otherwise} \end{cases} \quad (7)$$

Where T_j the jth is sleep mode, $T_{\min}$ is the minimum sleep intervals, $T_{\max}$ is the maximum sleep intervals, j is a positive integer. $T_{\min}$ is determined by examining the inter arrival time of a DL traffics in order to reduce the average response delay the DL frames may had incurred in waiting for the MS to wake up.

The weighted average inter-arrival time (Taverage) in between the DL frame from BS to the MS is obtained as follows:

$$T_{average} = T_{\min} + T_{\max} / 4 \quad (8)$$

The weighted average variance (σ_n) of the inter arrival time of the DL frame, is also obtained as follows:

$$\sigma_n = (1-\beta)\sigma_{n-1} + \beta\left|T_{average} - T_d\right| \quad (9)$$

T_d is the time taken after which the DL frames arrive at the BS for MS since it went into sleep mode last, β is a positive integer.

Finally, the modified maximum sleep interval (Tmax) is obtained as follows:
We also introduce a Modified Tmax that takes the average of the sleep mode based on the traffic load in order to minimize the longer sleep intervals which subsequently results in response delay adopted from [11]. The reduction of the longer sleep intervals has also minimized the response

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delay of the MS. The (Tmax) is computed when initial sleep intervals and frame response delay are identified. When the sleep interval approaches Tmax, the sleep time becomes larger resulting to a longer sleep interval, which is an important problem. Since, traffics arrives with an increase sleep interval, as observed in Figure 1, and until at the listening intervals the MS remains as Sleep.

We also assume frame arrival following a Poisson distribution with arrival rate λ. Tj is the length of the jth sleep interval and L is the length of the sleep interval.
Here**,** we assumed an incoming frame arrival at the MS during its idle state, and the possibility (Pr) of frame arrival given as follows:

$$\Pr(n = T_t) = \Pr(e_1 = true) = 1 - e^{-\lambda (T_j + L)} \quad (10)$$

$$= \sum_{k=1}^{\infty} \Pr(n = k) \sum_{j=1}^{k} (T_j + L) \quad (11)$$

we assumed that there is at least one frame arrival at the MS in the jth sleep window. Implaying that no packets in the 1st, 2nd, 3rd..to (j−1)th sleep interval but there is at least one arriving frame in the jth sleep interval. The (Pr) probability of frame arrival in the jth sleep interval is also obtained as follows:

$$\Pr(n = j) = \prod_{i=1}^{j-1} \Pr(e_i = false) \Pr(e_j = true) = e^{-\lambda \sum_{i=1}^{j-1} (T_j + L)} 1 - e^{-\lambda (T_j + L)} \quad (12)$$

Let M satisfy the following:

$$\left(1+\frac{k}{\lambda}\right) 2^{j-1} T_{min}, \quad \text{if} \left(1+\frac{k}{\lambda}\right) 2^{j-1} T_{min} < T_{max} \text{ ; M is an integer.}$$

The jth sleep window is obtained as follows:

$$T_j = \begin{cases} (1+\frac{k}{\lambda}) 2^{j-1} T_{\min} & \text{if } j<M \\ \frac{T_{j-1}+T_{\max}}{4} & \text{Otherwise} \end{cases} \quad (13)$$

We also assume the packets resulting to the outflow or overrun from the sequence of sleep cycles will arrive at any moment during the last cycle with uniform probability. The length of jth cycle is $(T_j + L)$ and the possible response delay of packets is obtained in Equation (13).
From Equation (7), we let M satisfy

$$\left(1+\frac{k}{\lambda}\right) 2^{M-1} \quad T_{\min} = T_{\max}$$

And M is an integer. The jth sleep interval is given in Equation (12), then we substitute Equation (12) into Equation (11) and we have:

$$\Pr(n = j) = \begin{cases} Ze^{-\lambda T_{th}} e^{\lambda \lceil Q \; T_{\min} + L \rceil} e^{-\lambda \lceil Q 2^{j-1} T_{\min} + jL \rceil}. & \text{if } j<M \\ Ze^{-\lambda \lceil (Q 2^{j-1} - 1), \; T_{\min} - L + LM + T_{th} \rceil} & \text{if } j \geq M \end{cases} \quad (14)$$

Where $Q = \left(1+\frac{k}{\lambda}\right)$ *and* $Z = \frac{T_{j-1}+T_{\max}}{4}$

Let D represents frame response delay and the traffic arrival follow a Poisson distribution. The expected (E) response delay is obtained as follows:

$$E[D] = \sum_{j=1}^{\infty} \Pr\left(\frac{T_j + L}{4}\right) \quad (15)$$

From Equation (14) and Equation (13) the expected response delay is expressed as follows:

$$E[D] = \frac{L}{4} + \sum_{j=1}^{M-1} P_{rj} \frac{T_j}{4} + \frac{T_{j-1}+T_{\max}}{4(4)} \sum_{j=M}^{\infty} P_{rj} \quad (16)$$

