Advanced Power Management Techniques in Next-Generation Wireless Networks

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ABSTRACT

Because mobile devices are equipped with a limited amount of battery power, it is essential to have efficient power management mechanisms in mobile broadband networks such as mobile WiMAX and 3GPP Long Term Evolution that enable always on connectivity. This article presents the state-of-the-art power management methods in next-generation wireless networks with a focus on IEEE 802.16m[1] based next-generation WiMAX networks and 3GPP LTE. To minimize and optimize user equipment power consumption, and further to support various services and large amounts of data transmissions, advanced power conservation mechanisms are being developed in IEEE 802.16m and 3GPP. Two advanced power conservation mechanisms, sleep and idle modes, which are enhanced versions of the legacy IEEE 802.16 system's sleep and idle modes, were proposed and adopted in IEEE 802.16m. Similarly, 3GPP LTE adopts a discontinuous reception mechanism for power conservation in `RRC_CONNECTED` and `RRC_IDLE` states. Power management techniques in WiMAX and 3GPP LTE provide less control signaling and operational overhead while providing more efficient power saving, and use simpler operation procedures than the existing power management techniques.

INTRODUCTION

With the proliferation of wireless services and anytime anywhere communication providing always on connectivity, mobile devices are getting smaller and smarter. Therefore, next-generation wireless standards, such as IEEE 802.16m [1] and Third Generation Partnership Program (3GPP) Long Term Evolution (LTE) [2], should provide very efficient power conservation mechanisms to achieve longer battery life while providing enhanced user experience and quality of service (QoS).

Mobile stations (MSs) are not always engaged in active communications. For significant durations, MSs are waiting for incoming or outgoing packets. These standby periods can be used for power conservation. The power management methods for existing voice-dominant wireless systems are designed based on the following principles. The circuit-switched voice traffic pattern is deterministic in nature (i.e., continuous traffic during a voice call followed by no traffic after the call is over). Therefore, keeping the radio on during the voice call and using idle mode while the mobile node is not on a call works best. As voice calls have low data rates, the devices use a small frequency band and/or time period for transmission/reception operations. Finally, the total average talk time per day by an average mobile phone user is not high. On the other hand, traffic in next-generation broadband wireless systems is bursty with significant periods of no traffic during a session (e.g., reading time during a web browsing session). Therefore, it is inefficient to keep the radio on during the entire session. Users spend significant amounts of time using different mobile Internet applications. Thus, the always on feature of mobile Internet consumes significant power. Finally, as the average data rate used by Internet applications is very high, the devices have to use a larger frequency band and/or time period for transmission/reception operations. Due to these reasons, the power management techniques of voice-oriented wireless networks are not applicable for next-generations wireless data networks.

In mobile networks an MS can be in one of the following states:
- State I: Receive or send traffic
- State II: Do not receive or send traffic while in active session(s)
- State III: Not in an active session

When an MS is in either state II or III, it can temporarily shut down its transmitter and receiver for power saving. During states II and III, sleep mode/discontinuous reception (DRX) in `RRC_CONNECTED` state and idle mode/DRX in `RRC_IDLE` state can be used in WiMAX/3GPP LTE.

The mapping of power management modes to a generic traffic model is shown in Fig. 1 where the MS sends/receives bursts of packets followed by inter-burst intervals. The time interval between consecutive sessions is the inter-ses-

[1] *At the time of writing this article, the power management techniques discussed in this article are based on the draft standard D4, which is in the IEEE 802.16 Working Group letter ballot process.*

sion interval. Depending on the state of traffic, an MS remains in one of the following operational modes: connected mode, power management mode in state II (sleep mode — IEEE 802.16m, DRX in RRC_CONNECTED — 3GPP LTE), and power management mode in state III (idle mode — IEEE 802.16m, DRX in RRC_IDLE — 3GPP LTE).

In this article we provide a technical overview of power management in IEEE 802.16m and 3GPP LTE. The remaining part of the article is organized as follows. We describe the general operation as well as advanced concepts, such as listening window (LW) extension, and voice over IP (VoIP) support of IEEE 802.16m sleep mode and 3GPP LTE DRX in RRC_CONNECTED mode in the next section. We then present the operation and distinct features, such as multiple paging group (PG) operation, mobility-based paging area design, deregistration with content retention mode, multicarrier paging, and cell (re)selection, of idle mode operation in IEEE 802.16m and DRX in RRC_IDLE 3GPP LTE. Finally, we conclude with the advantages of advanced power management mechanisms.

