Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Proposal for IEEE 802.16m Sleep Area Design**
Date Submitted	07-07-2008
Source(s)	Shantidev Mohanty (shantidev.mohanty@intel.com) Intel Corporation Muthaiah Venkatachalam (Muthaiah.venkatachalam@intel.com) Intel Corporation Shailender Timiri (Shailender.b.timiri@intel.com) Intel Corporation
Re:	Call for Contributions on Project 802.16m System Description Document (SDD) IEEE 802.16m Mobility Management and Power Saving
Abstract	Proposal for IEEE 802.16m Sleep Area Design
Purpose	Discussion and Approval
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Proposal for IEEE 802.16m Sleep Area Design

Shantidev Mohanty, Muthaiah Venkatachalam and Shailender Timiri

1. Introduction and Background

In the reference system, IEEE 802.16e-2005 STD [2], during sleep mode operation a mobile station (MS) performs handoff when it moves from one BS to another. When traffic arrives for a sleep mode MS, its serving BS sends a mobile traffic indicator (MOB-TRF-IND) message.

This contribution studies the air-link signaling overhead associated with sleep mode operation in the reference system. Based on the results of these studies the contribution proposes the concept of sleep area that consists of one or more BSs for IEEE 802.16m system to reduce the air-link signaling overhead associated with sleep mode operation.

In Section 1.1 this contribution studies the air-link signaling associated with reference system sleep mode operation for different sleep durations and speed of sleep mode MSs. Section 1.2 summarizes the advantages and disadvantages of sleep mode operation in reference WiMAX system. The design considerations of sleep mode operation in IEEE 802.16m are provided in Section 2. The proposed adaptive sleep area concept is described in Section 3.

1.1 **Analysis of sleep mode operation in IEEE 802.16e-2005 STD**

The operation of sleep mode in IEEE 802.16e-2005 STD is illustrated in Figure 1 that shows the availability intervals (AI) and unavailability intervals (UAI) of a sleep mode SS. IEEE 802.16e specifies that the duration of AI is constant whereas the duration of UAI may double up to a maximum value or remain constant. The duration of the first UAI is denoted as *Initial UAI* and the duration of the unavailability interval at a particular time is given by

$$UAI = \min (2*(\text{Previous } UAI), \text{Final } UAI \text{ base}*2\text{\^{}}(\text{Final } UAI \text{ exponent})$$

Where *Final UAI base* is the final UAI base and *Final UAI exponent* is the final UAI exponent. It may be noted that when *Final UAI base = Initial UAI* and *Final UAI exponent* = 0, the duration of UAI is constant.

Figure 1: Figure illustrating SS's sleep mode operation.

Thus, while in sleep mode the SS alternates between the AI and UAI. During its AI when the sleep mode SS realizes that it has moved beyond the coverage area of its serving BS it performs handoff to the target BS. This is shown in Figure 2. When a sleep mode SS has traffic to send or receive, it terminates its sleep mode operation and returns to active mode. The termination of the sleep mode operation of an SS can be initiated either by the BS or the SS. The BS initiates the sleep mode termination when it receives DL traffic for the sleep mode SS. On the other hand, the SS initiates the termination of its sleep mode when it wants to send UL traffic. When the BS initiates the termination of the sleep mode operation of one or more SS, it broadcasts a Mobile Traffic Indicator (MOB-TRF-IND) message that contains the SLPIDs of one or more SS whose sleep mode needs to be terminated. Thus, during one sleep instance, i.e. the time an MS enters sleep mode until the time its sleep mode is terminated, the MS may perform one or more handoffs and receive one MOB-TRF-IND message. Therefore, the amount of air-link signaling overhead during one sleep instance is given by

