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Proposal for IEEE 802.16m Paging Area and Paging Cycle Design

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1. Introduction and Background

During idle mode operation a mobile station (MS) performs location update when it moves from one paging group to another. Thus, the air-link signaling overhead associated with location update is proportional to the number of location updates. Therefore, larger paging groups decrease the air-link signaling overhead associated with location update due to fewer number of location updates. On the other hand, when an idle mode MS needs to be paged, as all the base stations (BSs) of MS's current paging area broadcast the paging message for the MS the air-link signaling overhead associated with paging operation is proportional to the size of a paging group. Therefore, the design of paging group needs careful consideration to minimize the total air-link signaling overhead associated with location update and paging operation.

Another aspect of the idle mode operation is the duration of paging cycle. As an idle mode MS wakes up once in every paging cycle the power consumption by an idle mode MS is inversely proportional to paging cycle duration. The longer paging cycle reduces the power consumption at the expense of longer paging latency. While paging latency is critical for real time applications such as VoIP, it is not critical for non-real time applications such as email delivery. Thus, the longer paging cycles can be used for idle mode MS that are not subscribed for real-time applications to reduce their power consumption especially when the MS has low battery power.

In this contribution an attempt has been made to provide recommendations on the design principles for the paging groups to minimize the air-link signaling overhead associated with location update and paging in IEEE 802.16m wireless systems. In addition, recommendations are provided for the duration of paging cycles for low battery terminals supporting non-real time applications that can tolerate longer paging latency.

This contribution proposes the design of paging areas based on the geo location, speed, and call profile (e.g. average number of calls received per hour) of the idle mode MSs. In addition, it proposes to consider the battery level of an idle mode MS to decide its paging cycle.

It is imperative to identify the issues with the design and performance of paging group and paging cycle of the reference system, IEEE 802.16e-2005 STD [2], before providing any new solution. Therefore, in the following section the performance of paging group and paging cycle in mobile WiMAX reference system are critically reviewed.

1.1 Analysis of paging area design in IEEE 802.16e-2005 STD

In IEEE 802.16e-2005 STD paging area is statically configured and common of all the MS. For example, N neighboring BSs forms a paging area and all the idle MSs in the coverage of these N BSs belong to the same paging area. The signaling overhead associated with this static configuration of paging areas is investigated as follows.

The total amount of air-link resources, L, used for an idle mode MS during a single idle instance (a single idle instance is defined as the event from the time an MS enters idle mode until the time it comes out of idle mode due to call arrival) to carry the signaling messages during location updates and paging operation (it is considered paging operation is carried once for a single instance of idle mode operation upon the arrival of incoming call for the idle mode MS) is given by

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

where,
E[h] = the number of location updates per idle instance

$$= \frac{\textit{average duration of idle instance}}{\textit{paging area residency time}}$$

$$= \frac{E[T_i]}{E[Tpa]} \quad \text{……………………………………………(2)}$$

α = effective air-link resources used during one location update event

N = number of cells in a paging area of radius R

$$= \frac{\pi R^2}{\pi r^2} = \frac{R^2}{r^2} \quad \text{…………………………………………..(3)}$$

β = effective air-link resources used per MS in a single paging message

r = cell radius

average duration of idle instance = duration from the time when an MS enters idle mode until the time it is paged due to call arrival

paging area residency time = average time spent by an idle mode MS in a single paging area.

Substituting (2) and (3) in (1) and noting that the paging area residency time $E[T_{pa}]$ is given by eq. (5) of [4], ($E[T_{pa}] = \frac{\pi R}{2E[v]}$, E[u] = average speed of the idle mode MS), the total resources used is given by

$$L = \frac{2E[T_s]E[v]\alpha}{\pi R} + \frac{R^2\beta}{r^2} \quad \text{………………………(4)}$$

Using Eq. (4) it can be observed that for a fixed paging area size air-link signaling overhead for an idle mode MS during a single idle instance is proportional to average idle duration and average speed of the idle MS. L for different speed is shown in Figure 1. Similarly, L for different average duration of idle instance is shown in . Figure 1 shows the air-link signaling overhead for both simulation and mathematical analysis. As shown in Figure 1 the signaling overhead during one idle instance increase proportional to the speed of the idle mode MS. This is because the number of location updates increase proportional to the speed of the idle mode MS as shown in Figure 6. In case of static configuration of the paging areas as the number of BSs per paging group is fixed the paging overhead remains constant for different speed whereas the location update overhead increases for higher speed due to increased number of location updates as shown in Figure 3.

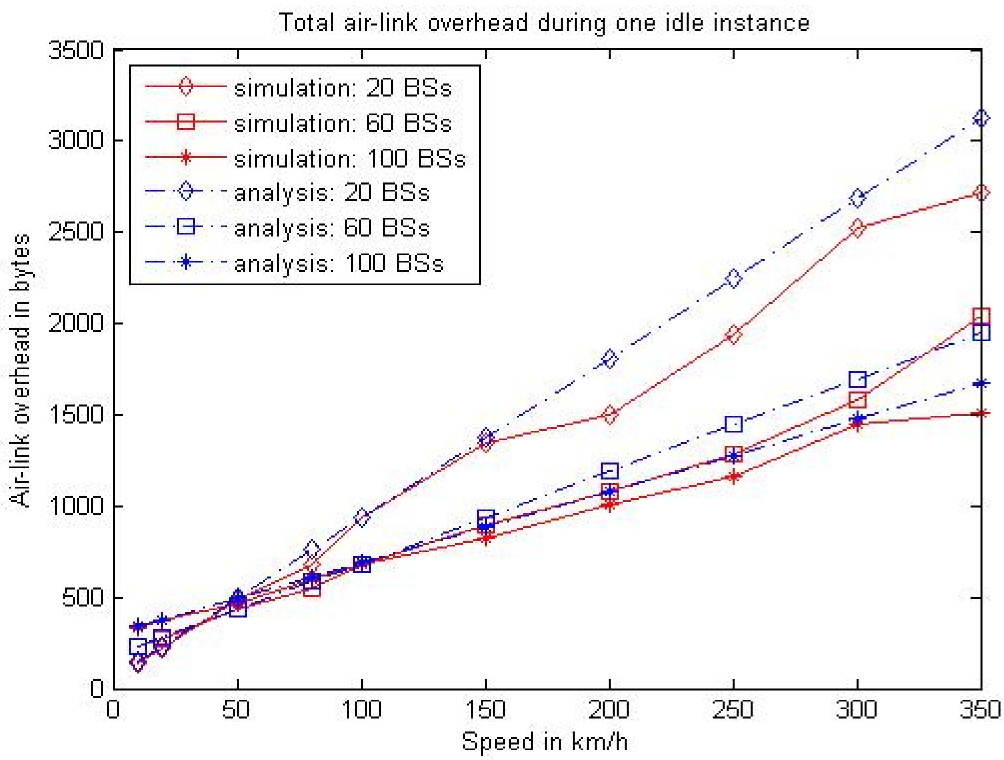

Figure 1: Air-link signaling overhead during one idle instance for different speed and static paging area sizes.