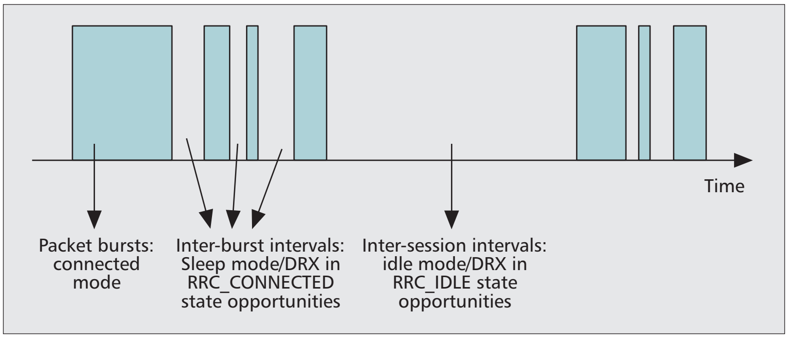

Figure 1. *Mapping of power management modes to a generic traffic model.*

POWER MANAGEMENT IN STATE II

When an MS is in an active session, it could initiate sleep mode in IEEE 802.16m for power saving during inter-burst intervals, shown in Fig. 1. While in sleep mode the MS alternates between LW and sleep window (SW). The sum of LW and SW is defined as a sleep cycle. During SW, the base station (BS) does not transmit any packet to the MS. The MS listens to traffic indications from the BS during LW to check for pending downlink traffic.

Sleep mode operation of IEEE 802.16m illustrated in Fig. 2 can be divided into the following stages:

Sleep mode initiation: The sleep mode can be initiated by a BS or an MS when the MS is in the connected state.

Sleep mode operation: While in sleep mode, an MS alternates SW and LW. SW and LW can be dynamically or statically changed in order to adaptively provide sleep patterns for various traffic types such as best effort and real time. During LW, the MS monitors the downlink to check for a traffic indication message. The traffic indication can be either positive or negative. Upon receiving a positive traffic indication, the MS shall wait for pending downlink traffic. Upon receiving a negative indication, the MS terminates the current LW and starts SW.

Sleep mode exit: The sleep mode can be terminated in case of handover, idle mode initiation or return to normal mode. The sleep mode termination can be initiated by a BS or an MS.

The sleep mode operation in IEEE 802.16m has the following advanced features to achieve higher power saving:

Traffic exchange during sleep operation without sleep mode termination: To eliminate the signaling overhead and latency associated with the termination and reinitiation of sleep mode incurred when a sleep mode MS needs to send or receive traffic, IEEE 802.16m implements methods to dynamically extend the LW beyond its default value. During such extended LW, the sleep mode MS is able to transmit/receive traffic.

Predefined sleep cycle settings adaptive to application characteristics: To adapt to varying characteristics of different applications, sleep mode uses a predefined set of operational parameters. For additional flexibility, predefined operational parameters can be modified by the MS or BS.

Dynamic adjustment of sleep cycle during sleep operation: The sleep cycle can be changed during sleep operation to adjust to changes in traffic pattern. The new sleep cycle can be the same as the first initial sleep cycle for real-time services, doubled for best effort type of services or a new negotiated value after sleep mode interruption.

LW early termination: The LW can be terminated before its scheduled time to achieve higher power saving. This can be done upon receiving a negative traffic indication or an explicit indication from the BS during LW.

VoIP-specific sleep operation: As the VoIP traffic characteristic of deterministic traffic exchange is different from other applications, IEEE 802.16m provides special sleep mode operation for VoIP by providing LW and SW periods considering VoIP traffic patterns to achieve improved power saving.

Multicarrier sleep operation: The major difference of multicarrier sleep mode operation from single-carrier sleep mode is which carrier(s) is used for the transmission of traffic indication and/or data. If traffic indication is enabled, one active carrier[2] is used as a primary carrier[3] through which the MS receives the traffic indication message. All active carriers can be used for data communication depending on the characteristics of traffic. If the traffic indication is disabled, the MS monitors the active carriers during the LW, and the BS may allocate the DL data on the primary carrier and the active secondary carrier(s), and the MS receives the data on the primary carrier and the active secondary carrier(s) during the LW. When an MS has packets to transmit in the uplink during multicarrier sleep mode operation, it can transmit the bandwidth request on its primary carrier. Upon receiving the bandwidth request on the primary carrier, the BS assumes that the downlink/uplink data transmission over all active carriers is allowed during the LW.

In this section we describe some of the advanced features of IEEE 802.16m sleep mode

[2] *Carriers are activated through control messages exchanged between the BS and the MS from available carriers supported by the MS.*

[3] *An orthogonal frequency-division multiple access (OFDMA) carrier on which the BS and MS exchange traffic and full PHY/MAC control information. Furthermore, the primary carrier is used for control functions for MS operation, such as network entry.*