$$L = E[h]\alpha + \beta \quad \text{...(1)}$$

where,

E[h] = the number of handoffs per sleep instance

$$= \frac{average\ duration\ of\ sleep\ instance}{cell\ residency\ time}$$

$$= \frac{E[T_s]}{E[Tca]} \quad \text{..(2)}$$

α = effective air-link resources used during one handoff event

β = effective air-link resources used per MS in a single MOB-TRF-IND message

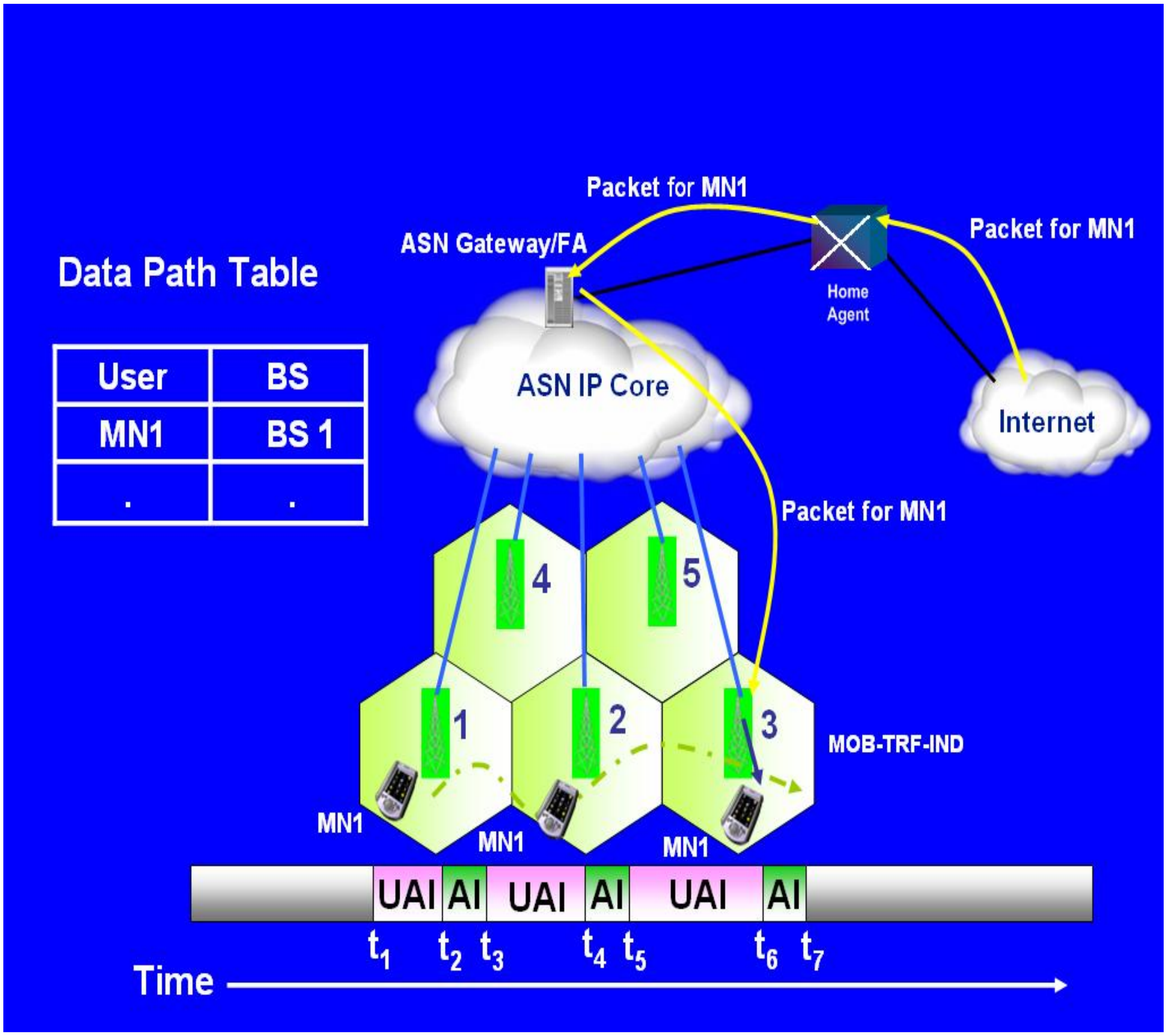
r = cell radius

average duration of sleep instance = duration from the time when an MS enters sleep mode until the time it terminates its sleep operation due to DL/UL traffic arrival

cell residency time = average time spent by a sleep mode MS in a single cell

Substituting (2) in (1) and noting that the cell residency time $E[T_{ca}]$ is given by eq. (5) of [4], ($E[T_{ca}] = \frac{\pi r}{2E[v]}$, E[υ] = average speed of the sleep mode MS), the total resources used is given by

$$L = \frac{2E[T_s]E[v]\alpha}{\pi r} + \beta \quad \text{............................(3)}$$



User	BS
MN1	BS 1
.	.

Figure 2: Diagram showing handoff during sleep operation.

From Eq. (3) it can be observed that air-link signaling overhead for a sleep mode MS during a single sleep instance is proportional to average sleep duration and average speed of the MS. L for different speed and sleep duration is shown in Figure 3. The results in Figure 3 show that air-link signaling overhead for both simulation and mathematical analysis increases proportional to the speed and average sleep duration. This is because the number of handoffs performed by a sleep mode MS during single sleep instance increases proportional to these parameters as shown in Figure 4. Therefore, although the overhead associated with MOB-TRF-IND remains the same the overhead associated with handoffs increases proportional to speed and sleep duration as shown in Figure 5.

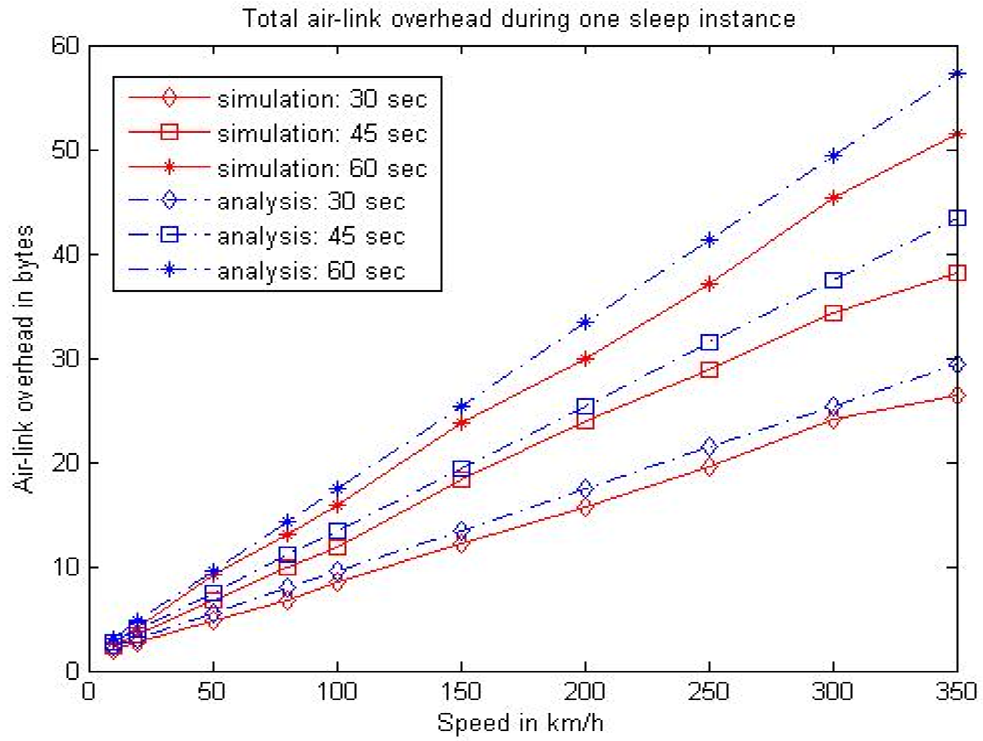


Figure 3: Total air-link signaling overhead during one sleep instance.

