Introduction to mobile WiMAX Radio Access Technology: PHY and MAC Architecture

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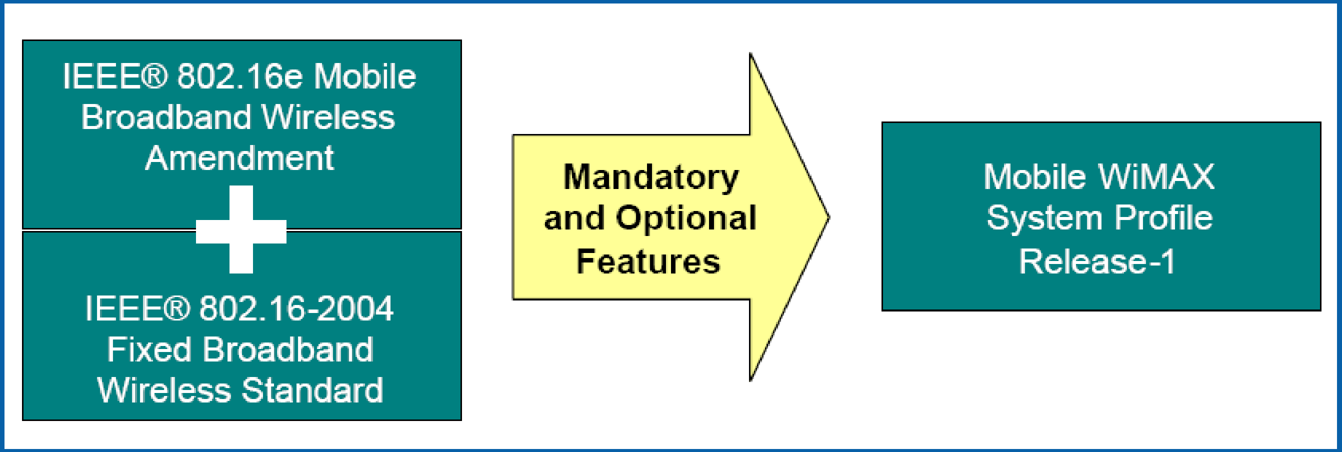
Outline

- What is mobile WiMAX?
- Salient features of mobile WiMAX
- IEEE 802.16 Reference Model
- Air-Interface Protocol Stack
- WiMAX Network Reference Model
- Review of mobile WiMAX Physical Layer
- Review of mobile WiMAX MAC Layer
- Performance of mobile WiMAX
- Next Generation of mobile WiMAX
- Back up
  - mobile WiMAX system profile feature set

What is mobile WiMAX?

- Mobile WiMAX is a rapidly growing broadband wireless access technology based on IEEE 802.16-2004 and IEEE 802.16e-2005 air-interface standards.
- The WiMAX Forum* is developing mobile WiMAX system profiles that define the mandatory and optional features of the IEEE standard that are necessary to build a mobile WiMAX compliant air interface which can be certified by the WiMAX Forum.
- mobile WiMAX is not the same as IEEE 802.16e-2005, rather a subset of the IEEE STD 802.16 standard features and functionalities.



* http://www.wimaxforum.org

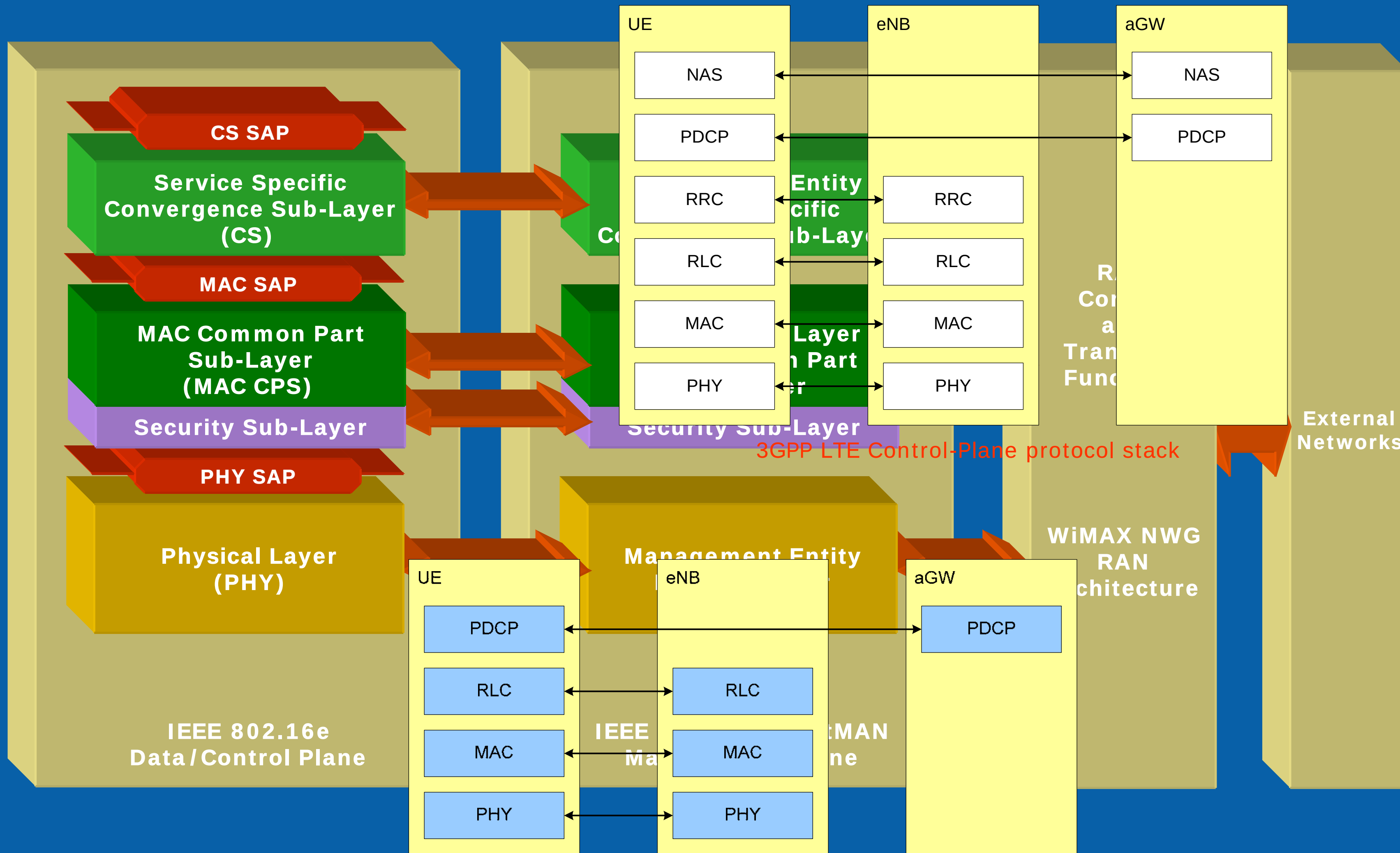
Salient Features of mobile WiMAX

- The mobile WiMAX air interface utilizes Orthogonal Frequency Division Multiple Access (**OFDMA**) as the radio access method for improved multipath performance in non-line-of-sight environments.
- **High Data Rates:** The use of multiple-input multiple-output (MIMO) antenna techniques along with flexible sub-channelization schemes, adaptive modulation and coding enable the mobile WiMAX technology to support peak downlink (DL) data rates up to 128 Mbps per sector and peak uplink (UL) data rates up to 56 Mbps per sector in 20 MHz bandwidth (DL 2x2 MIMO, UL 1x2 Virtual MIMO).
- **Quality of Service (QoS):** The fundamental premise of the IEEE 802.16 medium access control (MAC) architecture is QoS. It defines service flows which can be mapped to fine granular IP sessions or coarse differentiated-services code points to enable end-to-end IP based QoS. Additionally, sub-channelization and medium access protocol (MAP) based signaling schemes provide a flexible mechanism for optimal scheduling of broadcast and unicast traffic using space, frequency, and time physical resources over the air interface on a frame-by-frame basis.

Salient Features of mobile WiMAX

- **Scalability***:* The mobile WiMAX technology utilizes scalable OFDMA (SOFDMA) and has the capability to operate in scalable bandwidths from 1.25 to 20 MHz to comply with various spectrum allocations worldwide.
- **Security:** The mobile WiMAX incorporates the most advanced security features that are currently used in wireless access systems. These include Extensible Authentication Protocol (EAP) based authentication, Advanced Encryption Standard (AES) based authenticated encryption, and Cipher-based Message Authentication Code (CMAC) and Hashed Message Authentication Code (HMAC) based control message protection schemes.
- **Mobility:** The mobile WiMAX supports optimized handover schemes with latencies less than 50 ms to ensure real-time applications such as Voice over Internet Protocol (VoIP) are efficiently supported without service degradation. Flexible key management schemes assure that security is maintained during handover.