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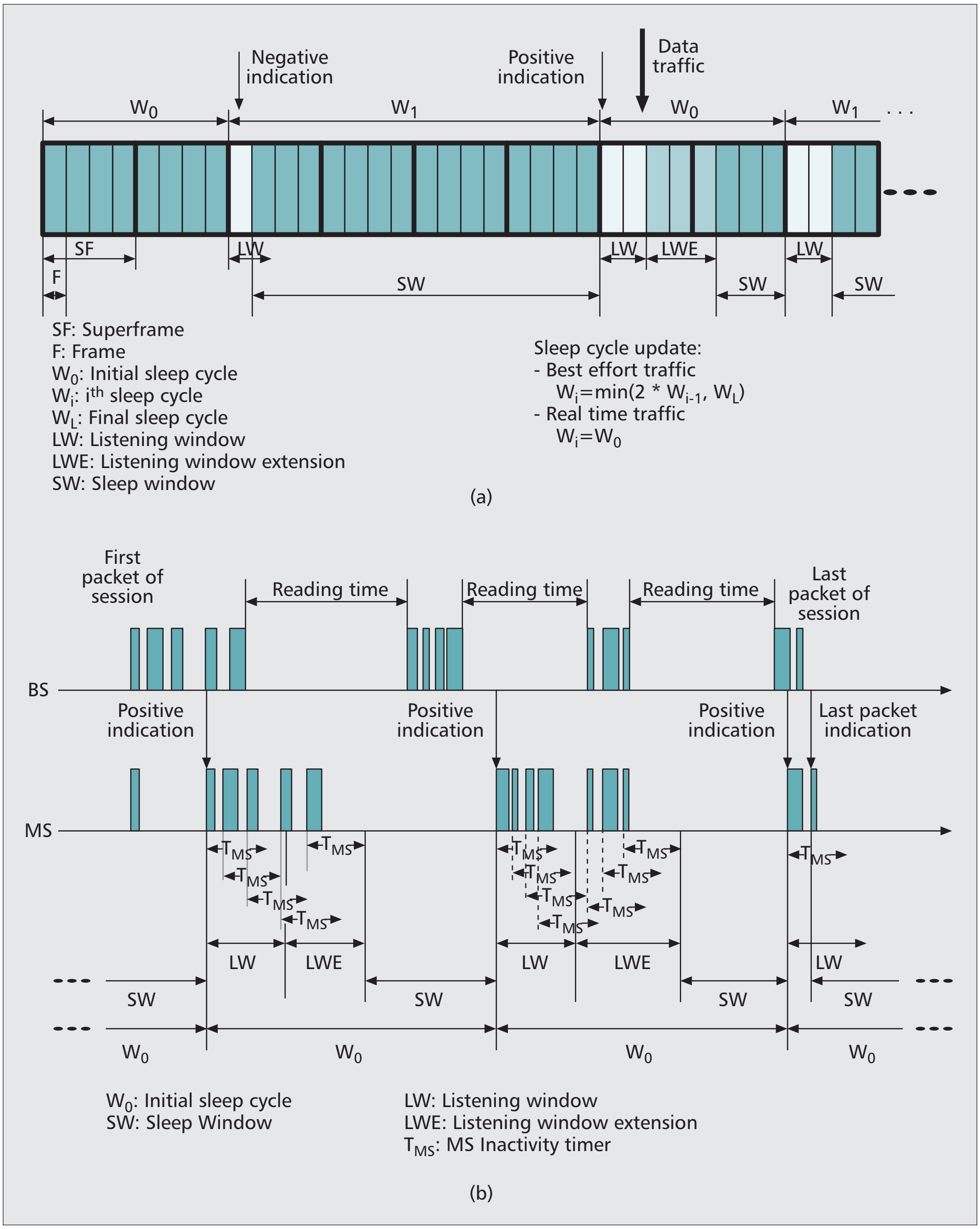

Figure 2. *Sleep mode operation and sleep mode example: a) sleep mode operation; b) sleep mode example with HTTP traffic.*

operation outlined earlier. We then describe LTE DRX in RRC_CONNECTED state.

SW and LW Operation

Adaptive SW and LW operation makes IEEE 802.16m sleep mode simple and efficient. Figure 2a shows sleep mode operation. In a sleep cycle, MSs save power during SW and monitor traffic indication broadcast by BS during LW. After initiating the sleep operation, each sleep cycle can be dynamically updated depending on the traffic characteristics. LW ends on meeting one of the following conditions: receiving an explicit termination order from the BS, reaching the end of the current nominal end of the LW, or reaching the end of the sleep cycle. In Fig. 2a the first LW is terminated upon reception of a negative indication. The second LW is extended to receive downlink data whose transmission continues beyond LW. The third LW ends at the default LW value because it is neither terminated early nor extended. Figure 2b shows how SW and LW operate dynamically in case of HTTP traffic [3]. A web page download consists of the main page download followed by several embedded objects. In the example of Fig. 2b there are three reading time intervals, which is the time duration the user spends in reading the downloaded web page before transitioning to another page, until the end of the HTTP session. Each packet burst consists of several embedded objects. The first group of packets arrives at the BS, but the BS

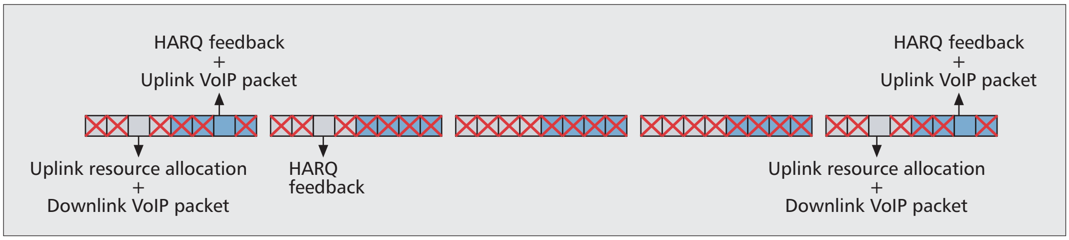

Figure 3. *VoIP support in sleep mode operation.*

cannot transmit those packets because the MS is in SW. The BS waits until the beginning of the MS's LW and transmits a positive indication to notify the MS about the pending downlink traffic. Then pending packets are transmitted to the MS. Upon receiving each packet, the MS starts an MS inactivity timer (T_{MS}), which is used for LW extension. If the BS knows the last packet of a session, the BS can transmit an indication to the MS for LW early termination.

