A Novel Architecture for IEEE 802.16m Subscriber Station for Joint Power Saving Class Management

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***Abstract*— IEEE 802.16m amendment is being drafted to meet the 4G network requirements as an extension to 802.16e-2005. In 802.16e, a Subscriber Station (SS) can have multiple connections to a Base Station (BS) for supporting different services simultaneously. SS negotiates sleep-mode with BS by exchange of management information for one or more connections per active Power Saving Class Identifier (PSC_ID) belonging to a Power Saving Class (PSC). However, after this negotiation, SS may not be able to switch to actual sleep-mode (low power operation) as connections belonging to other PSC_ID may be in the transmission or reception mode. Moreover, this causes an overhead of management messages exchanged between the SS and BS per PSC_ID that results in excess packet delay as well as wastage of power and bandwidth.**

In this paper, we propose a novel architecture referred as *Sleep-Mode Manager Architecture* to negotiate the sleep mode for the SS and to compute the sleep-mode per quality of service (QoS) class by aggregating the unavailability periods of all the active PSC_ID traffic. This architecture reduces the overhead of management messages, thereby conserving bandwidth and energy as well as supporting dynamic adaptation in sleep-mode parameters. Our simulation and analysis results reveal that the proposed architecture performs substantially better than the 802.16e standard and the relative performance improves with increasing number of active PSC_IDs which can be implemented in 802.16m. Furthermore, through analysis we find that the efficiency of device switching to sleep-mode improves from 7.1% in case of single PSC_ID to 35% in case of joint power class management for ten simultaneous connections. Simulation reveals that, the management message exchange overhead in case of proposed joint power saving class reduces to 1/5th of that in case of individual PSC_ID management in case of four simultaneous PSC_IDs.

***Index Terms*—IEEE 802.16e, IEEE 802.16m, Sleep-Mode, Power Saving, QoS**.

I. INTRODUCTION

PAST decade has witnessed an unprecedented growth in wireless broadband technologies, starting from fixed and portable wireless local area networks to high bandwidth to support vehicular users in metropolitan cities. Mobile-WiMAX based on the IEEE 802.16e-2005 standard [1], is a frontrunner amongst the various current generation technologies offering granular quality of service (QoS) as well as high bandwidth to users. It serves as a bridge between the broadband wireless access networks and high mobility cellular technologies. Across research community, the current focus is to develop the next generation (4G) wireless broadband technologies that comply with International Mobile Telecommunication – Advanced (IMT-Advanced) standard requirements [2] under International Telecommunication Union-Radio Communications Sector's (ITU-R). IMT-Advanced aims at achieving peak data rates of 100 Mbit/s for high and 1 Gbit/s for low mobility scenarios to support advanced services and applications. The IEEE 802.16m [3] task group is working towards meeting above requirements, too. However, as the requirement to support high definition multimedia over mobile devices at vehicular speeds are going to be achieved, it becomes imperative to ensure that the devices do not consume much battery power. Hence, the mechanism for optimized management of limited stored energy is thus turning into a very significant area of research.

The IEEE 802.16e standard attempts to address above issues by negotiating individual sleep-mode intervals between the SS and the BS per active Power Saving Class Identifier (PSC_ID) for each Power Saving Class (PSC). A PSC is defined according to a group of Medium Access Control (MAC) layer connections that have common traffic demand properties and can follow a common algorithm for determining the sleep interval. There are three basic types of PSCs (Class A, B, C and also referred as Type-I, II and III, respectively), which are identified by their parameter sets, type of payload data unit (PDU) and algorithm for computing sleep interval. PSC of Type-I is recommended for connections of Best Effort (BE) or Non Real Time Variable Rate (NRT-VR) QoS services. PSC of Type-II is recommended for connections of Unsolicited Grant Service (UGS), extended Real Time Variable Rate (eRT-VR), Real Time Variable Rate (RT-VR) QoS services. PSC of Type-III is recommended for multicast connections as well as for management operations, for example, periodic ranging,

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service establishment etc.

Here we define a few terms, to be used in following sections, related to sleep mode mechanism. *Unavailability period/interval* is a time interval that does not overlap with any listening window of any active PSC from a SS (see Figure 1). *Availability period/interval* is a time interval that does not overlap with any Unavailability interval of any of the active PSCs. SS can switch to a low power mode of operation during the Unavailability period/interval.

In IEEE 802.16e, the efficiency of present sleep-mode management mechanism drops as the number of active connections increase [18]. This occurs because two connections bearing similar characteristics may also get classified into separate PSC_IDs. For example in PSC Type-II, two UGS data streams can be classified into different PSC_IDs if they follow different arrival time patterns. For instance, voice over IP codec with silence suppression and those having constant bit rate can be classified into different PSC_IDs [1]. This phenomenon is pronounced for PSC Type-I, because the BE and NRT-VR services are bursty and their arrival patterns can change with time. This mechanism brings about an overhead of management messages such as Mobile Sleep Request (MOB_SLP-REQ) and Mobile Sleep Response (MOB_SLP-RSP) that are exchanged on a PSC_ID basis. This phenomenon is explained in the example below.

Further, the 802.16e standard [1] requires several messages to adapt the sleep cycle operation in accordance with changes in traffic pattern. If a traffic pattern change happens for a PSC, then to change an existing PSC of Type-II for example, the SS is required to send a MOB-SLP-REQ message to first deactivate the PSC and then send another message to reactivate another PSC. These messages exchanged are expensive in terms of signalling overhead and the latencies involved. In case of PSC of Type-I, the SS needs to restart the sleep cycle by negotiating parameters with the BS through MOB_SLP-REQ and MOB_SLP-RSP messages.