IEEE 802.16 Reference Model

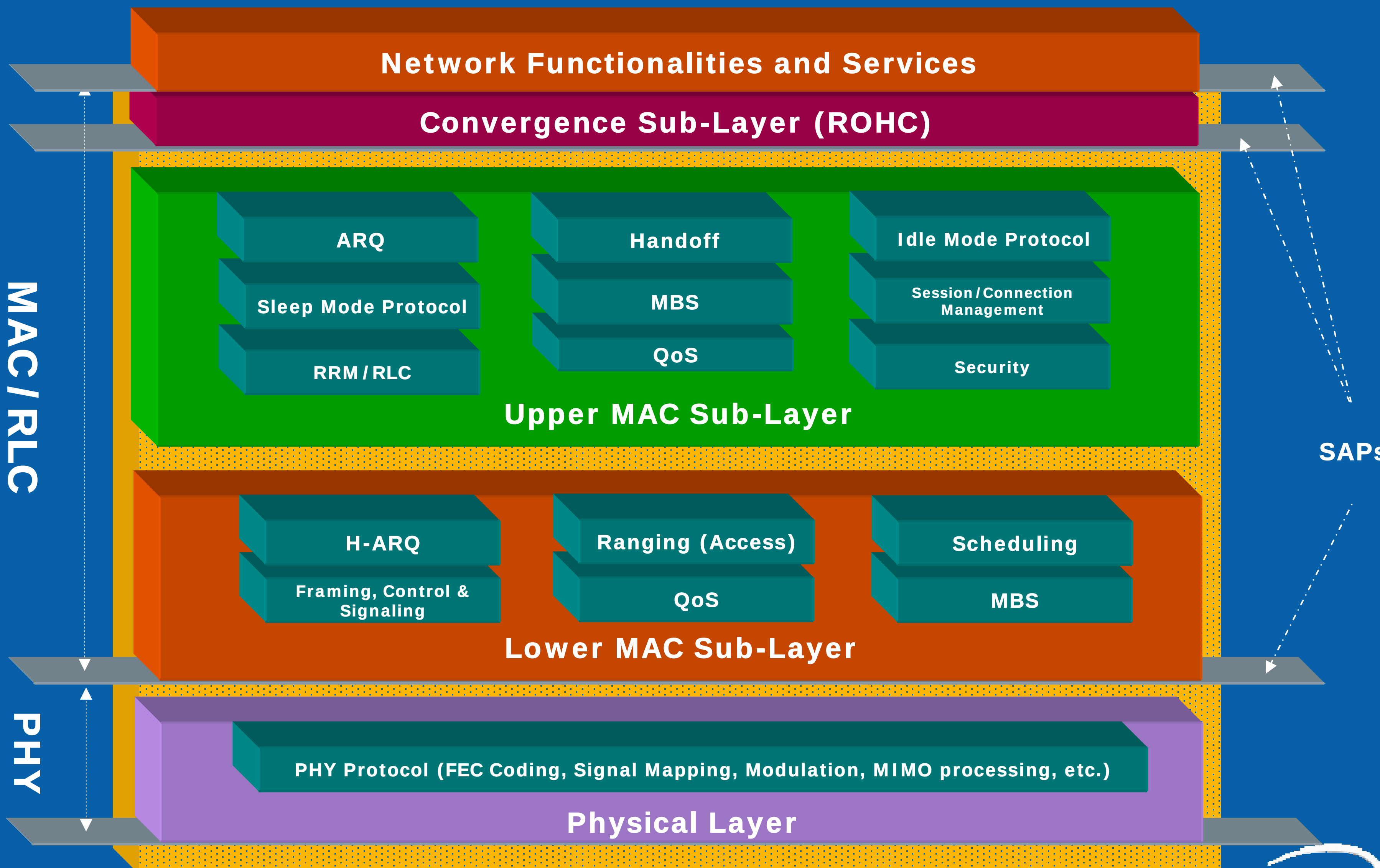


3GPP LTE User-Plane protocol stack

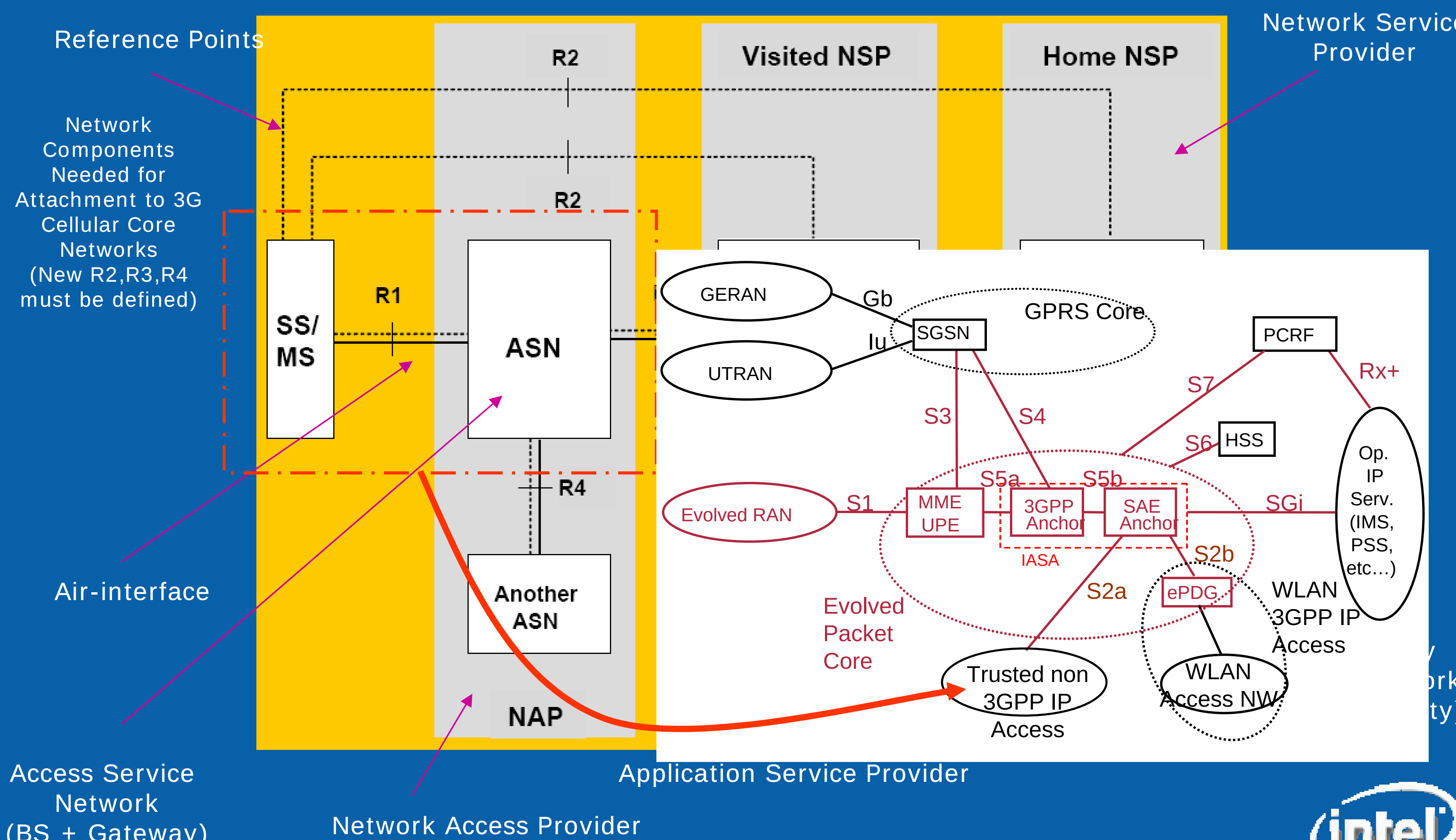
IEEE 802.16 Reference Model

- **Service specific convergence sublayer (CS)**
  - Mapping of external network data received through the CS SAP into MAC SDUs received by the MAC CPS through the MAC SAP
  - Classifying external network SDUs and associating them to MAC SFID and CID
  - Payload header suppression/compression (PHS)
- **MAC common part sublayer (MAC CPS)**
  - Core MAC functionality of system access (idle/sleep/active mode protocols)
  - Connection establishment and maintenance
    - **Basic connection** for transfer of time-critical MAC messages
    - **Primary management connection** for transfer of more delay tolerant MAC messages
    - **Secondary management connection** for transfer protocol messages such as DHCP
    - **Transport connections** for transfer of service (data, voice, etc.) traffic
  - Quality of Service (QoS)
  - Scheduling of users for both DL and UL
  - Control and signaling
- **Security sublayer**
  - Authentication (user authentication is part of core network services)
  - Secure key exchange and Encryption
- **Physical layer**
  - Physical layer protocol and functions

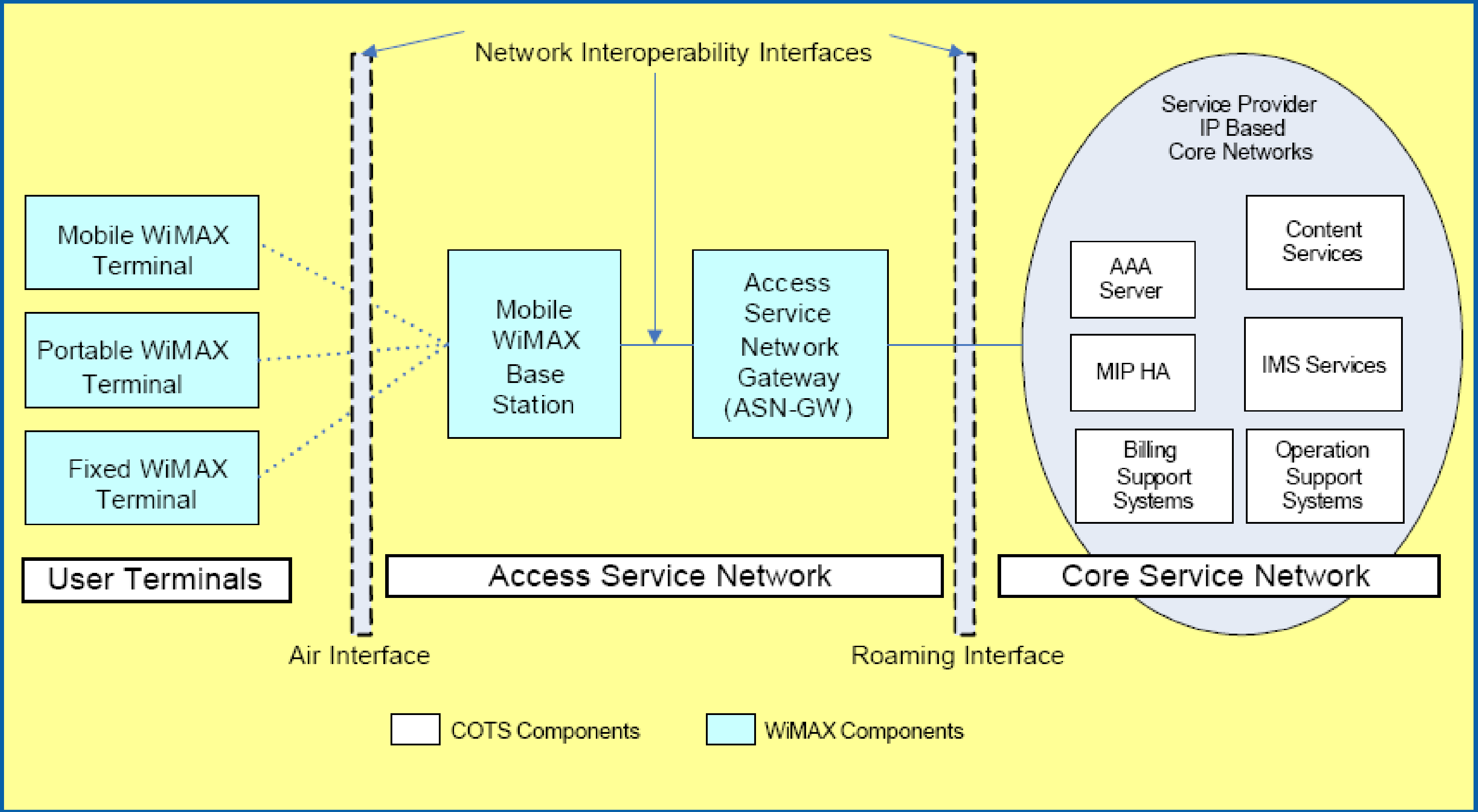
Air-Interface Protocol Stack



WiMAX Network Reference Model



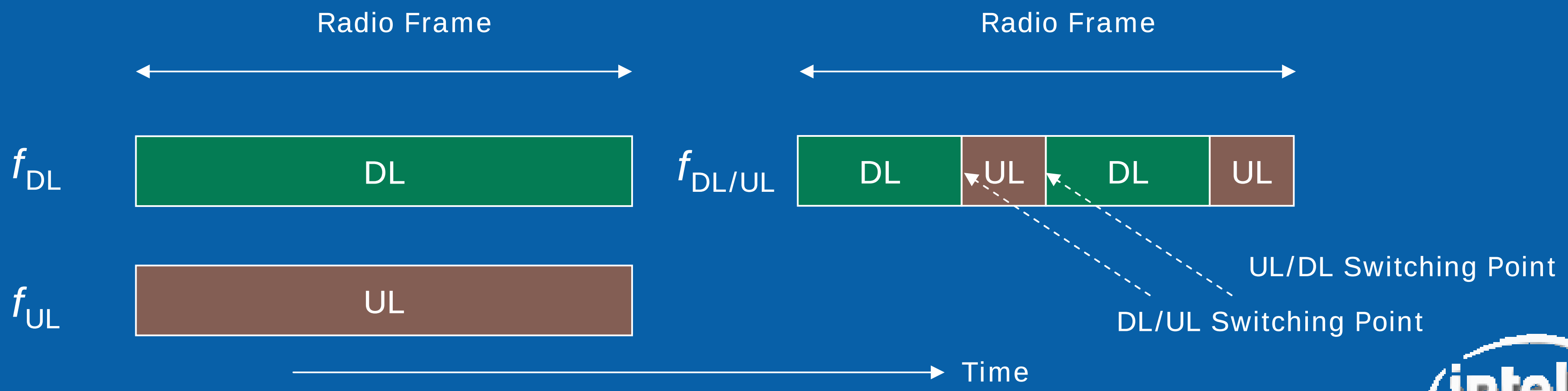
WiMAX Network IP-Based Architecture



Review of mobile WiMAX Physical Layer

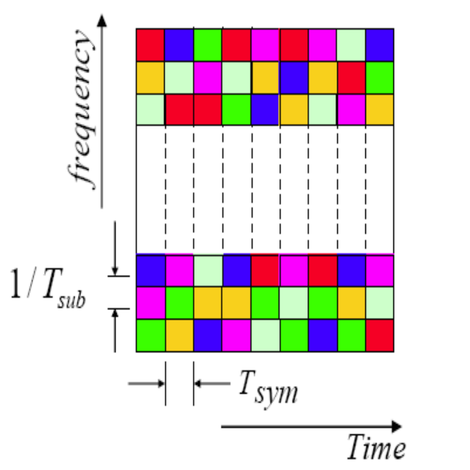
Duplex Mode

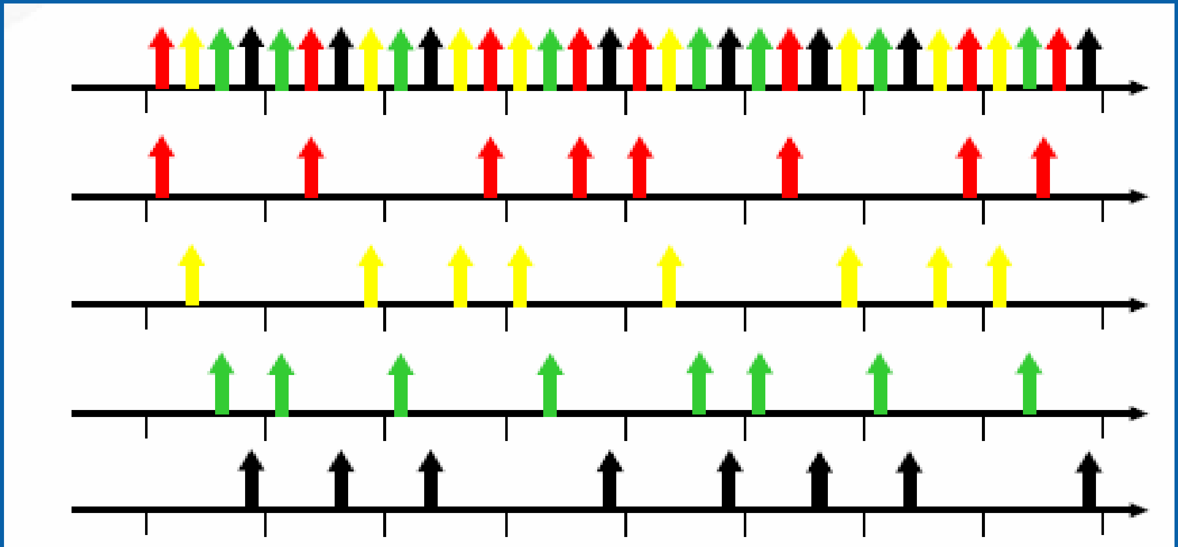
- The IEEE 802.16e-2005 air-interface supports both Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) modes; however, the initial release of mobile WiMAX profiles only includes the TDD mode of operation.
- The TDD mode is preferred for the following reasons:
  - It enables dynamic allocation of DL and UL resources to efficiently support asymmetric DL/UL traffic (adaptation of DL:UL ratio to DL/UL traffic).
  - It ensures channel reciprocity for better support of link adaptation, MIMO and other closed-loop advanced antenna techniques such as transmit beam-forming.
  - Unlike FDD, which requires a pair of channels, TDD only requires a single channel for both downlink and uplink providing greater flexibility for adaptation to varied global spectrum allocations.
  - Transceiver designs for TDD implementations are less complex and therefore less expensive (restrictions in the number of DL/UL switching points).