VoIP Support in Sleep Mode

During talk periods of a VoIP session, an MS exchanges one set of packets every 20 ms, and during its silent periods the MS exchanges a silence insertion descriptor (SID) every 160 ms, resulting in a deterministic traffic exchange pattern between the MS and the BS in only some of the subframes,[4] as shown in Fig. 3.

Therefore, in order to minimize power consumption, an MS in a VoIP session can remain *ON* only during those subframes where there is VoIP or hybrid automatic repeat request (HARQ) control related traffic and remain *OFF* in all other subframes, marked as crossed in Fig. 3. While during active periods the MS sends/receives a VoIP packet during every LW, during silence periods the AMS may not send/receive any packet during some of the LWs. To achieve further power saving during a VoIP session, IEEE 802.16m uses the following types of LWs during active and silence durations:

- Type 1: Fixed sleep cycle (e.g., 20 ms) with longer LW (scenarios 1, 2, and 3 of Fig. 4)
- Type 2: Fixed sleep cycle (e.g., 20 ms) with shorter LW (scenarios 4 and 5 of Fig. 4)

The number of subframes where the MS is actively transmitting or receiving varies depending on the activity state of the voice codec as illustrated in Fig. 4. Therefore, depending on the activity period, the LW can be shorter or longer.

3GPP LTE DRX in RRC_CONNECTED State

DRX in `RRC_CONNECTED` state is used for power saving while user equipment (UE) is in `RRC_CONNECTED` state. DRX mode can be enabled in `RRC_CONNECTED` state if there is no traffic longer than `DRX inactivity timer` or if the UE receives a MAC control element (CE) to enter DRX mode, as shown in Fig. 5. While in DRX operation the UE alternates between `On Duration`, where it transmits and/or receives traffic, and `Opportunity for DRX`, where the UE may turn off its transmitter and receiver for power conservation [4]. DRX cycle is defined as the time duration of the sum of `On Duration` and `Opportunity for DRX`. Figure 5 shows an example of DRX operation. DRX in `RRC_CONNECTED` mode can optionally first start with `Short DRX Cycle`, then operate with `Long DRX Cycle` after `DRX Short Cycle Timer`. When `Short DRX Cycle` is not enabled, DRX operation starts with `Long DRX Cycle`. When using DRX operation, the UE listens to the subframes of `On Duration` for the packet data control channel (PDCCH) and may be turned off during the subframes of `Opportunity for DRX`. When retransmission of data is expected from the evolved node-B (eNB) (i.e., when a HARQ round-trip time [RTT] timer expires), the UE has to wait the retransmission until `DRX Retransmission Timer` expires. For VoIP service, immediately after a VoIP packet transmission, eNB can initiate DRX operation with `Short DRX Cycle` which is the same length as the periodicity of a VoIP packet.

Power Management in State III

To use inter-session intervals (state III) shown in Fig. 1 for a battery conserving opportunity, the MS could initiate idle mode in IEEE 802.16m. In idle mode the MS relinquishes its connections and states associated with its BS. However, the MS's context referred to as idle mode retention information (IMRI), such as security keys, service flow parameters, and the MS's capabilities, are stored in a network entity (e.g., a paging controller [PC]). IMRI is used to expedite network re-entry from idle mode. The idle MS is tracked at the granularity of a group of BSs known as a PG. The MS periodically turns on its radio at negotiated intervals determined by `PAGING_CYCLE` and `PAGING_OFFSET` [1], and monitors paging messages to check for pending downlink traffic. If a paging message indicates downlink traffic or there is uplink traffic to transmit, the MS performs network re-entry. Otherwise, it remains in idle mode.

Idle mode operation of IEEE 802.16m can be divided into the following stages:

Idle mode initiation: The idle mode can be initiated by a BS or an MS when the MS is not in a session. During idle mode initiation, the MS and the network can negotiate the IMRI that can be used to expedite the MS's network re-entry from the idle mode. At this stage, the MS can inform the network of its mobility information so that the network can assign PGs of appropriate size to the MS. If multiple PGs are assigned to the MS, a primary paging listening interval (P-PLI) and multiple secondary PLIs (S-PLIs) are allocated to the MS.

Idle mode operation: While in idle mode, the

The idle mode can be initiated by a BS or an MS when the MS is not in a session. During idle mode initiation, the MS and the network can negotiate the IMRI that can be used to expedite the MS's network re-entry from the idle mode.

