CHAPTER 5

SLEEP MODE OPTIMIZATION ALGORITHM

Chapters 3 introduced the Scheduling Scheme and Chapter 4 explained the Resource management and Call Admission Control schemes that aim to provide better QoS provisioning in IEEE 802.16m systems. These schemes, however, are resource management strategies, and they are more concerned towards improving the QoS concerns of real-time services and therefore, do not address the issues governing non-real time services.

An analytical analysis on the estimation of power consumption and delay faced by non-real time packets in IEEE 802.16m networks is presented in this presented. A deep analysis on the sleep mode characteristics of the network is also carried out. Based on the insights obtained from these theories we propose a methodology wherein the non-real time packets that are using the Best Effort Services could exploit the sleep mode characteristics to ensure improved throughput. The same has been demonstrated through simulations.

The rest of this chapter is organised as follows. Section 5.1 provides an overview of the proposed algorithm and discusses its objectives. Section 5.2 introduces the sleep mode characteristics of IEEE 802.16m systems. Section 5.3 describes the proposed algorithm which aims to maximize the throughput of the non-real time services is proposed. Section 5.4 presents the performance evaluation of the proposed algorithm. Section 5.5 summarizes the chapter.
5.1 SCHEME OUTLINE AND OBJECTIVES

A novel algorithm based on sleep mode operation of IEEE 802.16m systems is proposed. The proposed scheme aims to achieve the following objectives

1) Estimating the power and transmission delay experienced by the non-real time packets;

2) Improving the throughput of non-real time services;

5.2 SLEEP MODE CHARACTERISTICS OF IEEE 802.16M STANDARDS

WiMAX standards have been generically developed based on a system perspective. They are made of many special components that can be integrated and made to work together. It is important to understand the state diagram to describe the behaviour of the IEEE 802.16m systems. The various possible states of the system and the transitions between them are illustrated with the help of the state diagram. The state diagram may also present an abstract of the system. The mobile state transition diagram of IEEE 802.16m system is illustrated in Figure 5.1.

The IEEE 802.16m mobile station state transition diagram comprises four operational states. The states are used to reduce the network load. It also ensures that there is maximum transparency between the states and also ensures that the process is simple and also efficient to handle. Another important characteristic that is also encountered by the system is that it reduces the overall load on the network. Fast cell selection is another important feature handled by the systems.
There are basically four important states in the Mobile Systems, namely,

- Initialization State
- Access State
- Connected State
- Idle State

Figure 5.1 IEEE 802.16m Mobile State Transition Diagram
The most important work that has to be carried out by the BS is that the BS has to allocate channels to the MS that are requesting for channels. This is done in the Initialization State. The initialization state is done in two stages, namely, cell search and cell selection as illustrated in Figure in 5.2

**Figure 5.2 Initialization State Procedure in IEEE 802.16m**

### 5.3 SLEEP MODE OPTIMIZATION ALGORITHM

In IEEE 802.16m systems, there is a wide scope for the Mobile Stations to reduce their energy consumption. The reduction in energy consumption is possible whenever the MS is lightly loaded with real-time traffic and is operating in the sleep mode. There are three types of Power Saving Classes in IEEE 802.16m systems. The classes are classified based on the traffic type which means that different types of PSCs can be applied to
different slots based on the traffic types assigned to the slots. When a PSC is in the active mode, sleep windows are interleaved with the listening windows. The sleep windows extend over a fixed duration and repeat over a time for the PSC. A listening window is a time duration during which traffic can be exchanged between the MS and the BS while a sleep window is used to power down MS’s transceiver for power saving (Kalle et al 2009, Eunju Hwang et al 2010 and Sung-Min Oh et al 2008).