OFDMA Concept

- In OFDMA multiple access is two dimensional (time and frequency)
- Multiple users use separate subchannels for multiple access
  - Improved capacity
  - Improved scheduling and QoS support
  - Reduced interference (no intra-cell interference)
  - Improved link margin (subchannelization gain)
- Flexible subchannelization
  - Pseudo-random permutation (PUSC) for frequency diversity, or
  - Contiguous assignment (AMC) to enable beamforming
- Scalable structure to support variable bandwidths





OFDMA Numerology

Transmission Bandwidth (MHz)	1.25	5	10	20
Sampling Frequency (MHz) $f_s = 8000\lfloor nBW / 8000 \rfloor \quad n = 28/25$	1.4	5.6	11.2	22.4
FFT Size	128	512	1024	2048
Sub-Carrier Spacing (kHz)	10.94	10.94	10.94	10.94
Tu (us)	91.4	91.4	91.4	91.4

Cyclic Prefix (CP)	Ts (us)	Number of OFDM Symbols per Frame	Idle Time (us)
Tg=1/4 Tu	91.4 + 22.85=114.25	43	87.25
Tg=1/8 Tu	91.4 + 11.42=102.82	48	64.64
Tg=1/16 Tu	91.4 + 5.71=97.11	51	47.39
Tg=1/32 Tu	91.4 + 2.86=94.26	53	4.22

Frame Size – (Number of OFDM Symbols) * Ts

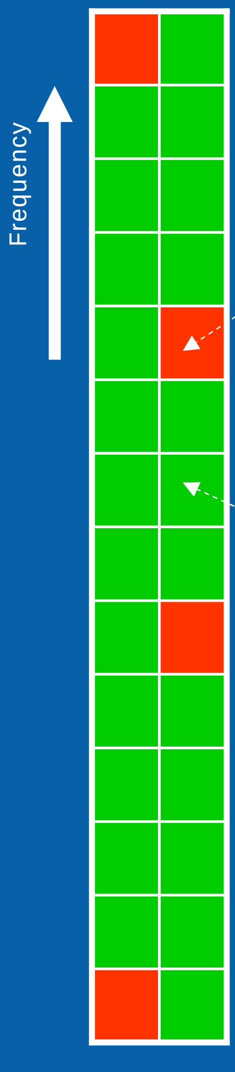
The idle time in FDD mode may be used for channel or noise measurements

Subchannelization and Slots

- OFDMA symbol is made up of sub-carriers
  - Data sub-carriers
  - Pilot sub-carriers
  - Null sub-carriers – guard bands and DC sub-carrier
- Standard supports multiple schemes for dividing the frequency/time resources between users – call these subchannelization schemes (PUSC, AMC, FUSC, TUSC, etc.)
- Subchannelization schemes define slots/sub-channels
- Slot is the basic unit of allocation in the time-frequency grid
  - Slot is a (logical) n x m rectangle where
    - n is a number of sub-carriers and m is a number of contiguous symbols
  - Slot contains 48 data carriers for all subchannelization schemes, but their arrangement is different in different schemes
  - Number of pilot carriers in a slot is different for different subchannelization schemes
- The term "subchannel" has a confusing definition in the standard
  - Subchannel is defined as a grouping of sub-carriers
  - Subchannels really refer to the frequency dimension of slots
- The number of used sub-carriers over the entire spectrum is different for various permutation schemes.

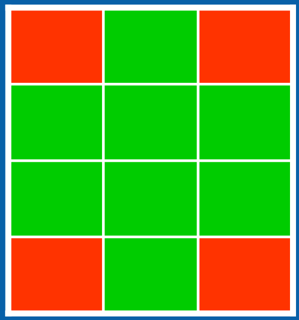
Subchannelization Schemes

CLUSTER in DL-PUSC Zone
Slot = 4 clusters over 2 symbols

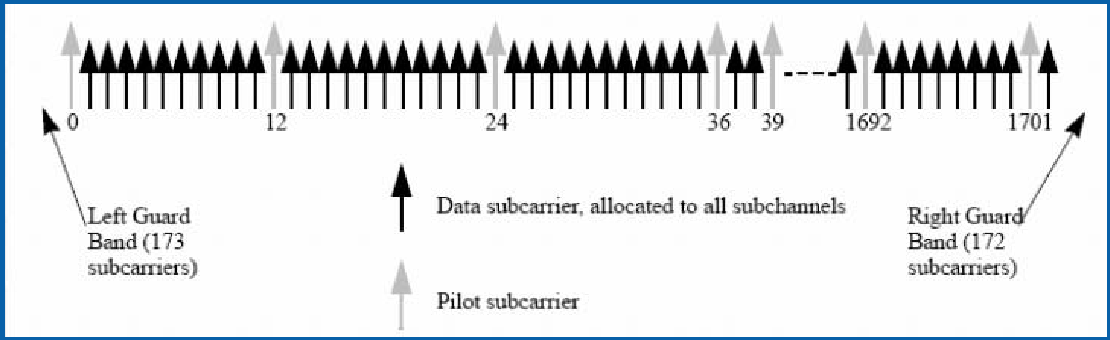


BIN in DL/UL AMC Zone
slot = m bin x n symbols
m x n = 6

TILE in UL-PUSC Zone
Slot= 6 tiles over 3 symbols

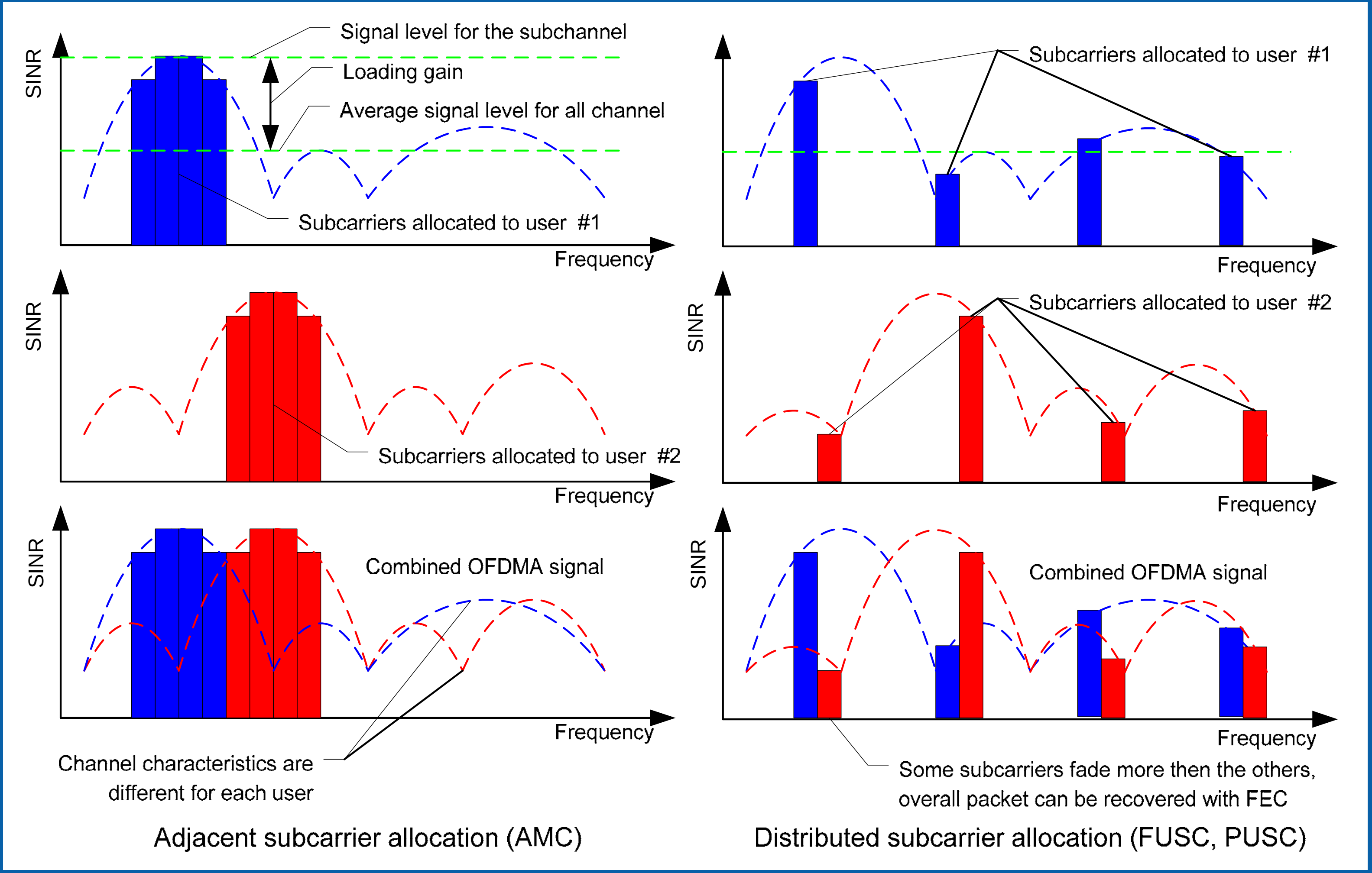


DL FUSC

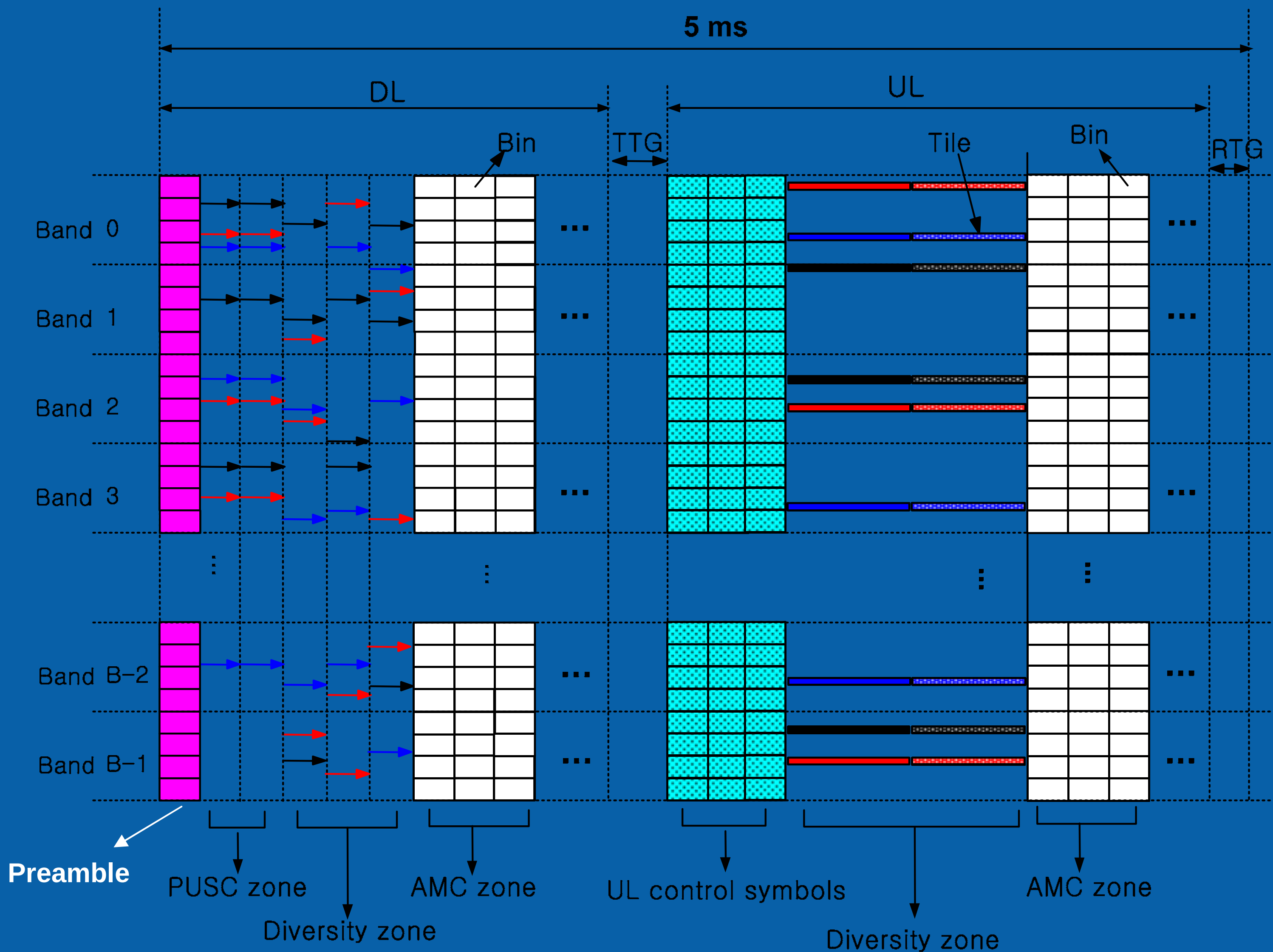


After assigning 83 common pilots, the remaining sub-carriers are divided into 48 groups of 16 sub-carriers. Slots are formed by taking one sub-carrier from each group.

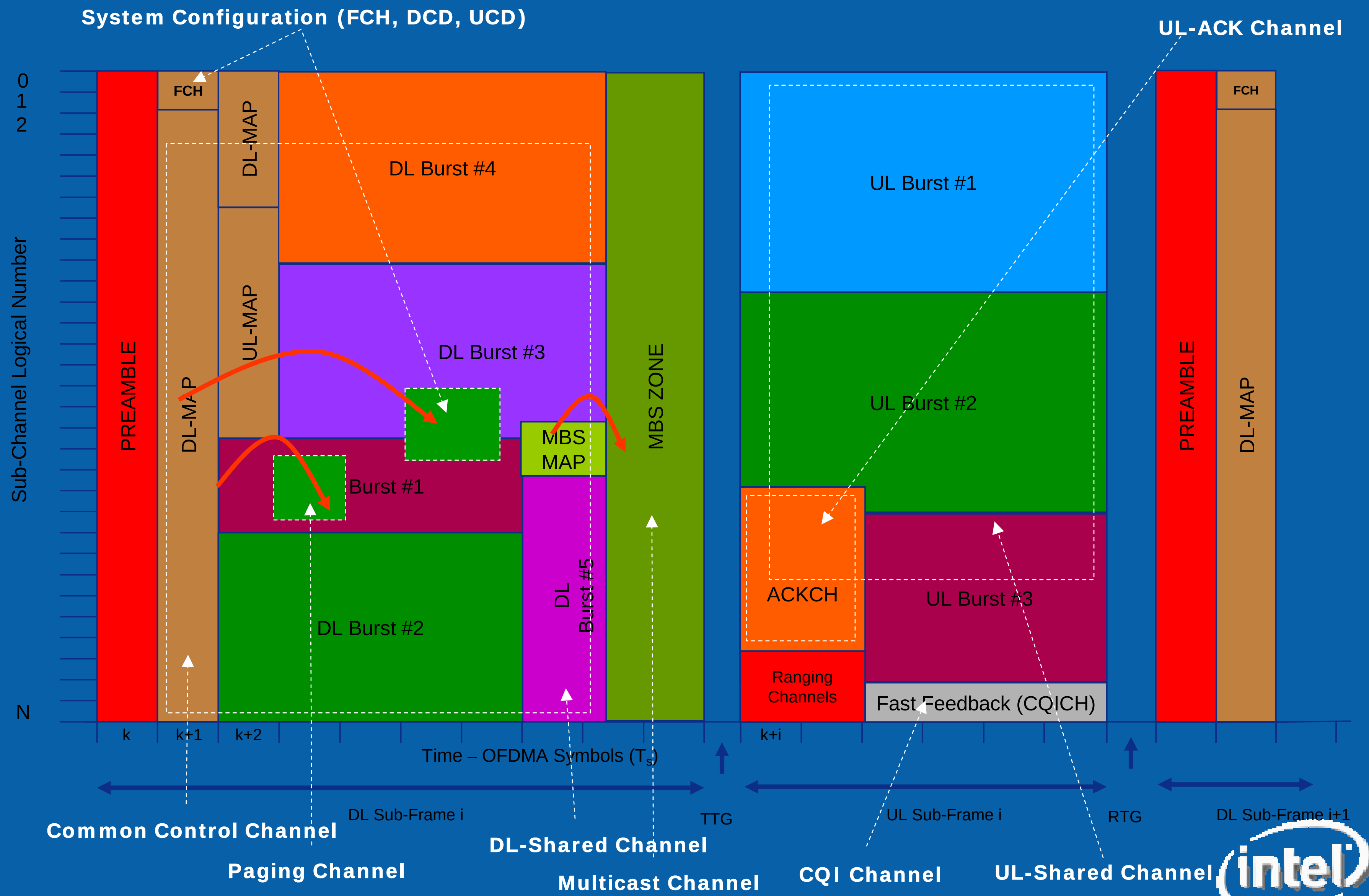
Localized and Distributed Resource Allocation