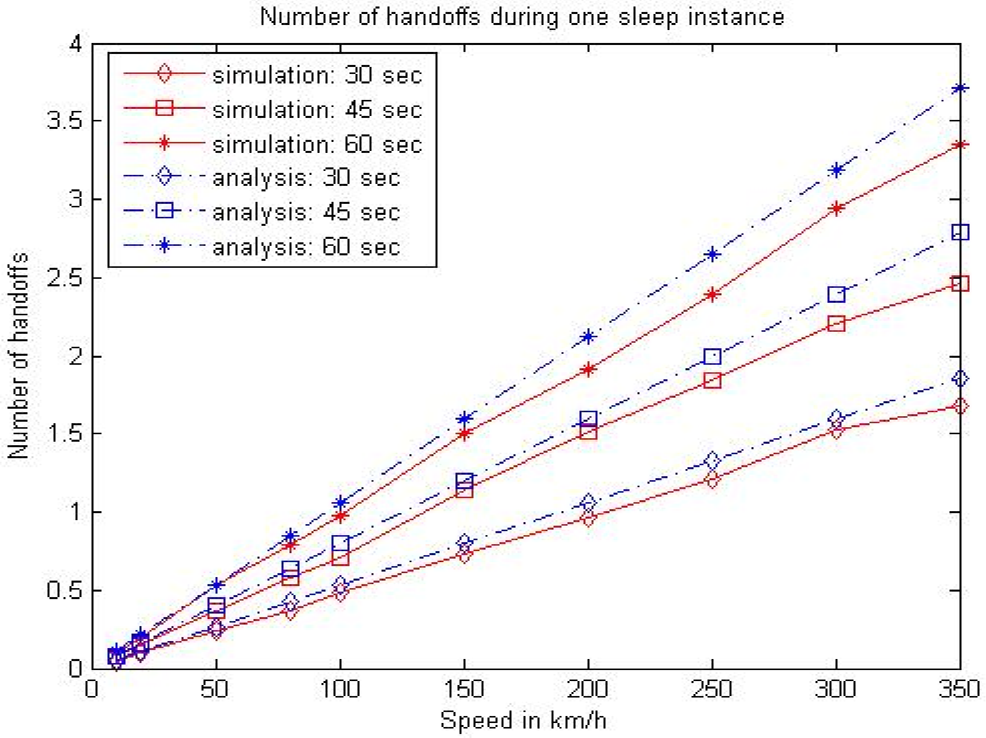


Figure 4: Number of handoffs by a sleep mode MS.

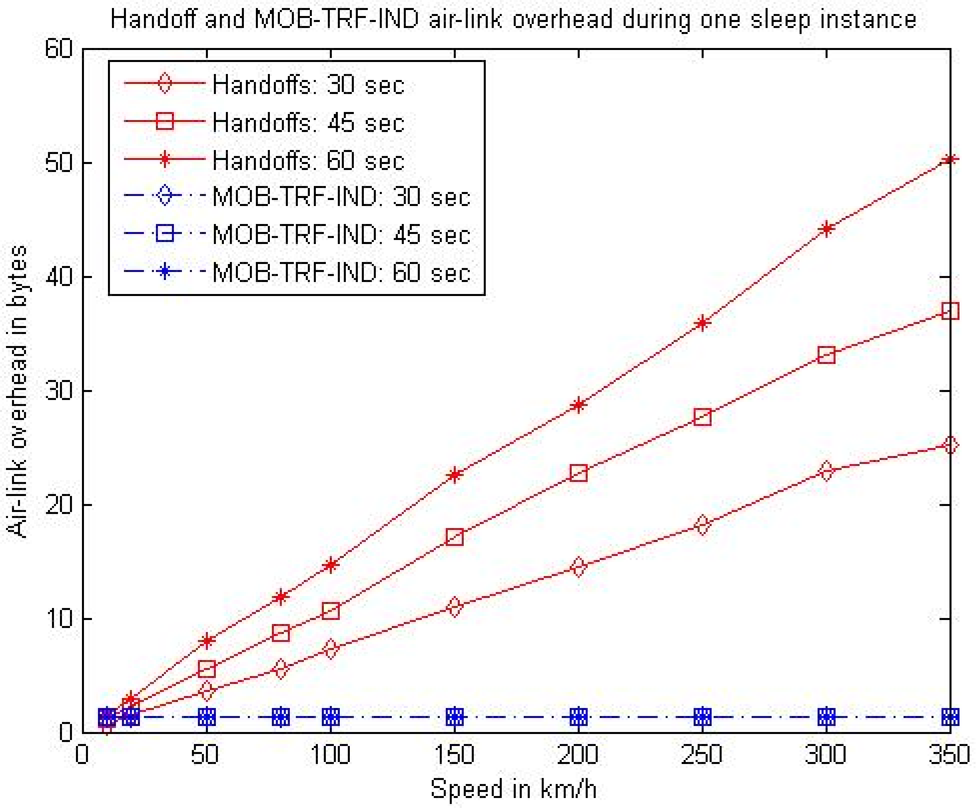


Figure 5: Air-link signaling resources used for handoff and MOB-TRF-IND during one sleep instance.

1.2 **Summary of Issues with the Reference System Sleep Operation**

Based on the above analysis, the advantages and disadvantages of sleep mode operation used in the reference system are summarized below.

Disadvantages

Because a sleep mode MS has to perform handoff every time it moves from one BS to another BS, the number of handoffs performed by the sleep MS is proportional to its speed for a particular sleep duration.

Because a sleep mode MS has to perform handoff every time it moves from one BS to another BS, the number of handoffs performed by the sleep MS is proportional to its sleep duration for a particular sleep speed.

Because of the above reasons the air-link signaling overhead associated with sleep mode operation is different for MSs moving with different speed.

It may be noted that the handoffs during sleep mode operation are not required as the MS is not engaged in any traffic send/receive operation. Thus, the resources used for these handoffs are wasted.

Advantages

As the sleep mode operation of an MS is limited to one BS, there is no need to have co-ordination among multiple BSs during sleep operation. Therefore, implementation of sleep operation is simple in the reference system.

2. Sleep Mode Operation in IEEE 802.16m Design Considerations

To eliminate the above shortcomings of sleep mode in the reference system, it is desirable to have following features for sleep mode operation in IEEE 802.16m.

1) Design of sleep area consisting of one or more BSs such that a sleep mode MS does not perform handoff as long as it resides in a particular sleep area.
2) To take into account the speed and sleep duration in determining the size of sleep area. The size of the sleep area could be larger for fast moving MSs and MSs using application that result in longer sleep duration, e.g. http traffic with long inactive duration between two consecutive packet bursts.