From Equation (16) we have

$$R = Qe^{-\lambda T_{th}} \; e^{\lambda \lceil Q.T_{\min} + L \rceil \sum_{j=1}^{M-1} 2^{j-2}} \; e^{-\lambda \lceil Q.2^{j-1} T_{\min} + jL \rceil}.Z \quad (17)$$

$$\frac{T_{j-1}+T_{\max}}{16} \sum_{j=M}^{\infty} P_{rj} = \frac{T_{j-1}+T_{\max}}{16} e^{-\lambda (\lceil Q.2^{j-1} - 1 \rceil T_{\min - L + LM + T_{th}})} \quad (18)$$

Unlike the existing scheme that makes use of larger sleep windows and the full length of the Tmax sleep intervals Figure 1, which subsequently results in a longer sleep period (time). The proposed ESPSS has introduced an average based sleep window that takes the average Tmax values in order to significantly minimize the longer response delay of the variant EBLAPS scheme. More so, when the sleep intervals subsequently approaches Tmax, the sleep intervals is increased incrementally as an average of the jth sleep window (Equation 1 and 9) in order to minimize the longer sleep intervals/response delay respectively. Thus, minimizing the response delay the DL frame may had incurred subsequently while appropriately or just in time processing/transmitting packets within their life time Figure 2.

$$\frac{T_{j-1}+T_{\max}}{16} \sum_{j=M}^{\infty} P_j = \frac{T_{j-1}+T_{\max}}{16} e^{-\lambda \lceil (Q.2^{j-1} - 1) T_{\min} - L + LM + T_{th} \rceil} \quad (19)$$

The sum of the average response delay of the proposed BM-ESPSS scheme is also expressed as follows:

$$2E[D] = \sum_{j=1}^{\infty} P_j (T_j + L) \quad (20)$$

$$\sum_{j=1}^{\infty} P_j = \frac{2E[D]}{T_j + L} \quad (21)$$

Substituting equation 17 and 18 into 16, we have

$$T_{max} = \frac{2E[D] - L - 2R}{e^{-\lambda \lceil Q. \; 2^{j-1} - 1 \rceil T_{\min} - L + LM + T_{th}}} - \frac{T_{j-1}}{16} \quad (22)$$

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A. *Procedure of Parameters Adjustment*

The key difference between the current scheme and the proposed scheme is the way of adjustments at the simulation time and the modification of the sleep parameters respectively.

The procedures of parameters adjustment of the proposed BM-ESPSS begins in a normal mode operation. And request for sleep if the mobile sleep request (MOB-SLP-REQ) is settled, the MS transits to sleep-mode else a positive (+) mobile traffic indication message (MOB-TRF-IND) is directed to the MS from the BS and the MS awake and process data on the queue. This process is continues until a Negative MOB-SLP-RSP is established from the BS (Figure 6). Else the MS reverts to normal mode operation and continue the process/end the process.