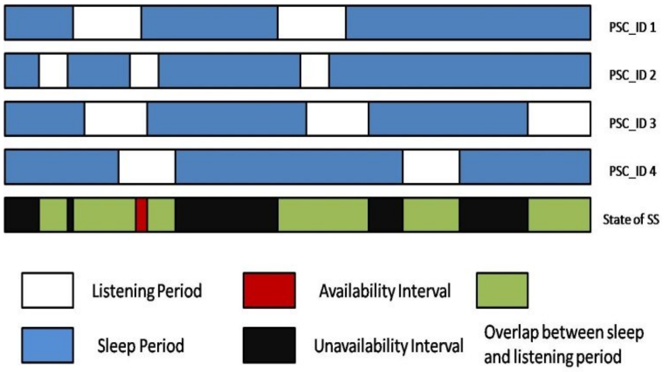

Figure 1. Sleep-mode intervals of four PSC_IDs of the PSC at a SS

Figure 1 shows an example of overlap amongst the sleep periods and listening periods of multiple connections belonging to PSC of Type-I from a SS. It may be observed that with increasing number of active connections with an assigned PSC_ID, the actual time when the device goes to low power mode (i.e., sleep mode) would become a small fraction of the total duration of operation because when some connection are in sleep mode rest of the connections may be active. Moreover, the management signaling exchanges for a connection to go to sleep mode does not materialize to make the device to go to low power mode (i.e., mostly unutilized) as the device needs to be in active state as one of the connections may still be in listening interval. It can be noted that the actual availability interval when all the four PSC_IDs are in active listening state is small. The overlapping region between sleep and listening periods of different PSC_IDs indicate that potential power saving can be achieved, if the listening intervals could be synchronized across the PSC_IDs. We strongly feel, this is possible through joint management of power classes belonging to the same PSC type.

IEEE 802.16m aims to optimize the sleep-mode performance by evolving enhanced sleep-mode management mechanisms which can balance the tradeoff between the QoS requirements of the applications and the power consumption. However, the focus of published research literature on the sleep-mode supported by IEEE 802.16e have been (i) Mathematical modeling and performance evaluation of the currently supported sleep mode operation in IEEE 802.16e; (ii) Adapting the sleep-mode parameters in accordance to the traffic variation of primarily a single PSC Type-I connection.

In recent publications [4]-[8], the authors have proposed analytical models and queuing analysis for the standard IEEE 802.16e power saving mechanism for PSC Type-I. The models are based on the Markov analysis (M/M/1 or M/G/1) queuing systems with vacation period. In some more recent literatures [9]-[15], the authors have proposed various strategies to adapt sleep mode parameters in accordance with the variation in traffic pattern in both uplink and downlink directions. The authors also provide analytical models that suggest the need to periodically adapt the sleep-mode parameters by means of measurement or prediction based on traffic statistics. In [16], the authors suggest the need to evolve a new PSC strategy to combine Type-I and Type-II mechanisms in order to optimize the sleep-mode behavior for voice connections with silence suppression. In [17], the authors propose a semi-Markov Decision Process method into the sleep-mode evaluation to decide the optimal power saving class.

To the best of the authors' understanding, there is no published research literature that attempts to solve the problems resulting from the individual management of PSC_IDs as described previously. This motivates the need to evolve an architecture and mechanism for the joint management of PSCs to reduce unutilized management signal in the previously explained example with Figure 1. Furthermore, in context of IEEE 802.16m based mobile devices; this management mechanism must combine all the individual PSC_ID based sleep-mode management mechanism by aggregating the traffic characteristics of all active connections belonging to a single PSC type.

In this paper, we propose a novel *Sleep-Mode Manager Architecture* at the SS to compute and manage the sleep-mode of the SS per quality of service (QoS) class by aggregating the unavailability periods of all the active PSC_ID traffic belonging to the same QoS class and having the same PSC type. This architecture optimizes the management messages exchanged between the SS and the BS, thereby conserving both bandwidth and energy. By means of mathematical modeling and simulation on Qualnet platform, we illustrate the efficacy of the proposed architecture as well as mechanism. Our simulation and analysis results reveal that the proposed architecture performs substantially better than the 802.16e standard and the relative performance improves with increasing number of active PSC_ID based connections. Through analysis we find that the probability of device switching to sleep-mode improves from 7.1% in case of individual PSC_ID management to 35% in case of joint power class management for ten simultaneous connections. Further through simulations we find that, for the considered scenario and parameters, the management message exchange overhead in case of proposed joint power saving class management reduces to $1/5^{th}$ of that in case of individual PSC_ID management for four simultaneous PSC_IDs.

In section II, we describe the proposed sleep-mode manager architecture. We also present the mathematical model and results of the joint power saving class management mechanism. Further, we discuss a sleep manager algorithm to maximize the unavailability period by considering the QoS requirements of the various supported QoS classes. Results of the simulations are presented in section III. Finally we conclude in section IV with the main outcomes of this paper and possible future extensions.