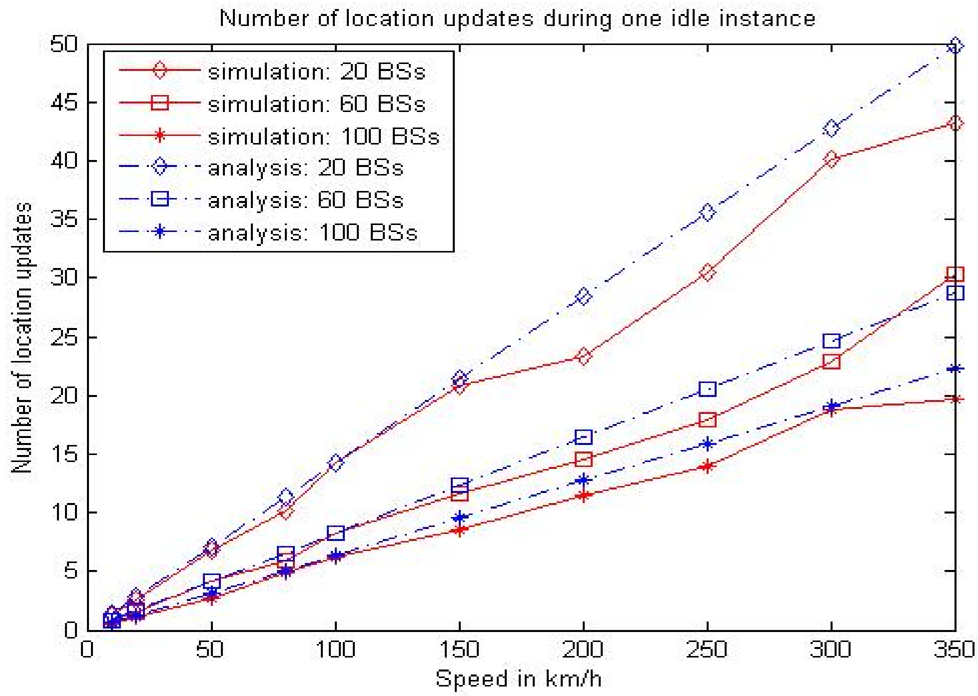

Figure 2: Number of location updates for different speed of idle mode MS.

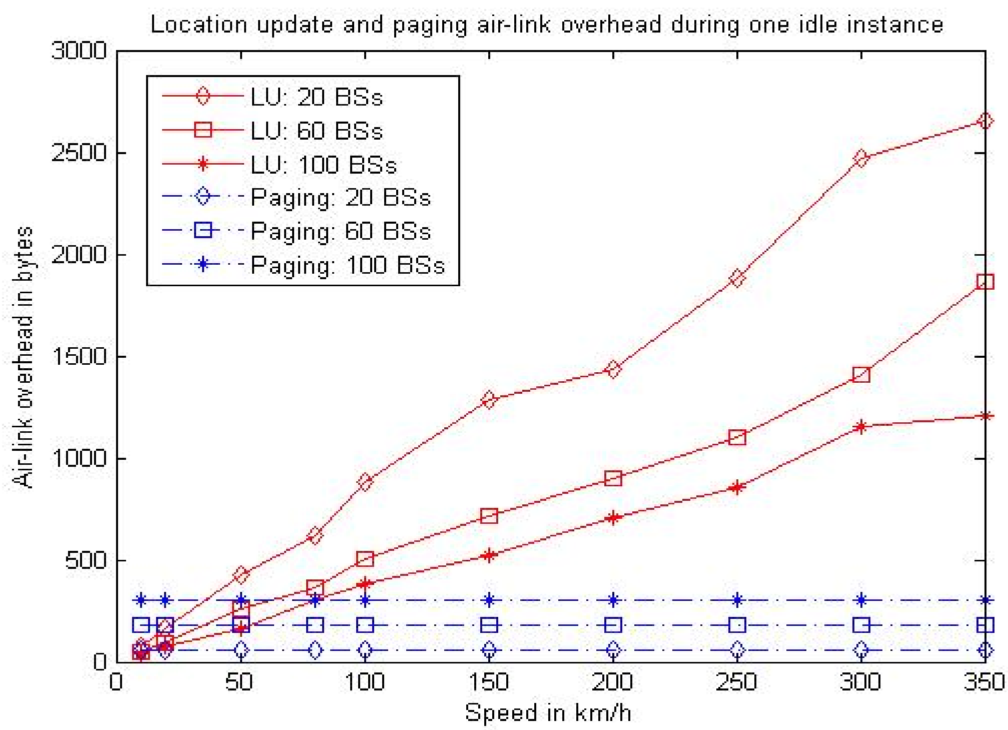

Figure 3: Location update (LU) and paging signaling overhead for different speed of idle mode MS.

Because of static configuration of the paging areas, the idle mode MSs that are near the edge of the paging areas moves out of the paging area quickly. Therefore, the idle MSs whose mobility profile is such that they move between the edge of the neighboring paging areas encounter larger number of location updates compared to idle mode MSs spend more time in the central part of a paging area. Figure 4 compares the number of location updates performed by an idle mode MS in two different scenarios: (1) when the MS moves uniformly in paging areas and (2) when the MS moves between the edge of the neighboring paging areas. Using Figure 4 it can be observed that the MS performs more number of location updates when it moves between the edges of neighboring paging areas. This increases the air-link overhead associated with MS's location update and thereby increase air-link signaling overhead as shown in Figure 5.

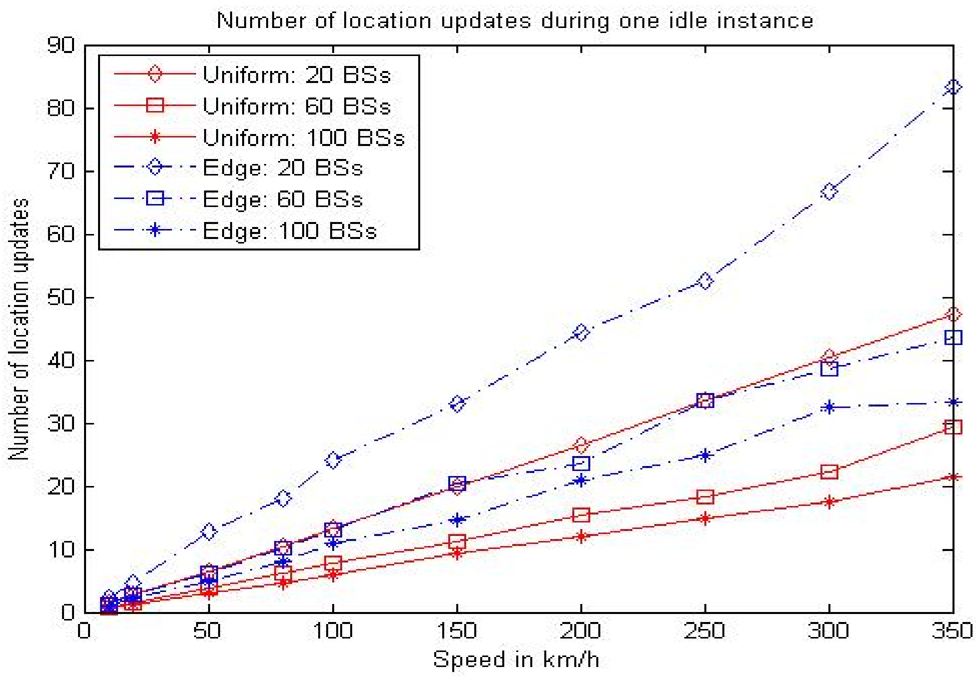

Figure 4: Number of location update comparison between uniform movement and edge movement.