mobile WiMAX Frame Structure

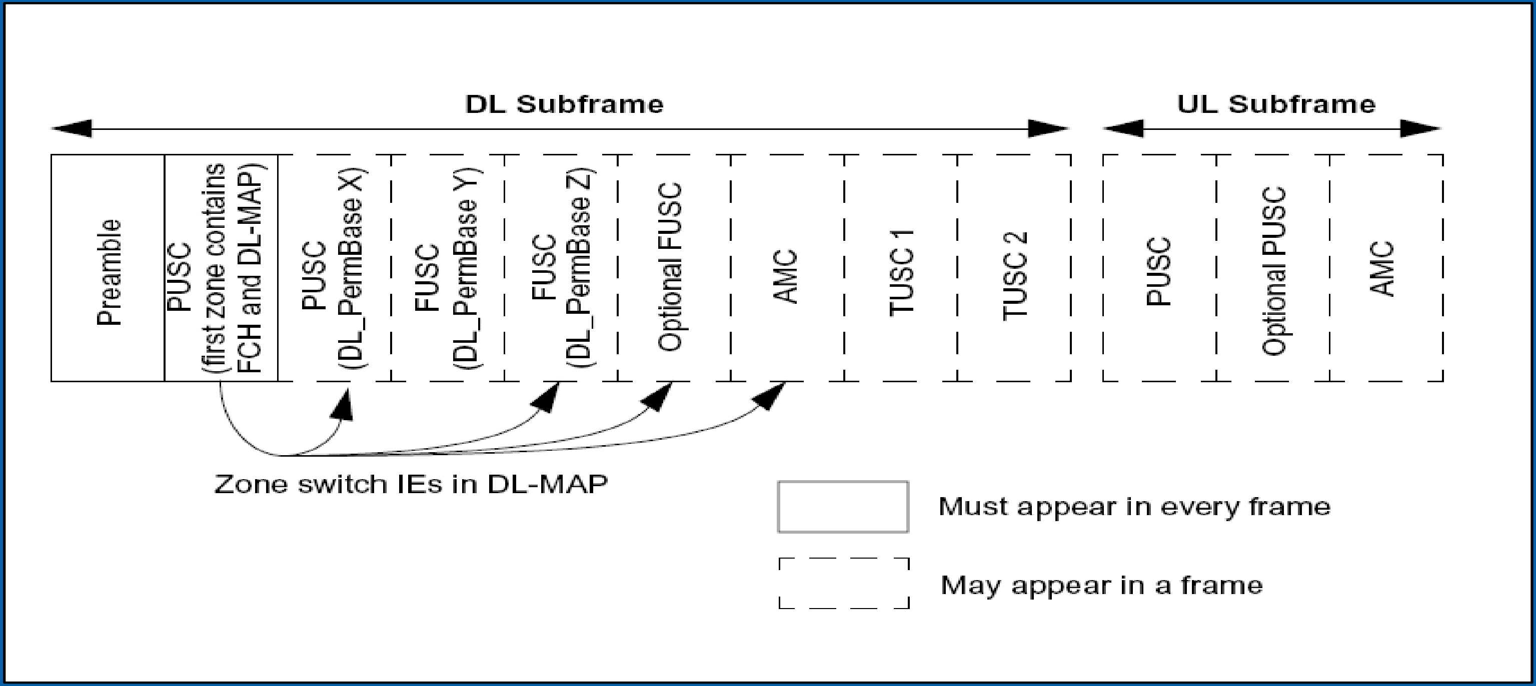


Mapping of the Physical Channels



Zones in TDD Mode

- First zone in DL/UL subframe
  - DL PUSC is mandatory
  - UL PUSC is default, but O-PUSC can be located at the first zone in UL
- Zone switch IE in DL/UL-MAP
  - DL: symbol offset, zone length, permutation, PermBase, STC type AMC type
  - UL: symbol offset, zone length, permutation, PermBase, AMC type



FCH and DCD / UCD
System Configuration Information

- **Frame Control Header Contents**
  - **Used Subchannels bitmap**
    Maps the used subchannel in the segment
    Allocated subchannel are renumbered logically
  - **Ranging Change Indication**
  - **DL-Map Coding parameters**
    - **Repetition Coding Indication (1,2,4,6)**
    - **Coding Indication CC and CTC (mandatory) and LDPC optional**
    - **DL-MAP Length**
  - **Total 24 bits**

Sub channel bit map	RNG	REP	Coding	DL-Map Len	reserved
6 bit	1 bit	2 bit	3 bit	8 bit	4 bit

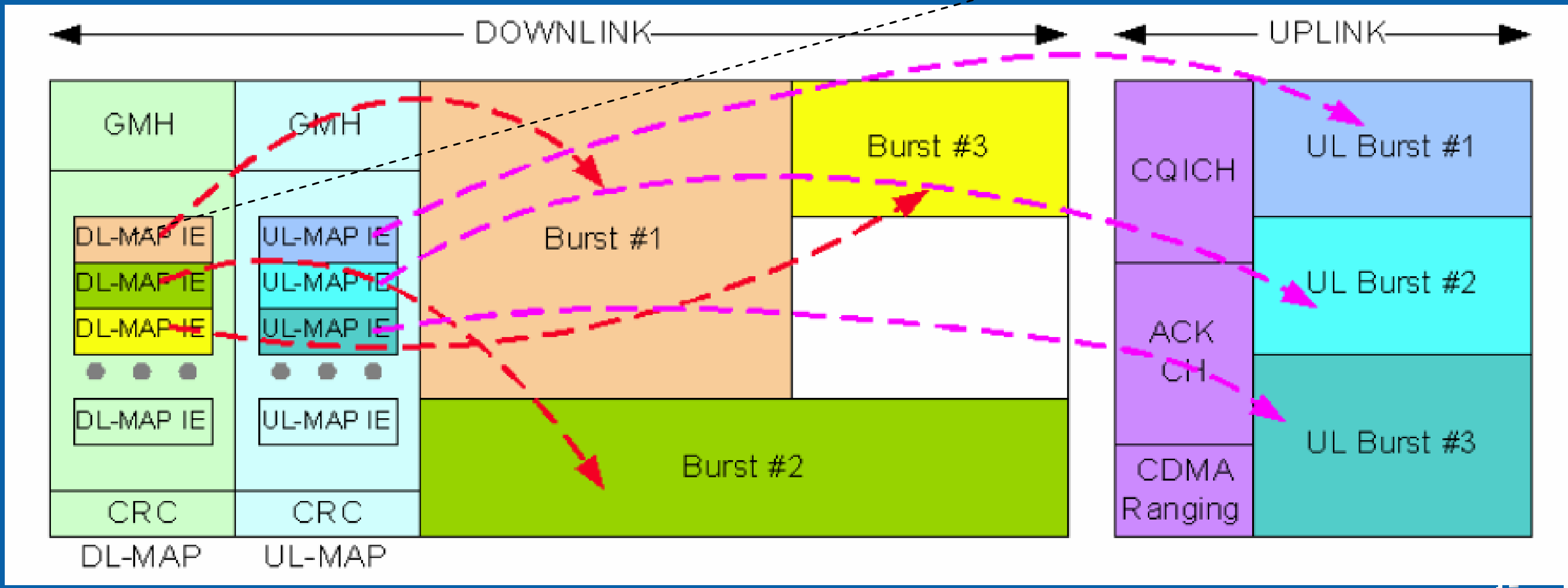
- **Fixed Location and Coding:**
  - First 4 slots of the segment
  - QPSK rate ½ with repetition coding of x4
- **DCD (Downlink Channel Descriptor)**
  - Downlink burst profile – CINR for each DIUC (MCS type), BS EIRP, Maximum RSS for initial ranging, TTG and RTG, H-ARQ ACK delay for DL burst, HO type and parameters, etc.
- **UCD (Uplink Channel Descriptor)**
  - Uplink burst profile – CINR for each UIUC (MCS type), Uplink center frequency, UL allocated subchannel bitmap, Ranging parameters, Band AMC parameters, H-ARQ ACK delay for UL burst, UL OLPC parameters, etc.

Medium Access Protocol (MAP)
Message-Based Control and Signaling

MAP Contains
- Information on DL/UL burst allocation
- Physical layer control message (IE: Information Element)

Normal MAP : DL-MAP & UL-MAP
- Management Messages (GMH and CRC)
- DL-MAP IEs and UL-MAP IEs
- Burst Profile (DIUC and UIUC)

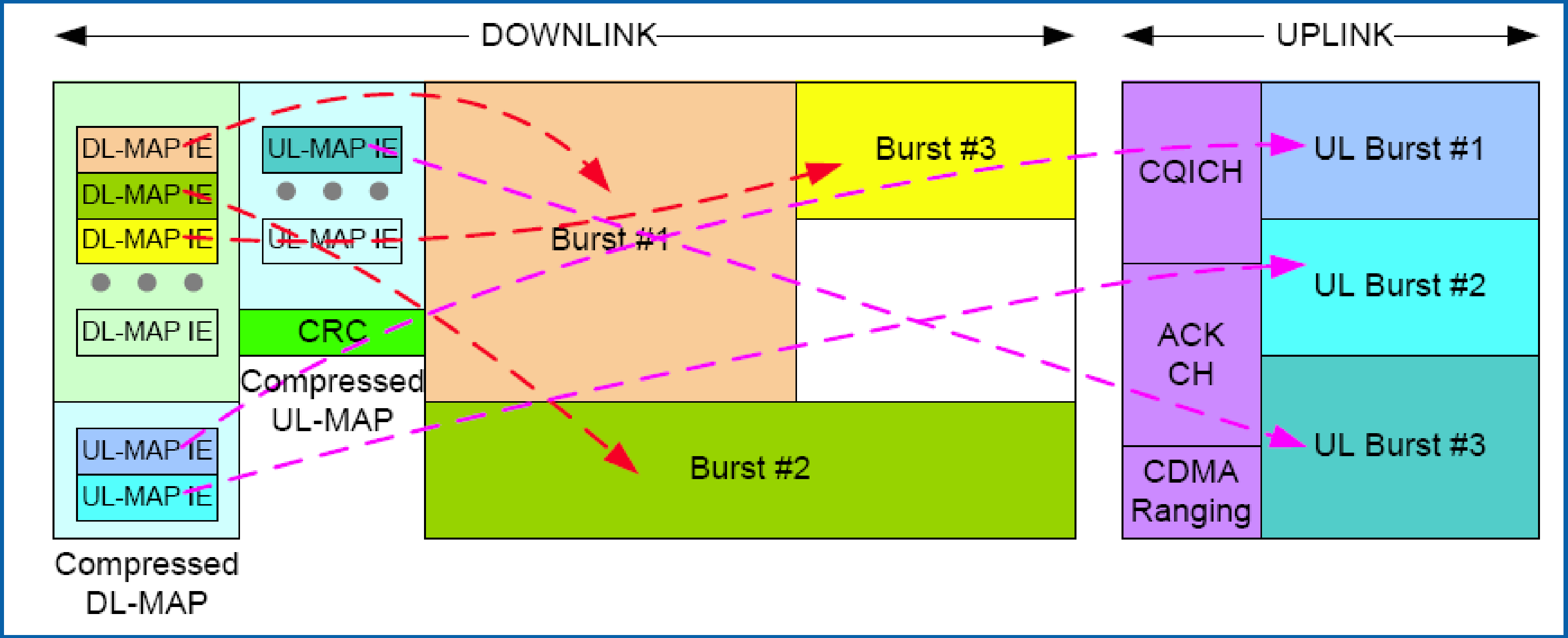
DIUC	List Of CIDs (optional)	Burst Allocation