II. PROPOSED JOINT POWER SAVING CLASS MANAGEMENT

A. *Proposed Sleep-Mode Manager Architecture*

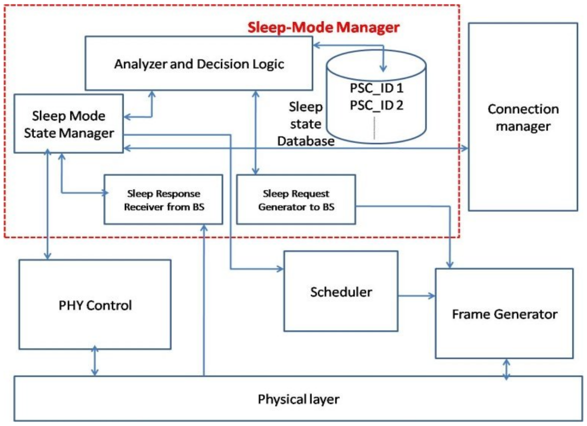

Figure 2. Proposed Sleep-Mode Manager Architecture

Figure 2 shows the block diagram of the various components of our proposed Sleep-Mode Manager Architecture. The Sleep-Mode Manager block comprises of the Sleep-Mode State Manager, Analyzer and Decision Logic, Sleep state database, the Sleep request (or response) receiver and generator. Sleep-Mode manager block is responsible to monitor individual connections associated with active PSC_IDs, aggregating their availability and unavailability period patterns, and deciding the parameters of the sleep-mode negotiation with the BS. Furthermore, it exchanges management messages with the BS for the joint power saving class management.

The PHY Control block interacts with both the physical layer (transceiver and radio) and the Sleep-Mode Manager block. This serves to selectively control the switching on and switching off the transceiver modules for power saving.

The Connection manager is a management entity in the MAC architecture that manages the service flows according to the QoS classes assigned at the time of connection setup. This block interacts with the Sleep-Mode Manager, to decide the parameters of sleep and listening periods in accordance with the active service flows.

The Scheduler is the entity in the MAC architecture that interacts with the Sleep-Mode Manager to decide the schedule of traffic exchange over the active connections. The Frame generator interacts with the scheduler and the physical layer to send and receive MAC PDUs (Protocol Data Units).

The Sleep-Mode State Manager monitors the Connection manager, Scheduler and the Frame generator to observe the traffic pattern over each of the active connections associated with active PSC_IDs. When it detects any of the active connections exceeding a threshold wait time when no packets are sent or received, it generates an event in the Analyzer and Decision Logic block.

The Analyzer and Decision Logic block then fetches the state of the PSC_ID from the Sleep state database. In case all the connections associated with the PSC_ID are in their unavailability interval, it maintains the *soft-sleep* state for the concerned PSC_ID. When all the active PSC_IDs associated with the same QoS class are in the *soft-sleep* state, it negotiates the sleep mode parameters with the BS through the Sleep request generator block.

This way it is able to synchronize amongst all the PSC_IDs belonging to the same QoS class. Further, it negotiates for sleep only when all the individual connections are in *soft-sleep* state, thus ensuring that the message exchange is not left unutilized. When any of the PSC_ID has to return back to active state (because the Sleep Mode State Manager can detect a change of state over each connection), the Analyzer and Decision Logic block interacts with Sleep state database and resets the state of the PSC_ID to active.

In other cases, the BS might instruct a particular PSC_ID to be in sleep. In this case the BS transmits MOB_SLP-RSP message to the SS. This message is also analyzed by the Sleep-Mode Manager and the particular PSC_ID can be set in *soft-sleep* state. Thus the Sleep-Mode Manager allows the SS to manage the sleep mode of all the PSC_IDs belonging to a single QoS class in a combined manner by aggregating the traffic characteristics of all individual connections.

Figure 3 shows the comparative state transitions possible in the IEEE 802.16e and the proposed joint power saving class management mechanism. Currently in IEEE 802.16e, the connected state (when SS and BS have established one or more transport connections) consists of three modes: sleep mode, active mode and scanning mode. In Figure 3, we have illustrated the active and sleep mode. During active mode, the SS and the BS perform normal operations to exchange the DL/UL traffic transaction. . A particular PSC_ID can transit from active mode to sleep mode (denoted through dotted line in Figure 3). The connections belonging to the particular PSC_ID may then go to sleep mode, although the SS may not be sleeping as other PSC_ID may be in active mode. The SS as a node goes to sleep only when all PSC_ID are in sleep mode state.

In our proposed joint power saving class management architecture, we introduce an extra intermediate state known as Aggregated Sleep Mode. The aggregated sleep mode represents the state when the SS actually enter the sleep (low power consumption), i.e., the unavailability interval. The aggregated sleep mode is activated only when all the PSC_ID have exited the active mode and are in sleep mode. The SS then goes from active mode to aggregated sleep mode.

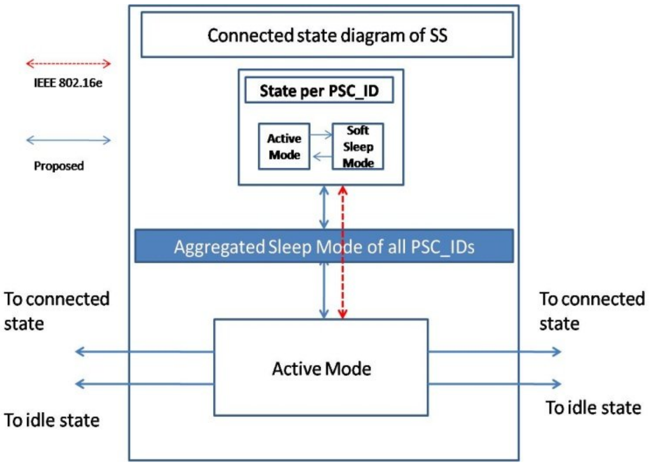

Figure 3. State transitions in the proposed architecture

To summarize the above architecture has the following advantages,

1. The overhead of management messages is minimal as sleep is not negotiated on a PSC_ID basis.

2. Changes in parameters for sleep mode do not require deactivation or activation of PSC. The overhead of the above management message exchanges is removed in proposed architecture. The parameters can be directly negotiated with sleep-manager.