Section 3 describes the methods proposed in this contribution to design sleep area for IEEE 802.16m systems.

3. Proposed Sleep Area Design Concept

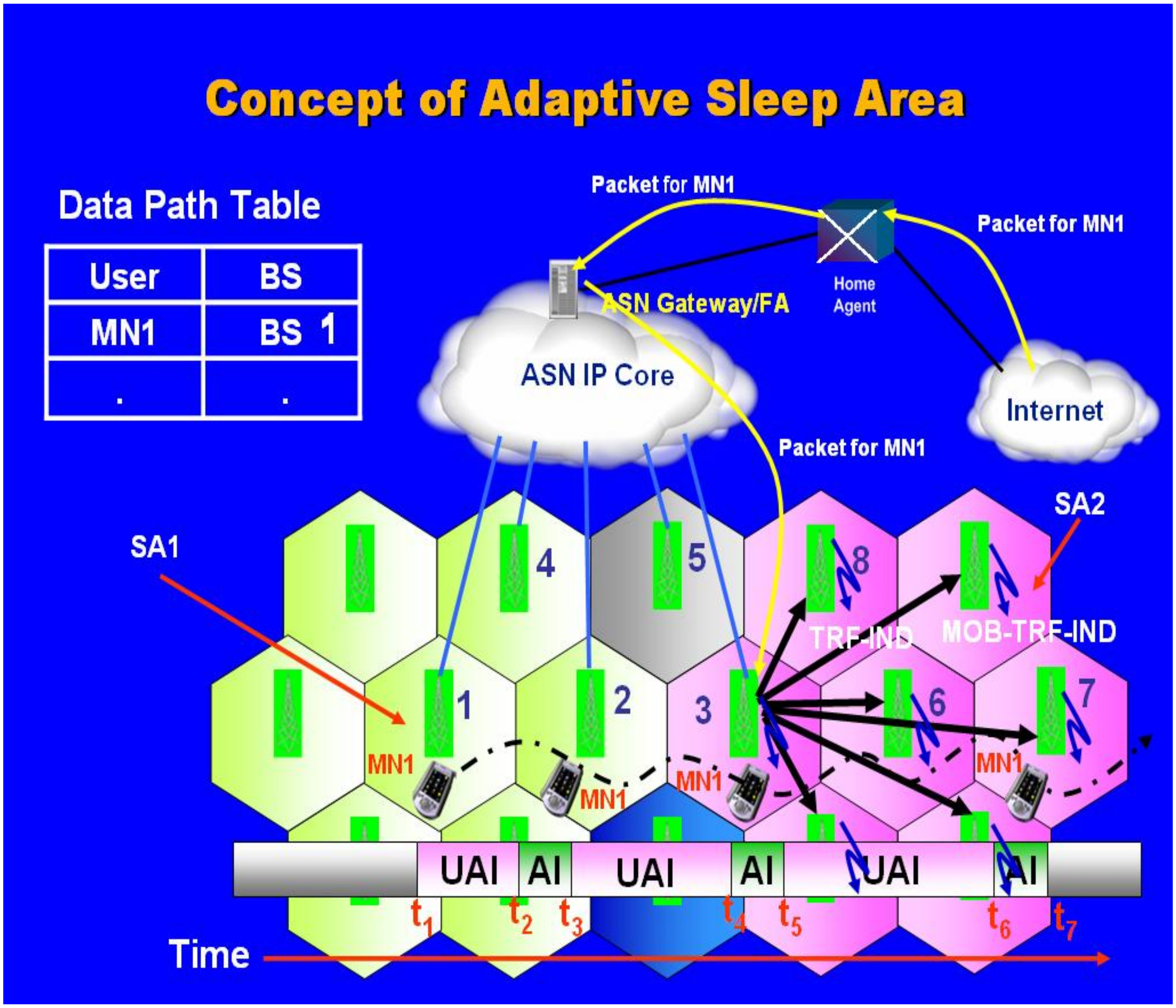
The following definitions are used to describe the contribution:

Sleep area: A geographic area containing one or more cells such as an SS in sleep mode does not perform handoff as long as it resides in a particular sleep area. In other words, an SS in sleep mode performs handoff only when it moves from one sleep area to another sleep area.

Adaptive sleep area: Sleep area whose geographic dimensions are decided by the average speed and sleep duration of SSs in sleep mode.

Anchor sleep BS of an SS in sleep mode: The BS of a sleep area that serves as the serving BS for a particular SS in sleep mode.

The basic idea proposed in this contribution is the use of sleep area. Thus, every SS in sleep mode is assigned a sleep area whose dimensions depend on SS's average speed and sleep duration. A sleep mode SS with higher average speed is assigned a larger sleep area compared to the sleep area of an SS with lower average speed. Similarly, an SS with longer sleep duration is assigned a large sleep area compared to an SS with shorter sleep duration. As described earlier, an SS in sleep mode performs a handoff only when it moves from one sleep area to another sleep area. By assigning larger sleep areas to SSs moving with higher speed, the contribution lowers the number of handoffs performed by the faster moving SS. Similarly, it reduces the number of handoffs performed by SSs with longer sleep duration. It may be recalled from the analysis of Eq. (3) that air-link resources used during sleep operation, L, depends on the number of handoffs performed by a sleep mode SS during one sleep instance. Thus, by reducing the number of handoffs the proposed contribution reduces L.



User	BS
MN1	BS 1
.	.

Figure 6: Figure showing the operation of adaptive sleep area concept.