[4] *A subframe is the minimum unit, which consists of 5, 6, 7, or 9 OFDMA symbols on physical layer parameters in the frame structure of IEEE 802.16m.*

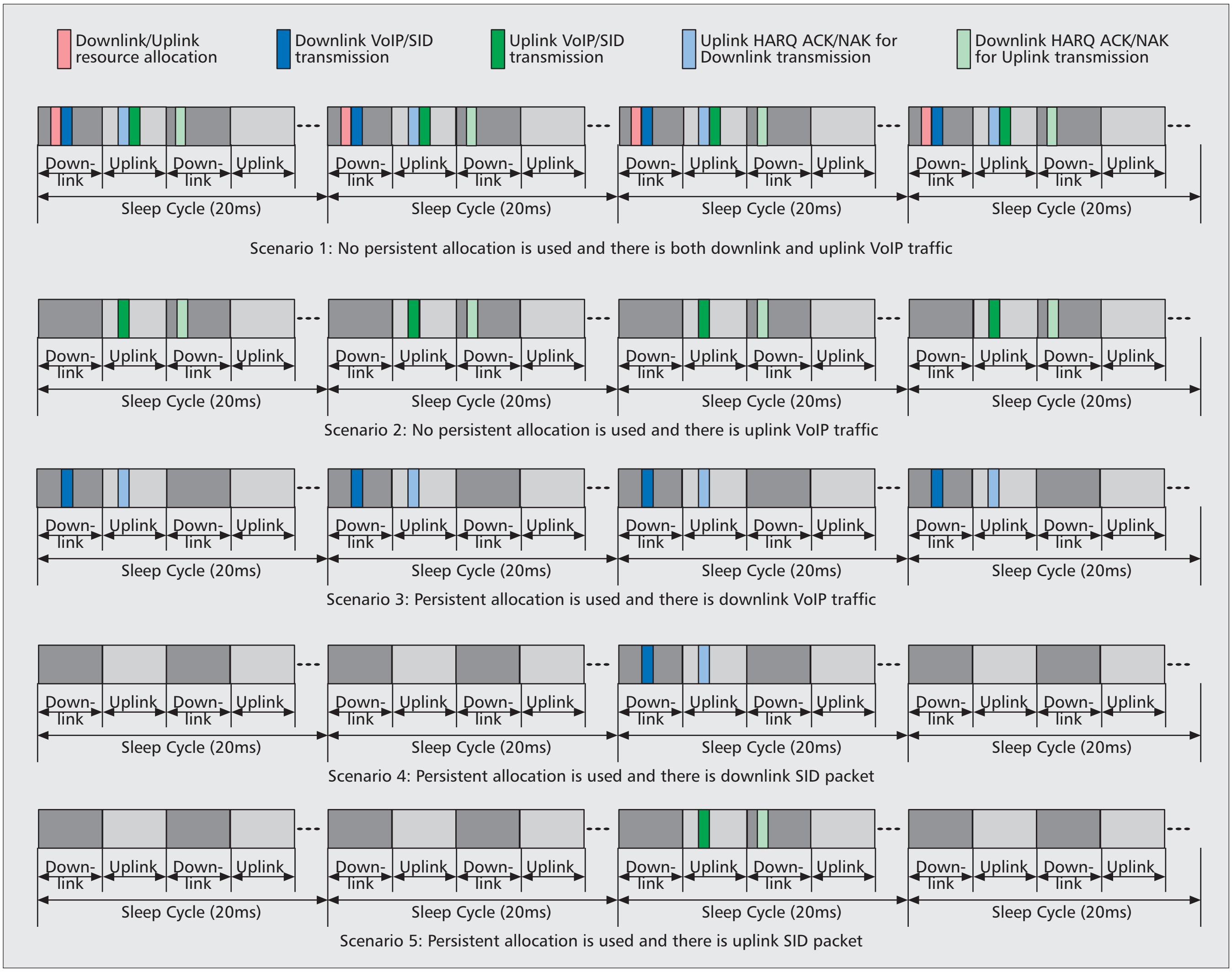

Figure 4. *The number of subframes that an MS needs to remain awake during different scenarios of a VoIP connection.*

MS alternates between paging unavailable intervals (PUIs) and paging listening intervals (PLIs). The MS monitors paging messages during P-PLIs. When P-PLI is not available due to the MS's movement to a secondary PG, the MS monitors S-PLI. A more detailed procedure is explained in the following section.

Idle mode location update: An MS performs location update upon meeting location update trigger conditions: *PG-based location update*, *timer-based location update*, and *power down location update*. Location update is used for the network to track MSs' locationd and manage idle mode MSs' context information. When the MS cannot find its assigned PG identifiers (IDs) during PLI, it performs location update in order to be assigned new PG ID(s). The idle mode timer is managed between the MS and the PC, which is a lifetime for IMRI. Before the expiration of the time, the MS performs location update to refresh the timer. The MS performs location update before power off to inform the network to release its IMRI.

Idle mode exit: An idle mode MS exits the idle mode if it has uplink traffic or receives a paging message indicating pending downlink traffic. Idle mode is terminated by carrying out network re-entry procedure. When a valid IMRI is present, some of the re-entry procedure can be skipped.

The idle mode operation in IEEE 802.16m has the following advanced features that significantly reduce the idle mode signaling overhead and achieve higher power saving:

Multiple PGs' assignment and management: Multiple PGs may be assigned to an MS in order to reduce frequent location update. When multiple PGs are assigned to an MS, the MS does not need to perform location update when it resides in one of these PGs. The use of multiple PGs enables multistage paging operation in a single paging cycle.