3. Since these parameters are negotiated with sleep-manager more robust system is available for adaptive power management according to changing traffic.

B. *Analysis of Joint Power Saving Class Management*

Let the SS have n active connections. For simplicity of analysis and to arrive at a convergent mathematical expression, we have assumed the uplink and downlink traffic follow Poisson distribution with mean traffic rate of λ_u^i and λ_d^i for the i^{th} $\left(i \in 1,2 \ldots n\right)$ connection respectively.

a) *Description of cases for analysis of probability of unavailability*

In [15], we presented analysis of an adaptive power saving algorithm for a single connection based on the same traffic assumption as above. We considered four cases wherein the SS can be in sleep. The four cases with the probability of their occurrence are mentioned below for individual traffic, say the i^{th} connection. The notations used in the equations are mentioned in Table 1.

TABLE I. NOTATIONS USED

Symbol	Notation
λ_u^i	Mean Transmission Rate of UL frame by ith connection at SS
λ_d^i	Mean Transmission Rate of DL frame by ith connection at SS
t_j	Sleep interval in the jth sleep cycle, where j = 1, 2, 3….
L	Listening Interval
w_n	Total sleep and listening interval till the nth sleep cycle where $w_n = \sum_{j=1}^{n}\left(t_j + L\right)$
t_u	Time of arrival of the UL frame at SS since it went into sleep mode
e_j	Event that there is at least one DL frame at BS for an MSS in the jth sleep interval at SS
$P\left(e_j\right)$	Probability of occurrence of event e_j
$P\left(\overline{e_j}\right)$	Probability of non-occurrence of event e_j
ϕ_n^k	Probability that SS wakes up in the nth sleep cycle for case k (k =1,2,3,4)

i) *Case 1 – An UL frame is present for transmission at SS in the n^{th} sleep interval while no DL frame arrives at BS for the SS till the n^{th} sleep interval*

The probability of occurrence of this case as deduced in [15] for i^{th} connection is given as,

$$\phi_n^1 = P(w_{n-1} < t_u < w_{n-1} + t_n)P\left(\overline{e_1}, \overline{e_2}, \ldots, \overline{e_{n-1}}\,\overline{e_{w_{n-1}<t_d<t_u}}\right)$$

$$= \left(e^{-w_{n-1}(\lambda_u^i + \lambda_d^i)}\right)\left(1 - e^{-t_n\lambda_u}\right)\left(e^{-\lambda_d^i (t_u - w_{n-1} - L)}\right) \qquad (1)$$

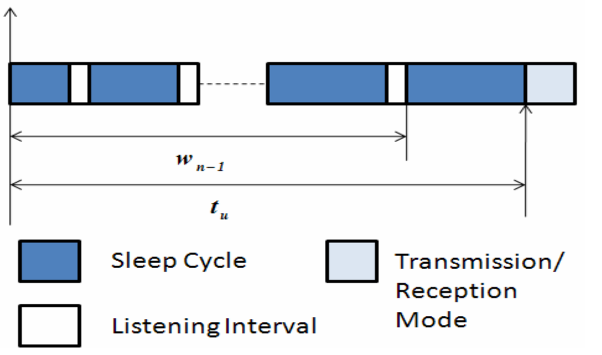

Figure 4. Case 1 - UL Frame available for transmission in nth sleep cycle

ii) *Case 2 – An UL frame is present at SS for transmission with at least one DL frame arriving at BS for the SS in the* n^{th} *sleep interval*

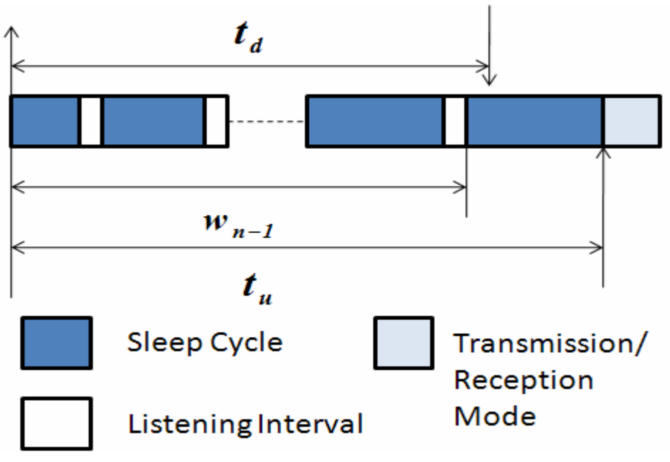

Figure 5. Case 2 - UL frame is present at SS for transmission with a DL frame arriving at BS for SS in the n^{th} sleep interval

The probability of occurrence of this case as deduced in [15] for i^{th} connection is given as

$$\phi_n^2 = P(w_{n-1} < t_u < w_{n-1} + t_n)P\left(\overline{e_1}, \overline{e_2}, \ldots, \overline{e_{n-1}}\,e_{w_{n-1}<t_d<t_u}\right)$$

$$= \left(e^{-w_{n-1}(\lambda_u^i + \lambda_d^i)}\right)\left(1 - e^{-t_n\lambda_u}\right)\left(1 - e^{-\lambda_d^i (t_u - w_{n-1} - L)}\right) \qquad (2)$$

iii) *Case 3 – An UL frame is present at SS for transmission in the listening interval after the* n^{th} *sleep cycle with no DL frame arriving at BS for the SS till* the nth sleep interval