The proposed contribution is described in more detail using Figure 6 that describes the sleep mode operation of a particular sleep mode SS, MN1. For illustrative purpose it is considered that the sleep area of MN1 consists of seven cells as shown by different colored cells in Figure 6. The algorithm to determine the sleep area size for a particular sleep SS is provided in the later part of this document. As shown in Figure 6 MN1 was in connected mode until time t_1. At time t_1 MN1 starts its sleep mode operation. The sleep mode operation of MN1 starts with the Unavailability Interval (UAI) and then MN1 alternates between UAI and Availability Interval (AI). As MN1 was associated with BS1 at the start of its sleep mode operation, the Access Service Network (ASN) gateway has BS1 as the serving BS of MN1 in its database. As BS1 is the serving BS for MN1 when

MN1 enters into sleep mode, BS1 becomes the anchor sleep BS for MN1. It may be noted that BS1 belongs to sleep area, SA1. Thus, as long MN1 resides in SA1, BS1 is the anchor sleep BS for MN1. ASN gateway has the anchor sleep BS of a sleep SS in its routing database. Thus, when ASN gateway receives traffic for a particular sleep SS, it forwards the traffic to the anchor sleep BS of that sleep SS. As mentioned earlier, as long as MN1 resides in SA1 it does not perform handoff even if it moves from one cell to another. From time to time each BS of a particular sleep area sends broadcast messages containing the sleep area identification (SAID). Using these messages a sleep mode SS learns about the sleep area where it is currently residing. While in sleep mode MN1 moves in the trajectory shown in Figure 6 and it is considered that by the first AI interval (from t_2 to t_3), MN1 has moved from cell 1 to cell 2. However, MN1 learns it is still inside the same sleep area, SA1, by listening to broadcast message containing the SAID of BS2 during it's AI. Thus, MN1 does not perform handoff when it moves from cell 1 to cell 2 as both these cells belong to the same sleep area. It may be noted that when the contribution is not used MN1 performs a handoff when it moves from one cell to another during its sleep mode operation. This way the proposed contribution reduces the number of handoffs for sleep mode SSs. This reduces the amount of resources used for handoffs.

During its second AI (from t_4 to t_5) MN1 realized that it has crossed it's earlier sleep area, SA1, and is now residing in a new sleep area with SAID, SA2. At this point MN1 performs a handoff to associate with BS3. During this handoff, the BS1, BS3, and ASN gateway may exchange different backbone signaling messages. Moreover, during this handoff MN1 and BS3 may as well exchange signaling messages over the air-link. At the completion of the handoff, the ASN gateway updates its database to reflect that MN1's serving BS has been changed from BS1 to BS3. BS3 becomes the anchor sleep BS of MN1 in sleep area, SA2. After this handoff the MN1 does not perform any handoff as long as it remains in sleep area SA2.

During MN1's third AI, it is assumed that traffic for MN1 has arrived at ASN gateway from the Internet through MN1's home agent (HA) as shown by the yellow arrows in Figure 6. ASN gateway checks its database for the serving BS for MN1 and forwards MN1's traffic to BS3. BS3 realized that MN1 is in sleep mode and its sleep area is SA2. BS3 has the knowledge about all the BSs that belong to sleep area SA2. After receiving traffic for MN1, BS3 realizes that MN1 is residing in SA2. However, it does not have information about the particular cell in which MN1 is residing. Thus, it sends a message to all the BSs in the SA2 to locate MN1. This message is referred to as Traffic Indicator (TRF-IND) message. One of the ways to send the TRF-IND message to all the BSs in a sleep area is to create a multicast group consisting of all the BSs in the sleep area. If this method is used then in BS3 in Figure 6 sends a TRF-IND message to the multicast group consisting of all the BSs in sleep area SA2. It may be noted that multicasting of TRF-IND message is one of the many possible ways using which a BS of a sleep area can send TRF-IND message to all the other BSs in the same sleep area. When the BSs of the sleep area SA2 receive the TRF-IND message from BS3, each of them including BS3 sends MOB-TRF-IND message containing the identification of MN1. This identification of MN1 uniquely identifies MN1 among all the sleep mode SSs residing in sleep area SA2. One of the possible format to encode this unique ID is described in the later part of this document. Because the sleep mode SS resides in the sleep area it receives the MOB-TRF-IND message from one of the BSs of the sleep area and learns that traffic is waiting for it at the network. Then, it terminates its sleep mode operation and return to active mode. If the sleep mode SS is residing in a cell other than the cell of its anchor sleep BS, then it perform a handoff during its return to active mode from sleep mode. As shown in Figure 6 MN1 receives the MOB-TRF-IND message from BS7. However, its anchor sleep BS is BS3. Thus, MN1 performs a handoff during its return to active mode from sleep mode.

The above illustration of the contribution shows that:

1. When MN1 moved from BS1 to BS7 during its sleep mode operation, it performed only two handoffs. One when it moved from sleep area SA1 to SA2, e.g., when it moved from cell 2 to cell 3 and the other one when it terminated its sleep mode while residing in cell 7. When the contribution is not used, MN1 performs four handoffs if it follows the trajectory shown in Figure 6 during its sleep operation. Thus, the use of sleep area concept reduces the number of handoffs. By doing this the contribution achieves the following advantages:
    a. It reduces the resources used to carryout handoffs for sleep mode SS.
    b. It reduces the power consumed by the sleep mode SS to perform handoffs. It may be noted that to perform an handoff a sleep mode SS consumes power while exchanging messages related to handoff procedures. Thus, by reducing the number of required handoffs during one sleep instance, the power consumed by the sleep mode SSs to carry out handoffs is reduced.
2. When the anchor BS of a particular sleep mode SS receives traffic for the sleep SS and wants to terminate the sleep mode operation of the said SS, it sends TRF-IND message to all the BSs in the sleep area of the said SS. When the sleep area consists of more than one cell, this results in multiple TRF-IND messages. This increases the backbone signaling overhead used during the termination of the sleep mode operation of the said SS. Moreover, when the sleep area of the said SS contains more than one BS, every BS in the sleep area broadcasts a MOB-TRF-IND message containing the identification of the said sleep mode SS over its air-link. This increases the amount of air-link resources used to send MOB-TRF-IND message.

The above analysis shows that while the proposed contribution reduces the resources used during handoffs, it increase the amount of resources used during sleep mode termination. It can be easily observed that the amount of resources used during handoffs is inversely proportional to the size of sleep area. On the other hand, the amount of resources used during the termination of sleep mode operation is directly proportional to the size of sleep area. Thus, the two factors, i.e., the amount of resources used during the handoffs performed by an sleep mode SS and the amount of resource used during the termination of sleep mode operation, that contribute to the overall resource used during the sleep operation of an SS have opposite relationship to the size of the sleep area. Therefore, there exists a sleep area hereafter referred as *minimum-resource sleep area* for which the sum of these two factors attains the minimum value. The size of the *minimum -resource sleep area* for which the summation of these two factors attains the minimum value depends on different parameters such as the speed of the sleep mode SS. The size of the minimum-resource sleep area can be determined using the following algorithm.