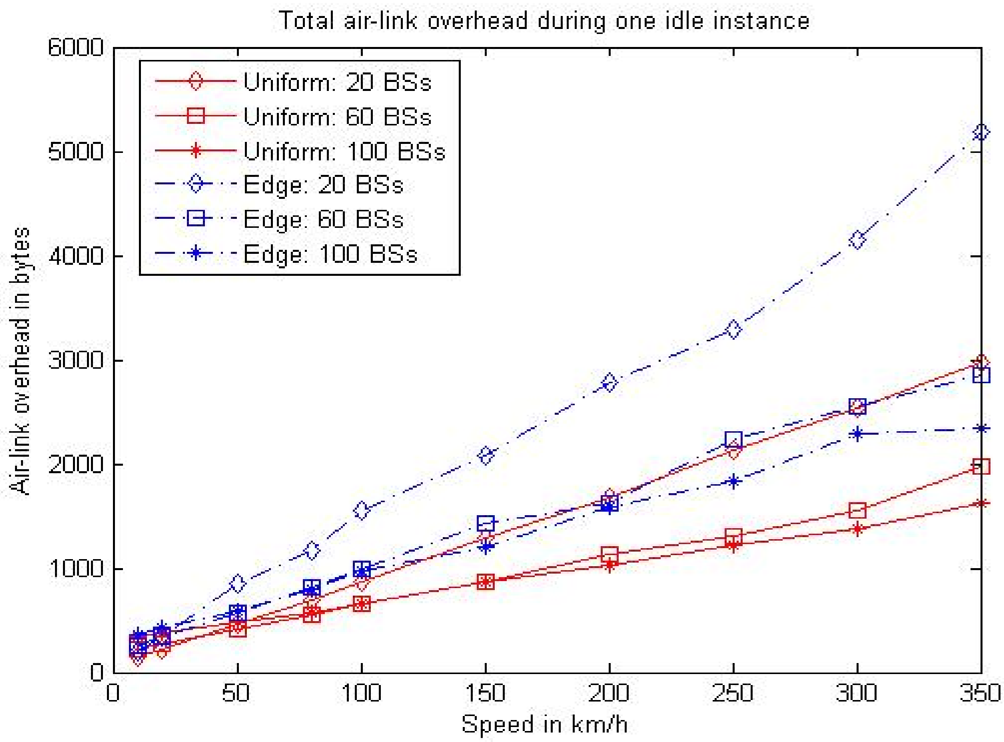

Figure 5: Air-link signaling overhead comparison between uniform movement and edge movement.

As an idle mode MS wakes up once in every paging cycle to listen for paging advertisement messages, the power consumption by an idle mode MS is inversely proportional to the duration of paging cycle. In the reference mobile WiMAX systems the paging cycle could be same for all the users irrespective of their battery power. Therefore, shorter paging cycles are not suitable for mobile devices with limited battery power, especially when the battery level of the devices is running low. Therefore, it is better to have longer paging cycles for devices that have low battery level when the longer paging latency introduced due to longer paging cycles does not affect the call delivery latency of application. This is applicable when a device supports non-real time applications such as email delivery.

1.2 **Summary of Issues with the Reference System Paging Area Design**

Based on the above analysis, the advantages and disadvantages of the paging area design procedures used in the reference system are summarized below.

1. Disadvantages

   a. Because of static configuration of paging areas the air-link signaling overhead associated with idle mode operation is different for idle mode MSs moving with different speed. As fast moving idle mode MSs perform frequent location updates compared to slow moving idle mode MSs, the fast moving MSs incur higher air-link overhead associated with their idle mode operation.

b. Because of static configuration of paging areas the MSs moving around the boundary regions of neighboring paging areas perform higher number of location updates compared to MSs moving uniformly in paging areas. This is because the static nature of paging areas MS may not be located in the central region of a paging area.

c. As MS's battery power is not taken into account while deciding its paging cycle, the MSs with lower battery power may not be able to use longer paging cycle to save power.

2. Advantages

a. The implementation of paging operation is simple in the reference system because of lack of complexity, e.g. static configuration of paging areas, use of same paging cycle for all idle mode MSs.

2. IEEE 802.16m Paging Area Design Considerations

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

1) Design of paging area in such a way that an idle mode MS is always located in the central region of a paging area when it performs location update in a new paging area.

2) Design of paging area in such a way that air-link signaling overhead is minimized for idle mode MSs moving with different speed.

3) Design of paging cycle based on the battery level of a idle mode MS.

The following sub-section proposes methods to achieve each one of these features.

3. Proposed Paging Area Design Considerations

3.1 Geo-location based Paging Area Design:

This contribution proposes geo-location based paging area design so that an idle mode MS is always located in the central region of a paging area when it performs location update in a new paging area. Using this proposal every time an idle mode MS moves to a new paging area it is new paging area is designed in such a way that the MS is located in the center of the new paging area during location update.

Using geo-location based paging area (PA) a PA of an idle mode MS is a logical region of the network that is centered around the current location of the MS. The current location of the idle mode MS corresponds to the most recent location information stored in the PC of the said idle mode MS. This logical PG that is constructed using the location of the idle mode MSs is referred to as Location-based Paging Area (LPG) in the remaining part of this document. The shape of LPG of an idle mode MS with center at the current location of the MS can be circular, elliptic, rectangular or any of shape that can be decided based on different factors such as the mobility pattern of the MS, network coverage etc. For example, an MS moving on a freeway may have a PG that is along the freeway, whereas an MS moving in the downtown of a city may have a circular PG. This is because the MS moving in the freeway will most likely remain in the freeway whereas the MS in the downtown will most likely move in a random direction. Although different shapes for LPG is possible, circular LPG is consider to illustrate this concept. The concepts proposed in this contribution are considered to be used when the PG of an idle mode is decided based on the current location of the MS.

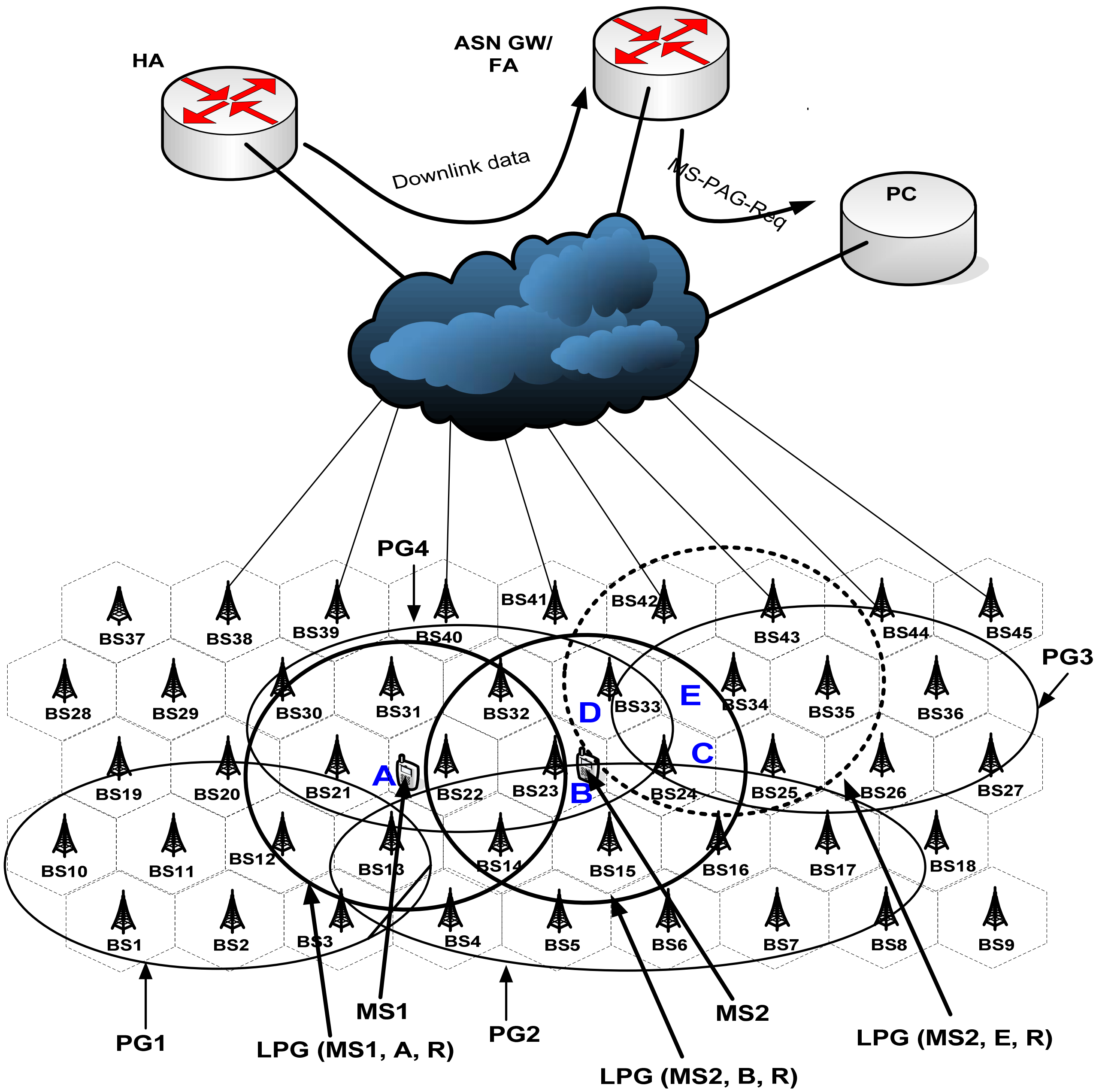

Figure 6: Idle mode operation when LPG is used.