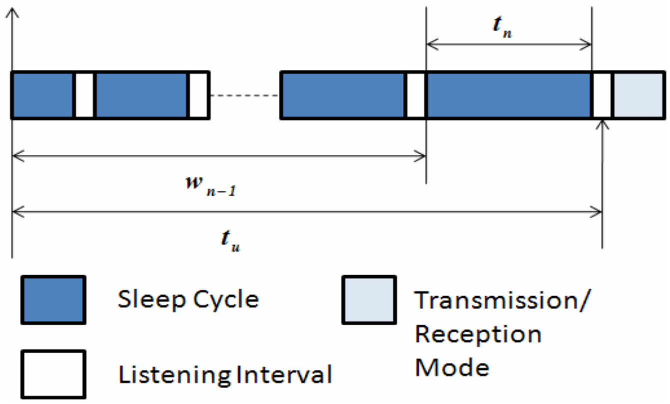

Figure 6. Case 3 - UL Frame available for transmission at SS in the listening interval after the n^{th} sleep cycle

The probability of occurrence of this case as deduced in [15] for i^{th} connection is given as

$$\phi_n^3 = P(w_n - L < t_u < w_n)P\left(\overline{e_1}, \overline{e_2}, \ldots, \overline{e_{n-1}}\,\overline{e_n}\right)$$

$$= \left(e^{-w_{n-1}(\lambda_u^i + \lambda_d^i)L}\right)\left(e^{-\lambda_u^i L} - 1\right) \qquad (3)$$

iv) *Case 4 – A DL frame arrives at BS for SS in the* n^{th} *sleep interval with no UL frame interrupting the sleep mode till* n^{th} *sleep cycle*

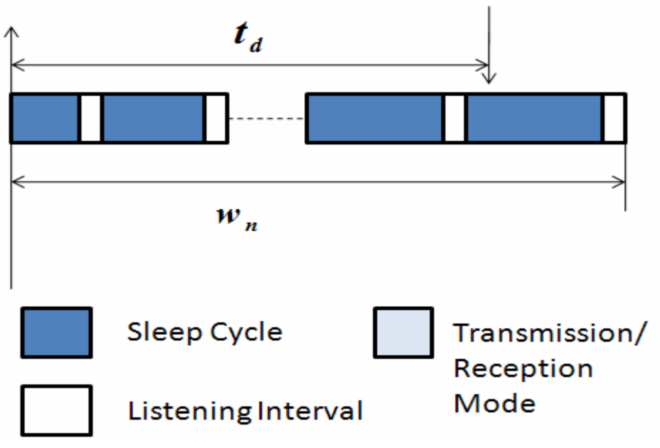

Figure 7. Case 4 - DL Frame arrives at BS in the n^{th} sleep interval

The probability of occurrence of this case as deduced in [15] for i^{th} connection is given as

$$\phi_n^3 = P\left(t_u > w_{n-1} + t_n\right)P\left(\overline{e_1}, \overline{e_2}, \ldots, \overline{e_{n-1}}\,\overline{e_n}\right)$$

$$= \left(e^{-\lambda_d^i t_n}\right)\left(e^{-w_{n-1}(\lambda_u^i + \lambda_d^i)}\right)\left(1 - e^{-\lambda_d^i (t_n + L)}\right) \tag{4}$$

b) Unavailability period due to Aggregated Traffic

As mentioned earlier, the uplink and downlink connections follow Poisson distribution. Let us represent arrival time of the uplink and downlink traffic as a set of random numbers for n connections as U_i and D_i with means λ_u^i *and* λ_d^i respectively.

The traffic characteristic of the aggregated traffic is represented by U_a and D_a respectively, as sum of random variables U_i and D_i respectively.

$$U_a = U_1 + U_2 + \ldots\ldots.. + U_n \tag{5}$$

$$D_a = D_1 + D_2 + \ldots\ldots.. + D_n \tag{6}$$

The sum of Poisson variables results in a Poisson distribution with mean as sum of means of individual variables. Thus the aggregated traffic for uplink and downlink can also be represented as a Poisson variable with means given as

$$\lambda_u^a = \sum_{i=1}^{n} \lambda_u^i \tag{7}$$

$$\lambda_d^a = \sum_{i=1}^{n} \lambda_d^i \tag{8}$$

Thus the aggregated traffic follows Poisson distribution for both uplink and downlink traffic with mean λ_u^a and λ_d^a respectively. Substituting values for the aggregated traffic model in the Equations 1-4 we can calculate the probability of the occurrence of the four cases and consecutively the probability being in sleep. Since we have considered aggregated traffic, these values correspond to the unavailability period.

c) *Unavailability Period when Power Class is managed for individual connections*

Let us consider n active connections with uplink and downlink traffic following Poisson distribution with means λ_u^i and λ_d^i respectively for the i^{th} connection, where $\left(i \in 1,2 \ldots n\right)$. The probability that the i^{th} connection is in sleep is represented by the equations 1-4 respectively. The probability of the unavailability period due to the sleep mode pattern of the i^{th} connection can be calculated as described below. All values are determined relative to the start of the sleep cycle of the i^{th} connection under consideration.

