802.16e MAC Enhancement

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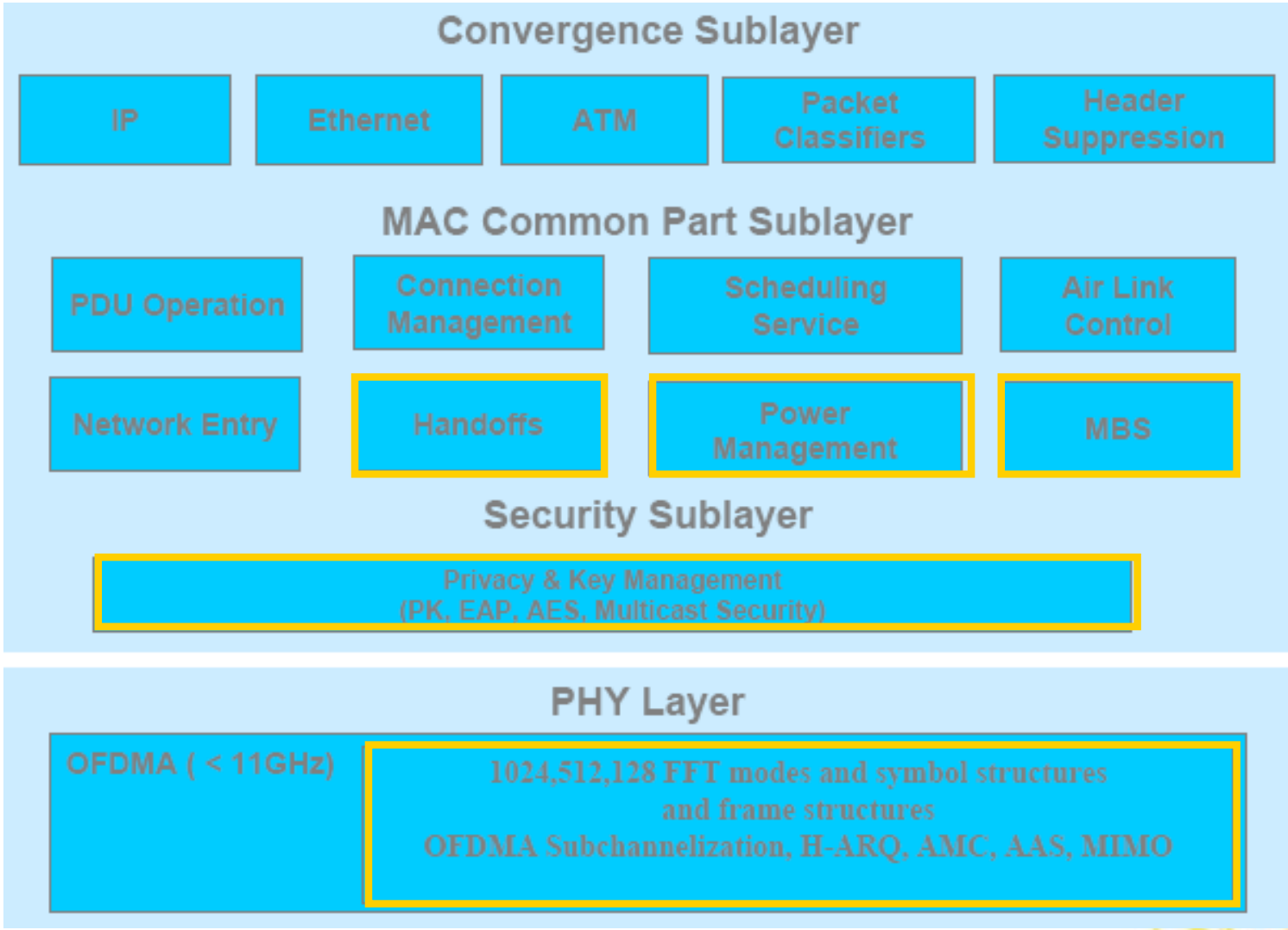
802.16-2004 MAC Summary

- Supports PMP, PtP and mesh networks
- Dynamic modulation and coding updates for both downlink and uplink
- Flexible MAC with various scheduling schemes allows for real-time, non-real-time and best effort services
- Inter- and Intra-user QoS support
- Supports ARQ scheme
- Supports transport protocols such as IP, Ethernet or ATM, and may be extended for future transport protocols

802.16e-2005 MAC Enhancements

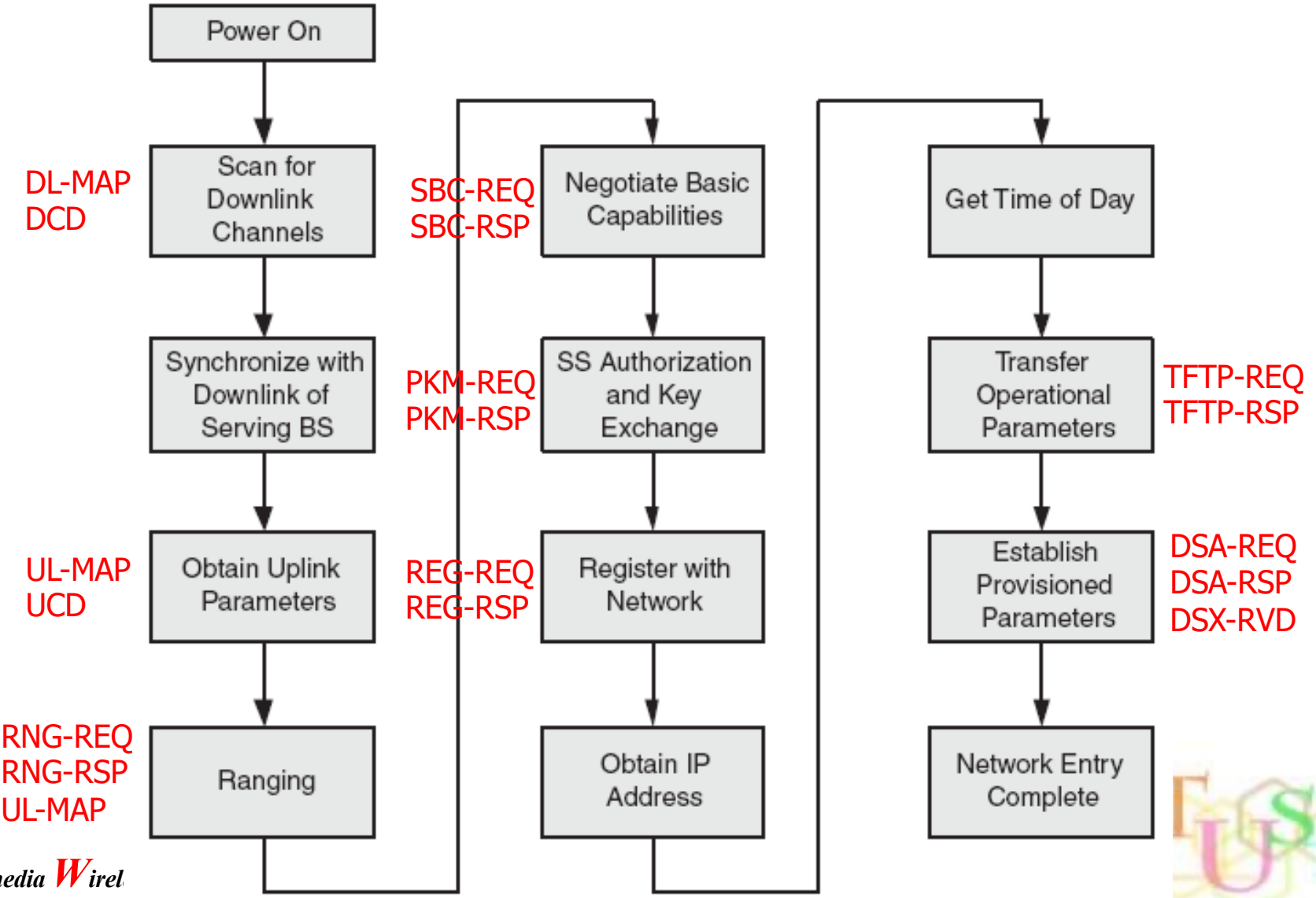
- Flexible MAC with various scheduling schemes
- Extended real-time polling service (ertPS)
- Sleep and Idle modes
- Physical layer HARQ
- Authentication: privacy key management (PKM)
- Handover mechanisms
  - Hard handover
  - Macro-diversity handover (MDHO),
  - Fast base station switching (FBSS)
- Band AMC and CQICH operation
- Multicast and broadcast services (MBS)