The geo-location based PA design is illustrated in Figure 6 that shows the LPG of two idle mode MSs, MS1 and MS2. Figure 6 also shows the statically configured PAs of reference mobile WiMAX system that are designed without considering the location of idle mode MSs. As described earlier in IEEE 802.16e the network coverage area is logically divided into different PAs either during initial network deployment or during the operation of the network. PG1, PG2, PG3, and PG4 are designed in this way. When these PGs are used to manage idle mode operations, the idle mode MSs moving in the boundary region of multiple PGs perform frequent location update and hence suffer from significantly larger location update overhead. For example, considering the dimensioning of PG1, PG2, PG3, and PG4 shown in Figure 6 when an idle mode MS moves from B to C (PG2 to PG3), C to D (PG3 to PG4), and from D to B (PG4 to PG2) the said idle mode MS performs three location updates although it has traveled only small distance.

Geo-location based PA design is illustrated using MS1 and MS2. It is considered that MS1 enters into idle mode, i.e., transition from connected mode to idle mode when it was located at point A. Similarly, it is considered that MS2 enters into idle mode when it was located at point B. As shown in Figure 6 the Location-based Paging Group (LPG) of MS1 is a circle centers at A and with radius R. This R can be decided either by the idle mode MS or its PC during using different factors. For example using MS1’s speed as proposed in the adaptive paging area design concept described in Section 3.2, fast moving idle could have larger PGs compared to slow moving idle mode MSs. Other factors and/or different methods could be used to determine the right value of R for an idle mode MSs and this contribution is applicable irrespective of the methods used to determine the size of a LPG. It may be noted that as the LPGs shown in Figure 6 are assumed to be circular, they can be specified by two parameters: center of the LPG and the radius (R) of the LPG. When other shapes are considered for LPG they can be specified using appropriate parameters. For example, elliptical LPGs can be specified using the center of the ellipse, the lengths of the major and minor axis of the ellipse. Considering circular LPGs, the LPGs in Figure 6 are uniquely identified by three parameters: idle mode MS that a LPG belongs to, center of the LPG, the radius of the LPG. The LPGs are specified using the following notation **LPG (idle mode MS that a LPG belongs to, center of LPG, radius of the LPG).** For example, LPG (MS1, A, R), LPG (MS2, B, R) and LPG (MS2, E, R) shown in Figure 6. For description of geo-location based PA design it is assumed that the radius of LPGs of different idle mode MSs is the same. It may be noted that the proposed concept is applicable when the radius of the PGs of different idle mode MSs are different.

The LPGs for idle mode MSs, MS1 and MS2 are considered to be circular with the center at the location where these MSs enters into idle mode. After entering idle mode when these MSs performs location update during their idle mode operation, (as described later) the LPG is centered at the location where these MSs perform location update. Thus, the LPG of an idle mode MS is centered at the location where the said MS enters into idle mode or at the location where the said MS performs its most recent location update.

As shown in Figure 6 the LPGs for MS1 and MS2 are different as they entered into idle mode from different locations. Similarly, it can be easily seen that when multiple idle mode MSs are present in the network, they may have different LPGs based on the location where they entered into idle mode or the location where they performed their most recent location updates.

The advantages of geo-location based PA can be easily observed by considered the movement of MS2 from B to C, C to D, and D to B. As these locations (A, B, C, and D) are located close to each other, these are all inside the LPG (MS2, B, R). Thus, when MS2 moves between these points, it does not have to perform location update. This reduces the unnecessary location update overhead that is incurred static configuration of PA is used as described earlier.

For idle mode MSs moving in a particular direction the geo-location based PA can be designed in such a way that instead of making the PA centered around the current location of the idle mode MS, the PA that is along the direction of MS's movement has one of its ends at MS's current location and is extended in the direction of MS's movement. This way the geo-location based PA can adapt to the movement pattern of an idle mode MS.

The location of an idle mode MS can be determined using different methods. For example Global Positioning System (GPS)-based location estimation technique can be used for this purpose. Other location estimation techniques such as assisted-GPS can be used for this purpose. In addition, triangulation technique using the location of three near by BSs can also be used to determine the location of the MS. Any other technique can be used to determine the location of the idle mode MSs. The location of a BS can also used to as the approximate location of the idle mode MSs in the coverage of the BS.

When geo-location based PA design is used, the procedures and the associated message flows during MS entering idle mode, location update, paging and idle mode exit operations are carried out as described in Appendix A.

3.2 Adaptive Paging Area Design:

This contribution proposes methodologies to determine the size of paging area in order to minimize the amount of air-link resources used during the idle mode operation of an MS. The air-link resources used during a single idle mode instance of an MS is given by Eq. (4) in Section 1.1. Analysis of Eq. (4) of Section 1.1 provides the following insights about the amount of resources used for location upate (LU) and paging operation, L.

1. Out of different parameters in Eq. (4), the only parameter that is MS specific is E[v]. Different idle 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 idle mode MS, the amount of resources (used for LUs and paging operation) for an idle mode MS with higher average speed more than the amount of resources (used for LUs and paging operation) for an idle mode MS with lower average speed. This is shown in Figure 1.
2. L depends on the number of LUs, E[h], performed by the idle mode MS during an idle instance. Therefore, L depends on the radius of the paging group (PG), R as shown in Figure 1. For a given R, E[h] depends on the average speed E[v] of an idle mode MS as shown in Figure 2.

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

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

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

It may be noted that out of all parameters that determine R_{min}, the only parameter that is MS specific is E[v]. Eq. (5) shows that an idle MS with higher average speed has higher R_{min} compared to an idle mode MS with lower average speed.

Thus the radius of minimum-resource PG for a particular idle mode MS is determined using Eq. (5). Once R_{min} is determined for an idle mode MS, the number of cells, N, in the said minimum-resource PG is calculated using

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

Where round function determines the nearest integer. Other functions such as $floor\left(\frac{R_{\min}{}^2}{r^2} \right)$ or $ceil\left(\frac{R_{\min}{}^2}{r^2} \right)$ could be used to determine the number of cells in the minimum-resource PG for the said idle mode MS.

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

The number of location updates performed by an idle mode MS is shown in Figure 8 for both statically configured and adaptive paging areas. It can be observed from this figure that when adaptive paging area is used the number of location updated performed by idle mode MSs moving with different speed is minimized. This minimizes the air-link signaling overhead associated with idle mode operation of an MS as shown in Figure 9.