i) Case 1

Probability of Unavailability Period with i^{th} connection =

$$\left(\phi_n^1 \forall i \in n\right) \prod_{\mathrm{j}=1}^{\mathrm{n}} P(t_u^j > t_u^i \forall i, j \in n \text{ and } i \neq j)$$
$$\prod_{j=1}^{n} P(t_d^j > t_u^i \forall j \in n \text{ and } i \neq j) \tag{9}$$

ii) Case 2

Probability of Unavailability Period with i^{th} connection =

$$\left(\phi_n^2 \forall i \in n\right) \prod_{\mathrm{j}=1}^{\mathrm{n}} P(t_u^j > t_u^i \forall i, j \in n \text{ and } i \neq j)$$
$$\prod_{j=1}^{n} P(t_d^j > t_u^i \forall j \in n \text{ and } i \neq j) \tag{10}$$

iii) Case 3 -

Probability of Unavailability Period with i^{th} connection =

$$\left(\phi_n^3 \forall i \in n\right) \prod_{\mathrm{j}=1}^{\mathrm{n}} P(t_u^j > t_u^i \forall i, j \in n \text{ and } i \neq j)$$
$$\prod_{j=1}^{n} P(t_d^j > t_u^i \forall j \in n \text{ and } i \neq j) \tag{11}$$

iv) Case 4 -

Probability of Unavailability Period with i^{th} connection =

$$\left(\phi_n^4 \forall i \in n\right) \prod_{\mathrm{j}=1}^{\mathrm{n}} P(t_u^j > w_n^i \forall i, j \in n \text{ and } i \neq j)$$
$$\prod_{j=1}^{n} P(t_d^j > w_n^i \forall j \in n \text{ and } i \neq j) \tag{12}$$

The average probability for the unavailability period, i.e. when the SS is actually in sleep, of the SS due to all *n* connections can be calculated from each of the four cases mentioned earlier as shown below.

Average Probability of Unavailability Period due to i^{th} connection =

$$\frac{\sum^{\text{duration of connection}} \left(\begin{array}{l}\text{Probability of unavailability Period}\\ \text{due to case j, } j \in 1,2,3,4\end{array}\right)}{\text{Total no. of sleep intervals}} \qquad (13)$$

$$\text{Average Probability of unavailability period} = \frac{\sum_{i=1}^{n} \left(\begin{array}{l}\text{Average Probability of the Unavailability}\\ \text{period for } i^{th} \text{ connection}\end{array}\right)}{n} \qquad (14)$$

A simulation was carried out based on the above analysis using a custom C++ based simulation environment. The parameters chosen were $\lambda_u^i = 0.125$ and $\lambda_d^i = 0.025$ as the number of connections (represented by i) was varied from 1 to 10 connections. The parameters for sleep interval where $t_{\min} = 2$ frame units, $t_{\max} = 64$ frame units and L = 1 frame units. The average probability of the unavailability period is calculated as the average value of all the four cases over the period of the simulation.

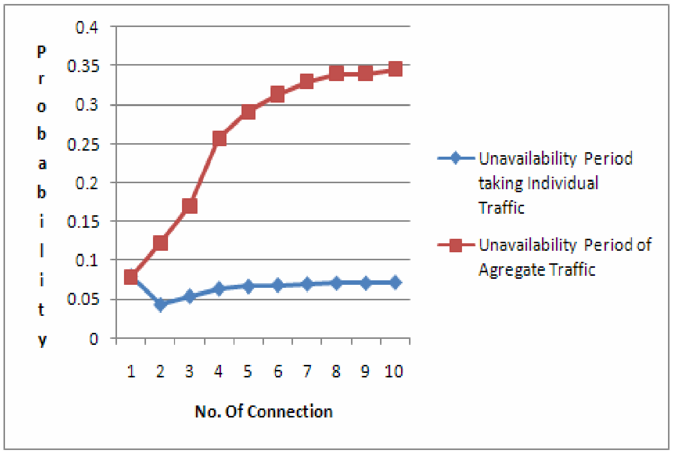

Figure 8. Average Probability of the Unavailability Period

Figure 8 shows the plot of the average probability of the unavailability period during the course of simulation as the number of connections is varied between the SS and the BS. When the number of connections is one, the probability of unavailability period in both cases is equal (0.0795), advocating the validity of the results. As the numbers of simultaneous connections are increased, the average probability of unavailability period using aggregated traffic is greater than that in the case of managing sleep mode for individual connections. Furthermore, we also observe that the relative performance of the proposed mechanism improves with increase in number of active PSC_IDs. More precisely, it may be observed that the ratio of probability of unavailability period in case of aggregated traffic pattern (due to joint power class management) to that in case of individual PSC management increases from 1:1 for one connection to 4:1 for five connections and a peak of 4.8:1 in case of ten simultaneous connections. In other words, the probability of device switching to sleep mode increases from 7.1% in case of individual PSC_ID management to 35% in case of joint PSC management for ten simultaneous connections. This reveals that managing sleep modes through aggregated traffic characteristics is more efficient than considering individual traffic pattern.

C. *Extension to Joint Power Class Management Architecture*

In the previous section we have shown that the probability of unavailability period is higher, when we consider aggregated traffic rather than individual connection. In this section, we discuss a sleep manager algorithm to maximize the unavailability period.