802.16e-2005 Protocol Stack



Source:
Ericsson

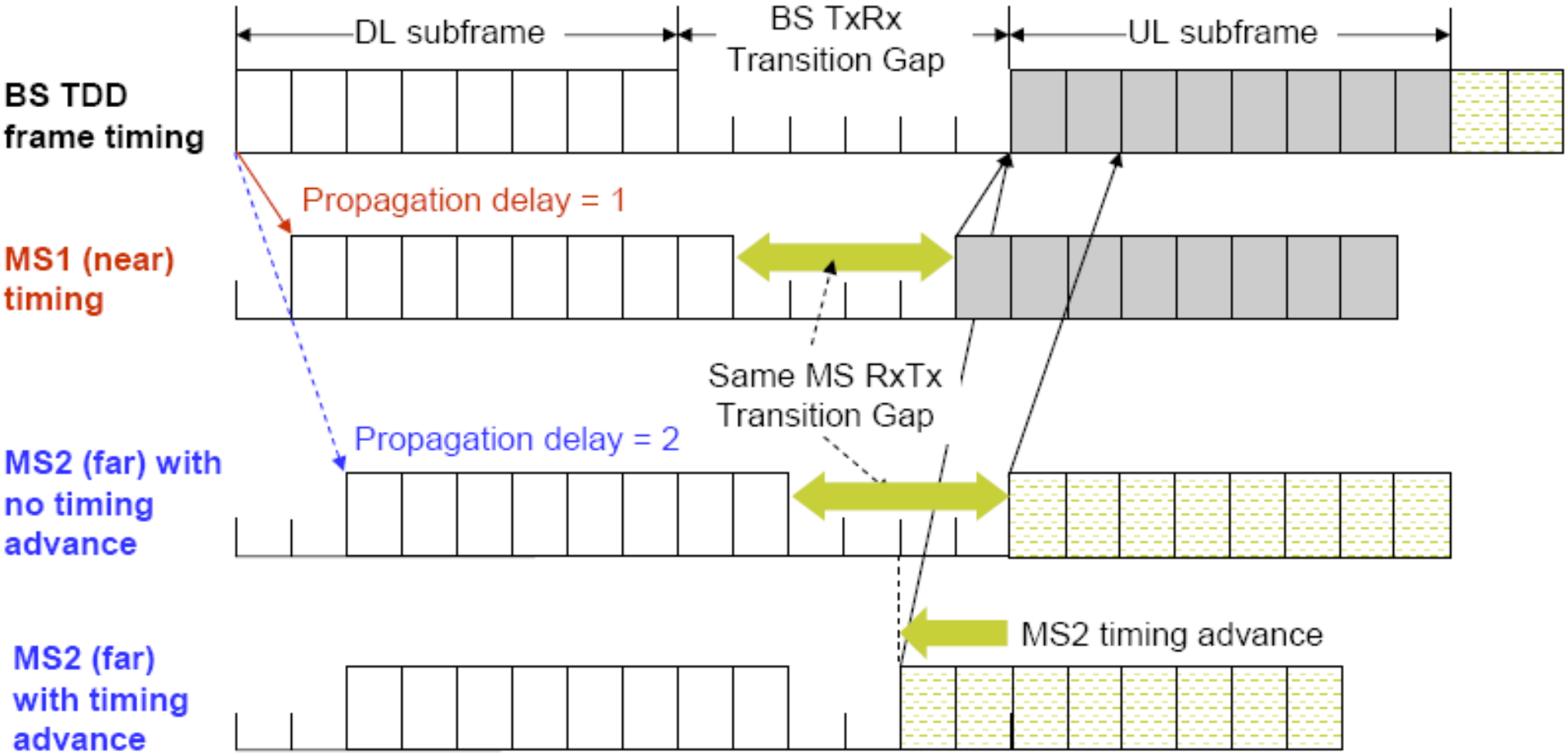
Network Entry



Ranging

- Initial ranging
  - Allows MS joining the network to acquire correct transmission parameters, e.g., time offset and TX power level
  - Enables the MS to communicate with the BS
- Periodic ranging
  - Allows MS to adjust transmission parameters.
  - Aids MS to maintain uplink communications with the BS
- Hanover ranging
  - Initial ranging of a neighbor BS

Timing Advance



Source: Ericsson

Quality of Service

- QoS-supporting is a fundamental part of WiMAX MAC-layer design.
- A connection-oriented MAC architecture is adopted.
  - Before any data transmission happens, the BS and the MS establish a unidirectional logical link, called a *connection,* between the two MAC-layer peers.
  - Each connection is identified by a *connection identifier* (CID), which serves as a temporary address for data transmissions over the particular link.

Quality of Service

- A service flow
  - a unidirectional flow of packets that provides a particular QoS and is identified by a service flow identifier (SFID).
- Five types of service flows:
  - Unsolicited Grant Service (UGS)
    - real-time applications with constant bit rate (CBR)
  - Real-Time Polling Service (rtPS)
    - real-time applications with variable bit rate (VBR)
  - Non-Real-Time Polling Service (nrtPS)
    - non-real-time applications
  - Best Effort (BE) Service
    - applications that don't have any QoS requirements
  - Extended Real-Time Polling Service (ertPS)

Quality of Service

Service Flow Designation	Defining QoS Parameters	Application Examples
Unsolicited grant services (UGS)	Maximum sustained rate Maximum latency tolerance Jitter tolerance	Voice over IP (VoIP) without silence suppression
Real-time Polling service (rtPS)	Minimum reserved rate Maximum sustained rate Maximum latency tolerance Traffic priority	Streaming audio and video, MPEG (Motion Picture Experts Group) encoded
Non-real-time Polling service (nrtPS)	Minimum reserved rate Maximum sustained rate Traffic priority	File Transfer Protocol (FTP)
Best-effort service (BE)	Maximum sustained rate Traffic priority	Web browsing, data transfer
Extended real-time Polling service (ErtPS)	Minimum reserved rate Maximum sustained rate Maximum latency tolerance Jitter tolerance Traffic priority	VoIP with silence suppression

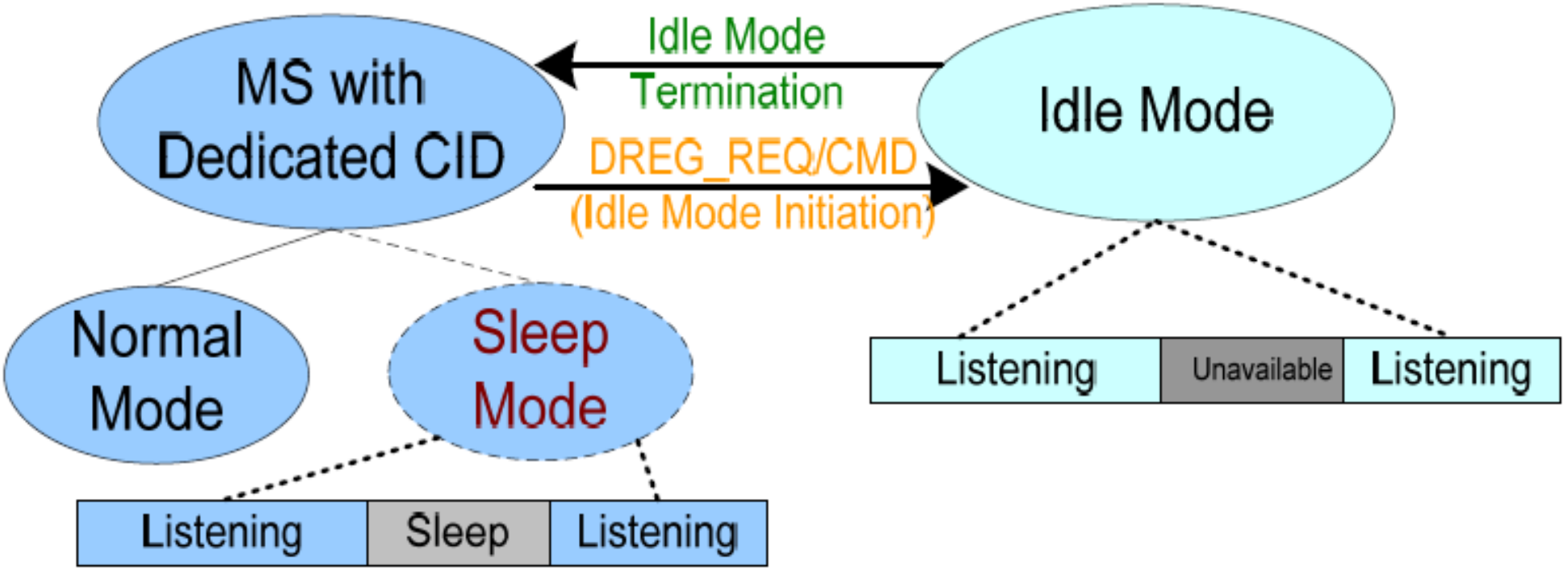
Power and Mobility Management

- Two fundamental requirements of a mobile wireless network
  - Power management
    - Enables the MS to conserve its battery resources, a critical feature required for handheld devices. Mobility management, on the other hand,
  - Mobility management
    - Enables the MS to retain its connectivity to the network while moving from the coverage area of one BS to the next.