Medium Access Protocol (MAP)
Message-Based Control and Signaling

Compressed MAP: Compressed DL-MAP & UL-MAP

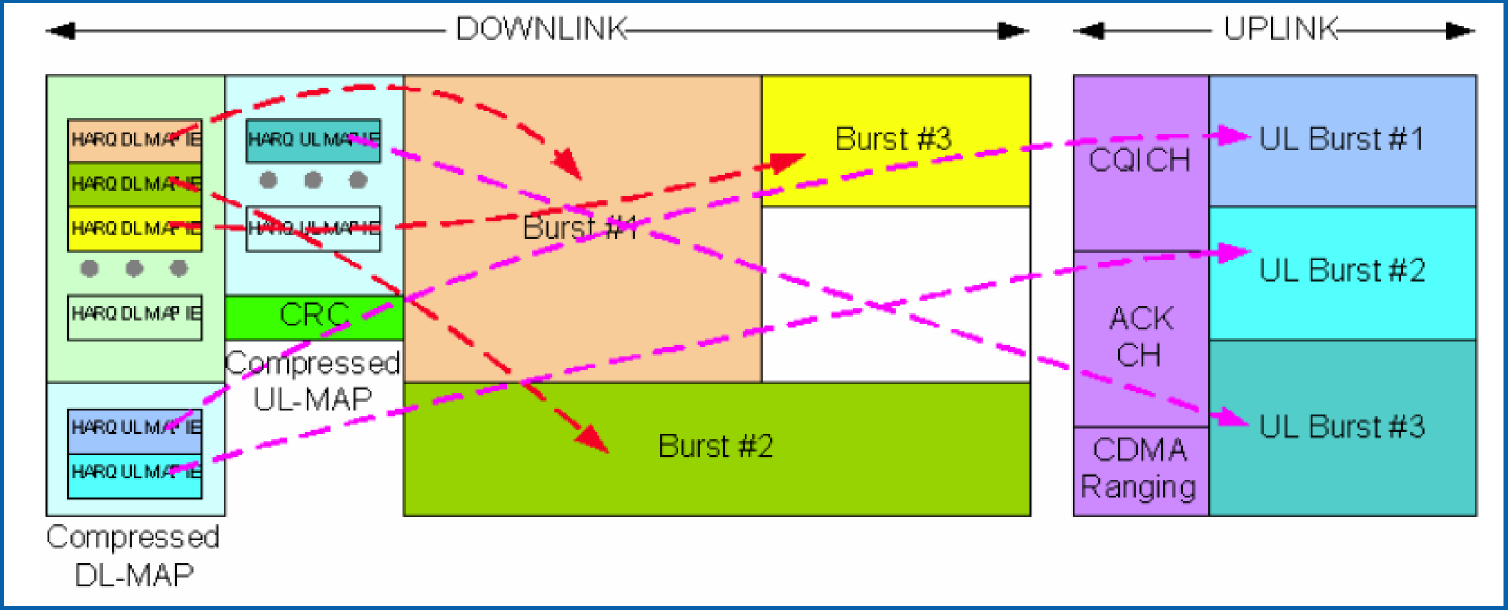
- No GMH and one CRC
- DL-MAP IEs and UL-MAP IEs
- Burst Profile (DIUC and UIUC)



Medium Access Protocol (MAP)
Message-Based Control and Signaling

Normal MAP Extension for H-ARQ

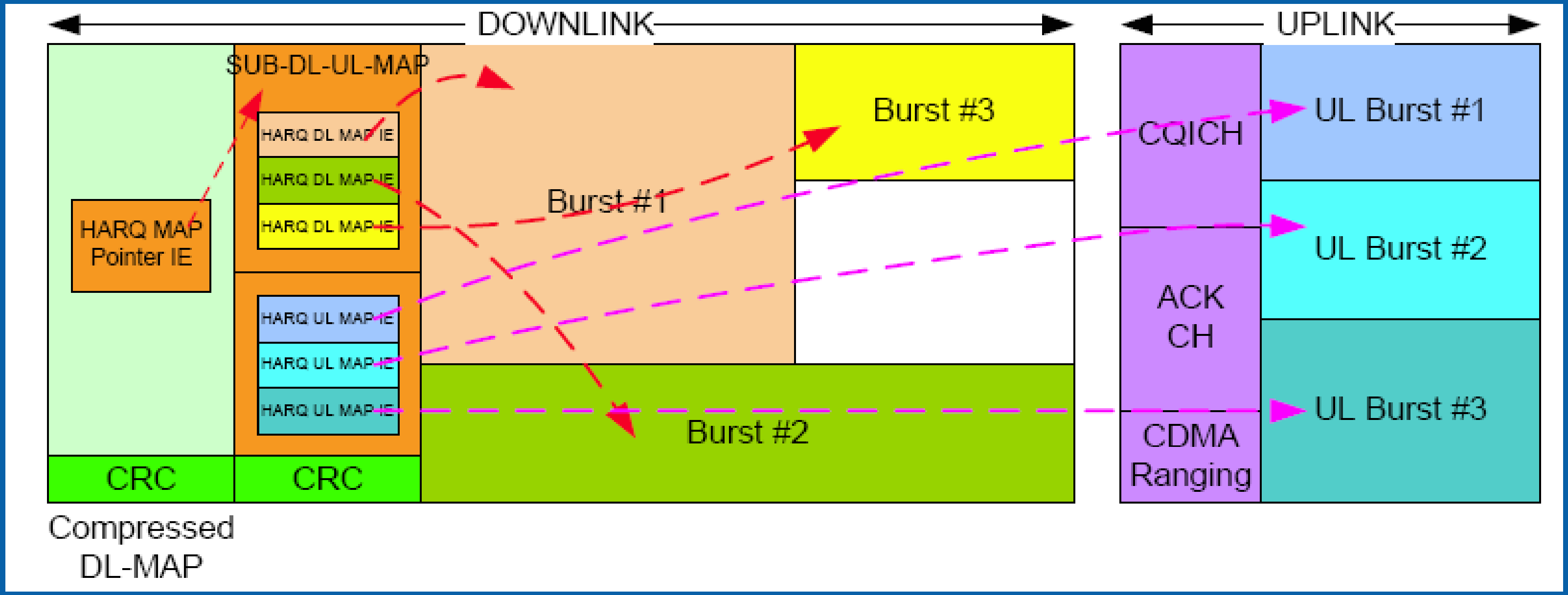
- The following modes of H-ARQ are supported by the HARQ DL/UL MAP IE:
  - Chase combining H-ARQ for all FEC types (H-ARQ Chase Combining). In this mode the burst profile is indicated by a DIUC.
  - Incremental redundancy H-ARQ with CTC (H-ARQ IR). In this mode the burst profile is indicated by the parameters N_{EP} (Encoded Packet Size), N_{SCH} (Number of Allotted Subchannels).
  - Incremental redundancy H-ARQ for convolutional code (H-ARQ CC-IR)



Medium Access Protocol (MAP)
Message-Based Control and Signaling

DL / UL Sub-MAPs

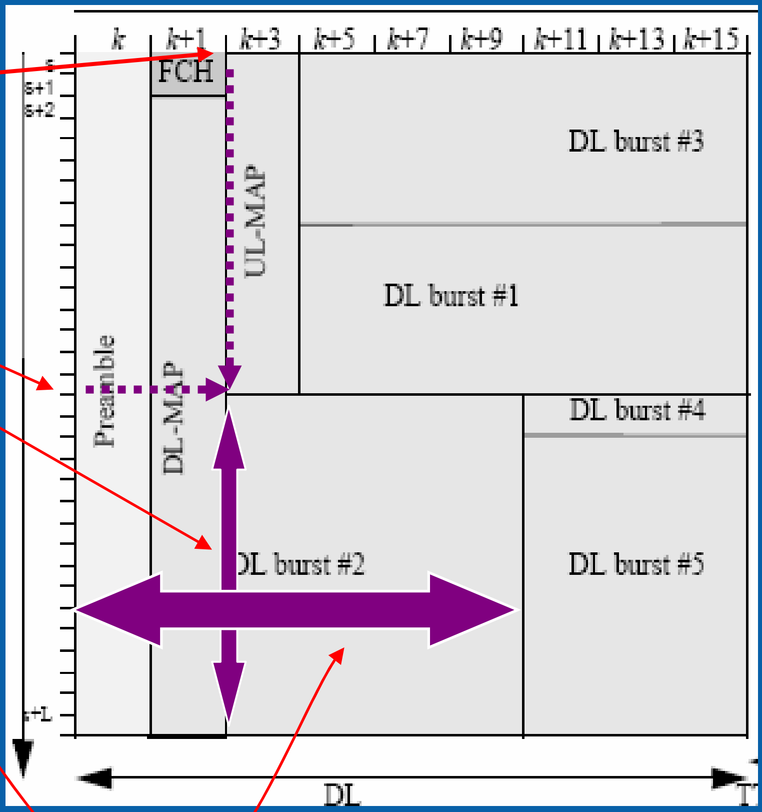
- Different modulation and channel coding with MAP
- HARQ for downlink and uplink
- Incremental Redundancy (IR) HARQ and Chase HARQ
- HARQ DL-MAP IEs and HARQ UL-MAP IEs
- N_{EP} & N_{SCH} / DIUC & UIUC



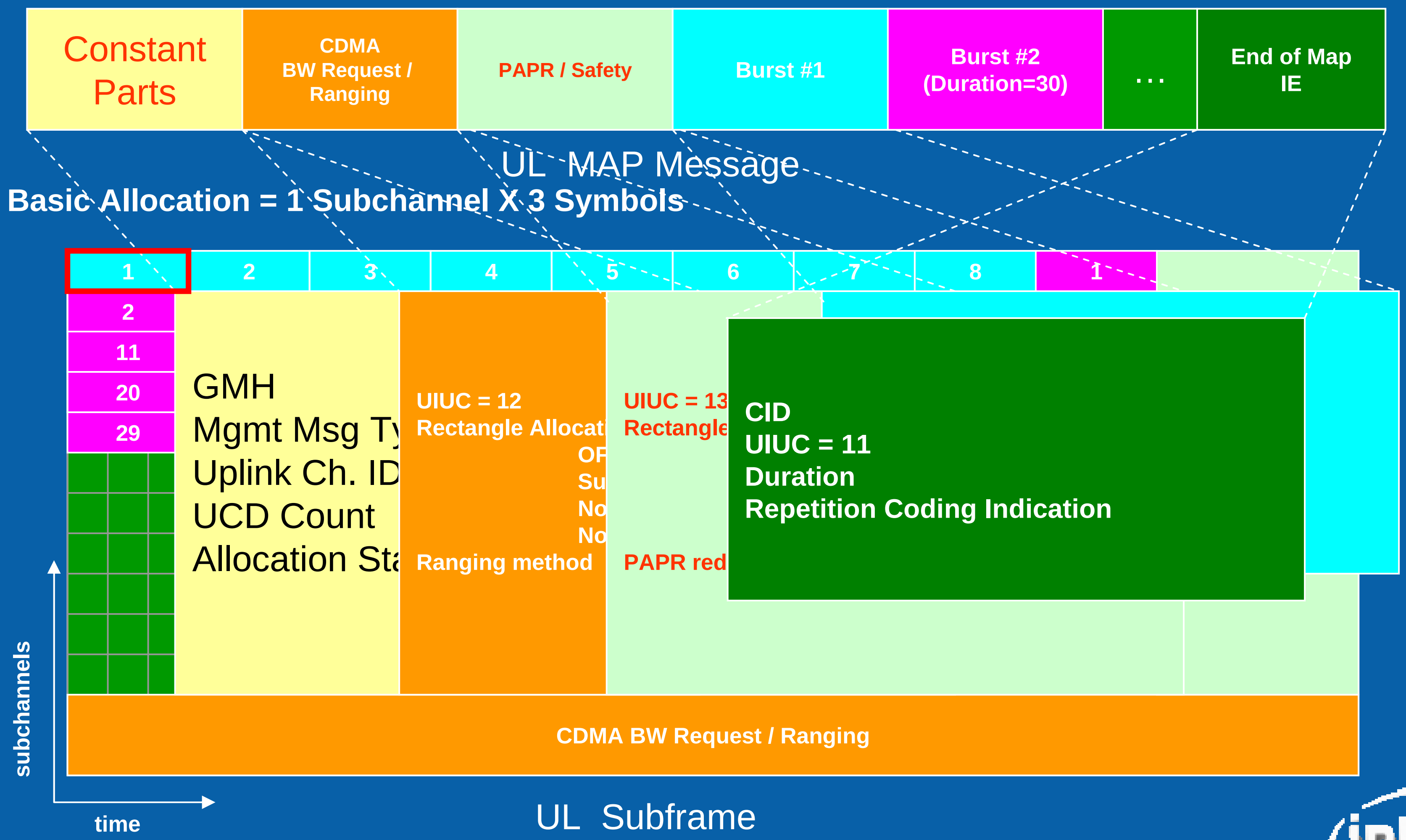
DL-MAP IE

DIUC	List Of CIDs (optional)	Burst Allocation
4 bit		32 bit

- Optional CID
  - Number of CIDs included (0-255)
  - CIDs List
- Burst Allocation
  - OFDMA Symbol offset
  - Subchannel offset
  - Number of Subchannels
  - Number of OFDMA Symbols
  - Boosting ((+6) to (–9) dB)
  - Repetition Coding Indication (1/2/4/6)



UL-MAP Allocations



Interval Usage Codes

- DIUC (Downlink Interval Usage Code)
  - 0~12 DL Burst Profiles — MCS schemes used in the burst
  - 13 Gap/PAPR — PAPR and Safety zones
  - 14 Extended DIUC 2 — Control IE
  - 15 Extended DIUC — Control IE
- UIUC (Uplink Interval Usage Code)
  - 0 Fast feedback channel — Zone for CQI etc.
  - 1~10 UL Burst Profiles — MCS schemes used in the burst
  - 11 Extended DIUC 2 — Control IE
  - 12 CDMA ranging/BW — Ranging / BW request zone
  - 13 PAPR/Safety — PAPR and Safety zones
  - 14 CDMA allocation IE — for CDMA BW request
  - 15 Extended DIUC — Control IE

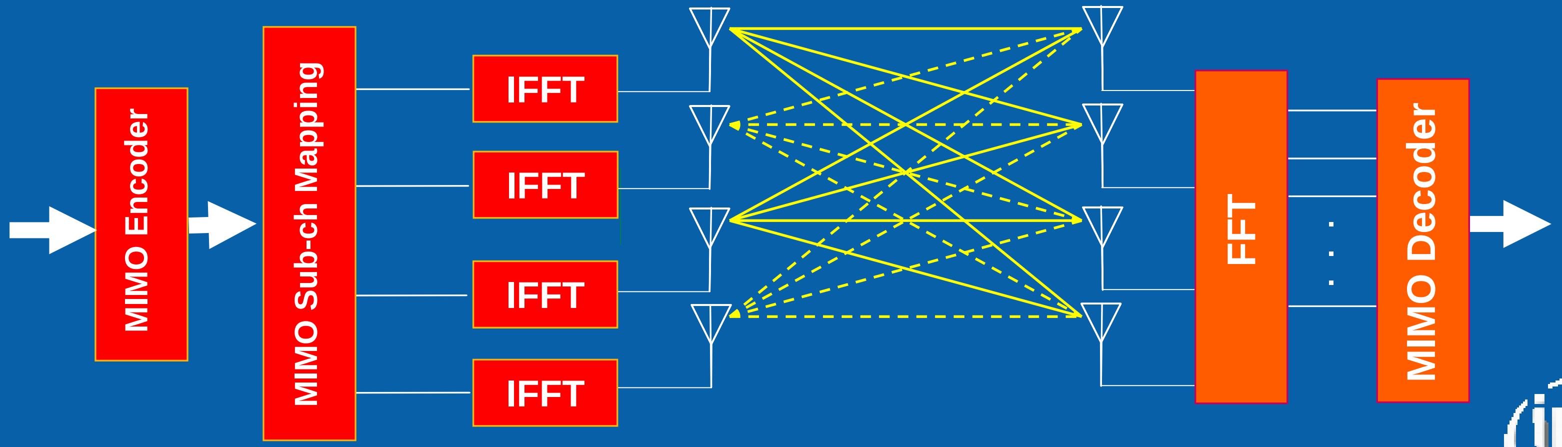
Adaptive Modulation and Coding

		DL	UL
Modulation		QPSK, 16QAM, 64QAM	QPSK,16QAM, 64QAM (optional)
Code Rate	**CC**	1/2, 2/3, 3/4, 5/6	1/2, 2/3, 5/6
	CTC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, 5/6
	Repetition	x2, x4, x6	x2, x4, x6