We define a Threshold Factor T_i, for i = 1, 2, 3, 4, 5. This represents the maximum frame time for which the unavailability period of the QoS Classes (UGS, ertPS, rtPS, nrtPS and BE) can be extended. These values are selected, considering the latency and jitter requirements of the respective QoS class, such that

$$T_1 < T_2 < T_3 < T_4 < T_5 \qquad (15)$$

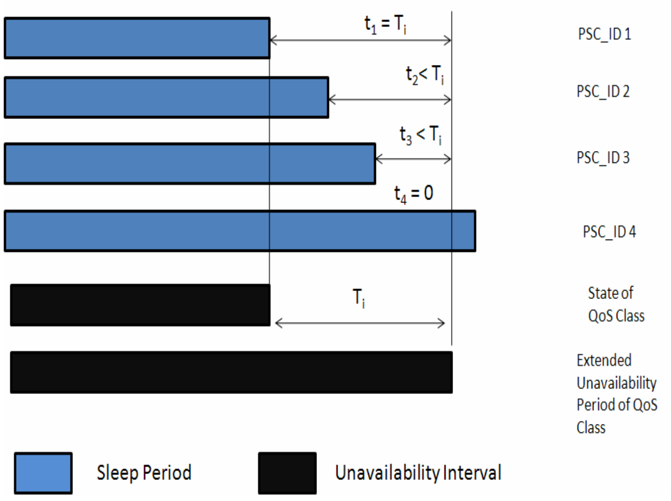

Figure 9. Extension of the unavailability period of QoS Class

Figure 9 shows the method by which unavailability period of the QoS class can be extended by the sleep manager to maximize the unavailability period of the SS. For all *n*

PSC_IDs belonging to the QoS class a value t_i is defined relative to the original unavailability period as shown in Fig. 9. The duration of extension of the unavailability period of the QoS class is then determined from a value given as t_{ext}^{j}, where *j* represents each QoS Class (UGS, ertPS, rtPS, nrtPS, BE) and calculated as

$$t_{ext}^{j} = \max\left(t_k \forall k, k \in n, T_j\right), \ j \in QoS\ Class \qquad (16)$$

This value with the original unavailability period is presented to the sleep manager. The unavailability period of the SS is then calculated as shown in Figure 10.

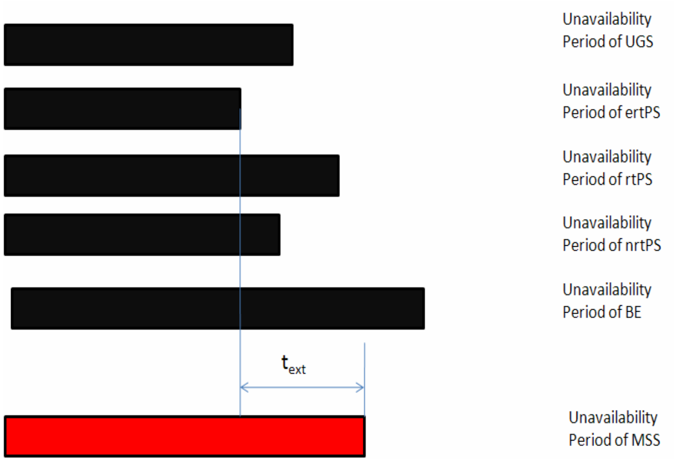

Figure 10. Unavailability Period of SS

The value by which the total unavailability can be extended is calculated as follows

$$t_{ext} = \min\left(t_{ext}^{j}, \forall j, \ j \in QoSClasses\right) \qquad (17)$$

Since all the computation is managed by the sleep manager it can handle dynamic changes in the parameters of T_i as well as other sleep mode parameters as required by QoS classes.

III. SIMULATION RESULTS AND DISCUSSION

Figure 11 shows the simulation scenario under consideration. Simulations are carried out on the Qualnet simulation platform. An SS is connected to a BS under an IP subnet. BS initiates downlink (DL) connections of exponential inter-arrival times with mean of 1 second and random on-off time with on time percentage of 0.3. Table II shows the simulation parameters used.

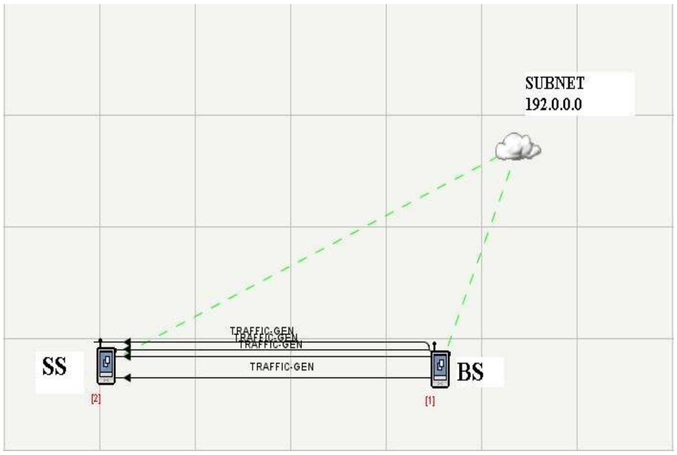

Figure 11. Simulation scenario

TABLE II. SIMULATION PARAMETERS

Parameter	Value
Transmission Power	15.0 dBm
MAC Frame Duration	20 ms
TDD Downlink Duration	10 ms
DCD/UCD Interval	5 sec
DCD/UCD timeout interval	25 sec
Simulation period	25 sec