One major disadvantage associated with the sleep mode operations of the existing 802.16m systems is that the listening window in the existing systems is fixed once the size is determined by the MS. Once the listening window session expires in the MS the BS will not be able to transmit anymore traffic even if it has more traffic destined to that particular MS in the sleep mode. In addition, The IEEE 802.16m standard, an MS with multiple connections can manage multiple PSCs independently. Or on the other hand a single PSC may be mapped to handle the multiple connections. In the first case where an MS with multiple connections is mapped with multiple PSCs a sleep window of a PSC might overlap with the listening windows of other PSCs. One important aspect of the systems is that the MS cannot power down its transceiver in such overlapped periods so that the energy cannot be saved.

A number of energy management mechanisms are available in literature (Chen et al 2009, Kong & Tsang 2007, Zhang 2007, Han & Choi 2006, Xiao 2005, Zhu et al 2007). However most of the schemes fail to do a proper estimation of the power required to transmit the non-real time traffic and they also fail to exploit the sleep mode characteristics of IEEE 802.16m systems. In order to overcome the shortcoming of the existing scheme we propose the following new strategies: (1) an MS is allotted only one PSC in the sleep mode; and (2) an adaptable listening window frame based on the Buffer status of the BS. By implementing the proposed scheme in a proven
Call Admission Control scheme and scheduling scheme it was proved that the traffic and QoS conditions of the non-real time traffic improved significantly.

There are two types of PSC’s available namely, PSC-I and PSC-II and they are classified based on the traffic. PSC-I is basically employed for Best Effort and non-real time traffic where PSC-II is employed to handle real-time traffic. As explained earlier, the proposed scheme aims to adopt two sleep mode cycles which comprise of the listening and sleep mode as illustrated in Figures 5.3 and 5.4. Figure 5.3 depicts the PSC-I, wherein the sleep cycle doubles once if reaches the threshold or maximum, irrespective of the nature of the traffic. Figure 5.4 illustrates the sleep cycle of PSC-II or real-time traffic.

![Figure 5.3 PSC Type 1 Operation](image)

![Figure 5.4 PSC Type 2 Operation](image)
The algorithm also adds a few advancements which will help to maximize the efficiency of the system. Firstly, only one PSC is served by the MS at any particular instant. This avoids unnecessary overlapping with the windows at the time of service. Secondly, MS reduces the size of the listening window when the receive buffer of the BS is empty. Third, provisions are included in the algorithm for the MS and BS to renegotiate the PSC assigned based on availability of resources. These new advents which have been introduced in the Resource Management Process helped to improve the QoS of the non-real time traffic of the IEEE 802.16m systems.

The traffic conditions of PSC-I and PSC-II are independently analyzed for better understanding. Most of the available literature deal only with non-real time traffic and all the schemes available in literature do not introduce the new amendments which are proposed earlier.

In this chapter, a new analysis carried out based on the amendments and the findings of the analysis and amendments are implemented on scheduling and CAC schemes and this performance is validated.

The listening windows are developed to accommodate both real time and non-real time traffic. One significant disadvantage of the listening practice is that the existing scheme does not match exactly with the requirement. This may be attributed to varying channel conditions. In this paper, we present a new technique wherein the window size is adjusted based on the requirements. Figure 5.4 illustrates the working of the adjustable listening and sleeps windows. At the beginning of the listening window, the BS starts transmitting the real time traffic followed by non-real time traffic. In order to proceed with the analysis the following conditions are considered:
1) Real time traffic arrives at the beginning of every frame

2) The non-real time traffic follows a Poisson process with an arrival rate of $\lambda(s)$

3) The real time and non-real time traffic follow an exponential distribution with expectations $\frac{1}{E_r}$ and $\frac{1}{E}$ respectively.

At the beginning of every listening window, before the real time packets that are to be served, the non-real time packets that were queued in the buffer of the previous window have to be served. As the BS is transmitting the packets of the previous window, new packets may arrive at the buffer. In order to differentiate between the two, an indexing ‘I’ is followed. ‘I’ is used to index the group of packets buffered while the packets of (I-1) group are being served. The time required to transmit the packets of the $i^{th}$ group is given by $t^i$.

