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Abstract	This document presents the needed enhancements that can be done to the IEEE802.16a standard in order to support mobility operation. The presented enhancements are mostly in the MAC layer and generic to all PHY modes of the standard (e.g. Sleep Mode and Handoff processes).
Purpose	Present how the IEEE802.16a can be enhanced in order to support mobility.
Notice	
Release	
Patent Policy and Procedures	

IEEE802.16e Mobility Enhancements

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1 General

This document presents the needed enhancements that can be done to the IEEE802.16a standard in order to support mobility operation.
The presented enhancements are mostly in the MAC layer and generic to all PHY modes of the standard (e.g. Sleep Mode and Handoff processes).
The enhancements for fast SS tracking is brought in context of the OFDMA PHY, while the idea can be adopted to other relevant modes.

2 Changes to the Standard required to support mobility

2.1 Changes to the OFDMA PHY

The OFDMA PHY specified in [2] is capable of handling mobile operating conditions. No changes are required in the PHY to support mobility under the assumptions stated at [8] (for further elaboration on this topic see [3]).

2.2 MAC related PHY enhancements

2.2.1 Extended OFDMA forward APC range

The Forward Automatic Power Control (FAPC) defined in [2] should have more degrees of freedom, in order to facilitate finer control of variations in the mobile channel.
The following change is proposed for this purpose:
See section 4.3 for specific text to be entered into the standard.

2.2.2 Fast correction of uplink power, frequency and timing

Fast uplink tracking is an extension of the fast uplink power control support defined in [2]. The extension is proposed in order to enable fast frequency and timing correction in the uplink, and offer better tracking of the variations introduced by the mobile channel.
See section 4.2 for specific text to be entered into the standard.

2.3 Power consumption reduction

2.3.1 The traffic model

In a mobile system, in which mobile SS are moving within the BS's sector, minimizing the energy usage of each SS is an important goal in the system design.
The typical traffic profile of a SS is of a bursty nature. According to the 4IPP (four Interrupted Poisson Process) traffic model suggested in [4], the SS has an *off* and an *on* period. An interrupted Poisson process is generating

packets during the *on* period and not generating packets during the *off* period. Two probabilities, *c1* and *c2,* are defined for switching between the periods.
The model was claimed to generate an accurate representation of traffic for Ethernet and Internet.

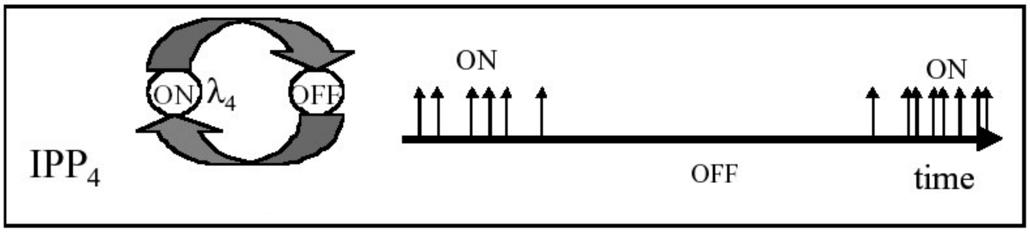

Figure 1: 4IPP traffic model

The 4IPP model presents (possibly) long idle periods, in which the SS does not generate traffic. This gives a motivation of using a *sleep-mode* mechanism for the SS, e.g. enable the SS to reduce power consumption in the idle intervals by turning off it's air-interface.

2.3.2 Proposed sleep-mode

A working SS that supports sleep-mode can be in one of two modes:

- Awake
- Sleep

When SS is in *awake-mode*, it is receiving and transmitting PDUs in a normal fashion. When SS is in a *sleep-mode*, it does not send or receive PDUs. In *sleep-mode* the SS may power down.

The two following intervals are defined:
Sleep-interval – The time duration from the point the SS has entered *sleep-mode* until it returns to *awake-mode*. During consecutive sleep periods the *sleep-interval* will be updated using an exponentially increasing algorithm with adjustable minimum and maximum limits.
Listening-interval – The time duration during which the SS, after waking up and synchronizing with the DL transmissions, can demodulate downlink transmissions and decides whether to stay awake or go back to sleep. The *Listening-interval* is agreed between the BS and the SS and is adjustable.