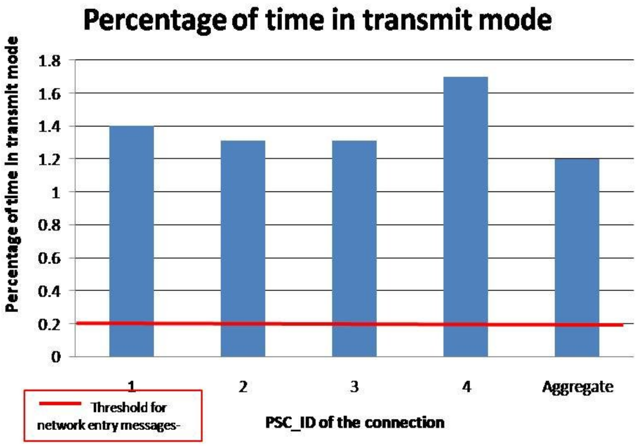

Figure 12. Percentage of time in transmit mode of the SS for DL connections

The number of connections is increased with time and the various statistics related to sleep mode management exchanges are collected. Figure 12 shows the variation of the percentage of time spent in transmit mode by the SS with individual PSC_IDs and the aggregated connection. It may be noted that, since all active connections are in DL direction, the transmission time at SS is mainly due to the management signaling messages, mainly the MOB_SLP-REQ and MOB_SLP-RSP messages. We observe that the minimum signaling required for the node to execute network entry procedure is 0.2% of the transmission time. It is evident from the Figure 12 that, the transmission time for the aggregated PSC_ID scenario (1.2 %) is lesser than all the individual PSC_IDs. This validates our proposal that joint power class management can save battery power.

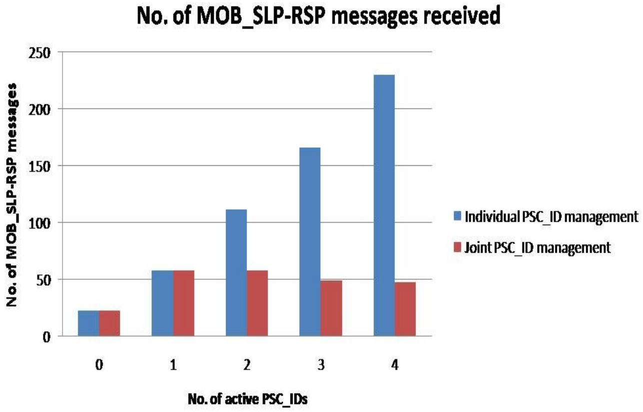

Figure 13. Number of MOB_SLP-RSP messages received with increasing number of active PSC_IDs

Figure 13 shows the variation of the number of MOB_SLP-RSP messages received by the SS during the period of simulation with the number of PSC_IDs active during simulation. We can observe that, even when no active PSC_ID existed, the SS receives a finite number (23) of MOB_SLP-RSP messages from the BS. These messages instruct the SS to switch to the low power mode. We can also observe that, as the number of active PSC_IDs increase, the relative benefits derived out of joint power saving class management improves, as the ratio of management messages received improves from 1:1 for one active PSC_ID to 4.8:1 for four active PSC_IDs.

Figure 14 shows the variation of the number of MOB_SLP-REQ messages transmitted by the SS during the period of simulation with the number of PSC_IDs active during simulation. It can be observed that when there are no connections in the DL for the SS, it doesn’t request for sleep interval from the BS. As in the case of MOB_SLP-RSP message, in this case also the relative performance improves with the increase in the number of active PSC_IDs. It can be noted that the ratio of MOB_SLP-REQ messages transmitted improves from 1:1 for one active PSC_ID to 5.3:1 for four PSC_IDs.

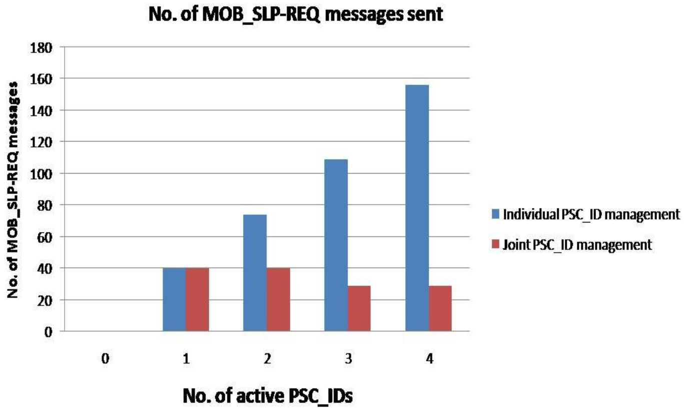

Figure 14. Number of MOB_SLP-REQ messages transmitted with increasing number of active PSC_IDs

On an average, combining the MOB_SLP-REQ and MOB_SLP-RSP messages, we find that the ratio of total messages transmitted improves from 1:1 for one active PSC_ID to 5.01:1 for four PSC_IDs. This suggests that, the management message exchange overhead in case of proposed joint power saving class management reduces to 1/5th of that in case of individual PSC_ID management for four simultaneous PSC_IDs.

It may be noted that, these results corresponds closely to that obtained through the analytical model (see Figure 8 for details). As the numbers of active PSC_IDs are increased, the relative performance of the joint power class management as against the individual PSC management improves as both the transmitted power and the number of management messages exchanged decrease. This in turn implies that as the number of active PSC_IDs is increased, the probability of finding common unavailability period amongst all active PSC_IDs increases in case of joint power class management.

IV. CONCLUSION

In this paper, we have proposed a novel Sleep-Mode Manager Architecture for IEEE 802.16m SS to efficiently utilize the bandwidth and power by clubbing the management message exchanges for sleep mode per power saving class between a SS and BS, instead of individual PSC_ID management. This proposed architecture takes care of QoS class of the traffic by aggregating the unavailability periods of all the active PSC_ID traffic. The results of analysis and simulation show that the proposed architecture is better than the power saving mechanism in 802.16e standard. Our proposed architecture introduces modularity and better control over the decision making process that switches the SS between availability and unavailability periods. Our work is applicable to the enhanced sleep-mode management mechanisms under investigation by IEEE

802.16m. Future work can include combination of algorithms to classify connections into power saving classes along with joint power class management.

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