Algorithm to determine the radius of minimum-resource sleep area:

The air-link resources used during a single sleep mode instance of an MS is given by Eq. (3) in Section 1.1 for IEEE 802.16e systems. As in the proposed sleep area concept more than one BS may broadcast the MOB-TRF-IND message to a sleep mode MS, the air-link signaling overhead is given by modifying Eq. (3) to

$$\begin{aligned} L_1 &= \frac{2E[T_s]E[v]\alpha}{\pi r} + N\beta \\ &= \frac{2E[T_s]E[v]\alpha}{\pi r} + \frac{R^2\beta}{r^2} \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where N is the number of BSs in a sleep area and R is the radius of the sleep area. Analysis of Eq. (4) provides the following insights about the amount of resources used during sleep operation when sleep area concept is used, L_1.

1. Out of different parameters in Eq. (4), the only parameter that is MS specific is E[v]. Different sleep mode MSs in a mobile WiMAX network may have different average speed. Thus, the amount of resources used by them is going to be different. Assuming that all other parameters have same value for each sleep mode MS, the amount of resources for an sleep mode MS with higher average speed more than the amount of resources for an sleep mode MS with lower average speed. This is shown in Figure 3.
2. L depends on the number of handoffs, E[h], performed by the sleep mode MS during a sleep instance. Therefore, L depends on the radius of the sleep area (SA), R. For a given R, E[h] depends on the average speed E[v] of a sleep mode MS.

The contribution proposes methodology to minimize L_1 in Eq. (4). The basic idea is to determine the radius of the SA for a particular sleep mode MS depending on the average speed of the said sleep mode MS in such a way that the amount of resources, L, used by a sleep mode MS during a single sleep instance is minimized. The SA that achieves minimum L is hereafter referred to as minimum-resource SA.

The radius of minimum-resource SA is determined by finding the value of R hereafter referred to as R_{min} that minimizes L_1 in Eq. (4). Using well known mathematics as described in Appendix B, R_{min} is given by

$$R_{\min} = \left[\frac{E[T_s]E[v]\alpha}{\pi\beta} \right]^{\frac{1}{3}} r^{\frac{2}{3}} \quad \text{------ Eq. (5)}$$

In addition depending on the application used by an SS E[Ts] could be different for different SSs. Eq. (5) shows that an sleep MS with higher average speed has higher R_{min} compared to an sleep mode MS with lower average speed. Once R_{min} is determined for an sleep mode MS, the number of cells, N, in the said minimum-resource SA is calculated using

$$N = round\left(\frac{R_{\min}{}^{2}}{r^{2}} \right) \quad \text{----- Eq. (6)}$$

Where round function determines the nearest integer.

The number of cells in an adaptive sleep area for sleep mode MSs moving different speed is shown in Figure 7. It can be observed from Figure 7 that slow moving sleep mode MSs have smaller sleep areas compared to fast moving sleep mode MSs.

Comparison of the number of handoffs performed by a sleep mode MS during a single sleep instance for IEEE 802.16e and adaptive sleep area concept is shown in Figure 8. It can be observed from this figure that when adaptive sleep area is used the number of handoffs performed by sleep mode MSs moving with different speed is minimized. This minimizes the air-link signaling overhead associated with sleep mode operation of an MS as shown in Figure 9.

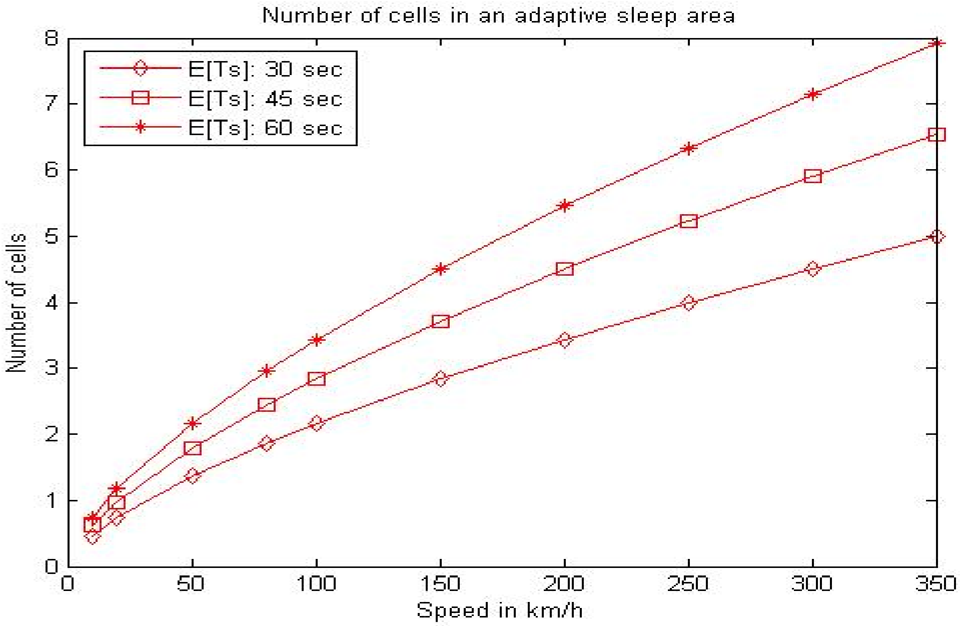


Figure 7: Number of cells in an adaptive sleep area.