Before entering sleep mode the SS must inform the BS and obtain its approval. The BS may buffer (or it may drop) incoming PDUs addressed to the sleeping SS, and will send notification to the SS in it's awakening periods about whether data has been addressed for it. The SS will awake according to the *sleep-interval* and will check whether there were PDUs addressed for it. If such PDUs exist, it will remain awake. An SS may terminate *sleep-mode* and return to *awake-mode* anytime (i.e. there is no need to wait until the *sleep-interval* is over).

The following points are summary of necessary items for supporting sleeping mode:

- The *sleep-interval* and the algorithm for increasing it
- BS support for buffering (or dropping) of packets for a SS that is in sleep mode
- BS and SS are synchronized with regards to the times in which the SS awakes
- The BS notifies the SS, about existence PDUs addressed for it

2.3.3 Sleep Mode Messages

The following messages are defined to support sleep-mode:

- ***Sleep-Request*** (SS→ BS): Request of the SS to enter into sleep mode. The message will include requested *sleep-interval* parameters (e.g. *min-window*, *max-window* and *listening-interval*).
- ***Sleep-Response*** (BS→SS): Authorization from the BS to the SS to enter *sleep-mode.* The message will include requested *sleep-interval* parameters (e.g. *min-window* and *max-window*), the *listening-interval* and a reference time for starting the process. This message is sent as a response to ***Sleep-Request*** or as an unsolicited instruction.
- ***Traffic-Indication*** (BS→SS): Indication of the BS to an SS in one of the frames during the *listening-interval*, that there have been PDUs addressed for it. For efficiency reasons, this message is a broadcast message.

See section 4.1 for specific text to be entered into the standard.

2.4 Handoff

2.4.1 Handoff process in the MAC layer

The proposed handoff scheme aims at guaranteeing a smooth handoff process that is compliant with the security and QoS notions of the MAC. The handoff scheme is based on the following elements:

A BS will advertise information about neighbor BS –Each BS will broadcast information about the network topology for their SS (i.e. who are the neighbor BS, the PHY settings required to synchronize with them, their capabilities and the service grade they can offer, their transmit power and (N+I) floor to speed up ranging, their DCD and UCD info, etc.). Each SS will thus be able to synchronize quickly with neighbor BS.

A BS will allocate time for each SS where it may listen to neighbor BS – Add a capability to indicate in the DL traffic map when a SS may not listen to its BS, and instead listen to neighbor BS. The allocated time duration should be long enough, so the SS can synchronize with the neighbor BS and estimate the quality of the PHY connection. The initiative to allocate these times may come from either the BS or the SS (because each can sense a bad signal quality). The decision when to allocate these times is with the BS.

A SS will listen to neighbor BS – In time intervals allocated by the BS, an SS will attempt to synchronize with neighbors BS and estimate the signal quality.

Handoff initiation – Based on signal quality (and possibly other factors), either an SS or a BS may request to initiate a handoff. Before executing the handoff, the neighboring BS are notified through the backbone of the handoff request. Each neighbor BS returns feedback about it's capability to service the SS. All the information concerning the SS (capabilities, security, registration information, connection information, etc.) is transmitted via the backbone to the neighbor BS.

Actual handoff – When the actual handoff takes place, the new host BS as well as all neighbor BS are aware of the SS handoff. The SS current host BS notifies it that the handoff should be executed, and may recommend a preferred new BS. The higher network layers are notified of the pending handoff as well.
After transitioning to the new host BS the SS performs the following steps:

1. Ranging and uplink parameters adjustment (power, frequency, time). This stage is similar to the one performed at initial network entry. During this stage the SS is assigned a new basic and primary management CID in the new host BS.
2. SS authorization. During this stage the SS performs the re-authorization part of the PKM protocol used at initial network entry (see [1] section 7.2). The BS authenticates the user and as the security context

has not changed (it has been transferred from the old BS via backbone) the security sub-layer can continue in normal operation.

3. Re-establish provisioned connections. During this stage the connections supported by the SS have to be re-established. This is necessary because the CID space is not global (i.e. there is no guarantee that a CID used in the old BS can be used in the new BS). There are also situations in which the new BS will not be able to provision some of the connections (due to lack of resource for example), and these will have to be closed, or changed. The new host BS is the initiator of the message handshake required to re-establish the connections.
4. Normal operation. At this stage normal operation commences. The SS still has to re-establish its IP connectivity in order to obtain a valid IP address for management purposes.