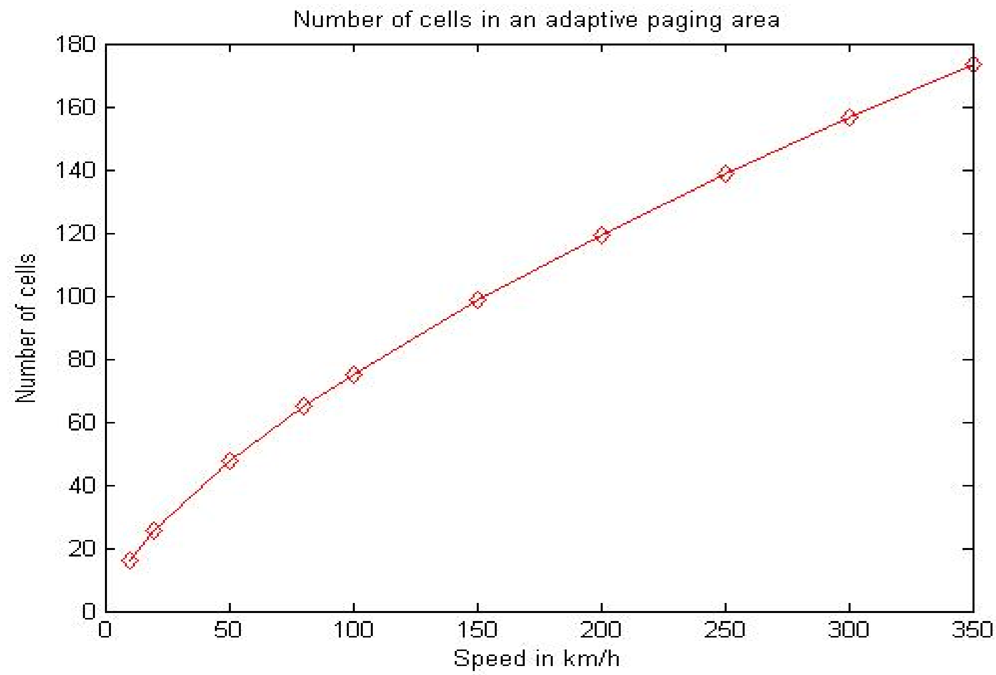

Figure 7: Adaptive paging area size for different speed using simulation.

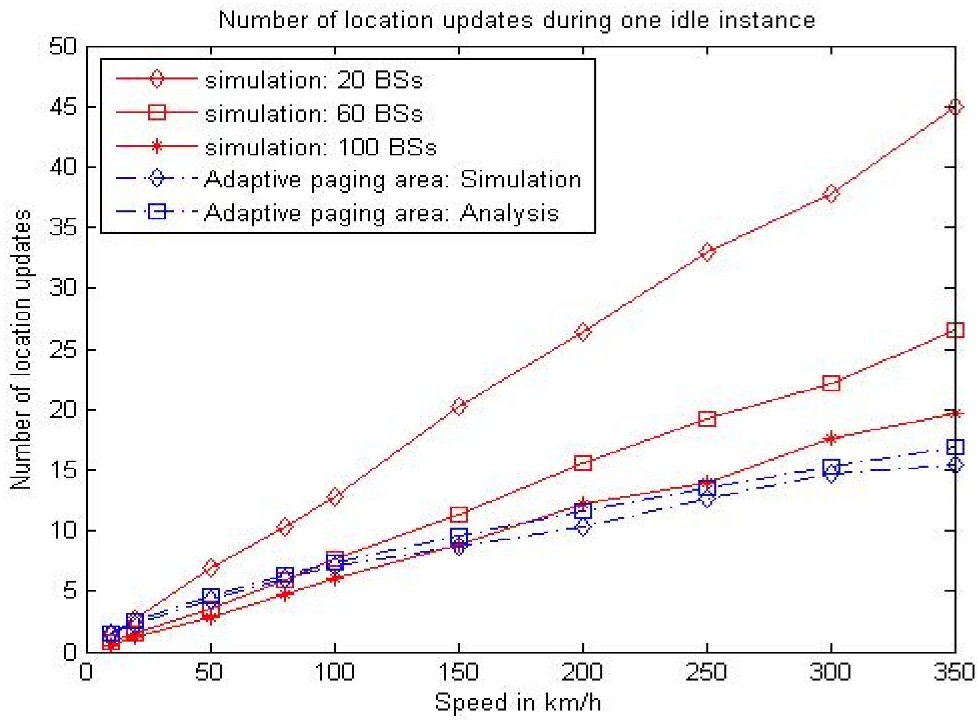

Figure 8: Number of location update comparison between adaptive and fixed paging area for different idle duration.

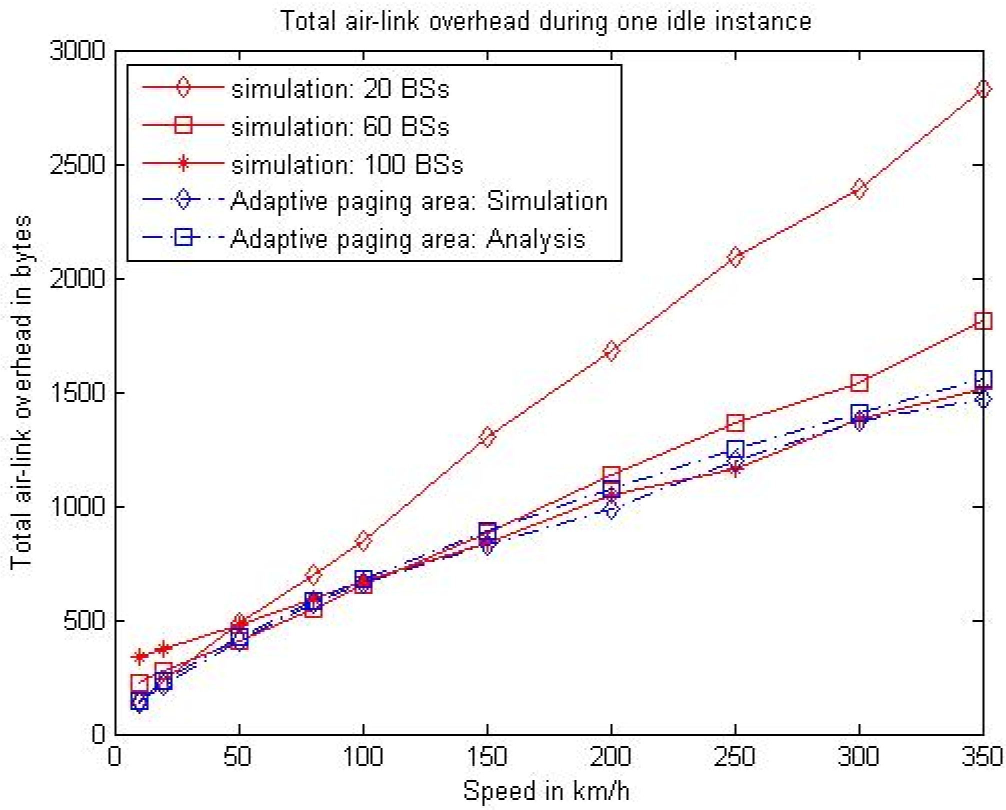

Figure 9: Signaling overhead comparison between adaptive and fixed paging area for different idle duration.

3.3 Paging cycle update depending on battery level of the mobile station

This section proposes methodologies to determine the paging cycle depending on the battery level of the mobile station. This section also includes the required MAC messaging to support battery level feedback.

The main objective of this part of the contribution is to minimize the power consumption and extend the battery life of the mobile station. Power consumption of mobile station depends on how often mobile station wakes up and how long the listen period is. Every time the mobile wakes up it reduces the battery life. In this contribution we are proposing to skip some paging cycles to decrease the power consumption. Figure 10 shows the diagram of the proposed scheme depending on the battery level of the users.