User mobility consideration: Based on user mobility, the network may assign PGs of different sizes and shapes to an MS to minimize the signaling overhead used during idle mode operation.

Elimination of paging and location update: Contrary to traditional idle mode operation where an idle mode MS performs location update and listens to paging messages, IEEE 802.16m specifies deregistration with content retention (DCR) mode, where the MS is in a special idle mode that does not require location update and its availability for paging messages.

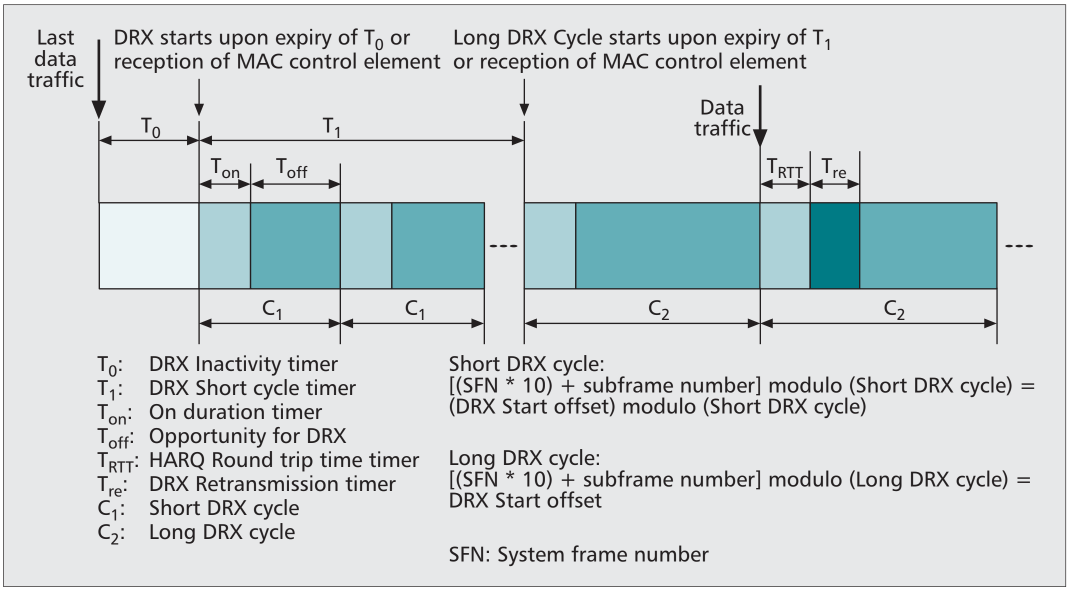

Figure 5. *Illustration of DRX operation.*

In multi-carrier operation mode in IEEE 802.16m, an MS can communicate with one or more physically separated carriers supported by a BS. To reduce signaling overhead, IEEE 802.16m provides an efficient way to page an idle mode MS through one of the carriers.

DCR mode achieves significantly higher power saving and can be used for seamless intersystem handoff.

Transfer of short message service without idle mode termination: In IEEE 802.16m an idle mode MS can send and receive short message service (SMS) messages without network reentry. For downlink SMS, the PC asks the MS to perform location update and transmit the message in the location update confirm message. Similarly, for uplink SMS, the MS performs location update and includes the SMS in the location update request. This method eliminates the overhead and power consumption associated with idle mode termination and re-initiation.

Paging overhead reduction: IEEE 802.16m standard groups the idle mode MSs with same paging cycle for allocation of idle mode identification. This reduces the length of idle mode identification used in the paging message because the paging cycle part of MSs' identifications can be specified once for multiple MSs. In addition, it adapts the number of paging messages to the paging load, thereby making the paging overhead adaptive to the number of MSs paged. The common part of all paging messages in a superframe is transmitted only once to further reduce paging overhead.

Multi-carrier paging: In multicarrier operation mode in IEEE 802.16m, an MS can communicate with one or more physically separated carriers supported by a BS. To reduce signaling overhead, IEEE 802.16m provides an efficient way to page an idle mode MS through one of the carriers.

In this section we discuss some selected advanced features of IEEE 802.16m idle mode operation outlined earlier. We then describe LTE DRX in RRC_IDLE state.

Network Model and Multiple PG Operation

A representative idle mode network model is shown in Fig. 6a. A PC is a functional network entity that administers the activity of idle mode MS [5]. A PC can administer multiple PGs. In IEEE 802.16m, multiple PGs can be assigned to an MS to reduce frequent location updates, paging delay, and paging overhead. Figure 6b illustrates a multiple PG configuration where the primary PG has a small coverage area and the secondary PG has a larger coverage area. An MS's operation for multiple PGs is illustrated in Fig. 6c. While the MS is in the primary PG coverage, it monitors the paging message transmitted during P-PLI which starts at T_1 (*Primary* PAGING_OFFSET). If the MS detects its movement to the secondary PG, it monitors the paging message transmitted during S-PLI, which starts at T_2 (*Secondary* PAGING_OFFSET). Unlike the conventional multistage paging methods where one paging cycle is used for the paging operation in one set of cells, the paging latency of IEEE 802.16m idle mode can substantially be reduced by employing two paging offsets in one paging cycle. In this case the BS sends the paging message for an MS in the MS's P-PLI. If the PC does not receive the response to this paging message within a predefined time, the PC sends another paging message to the MS during its S-PLI in the same paging cycle.