Some stages performed at initial network entry are **NOT** performed during handoff:

1. During the initial network entry process the SS authorization stage is followed by a registration with BS stage. During this stage at initial network entry, information relating to the capabilities of the SS and the BS is exchanged (e.g. what convergence layers are supported, PHS support, etc). As we assume that all BS are conforming to a certain *mobile-operation-profile*, there is no need to pass information beyond what has already been exchanged at network entry.
2. During initial network entry process the registration-with-BS stage is followed by the establish-IP-connectivity stage. During this stage the SS is assigned an IP address for management purposes. This stage is not skipped during handoff (because typically a new IP address will have to be assigned as the IP subnet to which the SS is connected may have changed). Instead it is postponed until the normal-operation stage is reached.
3. During initial network entry process the establish-IP-connectivity stage is followed by the transfer-operational-parameters stage (and also time-of-day establishment stage). This stage may be skipped, as none of the information contained in the configuration file is expected to change.

The diagram below shows how the handoff process interoperates with the existing network-entry and synchronization procedure (SS view).

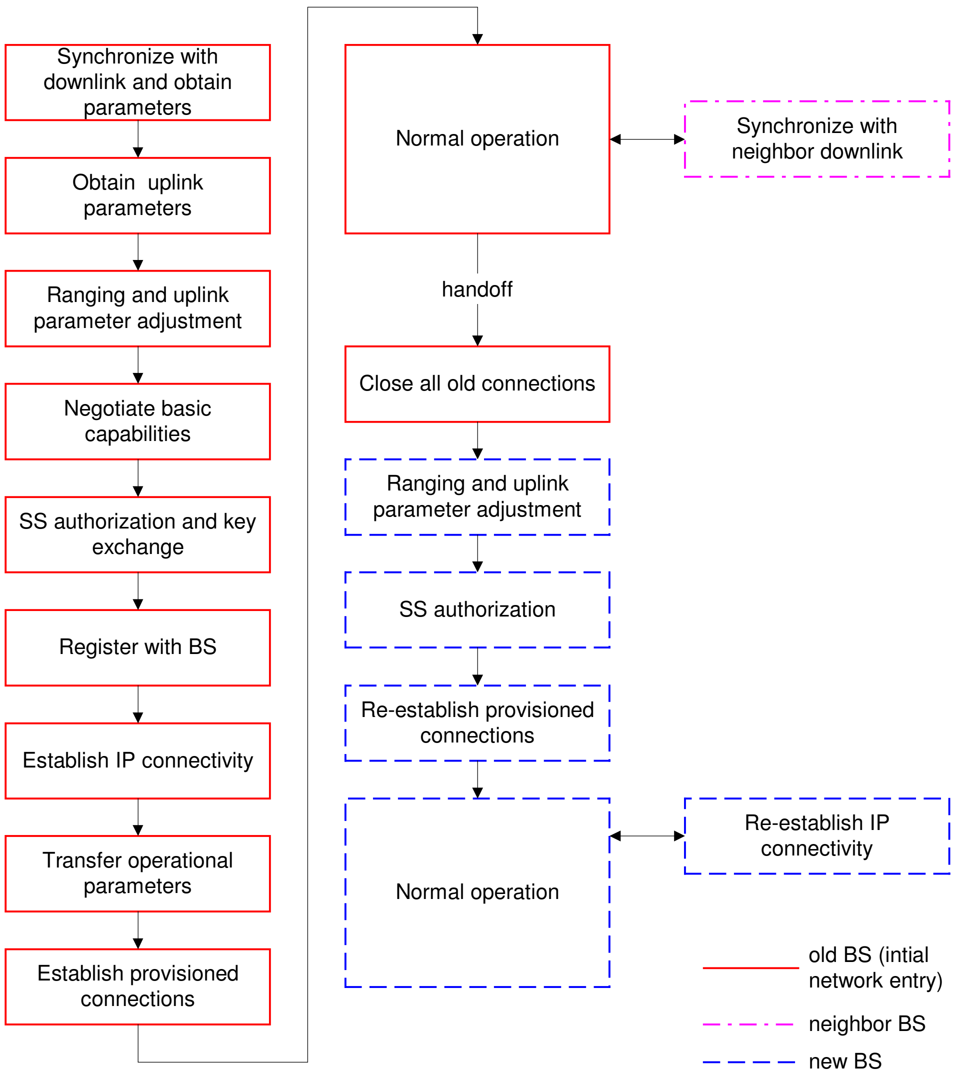

Figure 2: SS view of the network entry and handoff process

2.4.2 MAC messages for handoff

Signal-strength-query – Sent from BS to SS to get information about SS perceived signal quality from its host BS and from neighbor BS.