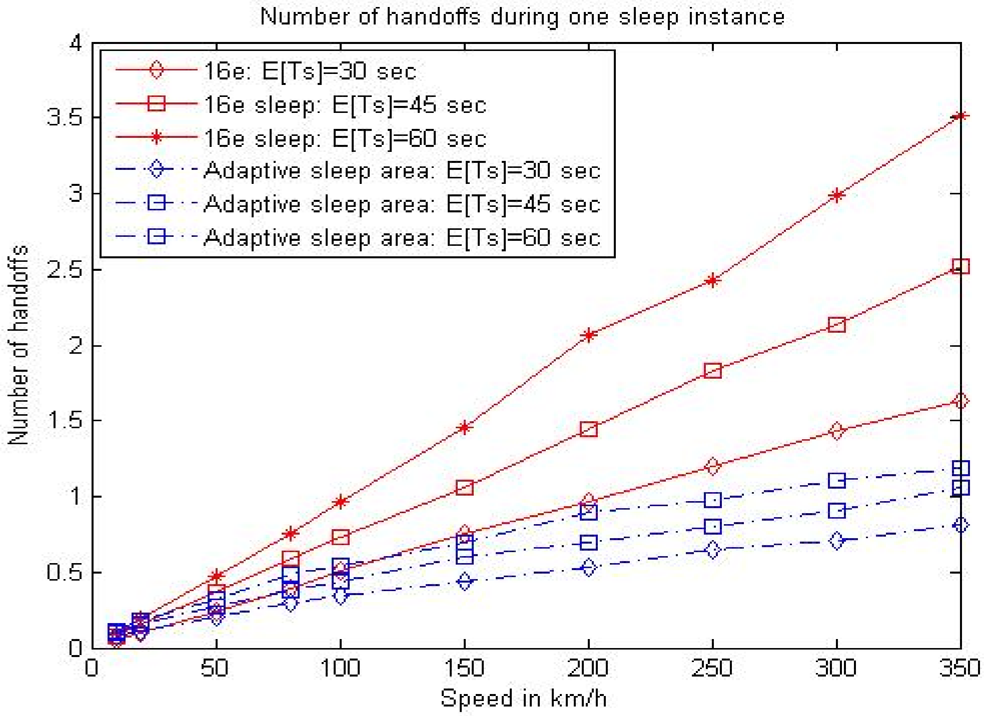


Figure 8: Comparison of number of handoffs in a single sleep instance in reference system and adaptive sleep area concept.

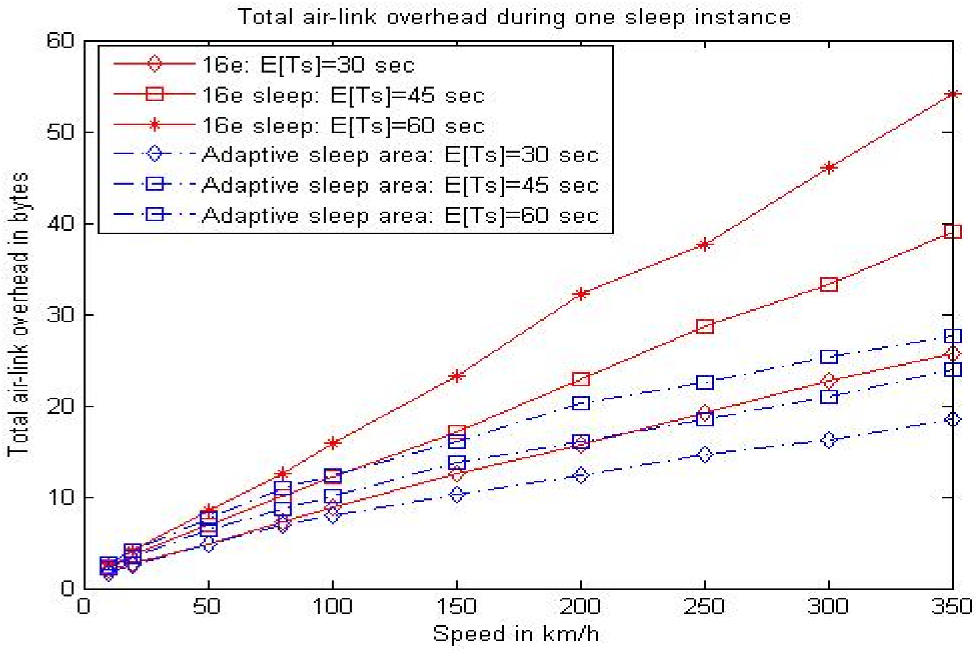


Figure 9: Comparison of air-link signaling overhead during one sleep instance for reference system and proposed adaptive sleep area concept.

Encoding of sleep ID when the sleep area concept is used:
The following encoding scheme is used to uniquely identify sleep mode SSs in a sleep area. The basic idea is that behind this encoding scheme is that the ID of a sleep mode SS has two parts: one identifying the anchor BS of the sleep mode SS and the second one identifying the SS among all sleep mode SS having the same anchor sleep BS as shown in Table 1.

Table 1: Format of sleep ID when the contribution is used.

Anchor sleep BS Index	ID of the sleep mode SS

The number of bits required to encode the anchor sleep BS index depends on the number of BSs of the sleep area. For example, if a sleep area has m number of BSs, then the number of bits required to encode the anchor sleep BS index is $n_1 = \lceil \log_2 m \rceil$. If there are 10 BSs in a sleep area, then $n_1 = \lceil \log_2 10 \rceil = 4$.
The number of bits required to encode the ID of the sleep mode SS depends on the maximum number of sleep mode SS that can be residing in the coverage area of the anchor sleep BS. Thus, if the mobile WiMAX network is designed to support maximum number of k number of sleep mode SSs, then the number of bits required to encode the anchor sleep BS index is $n_2 = \lceil \log_2 k \rceil$. It may be noted that according to IEEE 802.16e specifications n_2=10.

Therefore, the total number of bits required to encode the sleep ID = n_1+n_2.

In the previous sections, some important requirements and considerations in the design of adaptive sleep area were discussed.

4. Proposed Text for SDD

Insert the following text into Sleep Area Design sub-clause (i.e. Chapter xx in [3]):
------------------------------ Text Start ---

x. x.x.x Sleep Area Design

A sleep area is defined as the coverage area of one or more BSs such that an MS in sleep mode does not perform handoff as long as it resides in a particular sleep area. An MS in sleep mode performs handoff when it moves from one sleep area to another. When DL traffic is received for an MS in sleep mode all the BS in the current sleep area of the MS sends MOB-TRF-IND for the MS. The size of the sleep area depends on user’s mobility profile such as speed and characteristics of applications used by user such as the average period of inactivity between two consecutive traffic bursts.
------------------------------ Text End ---

5. References

[1] IEEE Std. 802.16e-2005, IEEE Standard for Local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, and P802.16Rev2/D3 (February 2008).