Power Management

- Mobile WiMAX defines signaling methods that allow the MS to retreat into a sleep mode or idle mode when inactive.
- *Sleep mode* is a state in which the MS effectively turns itself off and becomes unavailable for predetermined periods.
- To facilitate handoff while in sleep mode, the MS is allowed to scan other base stations to collect handoff-related information.

Power Management



Source: Ericsson

Power Management

- Sleep mode
  - is an optional mode of operation in WiMAX
  - An MS with active connections — one or more CIDs — negotiates with the BS to temporarily disrupt its connection over the air interface for a predetermined amount of time, called the *sleep window*.
  - Each sleep window is followed by a *listen window,* during which the MS restores its connection.
  - BS may buffer or drop all arriving SDUs associated with a *unicast* transmission to the MS.
  - For *multicast* transmissions, the BS delays all SDUs until the availability interval common to all MSs in the multicast group.

Power Management

- Sleep-mode operation takes place in one of three power-saving classes.
  - Power Save Class 1,
    - sleep window is exponentially increased from a minimum value to a *final sleep window size*.
    - typically used for MS is doing best-effort and non-real-time traffic.
  - Power Save Class 2,
    - has a fixed-length sleep window and is followed by a listen window of fixed length
    - used for UGS service.
  - Power Save Class 3,
    - a one-time sleep window; the power-saving operation becomes inactive at the end of the sleep window
    - typically used for multicast traffic or management traffic when the MS knows when the next traffic is expected.

Power Management

Type I: Parameters defining Sleep Cycle

Start frame number
Frame number of first sleep window after Sleep Mode is activated

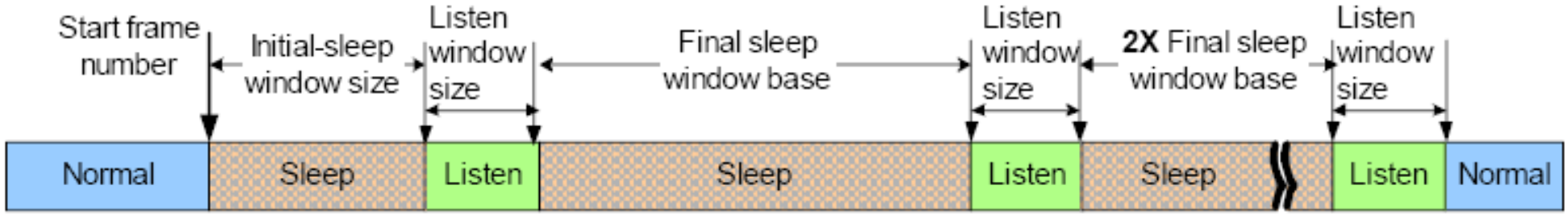
Initial-sleep window size
Assigned initial duration for the sleep window

Listen window size
Assigned duration of MS listening window

Final sleep window size; Base & Exponent
Assigned final value for the sleep interval

Sleep window size = **2X** size of previous window up to max. final sleep window size

Final sleep window size (max.) =
Final sleep window **Base** × $2^{(\text{Final sleep window } \textbf{Exponent})}$



Power Management

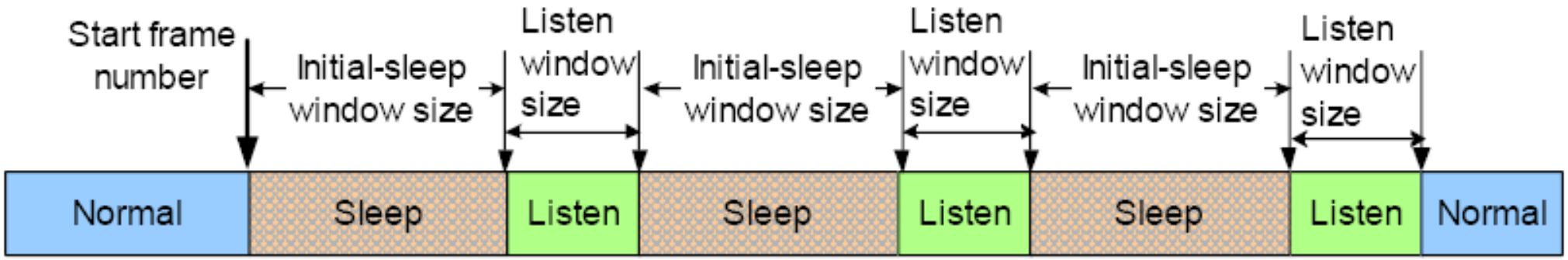
Type II: Parameters defining Sleep Cycle

Start frame number
Frame number of first sleep window after Sleep Mode is activated

Initial-sleep window size
Assigned initial duration for the sleep window

Listen window size
Assigned Duration of MS listening window

Sleep window size = Initial-sleep window for each sleep cycle



Power Management

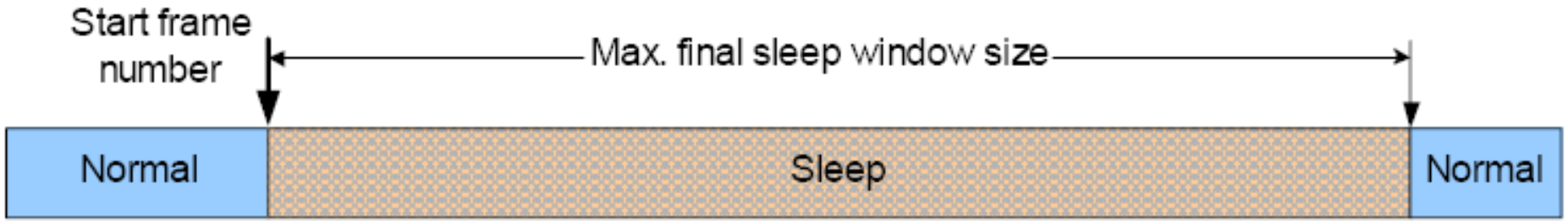
Type III: Parameters defining Sleep Cycle

Start frame number
Frame number of first sleep window after Sleep Mode is activated

Final sleep window size; Base & Exponent
Assigned final value for the sleep interval

Final sleep window (max.) =
Final sleep window **Base** × $2^{(\text{Final sleep window } \textbf{Exponent})}$

One sleep window equal to the max. final sleep window size

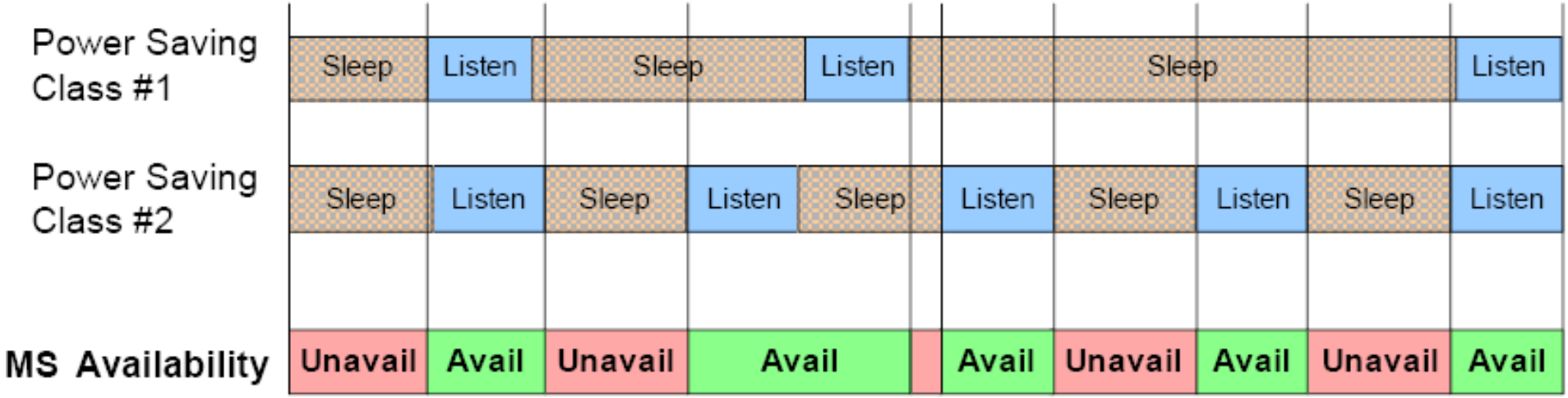


Power Management

MS Unavailable
Time that does not overlap with any Listen window of any active Power Saving Class

MS Available
Time where mobile is not unavailable

MS Availability



If Power Saving Class for at least one connection is not active
MS is available for ALL connections

Power Management

- Idle mode
  - is an optional mode of operation in WiMAX
  - it allows the MS to receive broadcast DL transmission from the BS without registering itself with the network.
  - Operation:
    - Groups of MSs are assigned to a *paging group*
    - MS periodically monitors the DL transmission of the network to determine the paging group of its current location.
    - MS performs a *paging group update* on detecting that it has moved to a new paging group to inform the network of the current paging group in which it is present.