Signal-strength-response – Sent as a response to the *Signal-strength-query* message, or may be sent unsolicited by the SS to cue the BS that a SS requires downlink allocations where it can find neighbors.

Handoff-request – May be sent by either the SS or the BS to indicate that a handoff is required. When sent by the SS, the SS indicates the possible new hosts (from signal quality point of view). When sent by the BS, the BS indicates the recommended new hosts. The SS may select one of the offered new host BS. The message also includes an indication when the handoff would take place.

Handoff-response – Sent by either BS or SS as a response to the Handoff-request message. When sent by a BS, the message indicates a recommended new host BS. The recommendation may be ignored by the SS at the risk

that if it chooses an alternative host BS, it might receive a worse level of service. When sent by a SS, the SS acknowledges receipt of Handoff-request message.
The message also includes an amended indication of the time when the handoff would take place (only the BS may amend this value, the SS has to repeat it).

Handoff-ACK – Sent by either BS or SS as a response to the Handoff-response message. This message terminates the three-way handoff handshake and guarantees the both SS and BS are synchronized.

Figure 3 below shows how the messages are used to perform the handoff.

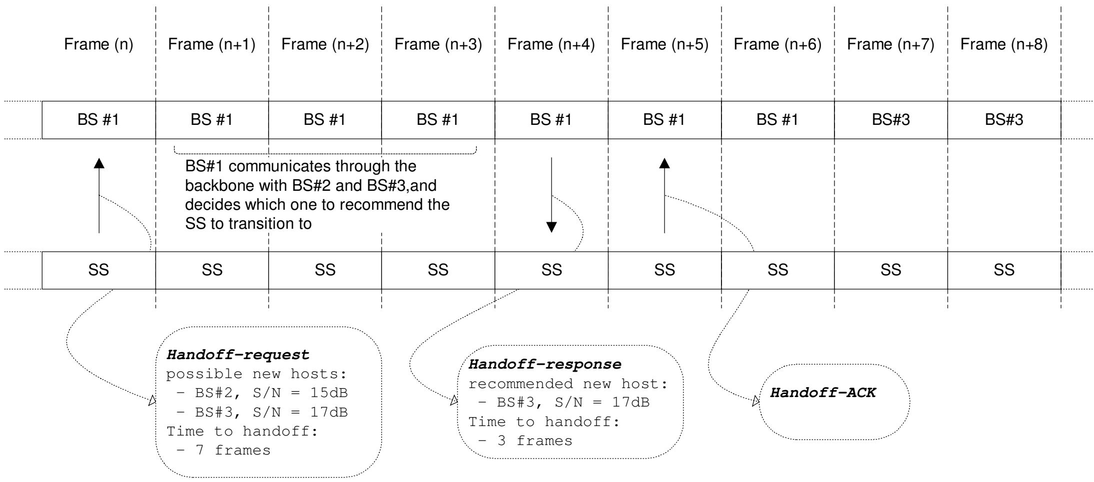

Figure 3: View of a handoff in the time domain

See section 4.4 for specific text to be entered into the standard.

2.4.3 Handling drops

A drop is defined as the situation where a SS has stopped communication with its old host BS before the normal handoff procedure has been executed. When a drop occurs, the SS shall attempt to follow the handoff stages as shown in Figure 2. In many situations this will suffice, as neighbor BS will either be aware of the SS or will be able to communicate with it's old BS via the backbone to the required information about it.

2.4.4 Communication through the backbone

The BS communicate through the backbone to perform the handoff, therefore to ensure interoperability between BS from different manufacturers the format of this communication should be standardized. It is proposed to use UDP as the transport protocol. Resource reservation and QoS over the backbone are not addressed.