MIMO Schemes

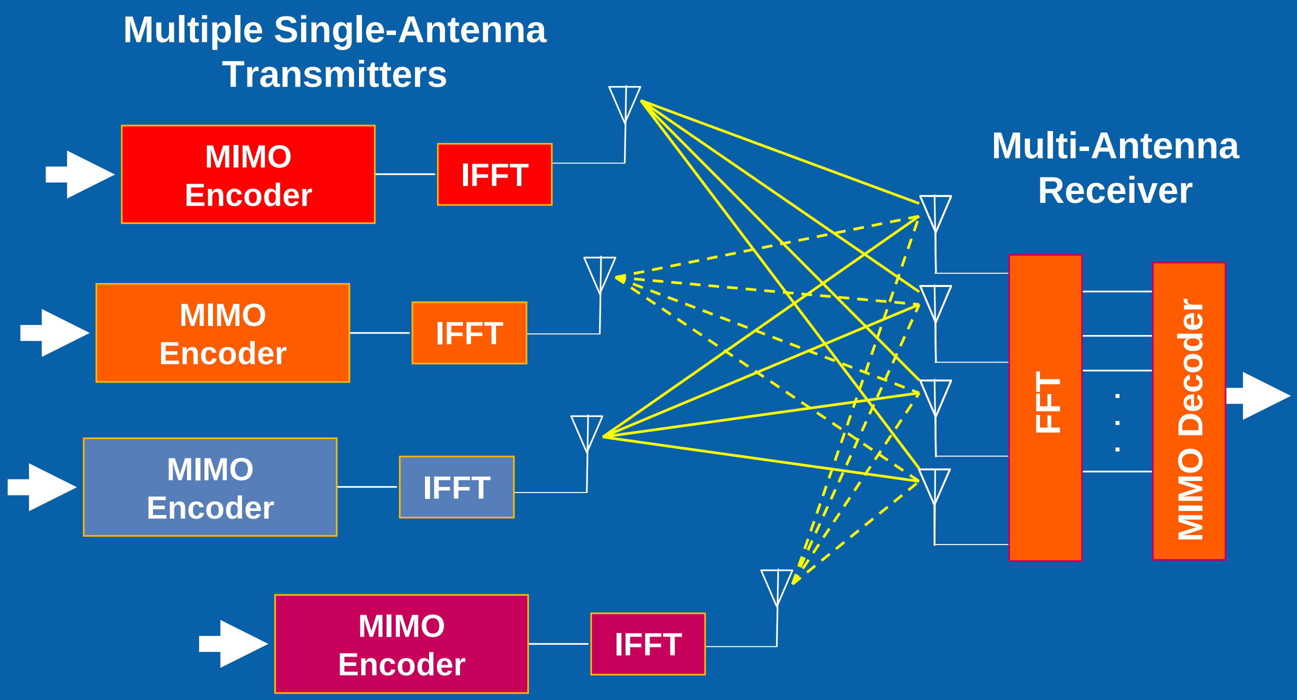
The mobile WiMAX air-interface supports a number of MIMO technologies

- **Beamforming (closed-loop):** the system uses multiple-antennas to transmit weighted signals to improve coverage and capacity of the system and reduce outage probability.
- **Space-Time Coding (STC; open-loop):** Transmit diversity techniques such as Alamouti scheme is supported to provide spatial diversity and to reduce fade margin.
- **Spatial Multiplexing (SM; open-loop):** to take advantage of higher peak rates and increased throughput. With spatial multiplexing, multiple streams are transmitted over multiple antennas. If the receiver also has multiple antennas, it can separate the different streams to achieve higher throughput compared to single antenna systems. With a 2x2 MIMO, SM approximately doubles the peak data rate by transmitting two data streams.

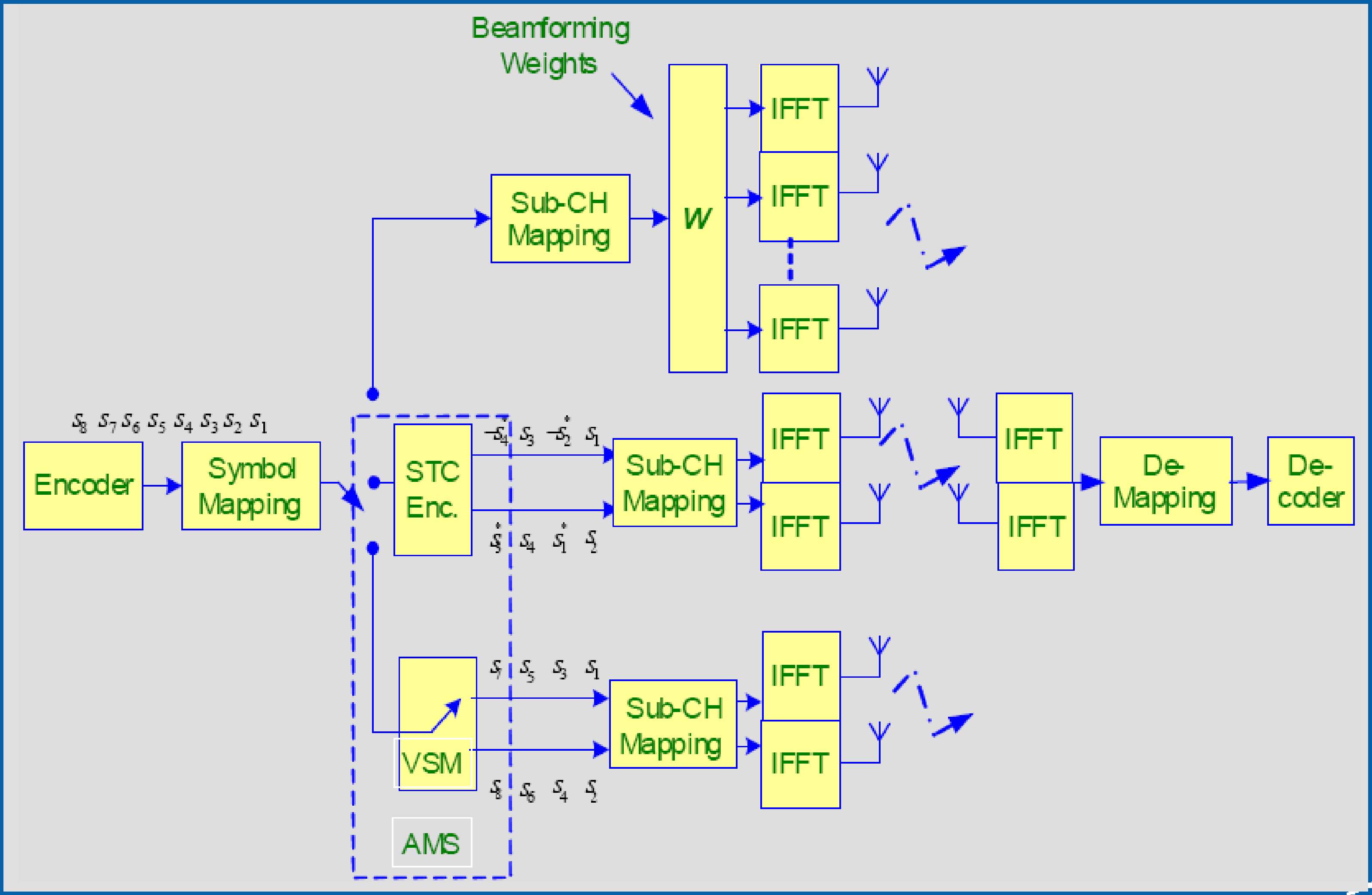


UL Collaborative MIMO (Virtual MIMO)

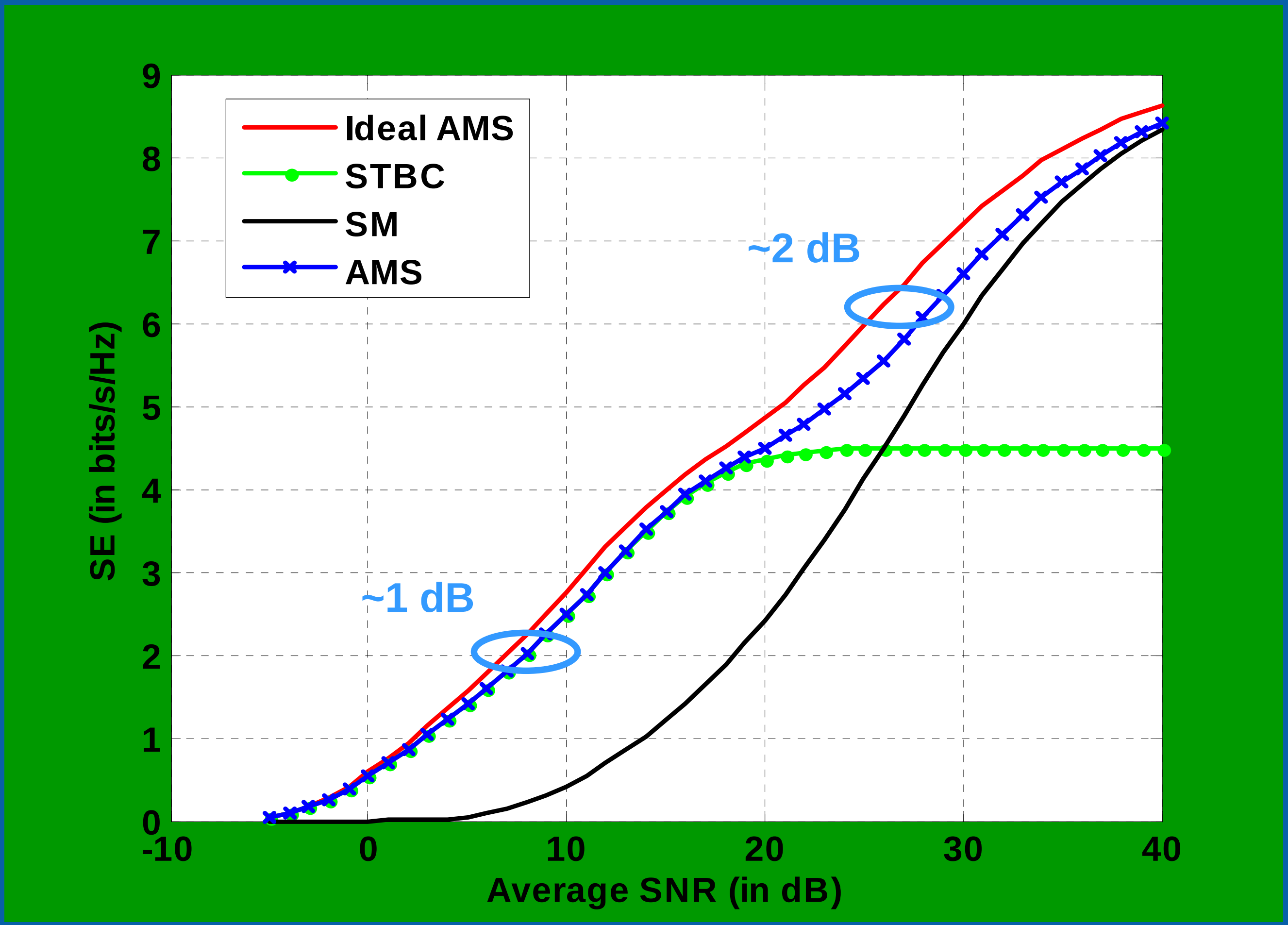
- Multiple mobile stations transmit simultaneously creating a "virtual" multi-antenna transmitter, resulting in increased network capacity.
- Mobile stations have one or two antennas, BS has multiple antennas.
- BS stores CSI from mobile stations and based on certain criteria; e.g., CQI chooses two or more mobile stations whose UL transmissions can be spatially multiplexed (using the same time-frequency resources).