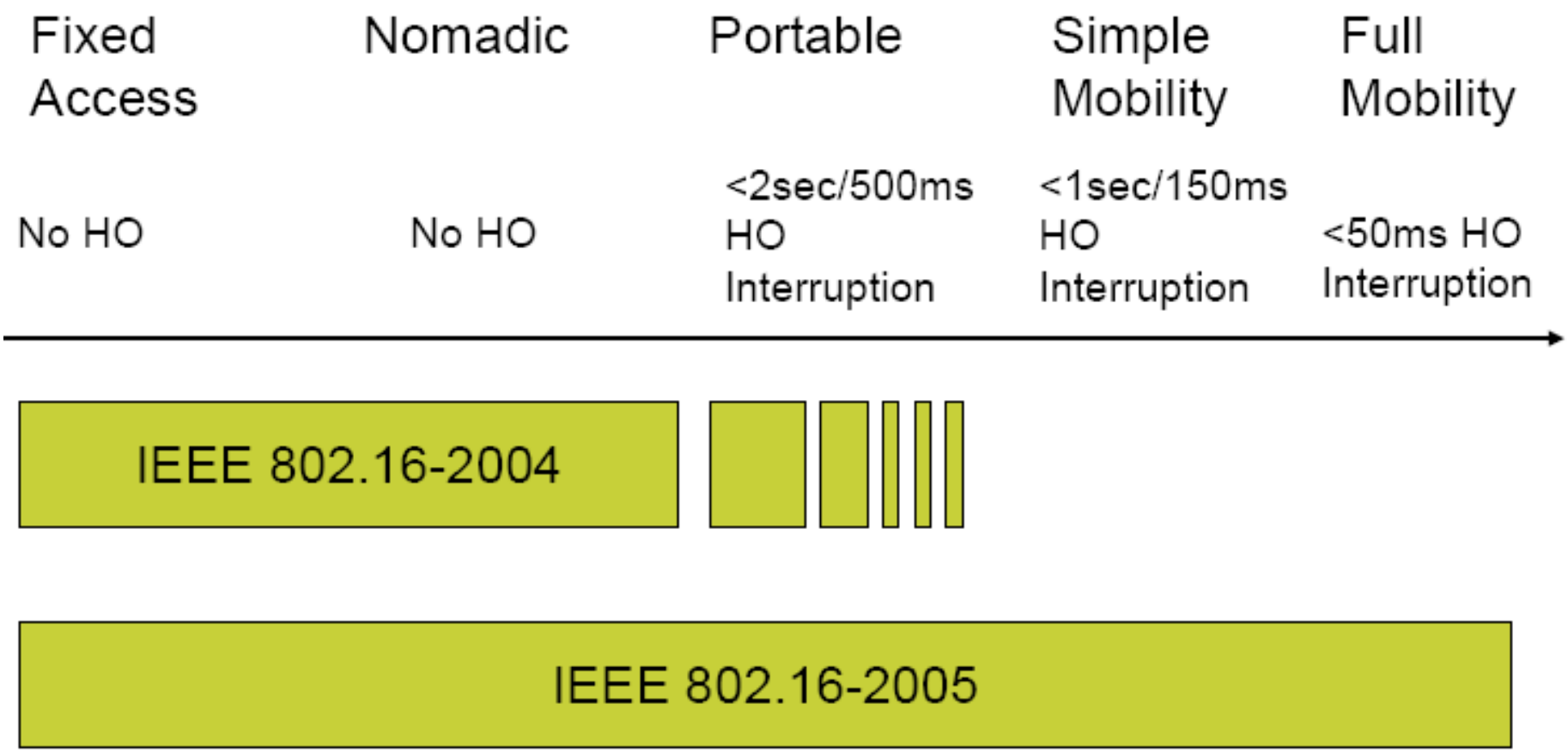
Power Management

- During idle-mode operation, the MS can be in either
  - *MS paging-unavailable interval*
    - MS is not available for paging
    - MS can power down, conduct ranging or scanning with a neighboring BS
  - *MS paging-listen interval*
    - MS listens to DCD and DL MAP of the serving BS
      - MS is paged: the MS responds to the page and terminates its idle-mode operation.
      - MS is not paged: the MS enters the next MS paging-unavailable interval.

Mobility Management

- WiMAX envisions four mobility-related usage scenarios:
  - **Nomadic**. The user is allowed to take a fixed subscriber station and reconnect from a different point of attachment.
  - **Portable**. Nomadic access is provided to a portable device, such as a PC card, with expectation of a best-effort handover.
  - **Simple mobility**. The subscriber may move at speeds up to 60 kmph with brief interruption (less than 1 sec) during handoff.
  - **Full mobility**: Up to 120 kmph mobility and seamless handoff (less than 50 ms latency and <1% packet loss) is supported.

IEEE 802.16 Mobility Support and WiMAX Forum Usage Scenarios



Source: Ericsson

Mobility Management

- IEEE 802.16e-2005 standard defines a framework for supporting mobility management, including
  - signaling mechanisms for tracking subscriber stations
    - move from one BS to another when active, or
    - move from one paging group to another when idle.
  - protocols to enable a seamless handover
- The WiMAX Forum has used the framework to develop mobility management within an end-to-end network architecture framework. The architecture also supports IP-layer mobility using mobile IP.

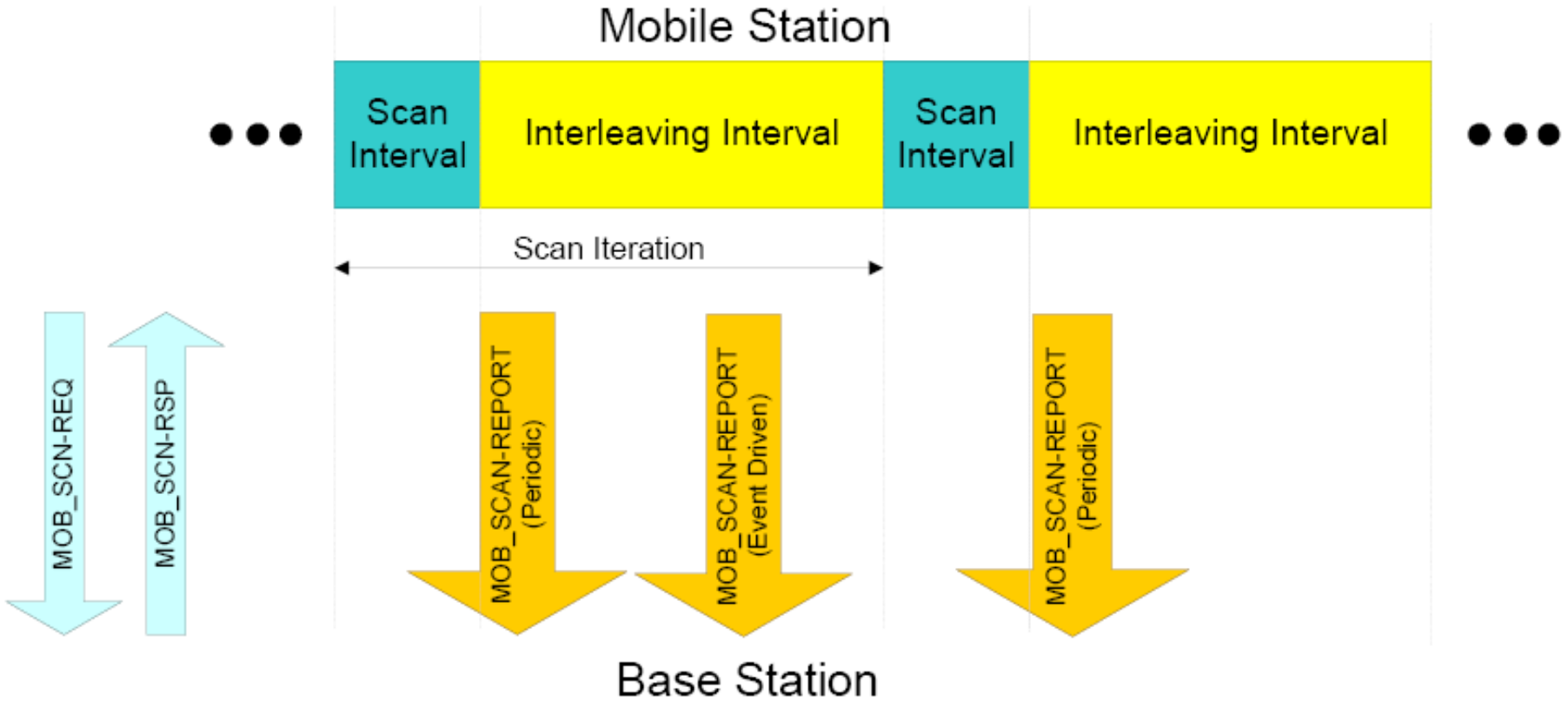
Mobility Management

- Three handoff methods are supported
  - *hard handover* (HHO) (M)
    - Scanning is performed during *scanning intervals* allocated by the BS. During these intervals, the MS is also allowed to optionally perform initial ranging and to associate with one or more neighboring base stations.
  - *fast base station switching* (FBSS) (O)
    - MS continuously monitors the *active set*, does ranging, and maintains a valid connection ID with each of them.
    - MS, only communicates with the *anchor BS*.
    - The MS simply reports the selected anchor BS on the CQICH.
  - *macro diversity handover* (MDHO) (O)
    - MS communicates on the downlink and the uplink with all base stations in a *diversity set* simultaneously.