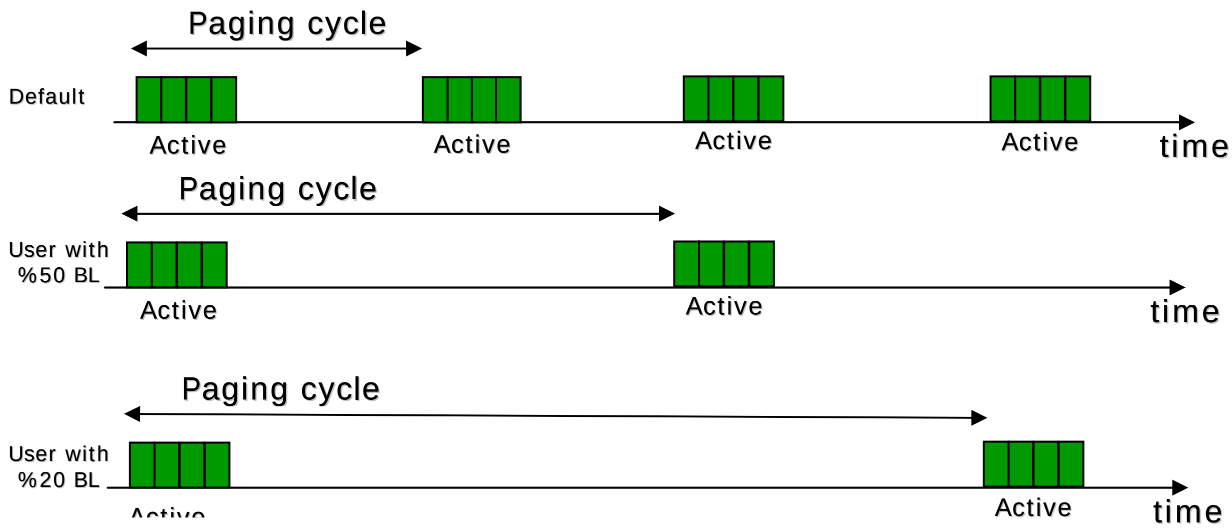

Figure 10: Adaptive paging cycle length depending on battery level.

The design of the paging cycle length faces a trade-off between two requirements: reduced power consumption at the MS and low delay in receiving paging message at the MS. Our proposal decreases the power consumption on the expense of increasing the delay of receiving the paging message. The mobile stations can request for such power optimization support at the call setup or during the call.

The design of the adaptive Idle Mode requires power state information for the users and MAC message to inform BS about the power state. The MS battery level feedback can be an event based feedback mechanism to tell the BS about the user's battery level. We expect the frequency of sending this feedback is on the order of a minute. It will be sent only when the battery level only when some battery level threshold is crossed or changed significantly..

Similarly, thermal status of the mobile station is also very useful information at the base station. The base station can schedule the transmissions and chooses the transmission rates based on this feedback to reduce the impact.

We propose two new MAC management messages which are BL-Feedback: MS Battery Level and Thermal Status Feedback and BL-ACK: MS Battery Level and Thermal Status Feedback Acknowledge. Table 1 shows an example MAC message which allows the transfer of battery level information of the users to the base station.

Table 1: Battery level feedback MAC management message format

Syntax	Size (in bits)	Notes
BL-Feedback_Message_Format () {		
Management Message Type=XX	8	
Battery Level	3	111: SS is plugged into a power source 110: Battery level is between 80 % and 100 %

		101: Battery level is between 65 % and 80 % 100: Battery level is between 50 % and 65 % 011: Battery level is between 35 % and 50 % 010: Battery level is between 20 % and 35 % 001: Battery level is between 10 % and 20 % 000: Battery level is between 0 % and 10 %
Thermal status	1	0: Thermal status is ok/not at a critical point. 1: Thermal status is at a critical point and SS needs cooling down.
}		

In the previous sections, some important requirements and considerations in the design of idle mode operation in IEEE 802.16m systems were discussed.

4. Proposed Text for SDD

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

------------------------------- Text Start ---

x. x.x.x Paging Area Design

The paging area can be designed in such a way that the idle mode MS is located in the paging area during idle mode entry or location update in a new paging area that minimizes the number of location updates by the MS. The paging area design takes into account users mobility profile and characteristics of applications used by user. In addition, the paging area design considers user's usage profile, e.g. the number of calls received by an MS in one hour.

The paging cycle design takes into account the mobile station's battery power level and the paging cycles can be increased when the battery level is below a threshold in order to optimize the power consumption. When the battery level at the mobile station is below a threshold value, mobile users send their battery level feedback information to adjust their paging cycle.

------------------------------- 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

When geo-location based PA is used, the procedures and the associated message flows during MS entering idle mode, location update, paging and idle mode exit operations are carried out as described below. It may be noted that the messages that are exchanged during these operations may include several information fields. In the following description only those information fields that are related to geo-location based PA are specifically mentioned and it is assumed that other information fields are present. Other information not related to this concept is not explicitly mentioned in the following description.

1. MS entering Idle Mode

MS initiated idle mode entry is considered to illustrate the operations during MS entering idle mode to describe the procedures carried out during idle mode entry of an MS when geo-location based PA is used. For example, the following procedures are used by MS1 and MS2 when they enter into idle mode from location A and B, respectively as shown in Figure 6. It may be noted that the procedures for network initiated MS entering idle mode has similar steps. The steps for MS initiated idle mode entry are as follows.

- When an MS decides to initiate idle mode, it sends deregistration request (DREG-REQ) message using the format defined in IEEE 802.16e to its serving BS (SBS). Along with other information specified in IEEE 802.16e standard, the MS includes its current location in the DREG-REQ message. The MS may include its desired LPG radius in the DREG-REQ. The MS location information can be encoded using the X, Y, and Z co-ordinates of the location. Other methods can be used by an idle mode MS to convey its current location in the DREG-REQ message.
- Upon receiving the DREG-REQ the SBS sends Data Path Release Request (Data Path Rel Req) message to the corresponding FA to trigger the data path release process for the MS. Along with other information contained in the Data Path Rel Req includes MS identification (MSID), SBS identification (BSID), MS location information, LPG radius (if present in the DREG-REQ message), MS's anchor PC identification (PCID).
- When the FA receives the Data Path Rel Req, it sends MS Information Report (MS Info Rprt) message to the PC identified by the PCID of the Data Path Rel Req

message. Along with other information MS Info Rprt contains the following information: MSID, MS location information, and LPG radius (if present in the Data Path Rel Req message).

- When the PC receives the MS Info Rprt message, it adds the MSID and its location information to its ldle Mode MS Information Table. The PC uses the ldle Mode MS Information Table to stores information about its idle mode MSs. If the MS Info Rprt contains information about MS's desired LPG radius and the PC agrees with this value, then PC may decide to use the LPG radius value requested by the MS to determine the size of the LPG for the MS. It may be noted that the PC may decide to LPG of size different than what the MS requested for. Once the PC decides about the LPG radius for the MS, it adds the LPG radius information to the entry in its ldle Mode MS Information Table corresponding to this MS. After the PC decides about the size of MS's LPG, it sends MS Information Response (MS Info Rsp) to the FA. MS Info Rsp message contains MSID, LPG radius, and PCID.
- When the FA receives the MS Info Rsp message, the FA adds the MSID, PCID information along with other information to its table and sends Data Path Release Response (Data Path Rel Rsp) message containing MSID, PCID, and LPG radius to the SBS.
- The SBS sends DREG-CMD message containing the PCID and LPG radius to the MS upon receiving Data Path Rel Rsp message. The MS goes to idle mode upon receiving DREG-CMD. The MS stores the PCID, information about its LPG center and radius to use during its idle mode operation. It may be noted that the LPG center is the location of the MS when it initiated its idle mode entry.

The message flow for MS entering the idle mode is shown in Figure 11.