Mobility-Based Paging Area Design

Mobility-based PG design addresses the following issues:
- Determination of paging area size based on speed
- Determination of paging area shape based on mobility trajectory

IEEE 802.16m provides the mechanism to determine the radius/size 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 air link resources usage is minimized. The PG that achieves minimum signaling overhead is referred to as minimum-resource PG [6]. When a mobility-based paging area is used, the number of location updates performed by idle mode MSs moving with different speed is minimized. In

DCR mode is an operational state where the device does not have to monitor and receive paging message while its context is stored in the network. Using the stored context the MS can expedite network re-entry from this situation. DCR mode can be initiated from connected and idle modes.

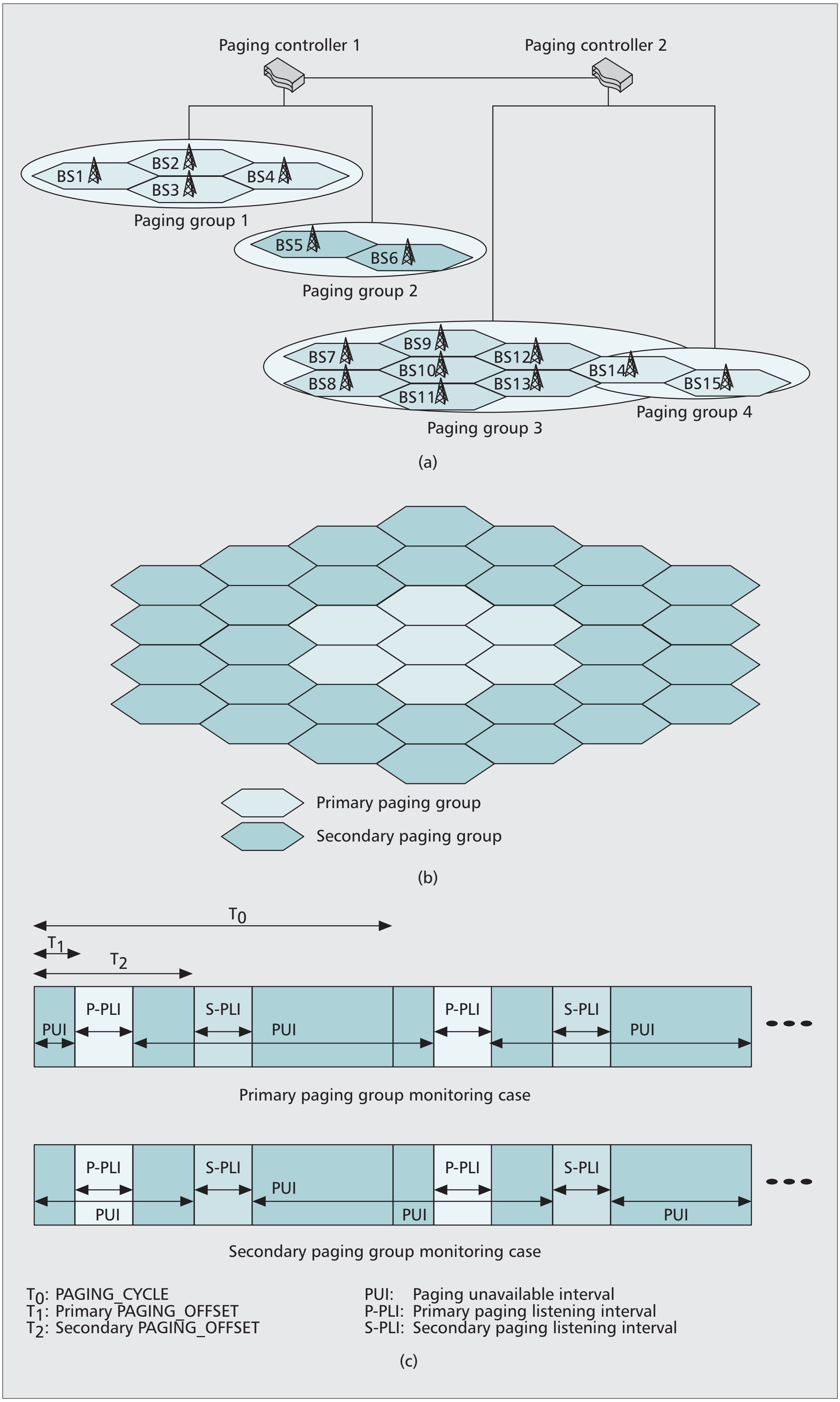

Figure 6. *Paging network model, multiple PG configuration and idle mode operation of mobile station: a) representative idle mode network model; b) an example of multiple PG configuration from an MS's perspective; c) idle mode operation of mobile station.*

addition to the speed-based PG design, the MS's trajectory can also be used to design the paging area such that MSs moving on highways can have a rectangular paging area along the highway compared to MSs moving in a local road where the PG can be circular.