Mobility Management

- Both FBSS and MDHO offer superior performance to HHO.
- Requirements: BSs in the active or diversity set have to
  - be synchronized,
  - use the same carrier frequency, and
  - share network entry–related information
- Support for FBSS and MDHO
  - not fully developed yet
  - not part of WiMAX Forum Release 1 network specifications

Scanning


Mobile Station
Scan Interval
Interleaving Interval
Scan Interval
Interleaving Interval
Scan Iteration
MOB_SCN-REQ
MOB_SCN-RSP
MOB_SCAN-REPORT (Periodic)
MOB_SCAN-REPORT (Event Driven)
MOB_SCAN-REPORT (Periodic)
Base Station

Scanning

- During a scanning interval,
  - MS measures the received signal strength indicator (RSSI) and the signal-to-interference-plus noise ratio (SINR) of the neighboring BS
  - MS can optionally *associate* with some or all the BSs in the neighbor list, which requires the MS to perform some level of initial ranging with the neighboring BS.

Association Levels

- Three levels of association are possible during scanning:
  - *Association level 0*
    - *scan/association without coordination*
    - contention-based ranging
    - RNG-RSP sent by neighboring BS
  - *Association level 1*
    - *scan/association with coordination*
    - The network provides the MS with a ranging code and a transmission interval for each of the neighboring BSs
    - RNG-RSP sent by neighboring BS
  - *Association level 2*
    - *network assisted association reporting*
    - Similar to association level 1
    - Serving BS may aggregate all ranging related information (sent via backbone) into a single MOB_ASC_REPORT

Stages of Handoff Process

- Cell reselection
  - MS performs scanning and association with one or more neighboring BSs to determine their suitability as a handoff target.
- Handoff decision and initiation
  - Decision can be taken by MS, BS, or external entity in WiMAX network
- Synchronization to the target BS
  - can be shortened if the target BS was notified about the impending handoff procedure and had allocated unicast ranging resources for MS
- Ranging with target BS
  - MS can skip or shorten this stage if it performed association with the target BS during the cell reselection/scanning stage
- Termination of context with previous BS

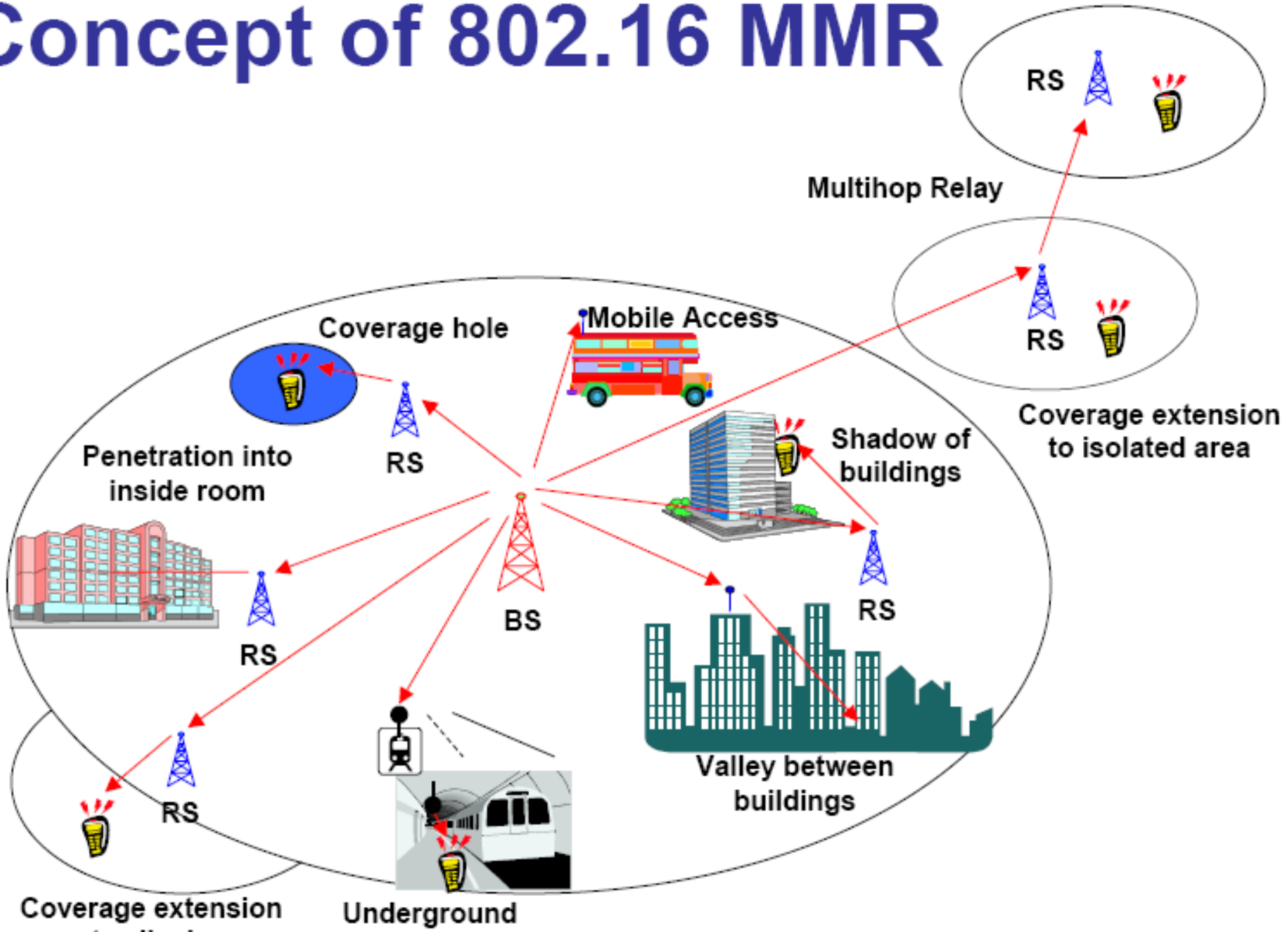
Stages of Handoff Process

- *Call drop* during the handoff process is defined as the situation in which an MS has *stopped communication with its serving BS in either DL or UL* before the normal handoff sequence has been completed.
- MS attempts a network reentry procedure with the target BS to reestablish its connection with the network when the MS detects a call drop.