The following messages are defined for backbone communication protocol:

BS-Host-Adv– This message is sent by a BS that wishes to notify neighbor BS that a certain SS is registered with it. The message may trigger a neighbor BS to request more information about the SS (either directly from the sender BS, or from some centralized resource that is outside the scope of this specification. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)

- List of SS MAC address (those supplied by the SS during initial-ranging phase of the network entry process)

SS-info-request – This message may be sent from one BS to another to request information about a SS. Typically the message will be sent as a reaction to reception of an *BS-Host-Adv* message, or in cases where a SS is trying to re-enter the network after a handoff. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)
- SS MAC address whose info is requested (as provided by the *BS-Host-Adv* message, or as provided by an SS trying to register after a handoff)

***SS-info-response* –** This message is sent from one BS to another BS as a response to a *SS-info-request* message. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)
- SS MAC address whose info has been requested (as provided by the *SS-info-request* message)
- SS capabilities info (PHY related capabilities, and capabilities negotiated during registration)
- SS security association state information (AK, SAID, TEK)
- Service flow information (as per the TLVs defined for the service flow encoding in [1]).

***Handoff-notification* –** This message is sent by a BS that requires an SS handoff. The message is sent to all neighbor BS. The message serves to alert the neighbor BS that a handoff event is going to happen. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)
- SS MAC address (those supplied by the SS during initial-ranging phase of the network entry process)
- Estimated time when the handoff will take place

***Handoff-notification-response* –** This message is sent from one BS to another BS in response to a *Handoff-notification* message. The message serves to inform the BS that sent the *Handoff-notification* message that it has been received. The message also provides information about the level of service the SS may expect if it transitions to it the sending BS. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)
- SS MAC address (as provided by the *Handoff-notification* message)
- A measure of the capability of the sender BS to support the service-flows associated with the SS (TBD how exactly to define this)

3 Fixed and mobile backwards compatibility

Backwards compatibility between the fixed and mobile SS is large part guaranteed by the fact the no change is required in the PHY layer. The mobile extension to [2] introduces new MAC messages to enhance the fast channel tracking capabilities of the PHY, introduce a reduced power mode of operation and perform handoffs. Fixed SS should never initiate or be the target of messages relating to handoff or sleep-mode and therefore these extensions pose no backwards compatibility problem.

4 Text to be inserted in the standard

4.1 Power consumption reduction

6.2.2.3.40 Sleep Request message (SLP-REQ)

SS supporting sleep-mode uses the SLP-REQ message to request permission from the BS to enter sleep-mode. The SLP-REQ message is sent from SS to the BS on the SS's basic CID. The message includes sleep-mode parameters as requested by the SS.

Table xxx: Sleep-Request (SLP-REQ) message format

Syntax	Size	Notes
SLP-REQ_Message_Format() {		
Management message type = 45	8 bit	
min-window	6 bit	
Max-window	10 bit	
listening interval	8 bit	
}		

Parameters shall be as follows:

Min window
Requested start value for the sleep interval (measured in frames).
Max window
Requested stop value for the sleep interval (measured in frames).
Listening interval
Requested listening interval (measured in frames).

6.2.2.3.41 Sleep Response message (SLP-RSP)

The SLP-RSP message shall be sent from BS to a SS on the SS's basic CID in response to an SLP-REQ message. The SS shall enter sleep-mode using the parameters indicated in the message.

Table xxx: Sleep-Response (SLP-RSP) message format

Syntax	Size	Notes
SLP-RSP_Message_Format() {		
Management message type = 46	8 bit	
Sleep-approved	1 bit	0: Sleep-mode request denied 1: Sleep-mode request approved
If (Sleep-approved == 0) {		
Reserved	7 bit	
} else {		
Start-time	7 bit	
min-window	6 bit	
max-window	10 bit	
listening interval	8 bit	
}		
}		

Parameters shall be as follows:

Sleep approved

Defines whether or not the request to enter sleep-mode has been approved by the BS.

Start-time

The number of frames (not including the frame in which the message has been received) until the SS shall enter the first sleep-interval.

Min window

Start value for the sleep interval (measured in frames).

Max window

Stop value for the sleep interval (measured in frames).

Listening interval

Value for the listening interval (measured in frames).

6.2.2.3.42 Traffic Indication message (TRF-IND)

This message is sent from BS to SS on the broadcast CID. The message is intended for SS that are in sleep-mode, and is sent during those SS listening-interval. The message indicates whether or not there has been traffic addressed to each SS that is in sleep-mode. A SS that is in sleep-modem, during its listening-interval, shall decode this message seek an indication addressed to itself.