DCR Mode Enhancements of Idle Mode

DCR mode is an operational state where the device does not have to monitor and receive a paging message while its context is stored in the network. Using the stored context, the MS can expedite network re-entry from this situation. DCR mode can be initiated from connected and idle modes. One of the use cases of DCR mode is that an MS enters DCR mode when the device goes into hibernation. When the MS gets out of hibernation mode, the MS can expedite network re-entry using stored context. Another use case of DCR mode is handover to another radio access technology (RAT). An IEEE 802.16m enters DCR mode while operating in another RAT and performs fast network re-entry upon its return to the IEEE 802.16m system.

Multicarrier Paging

When idle mode MSs are operating in multicarrier mode, excessive signaling overhead is incurred if a BS broadcasts MS's paging messages on all carriers. To eliminate such overhead, IEEE 802.16m transmits MS's paging message only through one of the carriers using one of the two mechanisms depending on the MS's multicast and broadcast service (MBS) subscription status:

- For non-MBS idle mode MSs: Different carriers of a BS may belong to one or multiple PGs. For each PG of a BS, one or more carriers are designated as paging carriers, meaning carriers that transmit the paging messages. Only one of the paging carriers of a PG broadcasts the paging message for an MS, thus reducing the paging overhead.
- For MBS idle mode MSs: When an MS is subscribed to MBS, its MBS carrier is used to broadcast its paging message. This ensures that when paging and MBS traffic arrive for an MS at the same time, the MS can receive both of them.

3GPP LTE DRX in `RRC_IDLE` State

The DRX mechanism of `RRC_IDLE` state in 3GPP LTE also takes advantage of state III. UE enters DRX in `RRC_IDLE` state when there is no transmission/reception of packets for an extended period of time, which is longer than `DRX Inactivity Timer`. In DRX of `RRC_IDLE` state, UE periodically turns on its radio to monitor the DL transmissions following the DRX cycle. Upon entering DRX in `RRC_IDLE` state, RRC connection with the eNB may be released by removing the UE context. However, network entities keep the UE context. During the `RRC_IDLE` state, UE should perform signal quality measurements of the serving and neighbor eNBs in order to select a proper serving eNB since the UE has to manage the mobility. When the UE detects packet arrival through paging, the UE has to return to `RRC_CONNECTED` state to receive the packet.

LTE DRX in `RRC_IDLE` state has the following advanced features that significantly reduce the signaling overhead and achieve higher power saving:

Cell selection optimization during `RRC_IDLE` State: For fast cell reselection to avoid lengthy scanning, leading to power saving, `LTE_IDLE` uses stored information cell selection, where UE in `RRC_IDLE` state stores information of carrier frequencies and optionally also information on cell parameters from previously received measurement control information elements or previously detected cells. Once the UE has found a suitable cell, the UE shall select it. If no suitable cell is found, the initial cell selection procedure shall be started [7].

Mobility-based `RRC_IDLE` optimization: LTE `RRC_IDLE` defines three mobility states for UE in `RRC_IDLE` state: normal-mobility, high-mobility, and medium-mobility states. Of these three mobility states, high-mobility and medium-mobility states are applicable if the parameters (`TCRmax`, `NCR_H`, `NCR_M`, and `TCRmaxHyst`) are sent in the system information broadcast of the serving cell [7], where `TCRmax`, `NCR_H`, `NCR_M`, and `TCRmaxHyst` are the duration for evaluating the allowed amount of cell reselection(s), the maximum number of cell reselections to enter high-mobility state, the maximum number of cell reselections to enter medium-mobility state, and the additional time period before the UE can enter normal-mobility state, respectively. UE is considered to be in medium-mobility state when its number of cell reselections during time period `TCRmax` exceeds `NCR_M` but does not exceed `NCR_H`. Similarly, it is considered to be in high-mobility state when its number of cell reselections during time period `TCRmax` exceeds `NCR_H`.

Cell ranking in `RRC_IDLE` state: The UE shall perform ranking of all cells that fulfill the cell selection criterion. The cells are ranked according to the *R* criteria specified in [7]. If a cell is ranked as the best cell, the UE shall perform cell reselection to that cell.

Conclusions

Power saving is becoming critical in next-generation wireless systems as mobile devices are required to have always on connectivity and advanced air interfaces require more computation power. Next-generation wireless networks provide advanced power saving mechanisms, idle mode and sleep mode in IEEE 802.16m and DRX mechanisms in 3GPP LTE. The basic mechanism of alternating available interval and unavailable interval provides efficient and simple power conservation method. Advanced features of power management techniques introduced in this article, will enhance the user experience substantially by providing the optimized operation for various applications' traffic patterns while providing extended battery life. In the future, the power saving techniques are expected to be enhanced to support advanced features such as machine-to-machine communication, client-

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> In the future, the power saving techniques are expected to be enhanced to support advanced features such as machine to machine communication, client-relay, and simultaneous operation of multiple radio interfaces.

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