802.16 On-going Projects

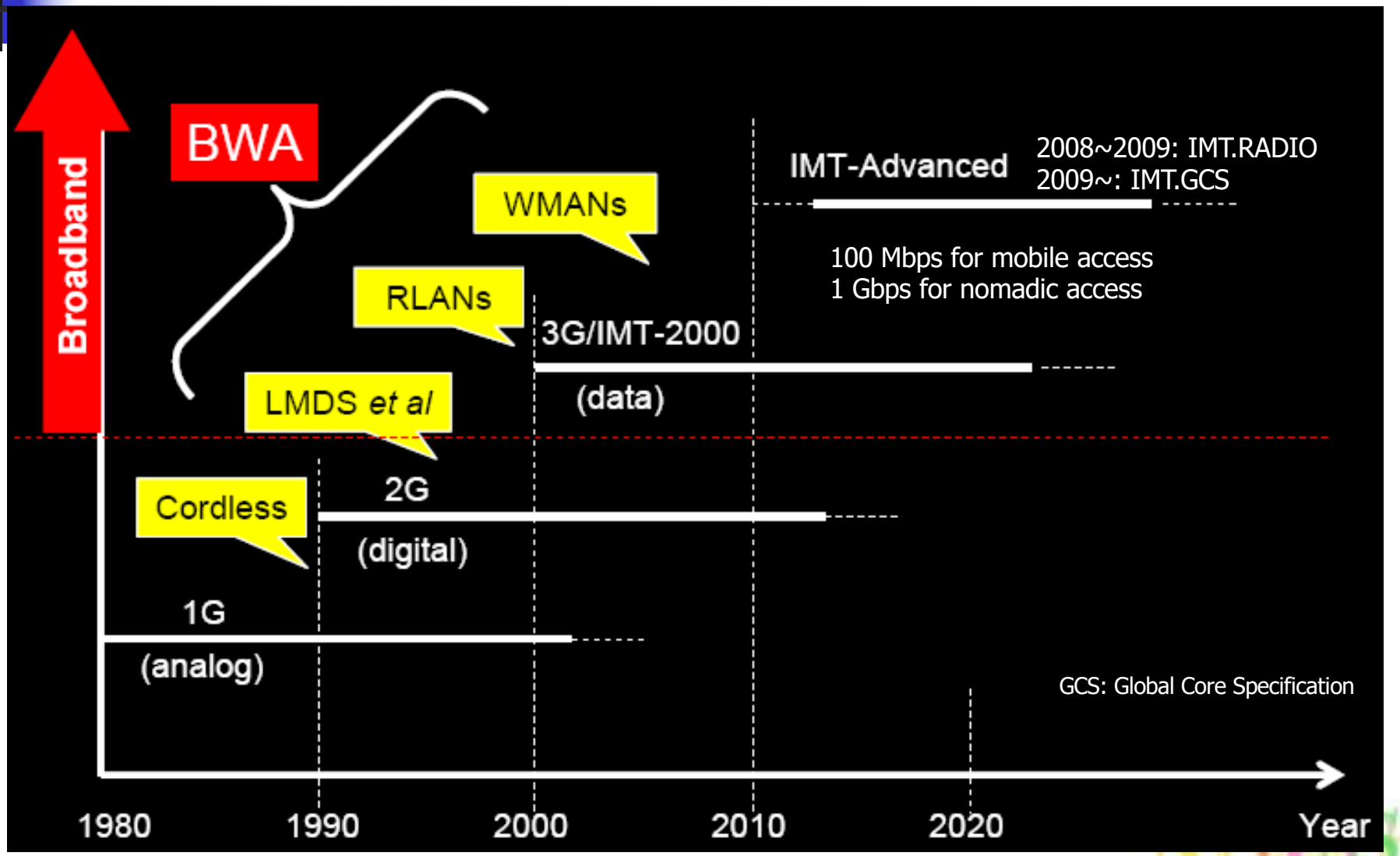
- Active TG and SG
  - Network Management (NetMAN) Task Group, developing:
    - Project g (Management Plane Procedures & Services)
    - Project i (Mobile Management Information Base)
    - Project k (Amendment to IEEE Std 802.1D on 802.16 Bridging)
  - License-Exempt Task Group:
    - TG h (License-Exempt Coexistence)
  - Maintenance Task Group:
    - developing IEEE Std 802.16-2004/Cor2-2006: Corrigendum to IEEE Std 802.16-2004
    - overseeing Working Group Maintenance Process
  - Relay Task Group:
    - TG j (Multihop Relay)
  - Task Group m (TGm):
    - TG m (Advanced Air Interface)

Concept of 802.16 MMR



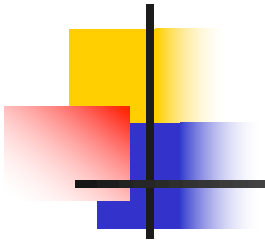
Source: IEEE

Generation of Mobile Wireless Systems



Reference

- IEEE 802.16 (http://www.ieee802.org/16/)
- WiMAX Forum (http://www.wimaxforum.org)
- J. G. Andrews, A. Ghosh, and R. Muhamed, “Fundamentals of WiMAX,” Prentice Hall, 2007
- A. Ganz, Z. Ganz, K. Wongthavarawat, “Multimedia Wireless Networks: Technologies, Standards, and QoS,” Prentice Hall, 2003



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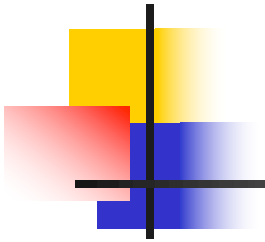


Backup

Key OFDM/OFDMA PHY Parameters

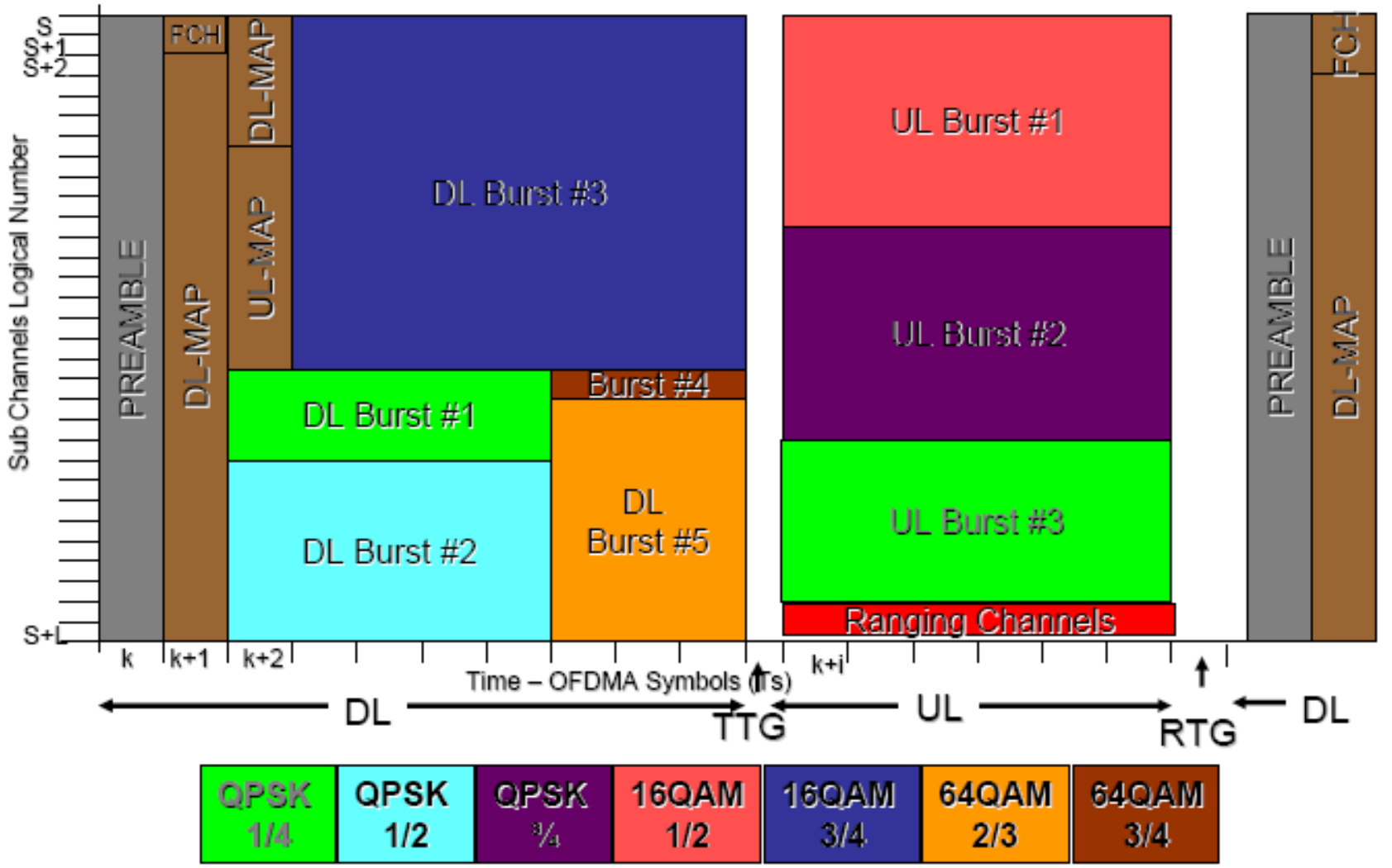
	OFDM	OFDMA
FFT size (max # subcarriers)	Fixed 256	Scalable 128, 512, 1024, 2048
Frame size	2-20ms	
Multiple access per OFDM symbol	One user	Multiple users
Bandwidth	1.25 to 28 MHz	
Modulation	BPSK, QPSK, 16QQAM, 64QAM	QPSK, 16QQAM, 64QAM
Coding	CC, RS-CC, CTC, BTC	CC, CTC, BTC, LDPC
Link adaptation	Channel feedback, open/closed-loop power control	Fast channel feedback (CQICH), open/closed-loop power control, H-ARQ
Multi-antenna techniques	AAS, STC	AAS, STC, MIMO