Table xxx: Traffic-Indication (TRF-IND) message format

Syntax	Size	Notes
TRF-IND_Message_Format() {		
Management message type = 47	8 bit	
Positive_Indication_List() {		Traffic has been addressed to these SS
Num-positive	8 bit	
for (i=0; i< Num-positive; i++) {		
CID	16 bit	Basic CID of the SS
}		
Negative_Indication_List() {		Traffic has not been addressed to these SS
Num-negative	8 bit	
for (i=0; i< Num-negative; i++) {		
CID	16 bit	Basic CID of the SS
}		
}		

Parameters shall be as follows:

Num-positive

Number of CIDs on the positive indication list.

Num-negative

Number of CIDs on the negative indication list.

6.2.16 Sleep-mode for mobility-supporting SS

6.2.16.1 Introduction

Sleep-mode is a mode in which SS supporting mobility may power down. Sleep-mode is intended to enable mobility-supporting SS to minimize their energy usage while staying connected to the network. Implementation of power-save mode is optional.

A SS that supports sleep-mode can be in one of two modes:

- Awake
- Sleep

When SS is in awake-mode, it is receiving and transmitting PDUs in a normal fashion. When SS is in a sleep-mode, it does not send or receive PDUs. In sleep-mode the SS may power down.

Two intervals are defined:
Sleep-interval – A time duration, measured in whole frames, where the SS is in sleep-mode. During consecutive sleep periods the sleep-interval shall be updated using an exponentially increasing algorithm with adjustable minimum and maximum limits.

Listening-interval – A time duration, measured in whole frames, during which the SS, shall be able to demodulate downlink transmissions. During this interval the SS shall decides whether to stay awake or go back to sleep based on an indication from the BS. The Listening-interval is agreed between the BS and the SS and is adjustable.

Before entering sleep-mode the SS shall inform the BS and obtain its approval. The BS may buffer (or it may drop) incoming PDUs addressed to the sleeping SS, and shall a send notification to the SS in it's awakening periods about whether data has been addressed for it.

A SS shall awake according to the sleep-interval and check whether there were PDUs addressed for it. If such PDUs exist, it shall remain awake. A SS may terminate sleep-mode and return to awake-mode anytime (i.e. there is no need to wait until the sleep-interval is over). If the BS receives data from a SS that is supposed to be in sleep-mode, the BS shall assume that the SS is no longer in sleep-mode.

6.2.16.2 Sleep-interval update algorithm

A SS shall enter sleep-mode after receiving an SLP-RSP message from the BS. In the first time it enters sleep-mode, it shall use the min-window value for the sleep interval. If during the following listening interval the BS has not signaled that traffic has been addressed for the SS, the SS shall re-enter sleep-mode an double the duration of the sleep-interval. This procedure shall be repeated as long as the resulting sleep-interval does not exceed the max-window value.

6.2.16.3 Traffic indication signaling

The BS shall indicate for each SS in sleep-mode, during its listening-interval, whether or not traffic has been addressed to it. The indication is sent on the TRF-IND broadcast message. If a SS fails to find an indication addressed to it, it shall assume that the BS no longer considers it in sleep-mode, and shall continue with normal operation. Once a SS has identified the indication addressed to it, it may skip the rest of the listening interval and return to sleep-mode.