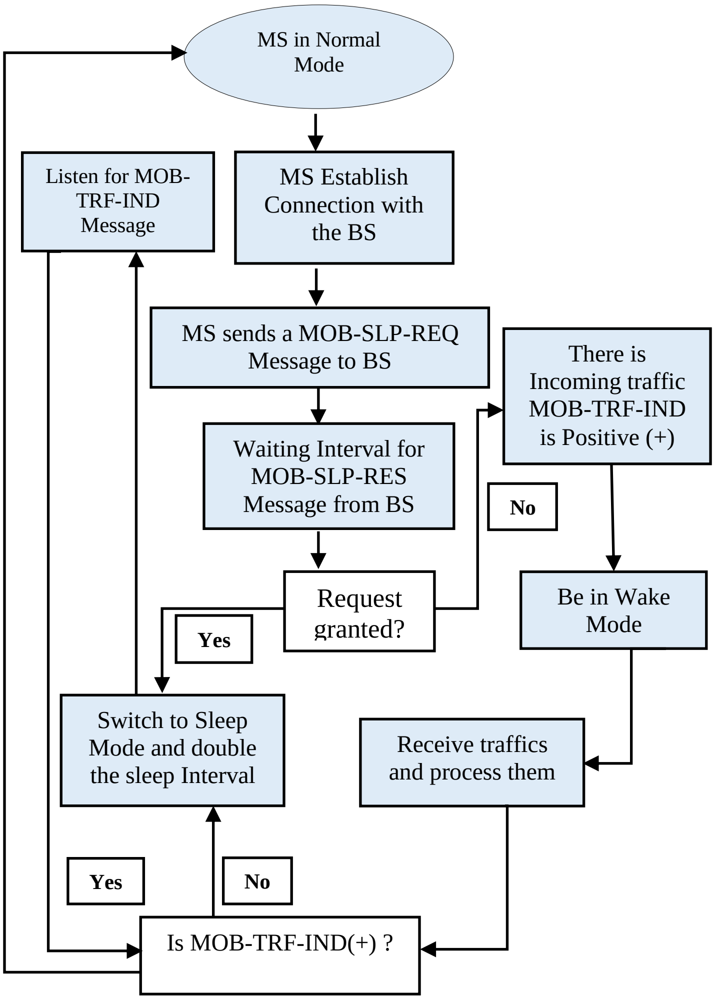

Figure 3: Procedure of Adjustment

B. *Algorithm 1: The proposed BM-ESPSS*

Input: $T_{smin\_\lambda} = j$, $T_{smax} = 1024$, $j = 1$

1. Calculate $T_{smin} = 2^{j-1}\, T_{smin\_\lambda}$
2. *if* ($T_{smin} < T_{smax}$);
3. $j = j + 1$ and repeat step 1
4. **Else**
5. Calculate $T_{smax} = 2^{j-1}\, T_{smin\_\lambda}$
6. *if* (Power($T_{smin}, T_{smax\_\lambda}$) < min_*PowerConsumption* &Delay($T_{smin}, T_{smax\_\lambda}$) < min_response Delay)
7. $T_{smin\_\lambda} = T_{smin}$, $T_{smax\_\lambda} = T_{smax}$
8. min_*powerConsumption* = *Power*($T_{smin}, T_{smax}, \lambda$)
9. min_*responseDelay* = *Delay*($T_{smin}, T_{smax}, \lambda$)
10. **Else**
11. *Input j*
12. *do step* 1
13. ***End***

IV. PERFORMANCE EVALUATION

The propose BM-ESPSS is simulated and compared with the Existing schemes via a DES. The evaluation is centered on the average-power-savings and response delay. The simulation model consists of a single base station (BS) with MS connected around it with downlink traffic communications, as seen in Figure 7 pdf [11] of the existing ESPSS scheme.

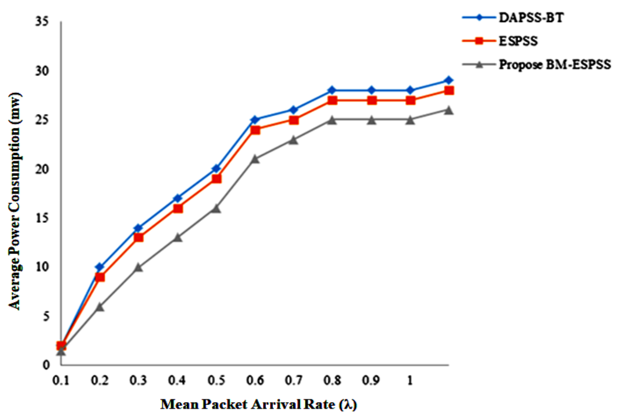

Figure 4: Illustrates the average power consumption vs mean arrival rates.

From the beginning the DAPSS-BT, ESPSS and the proposed BM-ESPSS has a similar Consumption rate with the existing schemes, but subsequently the proposed scheme outperformed the existing schemes due to the introduction of the average based sleep Mode as well as the modified sleep parameters. However, as the battery life becomes depleted, all the schemes tend toward similar performance.

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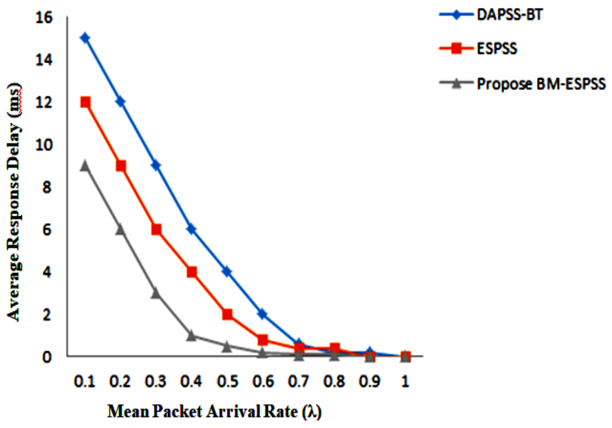

Figure 5: Illustrates average response delay vs mean arrival rates.

From the beginning the propose BM-ESPSS Scheme have significantly minimized the longer sleep mode as compared to the existing DAPSS-BT and ESPSS. Hence, minimized the delay incurred due to the Modified sleep mode parameters and the introduction of an average based sleep mode. However, when the Battery-Life is become depleted all the schemes have similar performance. Thus, our propose BM-ESPSS and the existing scheme converge towards same point respectively.

V. CONCLUSION

We have proposed a new scheme called Battery-Life Management with an Efficient Sleep-Mode Power Saving Scheme (BM-ESPSS) in WiMAX Networks. The proposed scheme introduced a modified average based sleep mode in order to enhance the parameters of the ESPSS in [11]. The proposed scheme also proposed an improved minimum and maximum (Tmin, Tmax) sleep interval which reduces the response delay while improving efficiency. The BM-ESPSS was evaluated using analytical models and a discrete event simulator. The simulation results show that the proposed BM-ESPSS accomplish better performance as linked to the current scheme in relations to the consumption rate and delay. In addition, the result also indicates that the proposed BM-ESPSS extends the battery life of MS by 19.88% and reduces the average delay by 7.96% while improving the QoS accordingly. The future work is to develop a dual traffic ago for both uplink and downlink scheme.

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