802.16 Physical Layer

Channel bandwidth	3.5MHz		1.25MHz		5MHz		10MHz		**8.75MHz[a]**	
PHY mode	256 OFDM		128 OFDMA		512 OFDMA		1,024 OFDMA		1,024 OFDMA	
Oversampling	8/7		28/25		28/25		28/25		28/25	
Modulation and Code Rate	**PHY-Layer Data Rate (kbps)**									
	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL
BPSK, 1/2	946	326	**Not applicable**							
QPSK, 1/2	1,882	653	504	154	2,520	653	5,040	1,344	4,464	1,120
QPSK, 3/4	2,822	979	756	230	3,780	979	7,560	2,016	6,696	1,680
16 QAM, 1/2	3,763	1,306	1,008	307	5,040	1,306	10,080	2,688	8,928	2,240
16 QAM, 3/4	5,645	1,958	1,512	461	7,560	1,958	15,120	4,032	13,392	3,360
64 QAM, 1/2	5,645	1,958	1,512	461	7,560	1,958	15,120	4,032	13,392	3,360
64 QAM, 2/3	7,526	2,611	2,016	614	10,080	2,611	20,160	5,376	17,856	4,480
64 QAM, 3/4	8,467	2,938	2,268	691	11,340	2,938	22,680	6,048	20,088	5,040
64 QAM, 5/6	9,408	3,264	2,520	768	12,600	3,264	25,200	6,720	22,320	**5,600**

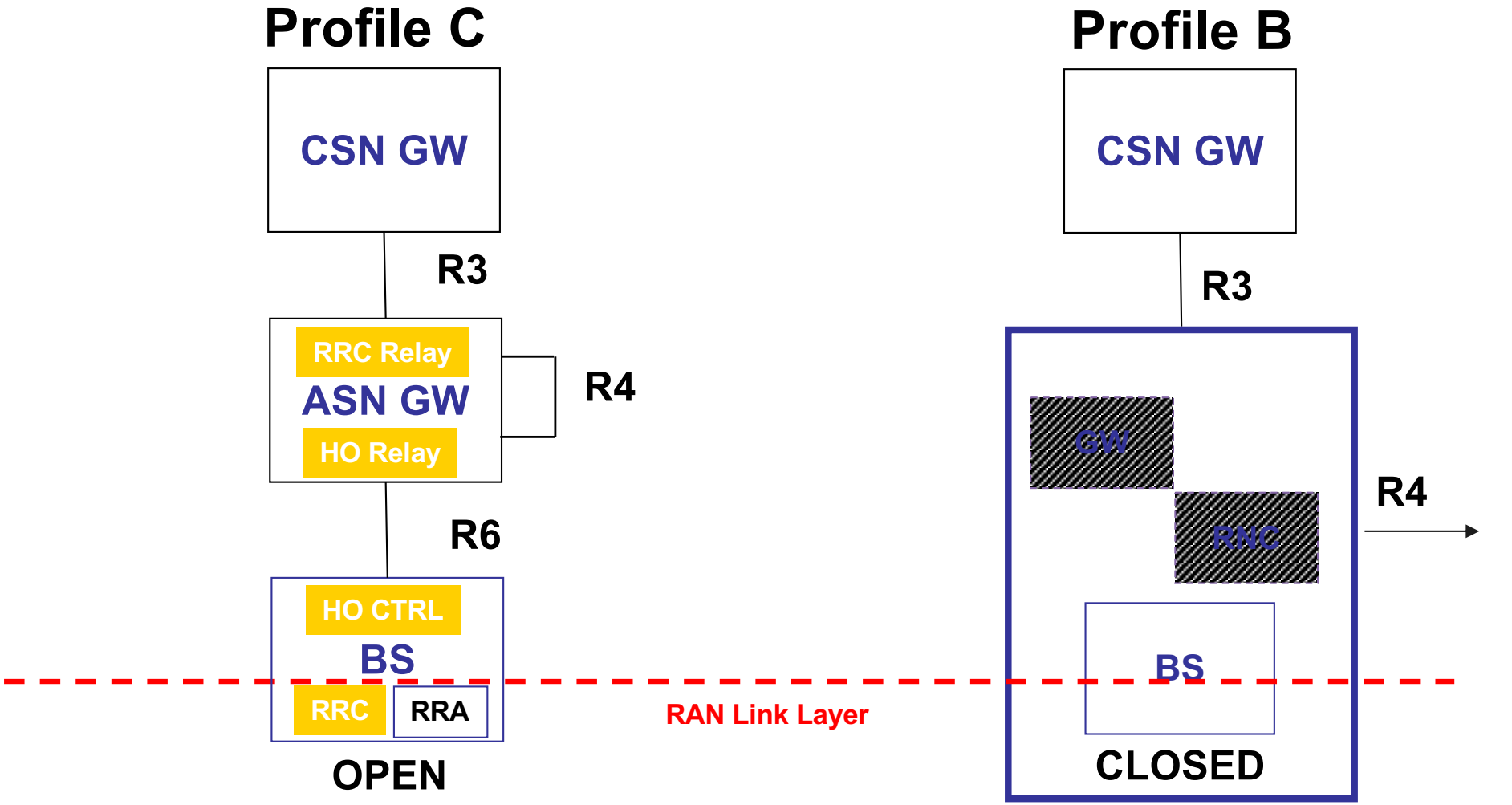
a. The version deployed as WiBro in South Korea.

OFDMA TDD Frame Structure



Source: Intel

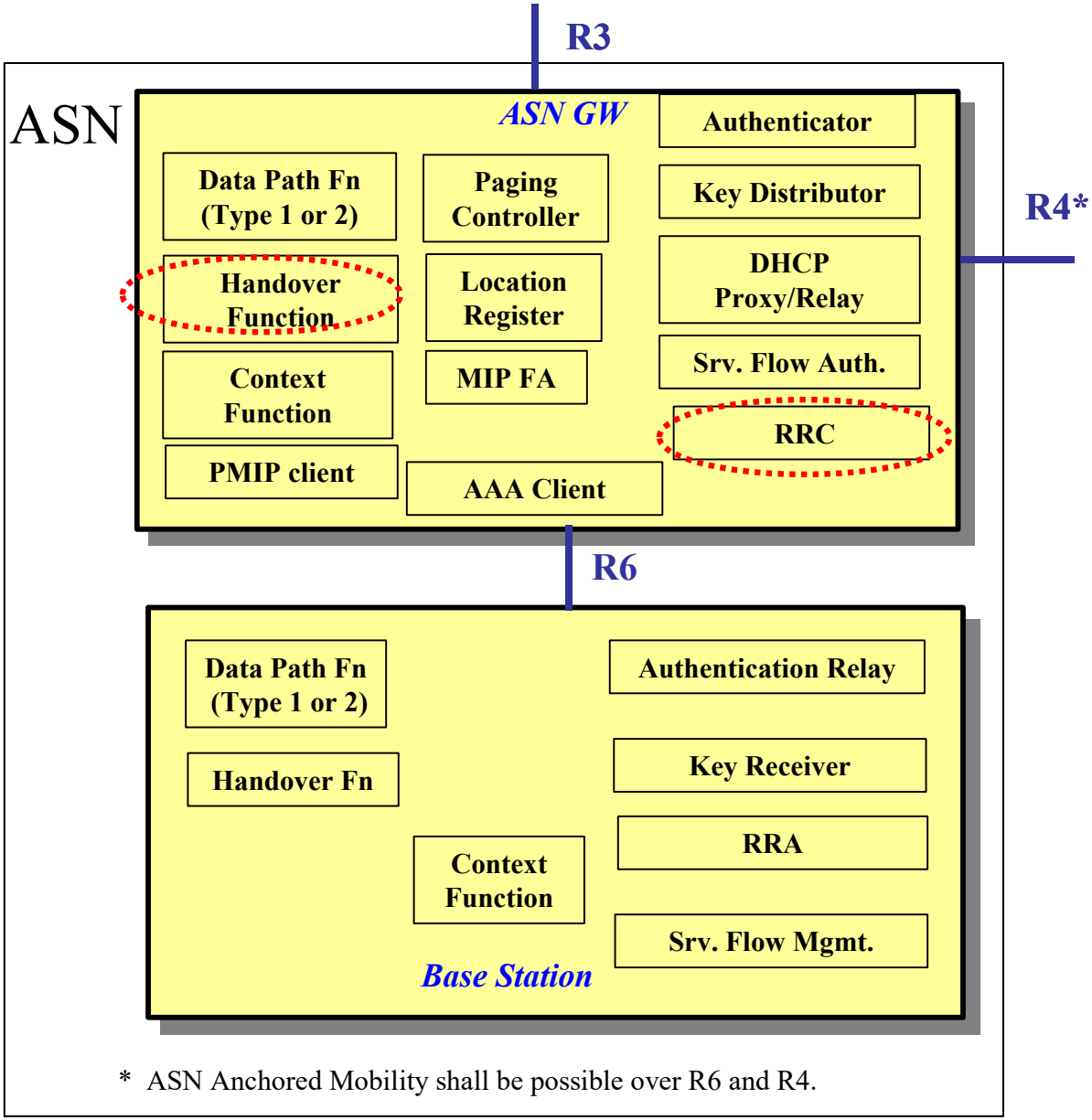
WiMax Network Profiles



The intent of ASN profiles is to provide a bound framework for interoperability amongst all the entities within the ASN