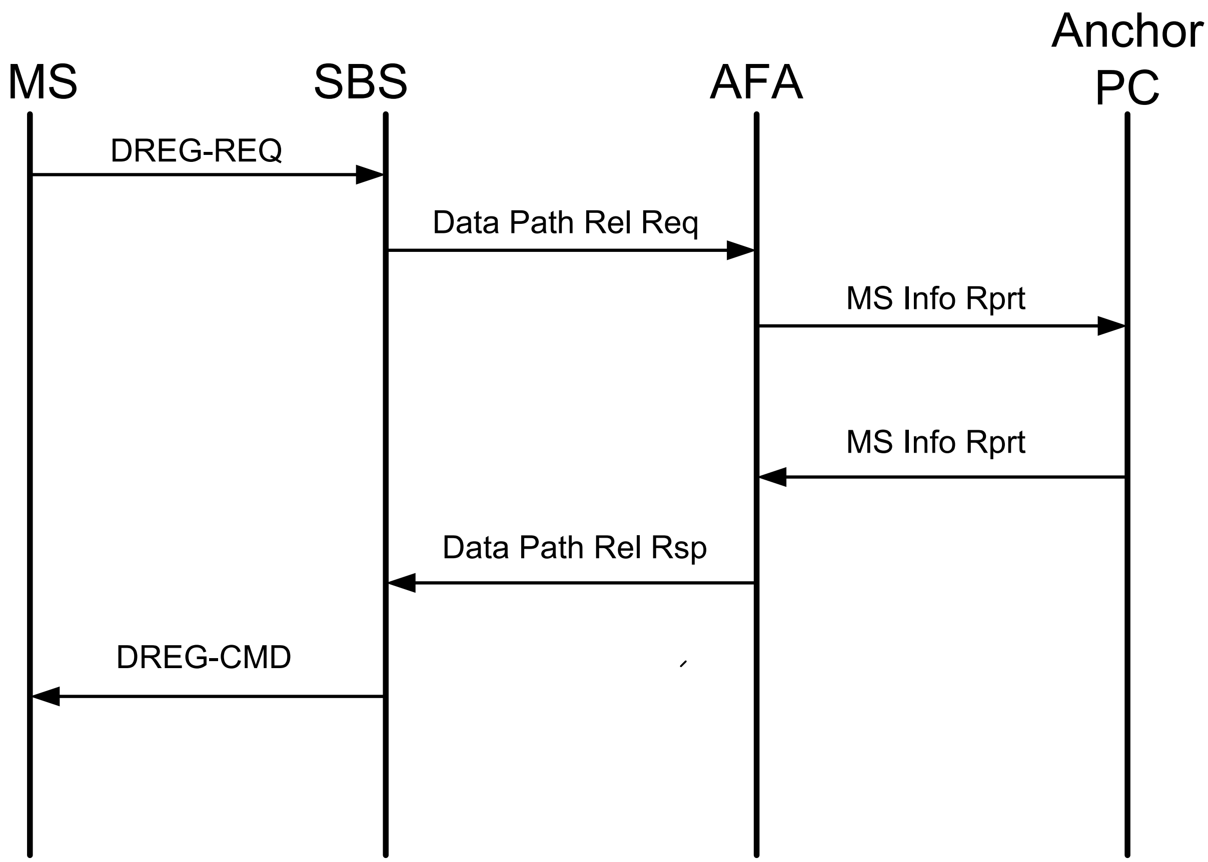

Figure 11: Message flows for MS entering idle mode.

2. MS Performing Location Update

When geo-location based PA is used an idle mode MS learns its current location during its Paging Listening Interval (PLI). Then, it determines if its current location is inside its LPG region. The MS learns about it by determining the distance between its current location and its LPG center. Assuming that (X, Y, Z) co-ordinates are used to denote the location information; the distance (D_{ms}) of MS's current location from the center of its LPG is given by Eq. (1).

$$D_{ms} = \sqrt{(X_c - x)^2 + (Y_c - y)^2 + (Z_c - z)^2} \text{ ------Eq. (1)}$$

where (X_c, Y_c, Z_c) are the co-ordinates of the LPG center and (x, y, z) are the co-ordinates of MS's current location. If D_{ms} is greater than its LPG radius, then the MS learns that it has moved out of its LPG and needs to perform location update.

During its PLI if the MS learns that it is inside its LPG, then the MS determines whether or not its current serving BS is located inside its LPG. It may be noted that the serving BS is the one from which the idle mode MS receives the broadcast messages. To determine whether or not its serving BS is located inside its LPG, the MS listens for broadcast message containing the location information of the BS. The BS can broadcast their location information by including this information in different broadcast messages such as Mobile Paging Advertisement (MOB-PAG-ADV), downlink channel descriptor (DCD) message etc. It may be noted that the BSs could use other methods to broadcast their location information. The idle mode MS determines the distance between its current serving BS and its LPG center, D_{bs}, using Eq. (2).

$$D_{ms} = \sqrt{(X_c - X_b)^2 + (Y_c - Y_b)^2 + (Z_c - Z_b)^2} \text{ ------Eq. (2)}$$

where (X_c, Y_c, Z_c) are the co-ordinates of the LPG center and (X_b, Y_b, Z_b) are the co-ordinates of MS's current serving BS location. If D_{bs} is greater than its LPG radius, then the MS learns that its current serving BS is outsize of its LPG. In this case the idle mode realizes that it needs to perform location update.

Using procedures described above an idle mode MS learns that it needs to perform location update.

An example scenario for location update for idle mode MS2 is illustrated in Figure 6 when MS2 is located at E during one of its PLI. When MS2 is located at E, it learns that it is inside its current LPG centered at A with radius of R. However, it learnt that its current serving BS, BS34 in Figure 6 is outside the LPG. Thus, MS2 performs location update and updates its LPG from LPG (MS2, A, R) to LPG (MS2, E, R). It may be noted that after every location update, the new LPG of the MS is centered at the location where the MS performs location update. For example, in the example scenario of Figure 6 point E becomes the center of MS2's new LPG as MS2 performs location update when it was located at E.

The message flows for location update procedures are shown in Figure 12. The location update procedure has the following steps.

- The MS sends ranging request (RNG-REQ) message to the serving BS (SBS) indicating that it needs to perform location update. The MS includes its anchor PC ID and its current location in the RNG-REQ message.
- Upon receiving RNG-REQ the SBS sends a location update request (LU_Req) message to the anchor PC of the said idle mode MS identified by PCID included in the RNG-REQ message. The LU_Req contains the following information: MSID, PCID, and current location information of the MS. Upon receiving the LU_Req message, the PC updates the location of the MS and sends the location update response (LU_Rsp) message to idle mode MS's current SBS.
- When the SBS receives the LU_RSP, it sends ranging response (RNG-RSP) to the MS informing about the successful completion of location update. Then, SBS sends location update confirm (LU_Confirm) message to the anchor PC of the MS.