The expectation of $t^{(0)}$ may be estimated by the given equation.

$$E[t^{(0)}] = \frac{1}{E_r} + \lambda \frac{E_s}{E}$$  \hspace{1cm} (5.1)

where $\lambda E_s$ is the number of packets that are buffered to be served.

During this interval, $t^{(0)}$ additional packets may arrive at the buffer which would increase the transmission time of the next window. The same condition is applied again until the buffer becomes empty.
\[ E[t^{(i)}] = \int_0^\infty t^{i-1} \int_0^\infty \sum_{k=0}^\infty k \ P_r[k] = k, t^{i-1}] \]  \hspace{1cm} (5.2)

Where the arrival of the packets is given by,

\[ \frac{\lambda^{(i-1)k}}{k!} e^{-\lambda t^{(i-1)}} e^{-Et} \]  \hspace{1cm} (5.3)

Therefore it may be stated that the size of the listening window in a sleep cycle should be equal to the total time required for transmissions until the last packet in the buffer of BS is to be served. The listening window size may be given by,

\[ T_{LW} = \sum_{i=1}^{\infty} E[t^{(i)}] \]  \hspace{1cm} (5.4)

\[ T_{LW} = \sum_{i=1}^{0} E[t^{(0)}] \mu^i \]

where \( \mu \) is the utilization period.

In order to estimate the packet transmission delay, estimation in the number of packets available at the buffer has to be estimated. At any instant of time the buffer will contain \( \lambda T_s \) non-real time packets at the beginning of every listening window. The buffer will become empty at the end of the listening window. Real time packets are served with a higher priority than non-real time packets. The non-real time packets are transmitted with an expected packet transmission time of \( \frac{1}{\mu} \). The number of packets that remain unserved in the buffer at any instant is given by,
\[ \bar{N} = \frac{1}{T_s} \int_0^1 \left( (1 + \lambda T_{SW} + \lambda t) - E_r t \right) dt \]

\[ + \frac{1}{T_{LW}} \int_0^{T_{LW}} \left( \lambda T_{SW} + \frac{\lambda}{E_r} + \lambda t \right) - \mu t) dt \] \hspace{1cm} (5.5)

The packet delay experienced by the packets may be derived from the litter law

\[ D = \frac{1}{\lambda} \left( N - \frac{1}{T_{SW} E_r} \right) \] \hspace{1cm} (5.6)

The average power consumed is given by

\[ P_c = \frac{PL_W T_{LW} + P_s T_S}{T_{SC}} \] \hspace{1cm} (5.7)

- \( P_{LW} \) – Power consumed by listening window
- \( P_S \) – Power consumed by sleep window
- \( T_{SC} \) - Sleep cycle period

5.4 PERFORMANCE EVALUATION OF THE SLEEP MODE OPTIMIZATION ALGORITHM

The observations from Figure 5.5 clearly illustrate that the throughput of the BE services in IEEE 802.16m systems has doubled by exploiting the sleep mode characteristics of the system. This is because the higher the power consumed, there is significant drop in the transmission delay experienced. It implies that the as the more power is supplied to the OFDMA slots; it results in the reduction in the number of packets that are
stored at the buffer for transmission. This results in shorter transmission delay thereby enhancing the throughput of the network significantly. Hence, it may also be shown that the non-real time traffic can be served more frequently by reduction of the sleep cycle period.

![Figure 5.5 Average Throughput of Best Effort Services](image)

**Figure 5.5 Average Throughput of Best Effort Services**

### 5.5 SUMMARY

In this chapter, the power consumed and transmission delay experienced by non-real time traffic in IEEE 802.16m systems is computed. Strategies are proposed to overcome the existing short comings and then the implemented. Simulation results have demonstrated that the proposed scheme was able to double the throughput of non-real time services by increasing the power of the slots that are used for transmitting the non-real time traffic. The analysis can be used to find out an optimised value of power for slot allocation for non-real time services.