Source: Nortel

WiMAX ASN Configuration – Profile A



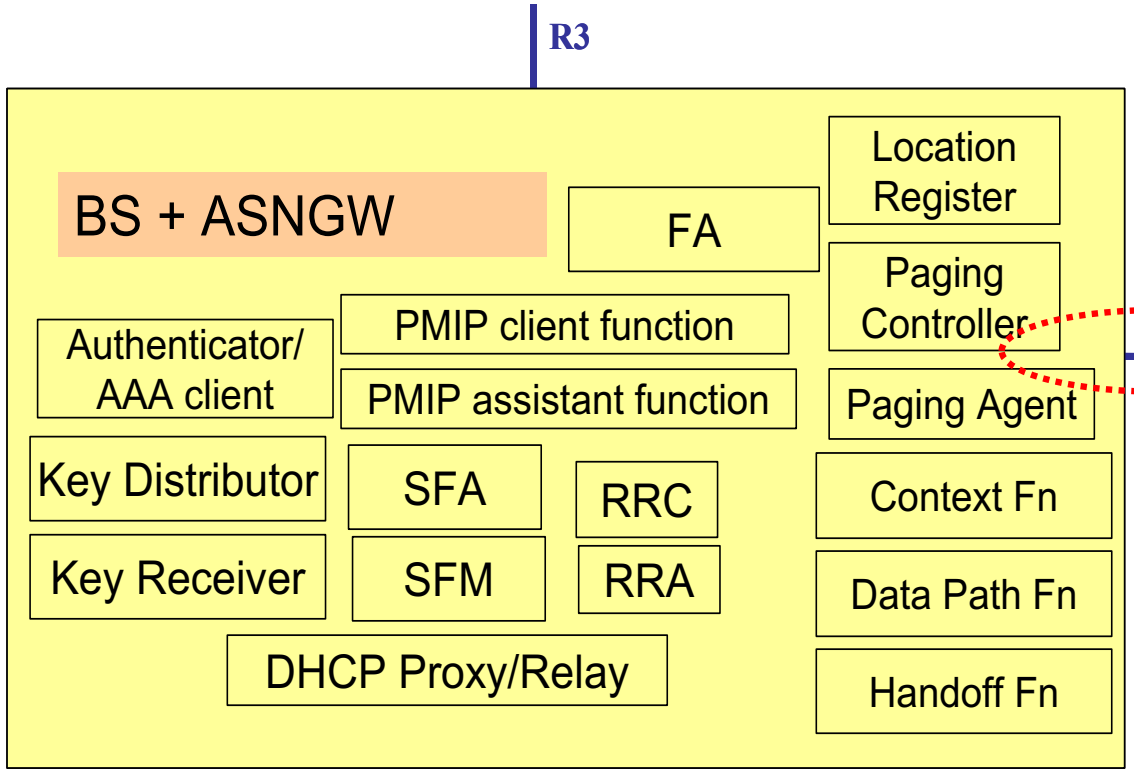
"Centralized" RAN functional processing between ASN-GW & BS

Key Attributes of Profile-A

- HO Control is in the ASN GW
- RRC is in ASN GW that allows RRM among multiple BSs
- ASN Anchored mobility among BSs shall be achieved by utilizing R6 and R4 physical connections.

Source: Nortel

WiMAX ASN Configuration – Profile B



Notes:

1. No assumptions made on physical co-location of functions within an ASN
2. Allow centralized, distributed or hybrid implementations within ASN. R6 not exposed in this profile.

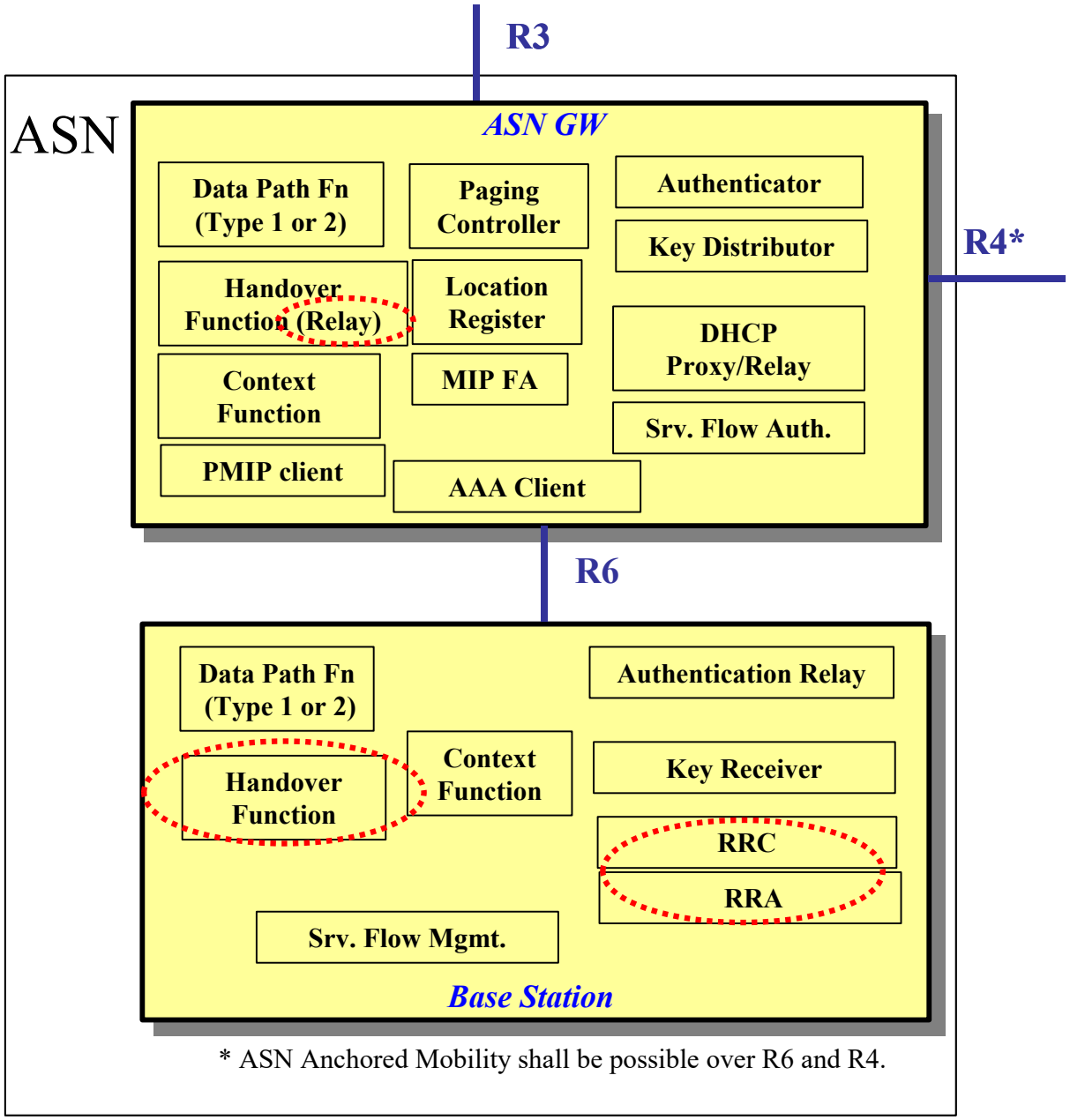
* ASN Anchored Mobility shall be possible over R4.

Key Attributes of Profile-B

- Profile B compliant systems will interoperate with other ASNs of any profile via R3 and R4 reference points.
- Anchored mobility shall be possible via R4.
- ASN conforming to profile B may include a single physical device or multiple physical devices.

Source: Nortel

WiMAX ASN Configuration – Profile C



"Centralized" RAN w/ "Distributed" RRM functional processing between ASN-GW & BS

Key Attributes of Profile-C

- HO Control is in the Base Station.
- RRC is in the BS that would allow RRM within the BS
- As in Profile A, ASN Anchored mobility among BSs shall be achieved by utilizing R6 and R4 physical connections

Source: Nortel

WiMAX ASN Profile Comparison

Profile	B	A	C
Control Methodology	Distributed	Centralized	Partially Centralized + Partially Distributed
Infrastructure	Combined ASN-GW+BTS	Hierarchy	Hierarchy
Target Scenario	Hot Spot	Large Scale	Large Scale
Difference	HO Decision in (ASN-GW +BTS)	HO Decision in ASN-GW	HO Decision in BTS & ASN-GW
Advantage	If use is within the BTS coverage, the HO interruption can be minimized	All the BS neighboring information will store in ASN which provide the prompt response no matter within or across BTS. Easy to implement for large scale deployment	Keep the flexibility to handle HO process within BTS or ASN-GW Coverage
Disadvantage	Large signaling overhead on HO, paging, Authentication and MIP setup when across the BTS	For Intra-BTS HO, the decision need to go through ASN-GW	The BTS required high capability & resource to store and handle HO process (& RRC/RRA)

Source: Nortel