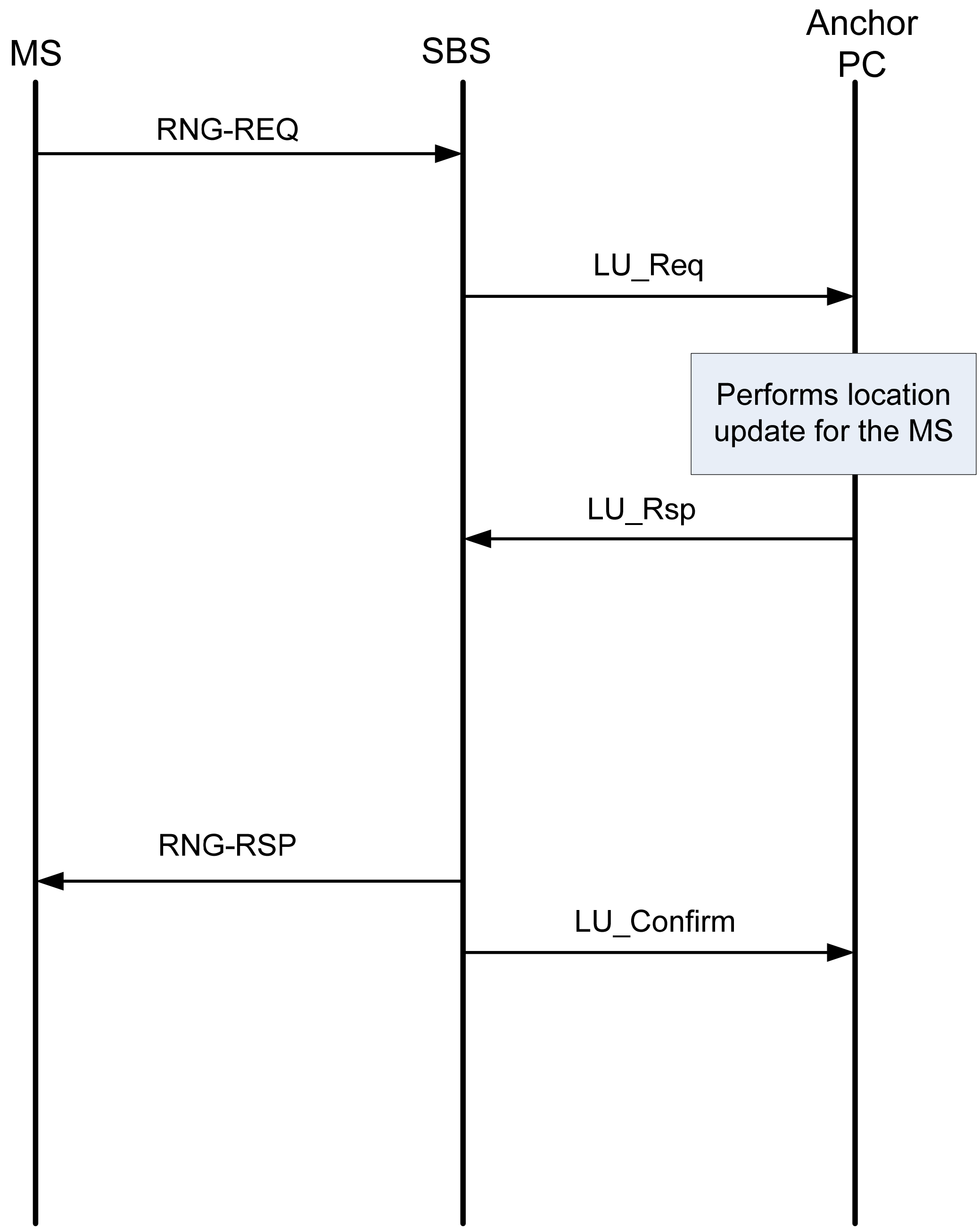

Figure 12: Message flows for location update.

3. MS Paging and MS Exiting Idle Mode

When the network want to locate an idle mode MS, it pages the MS using MOB-PAG-ADV message. It may be noted that the need to locate an idle mode user arises mostly because of the arrival of new packets destined for the MS. For the remaining part of this document, we assume that all the packets destined for the MS first reaches MS's home agent (HA). Then HA forwards the packets to the FA using Mobile IP address binding that is present in its database. It may be noted that the FA is the AFA if the user is in idle mode. The FA learns that the MS is in idle mode. Then, the FA and sends a MS Paging Request (MS-PAG-Req) message to the anchor PC of the MS. When the PC receives the paging message, the PC broadcasts paging message to all the BSs in the LPG of the MS. The MS resides in the coverage area of one these BSs and it receives the paging message and replies to it through ranging request (RNG-REQ) message indicating that it wants to exit idle mode and perform network re-entry from idle mode. This RNG-REQ message is received by MS's current serving BS (SBS). Then the SBS assists the idle mode MS to perform network re-entry from idle mode. The message flow for paging is shown in Figure 13.

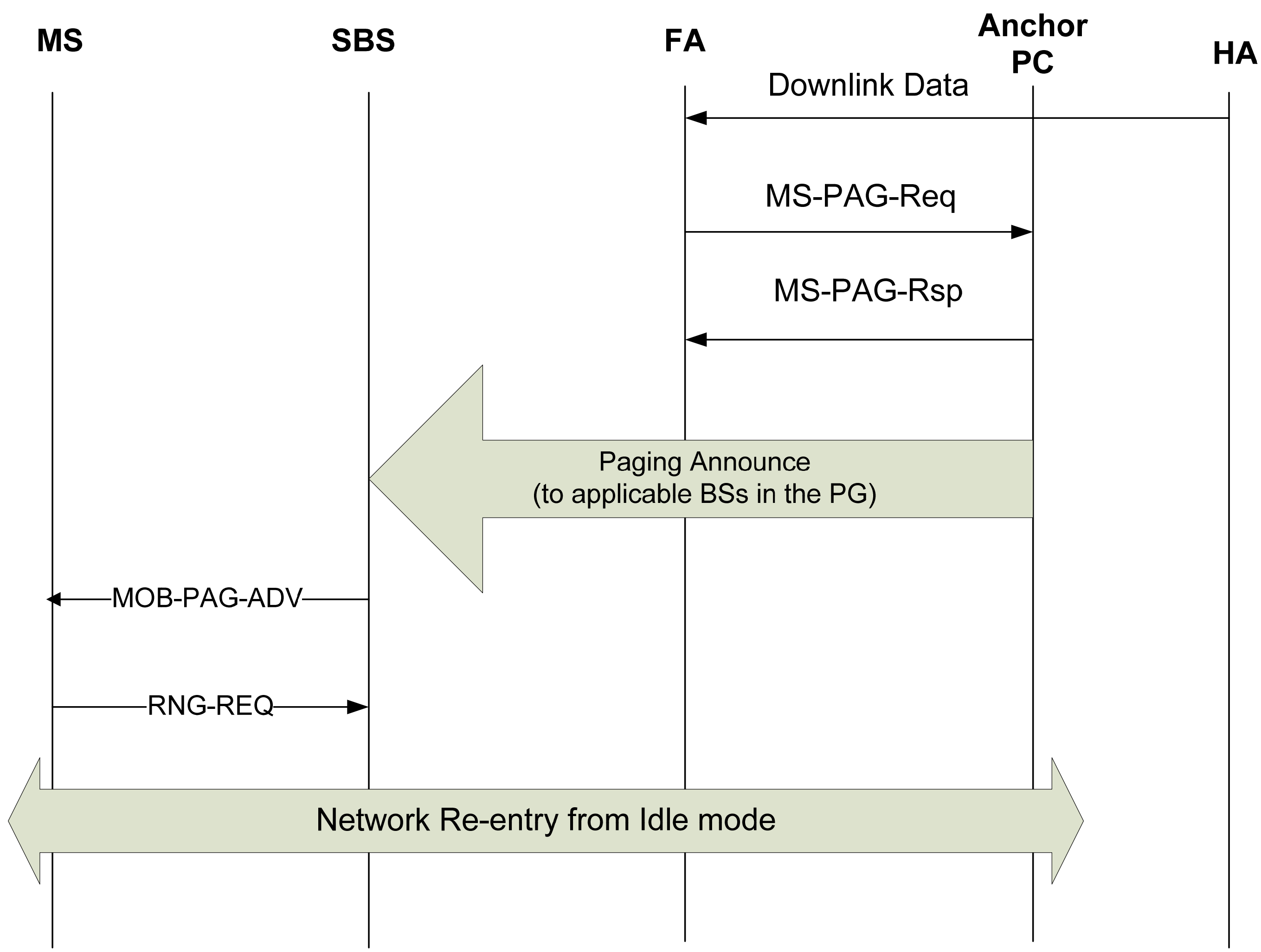

Figure 13: Message flows for Paging and MS network re-entry.

It may be noted that the messages that are exchanged during these operations may include several information fields. In the following description only those information fields that are related to geo-location based PA are specifically mentioned and it is assumed that other information fields are present. Other information not related to geo-location based PA is not explicitly mentioned in the description of different operations associated with idle mode.

Appendix B

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

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

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

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