[2] WiMAX Forum™ Mobile System Profile, Release 1.0 Approved Specification (Revision 1.4.0: 2007-05-02), http://www.wimaxforum.org/technology/documents.

[3] IEEE 802.16m-08/003r1, "The Draft IEEE 802.16m System Description Document"

[4] K. L. Yueng and S. Nanda, "Optimal Mobile-Determined Micro-Macro Cell Selection," : Proc. of IEEE International Symposium in Personal, Indoor and Mobile Radio Communications (PIMRC), 1995, Toronto, Canada (September 1995) pp. 294-299.

Appendix A:

One possible implementation of the contribution:

Based on the above discussion, sleep mode SSs with different speed have sleep areas of different sizes. One way to implement is that SSs with different speed have different sleep area sizes. Another way to implement is to have only a subset of speed values: for example low speed, medium speed, and high speed as define below.

Low speed if the average speed of the SS E[v] < 30 km/h
Medium speed if the average speed of the SS $30 \le E[v] < 60$ km/h
High speed if the average speed of the SS $60 \le E[v]$ km/h

To implement the above three possible sets of average speed values, sleep mode SSs are grouped into three groups: low-speed sleep mode SSs, medium-speed sleep mode SSs, and high-speed sleep mode SSs. This results in three different sleep area sizes, one for each sleep mode SS group. The mean value of the speed for each sleep mode SS group can be used in Eq. (5) to determine the R_{min} for each sleep mode SS group. It is considered that other parameters used in Eq. (5) can be determined for wireless networks based on their specifications. If the R_{min} of low-speed sleep mode SSs, medium-speed sleep mode SSs, and high-speed sleep mode SSs groups are, respectively denoted by R_{minL}, R_{minM}, R_{minH}, then

R_{minL} is calculated using E[v] = 15 km/h in Eq. (5).

R_{minM} is calculated using E[v] = 45 km/h km/h in Eq. (5).

R_{minH} is calculated using E[v] = 90 km/h in Eq. (5).

It may be noted that 30 km/h is the mean value of possible speed for low-speed sleep mode SSs and 60 km/h is the mean value of possible speed for medium-speed sleep mode SSs. E[v] = 150 km/h is used for high-speed sleep mode SS as a representative mean speed value for high-speed sleep mode SSs.

It may also be noted that except E[v] all other parameters are considered to be same for all sleep-mode SSs irrespective of their average speed.

Using R= R_{minL} in Eq. (6), the number of cells in the sleep area for low-speed sleep mode SSs denoted by N_L can be determined. Similarly, using R= $R_{minM,}$ in Eq. (6), the number of cells in the sleep area for medium-speed sleep mode SSs denoted by N_M and using $R_{minH,}$ in Eq. (6), the number of cells in the sleep area for high-speed sleep mode SSs denoted by N_M can be determined. Once N_L, N_M, and N_H are determined sleep mode SSs are assigned either one of the sleep areas depending on their average speed, i.e., a slow moving sleep mode SS is assigned to sleep area that consisting of N_L cells, sleep mode SSs having medium speed are assigned to sleep area that consists of N_M cells, and sleep mode SSs having high average speed are assigned to the sleep area that consists of N_H cells.

The contribution can be summarized as follows:

Configuration:
The sleep mode SSs are classified into different sets based on their average speed. The size of sleep area is determined for each of these sleep mode SSs sets by using the average speed value of the said set in Eq. (5) and Eq. (6).

Sleep area assignment:
A particular sleep mode SS is assigned a sleep area depending on its average speed.

Handoffs during sleep mode operation:
When a sleep mode SS moves from one sleep area to another, it performs a handoff to update its sleep area.

Sleep mode termination:
In case of SS-initiated sleep mode termination, the sleep mode SS first determines the BS in whose cell it is residing at the time of sleep mode termination. If this BS is same as SS's anchor sleep BS, then the SS can terminate its sleep mode by sending a sleep mode termination request to its anchor sleep BS. On the other hand, it is residing in a cell that does not belong to its anchor sleep BS, then first it performs handoff to this new BS and then returns to active mode from sleep mode.

In case of network-initiated sleep mode termination, the anchor sleep BS of the sleep mode SS sends TRF-IND messages to all other BSs in the sleep area of the said SS. Then, all the BSs in the sleep area of the said SS including said SS's anchor sleep BS broadcast MOB-TRF-IND containing the sleep ID of the said SS in their respective cells. When the said sleep mode SS receives the MOB-TRF-IND message containing its sleep ID, it may perform an UHO if its current cell is different than the cell of its anchor sleep BS. Then, the said sleep mode SS returns to active mode.

Appendix B

First the value of R where L_1 attains either maximum or minimum value is determined by solving the following equation:

$$\frac{dL_1}{dR} = 0 \text{ ------ Eq. (1)}$$

Value of R that satisfies Eq. (1) is given by

$$R = \left[\frac{E[T_s]E[v]\alpha}{\pi\beta}\right]^{\frac{1}{3}} r^{\frac{2}{3}} \text{ ----- Eq. (2)}$$

To determine whether L_1 attains maximum or minimum value for R given by Eq. (2), the second derivative of L_1, i.e., $\frac{d^2L_1}{dR}$ is evaluated for R given by Eq. (2). Using well known mathematics it can be easily verified that $\frac{d^2L_1}{dR}$ has positive value when evaluated for R given by Eq. (2). This shows that for R given by Eq. (2), L_1 attains the minimum value. This shows that R given by Eq. (2) is indeed the radius of minimum-resource sleep area. Therefore, the radius of minimum-resource sleep area is given by

$$R_{\min} = \left[\frac{E[T_s]E[v]\alpha}{\pi\beta}\right]^{\frac{1}{3}} r^{\frac{2}{3}} \text{ ------ Eq. (3)}$$