Adaptive MIMO Switching (AMS)



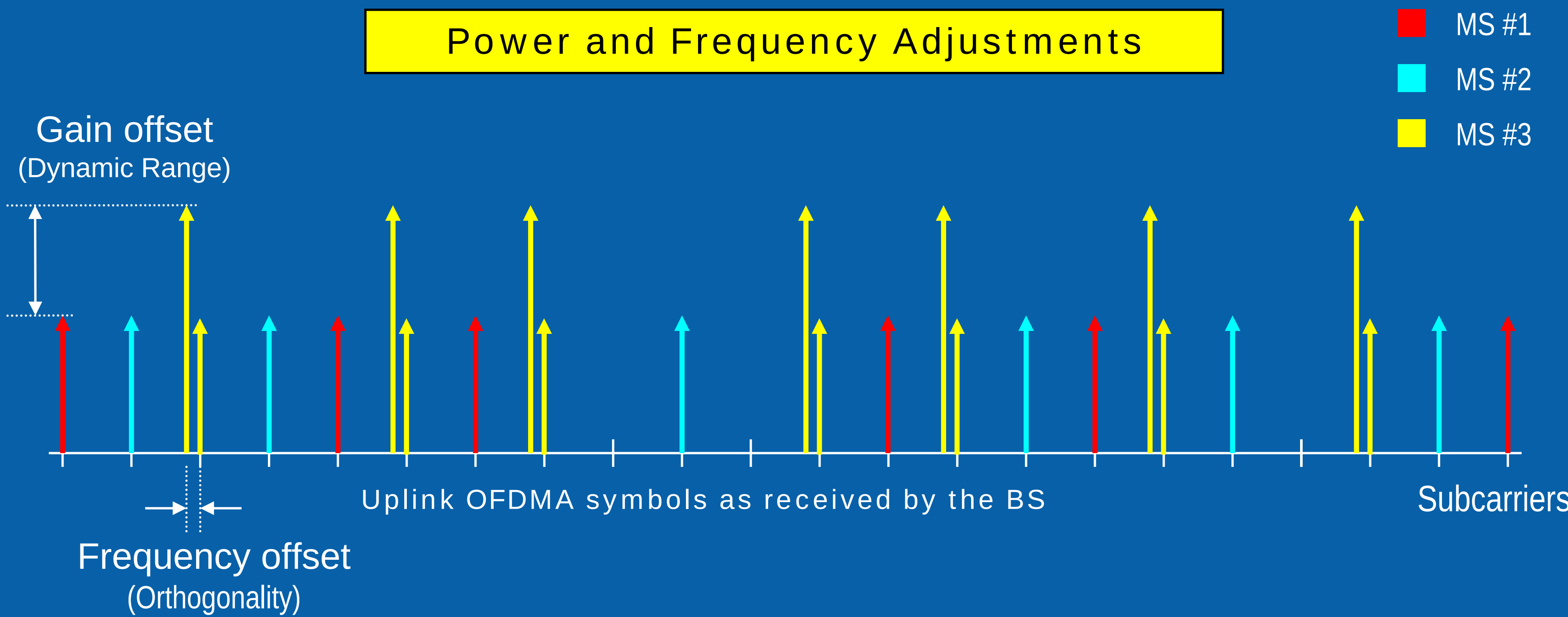
Adaptive MIMO Switching (AMS)



AMS overcomes the deficiencies of STBC and SM and leads to an spectral efficiency very close to the ideal one at both low and high SNR regions (across the cell)

Ranging

- The process in which the MS acquires frequency, time and power adjustments, after which all MS transmissions are aligned with the UL sub-frame received by the BS
- Process is based on MS transmitting a signal and BS responding with required adjustments (close-loop)

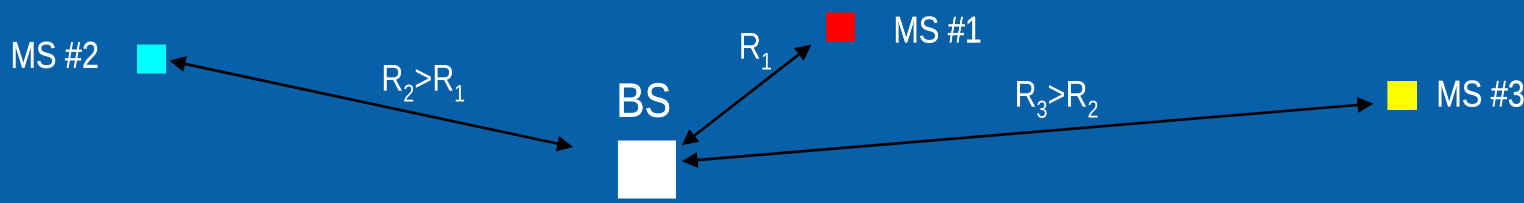


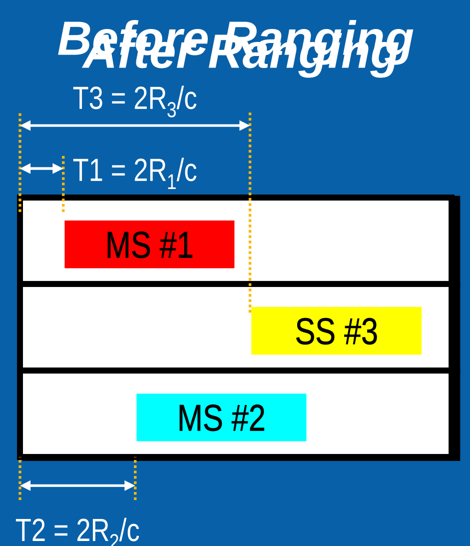
Before ranging
After ranging

Ranging

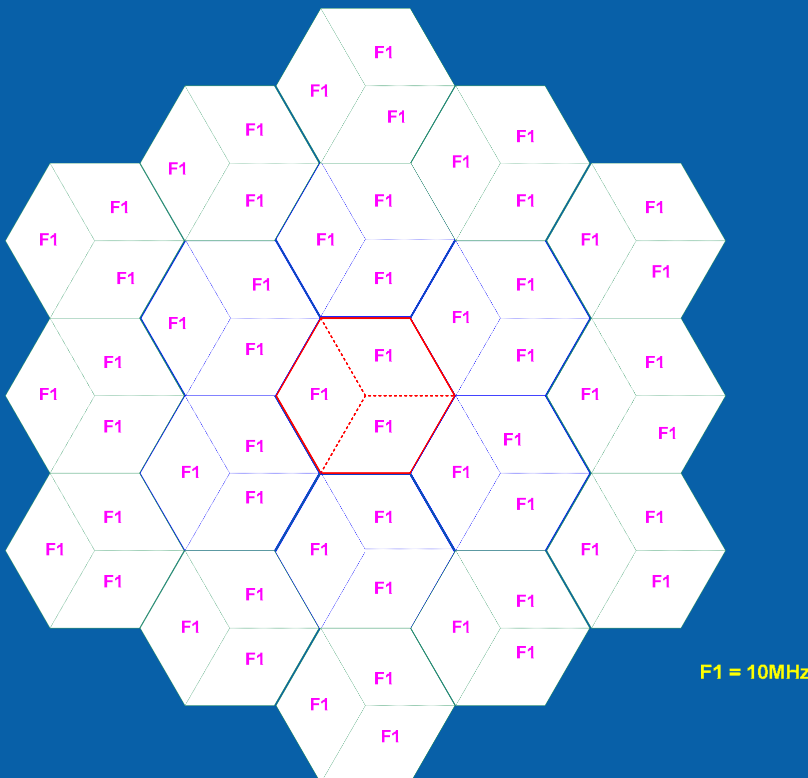
- Ranging types
  - Initial ranging/Handoff ranging
  - Periodic ranging
  - BW request ranging

Time Adjustment

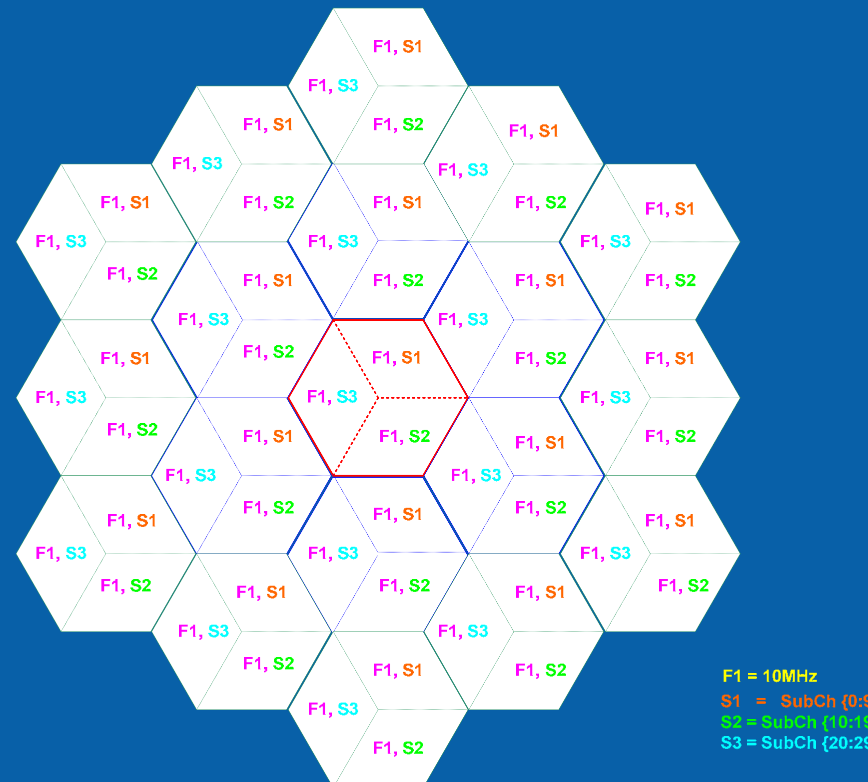




Frequency Reuse Schemes
Reuse One and Three with PUSC



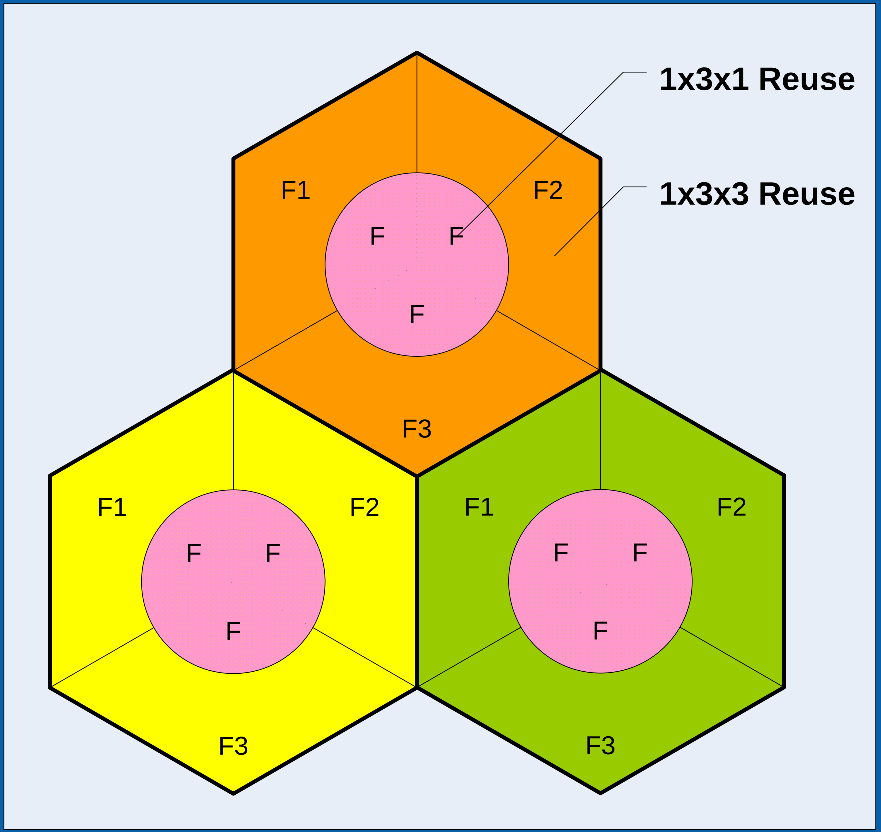
Reuse 1x3x1



Reuse 1x3x3

Fractional Frequency Reuse (FFR)

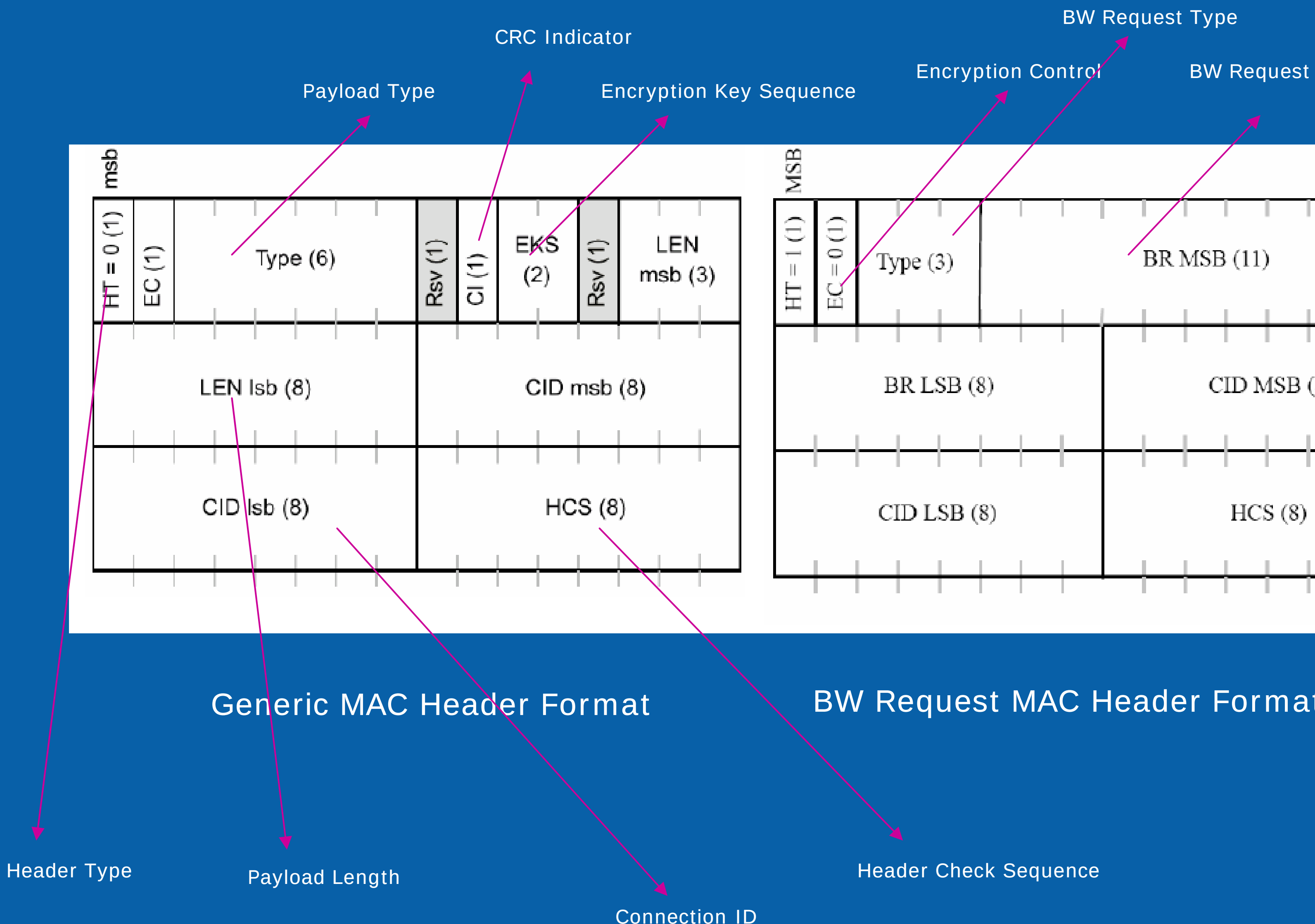
- Support frequency reuse 1/3/1 near cell center and utilize frequency reuse 1/3/3 near cell edges
- No frequency planning
- Frequency reuse one at cell center to maximize spectral efficiency
- Higher reuse factor at cell edge to reduce interference
- Flexible reconfiguration