6.2.16.4 Example of sleep-mode operation

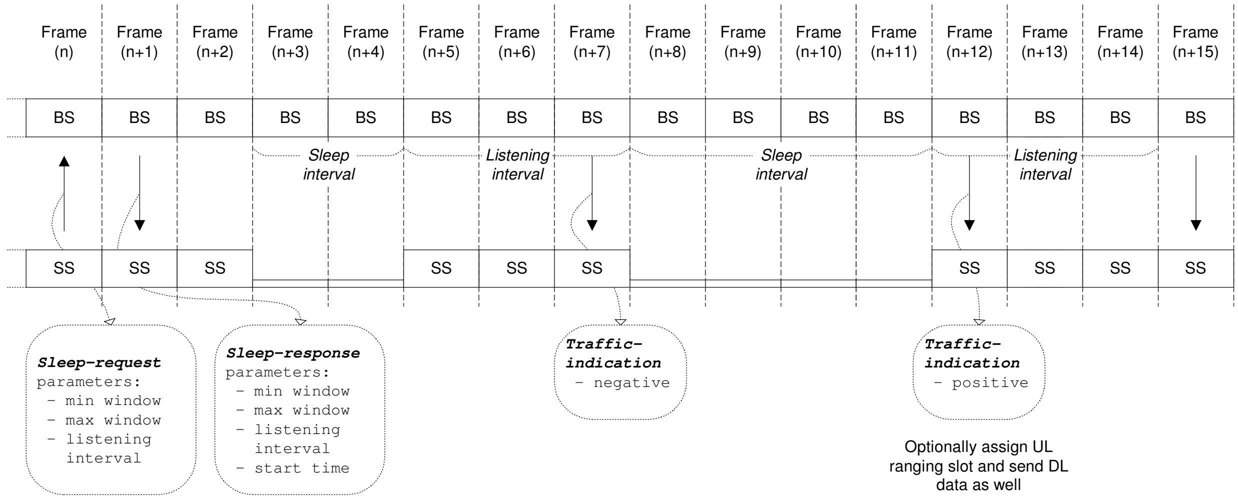

Figure xxx: Example of sleep-mode operation

4.2 Fast correction of uplink power, frequency and timing

8.5.5.3.5 UL-MAP Fast tracking indication

The UL-MAP Fast Indication in an UL-MAP entry used to provide fast power, time and frequency indications\corrections to SS that have transmitted in the previous frame.
The extended UIUC=15 shall be used for this IE with sub-code 0x03
The CID used in the Information Element should be a broadcast CID.

Table xxx—UL fast tracking Information Element

Syntax	4.2.1.1.1 Size	Notes
UL_Fast_tracking_IE() {		
extended UIUC	4 bits	Fast-Indication = 0x03
Number of Elements	8 bits	Number of Fast Indication bytes
for (*i* = 1; *i* <= *n*; *i*++) {		For each Fast Indication bytes 1 to n (n=Number of Element field)
Power correction	2	Power correction indication, 00: no change; 01: +2dB; 10: -1dB; 11: -2dB
Frequency correction	4	Frequency correction. Units are PHY-specific For OFDM/OFDMA: The correction is 0.1% of the carrier spacing multiplied by the 4-bit number interpreted as a signed integer (i.e. 1000: -8; … 0000: 0; … 0111: 7)
Time correction	2	Time offset correction. Units are PHY-specific For OFDM/OFDMA: The correction is floor(2 / F_s) multiplied by, 00: 0; 01: 1; 10: -1; 11: Not used
}		
}		

The UL Fast tracking IE is an optional field in the UL_MAP. When this IE is sent it provides an indication about corrections that should be applied by SS that have transmitted in the pervious UL frame. Each Indication byte shall correspond to one unicast allocation-IE that has indicated an allocation of an uplink transmission slot in the previous UL_MAP. The order of the indication bytes shall be the same as the order of the unicast allocation-IE in the UL-MAP.

4.3 Extended OFDMA forward APC range

In section **8.5.5.2 DL-MAP Information Element format**:

- Change number of bits of **OFDM Symbol offset** field from 10 to 9.
- Change number of bits of **Boosting**[*] field from 2 to 3.
- Changed the possible values of the **Boosting** field as follows: 000: normal (not boosted); 001: +3dB; 010: +6dB; 011: -3dB; 100: -6dB; 101: -9dB; 110: -12dB; 111: -15dB;

4.4 Handoff

TBD

[*] This field should be moved from UL-MAP IE to DL-MAP IE due to an editorial error, and should be fixed in the errata process.

References

[1] IEEE Std 802.16-2001 “Part 16: Air Interface for Fixed Broadband Wireless Access Systems”
[2] IEEE P802.16a/D7-2002 “Part 16: Air Interface for Fixed Broadband Wireless Access Systems – Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz”
[3] IEEE C802.16-SGM-02/23 “802.16a OFDMA PHY suitability for mobile applications”
[4] IEEE 802.16.3c-01/30r1 “Traffic Model for 802.16 TG3 MAC/PHY Simulations”
[5] RECOMMENDATION ITU-R M.1225 “GUIDELINES FOR EVALUATION OF RADIO TRANSMISSION TECHNOLOGIES FOR IMT-2000”
[6] IEEE C80216e-03_03 “OFMDA System Simulation in a Single/Multi Cell Configuration”
[7] IEEE 80216e-02_01 “Call for Contributions on Project 802.16e”
[8] IEEE 80216e-03_06 “IEEE802.16e Mobility System Perspective”