F=F1+F2+F3

Review of mobile WiMAX MAC Layer

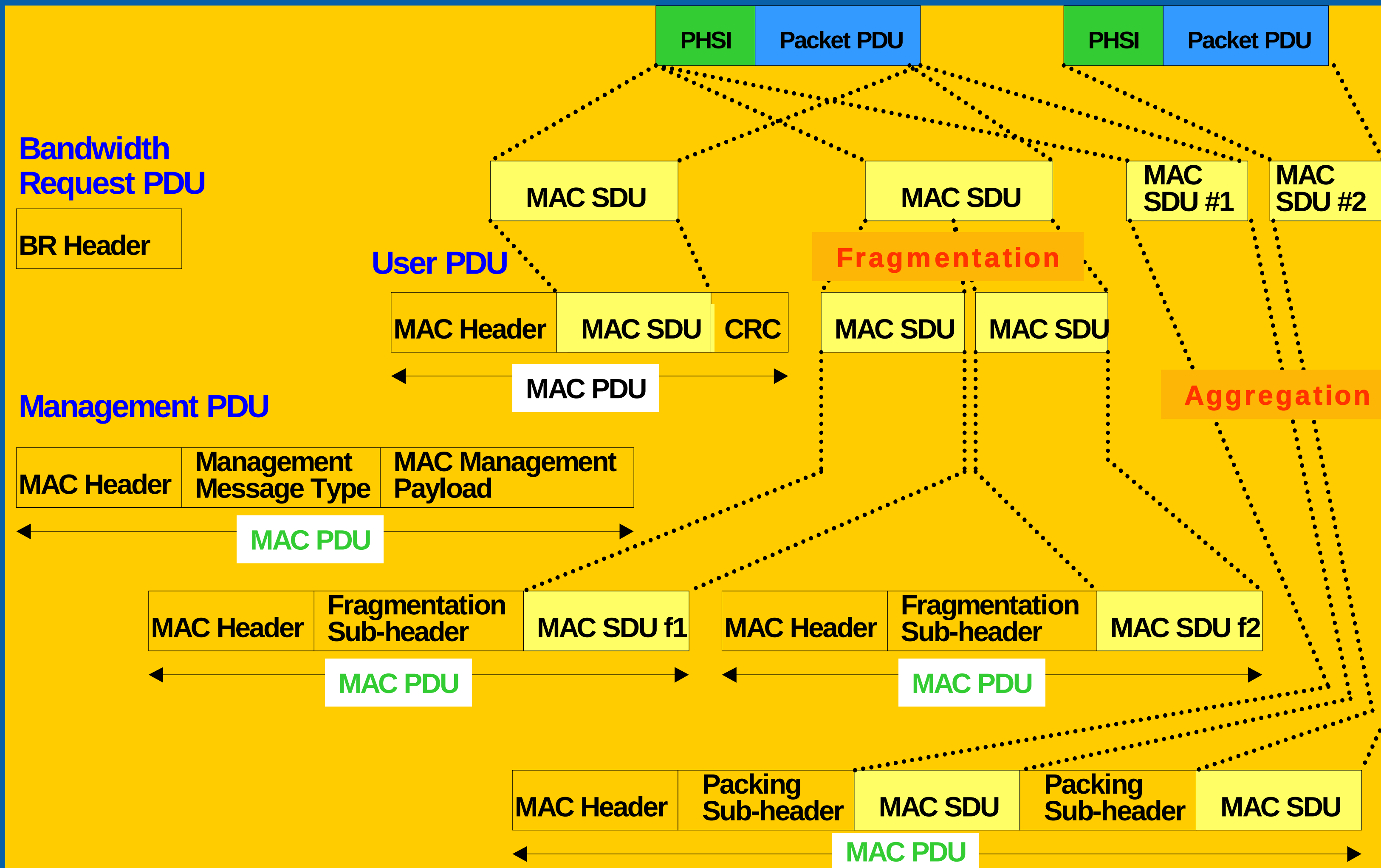
Generic MAC Header (GMH)



Generic MAC Header Format

BW Request MAC Header Format

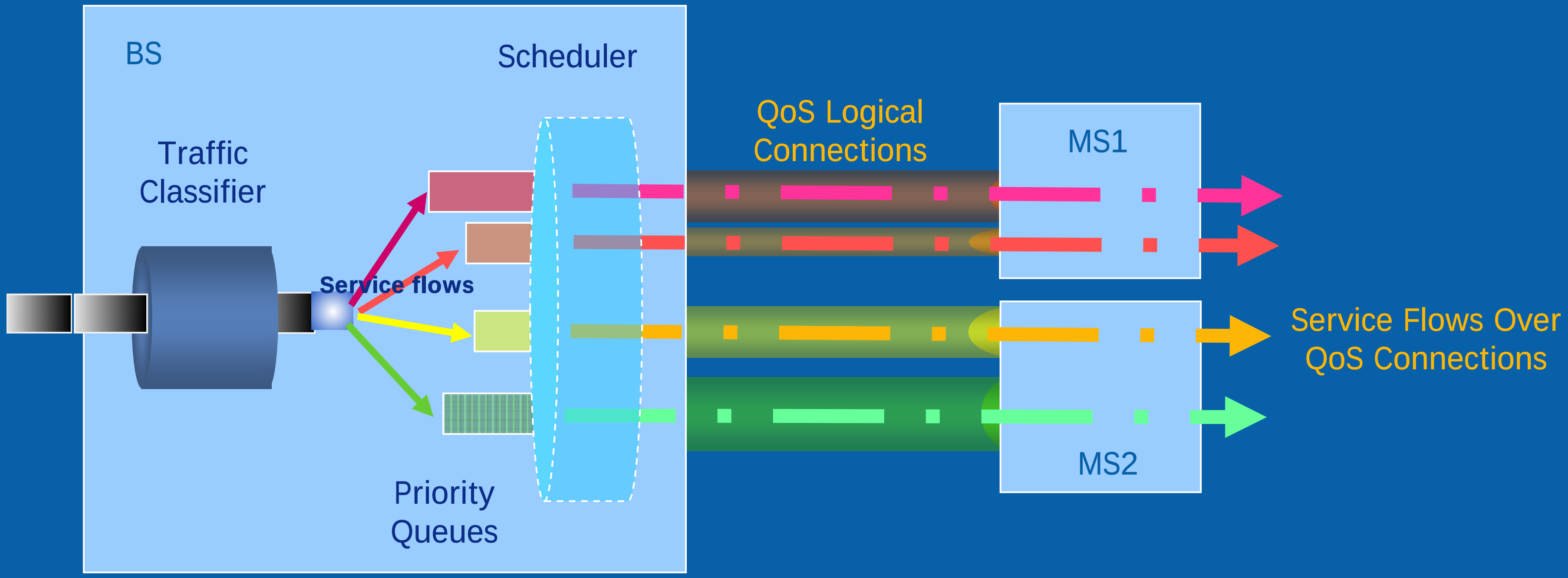
MAC PDU Construction



QoS–Data Service Types

QoS Class	Applications	QoS Specifications
UGS Un-Solicited Grant Service	VoIP	Maximum sustained rate Maximum latency tolerance Jitter tolerance
rtPS Real-Time Packet Service	Streaming Audio, Video	Minimum Reserved Rate Maximum Sustained Rate Maximum Latency Tolerance Traffic Priority
ErtPS Extended Real-Time Packet Service	Voice with Activity Detection (VoIP)	Minimum Reserved Rate Maximum Sustained Rate Maximum Latency Tolerance Jitter Tolerance Traffic Priority
nrtPS Non-Real-Time Packet Service	FTP	Minimum Reserved Rate Maximum Sustained Rate Traffic Priority
BE Best-Effort Service	Data Transfer, Web Browsing	Maximum Sustained Rate Traffic Priority

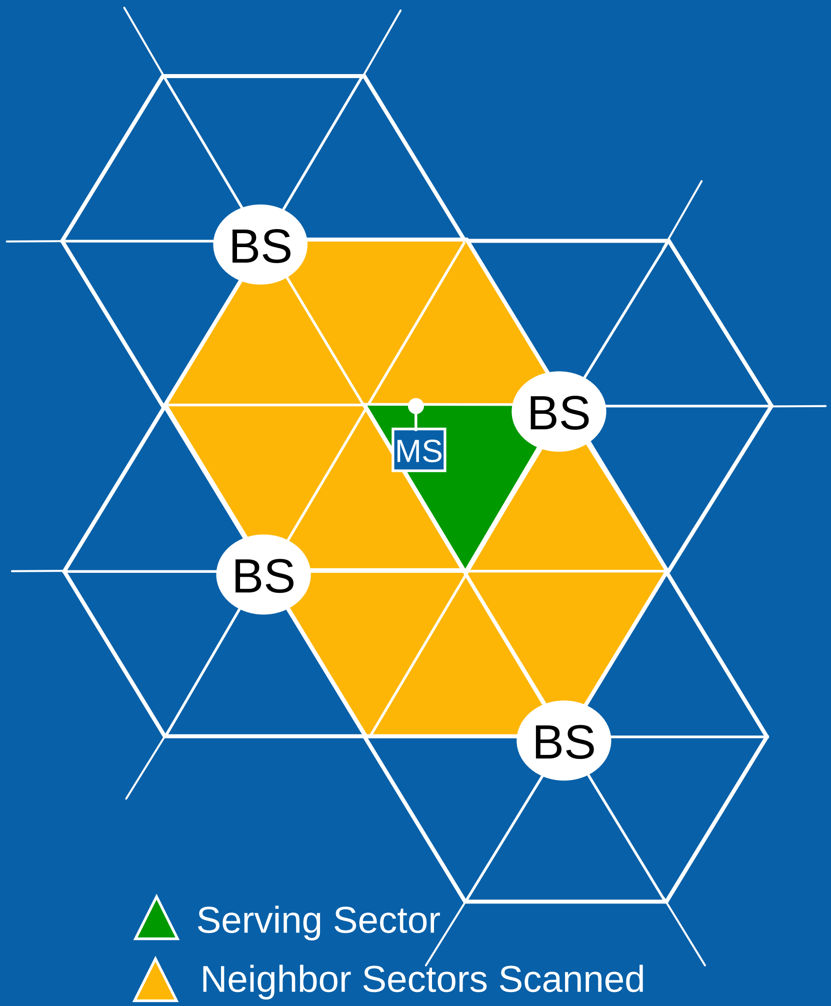
QoS: Connection-Oriented MAC



- Define QoS parameter for each connection
- Dynamically establish QoS-enabled connections
- Associate packets to service flows
- Associate service flows with QoS logical connections

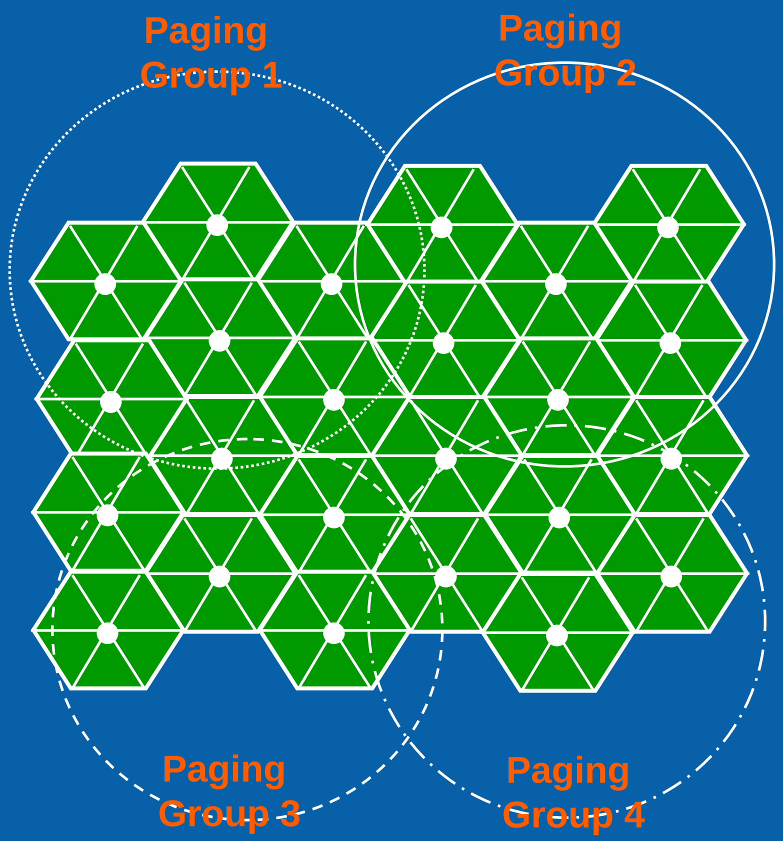
Handoff

- Handover Schemes
  - Optimized Hard Handover (OHHO)
  - Fast Base Station Switching (FBSS)
  - Macro Diversity Handover (MDHO)
- Handover Control
  - Mobile initiated
  - BS initiated
  - Network initiated
- Cell Selection
  - Neighbor Advertisements from Serving BS
  - Periodic intervals for scanning neighbor base stations
- Security for Handover
  - 3-way handshake for authentication key validation
  - TEK sharing for FBSS scheme

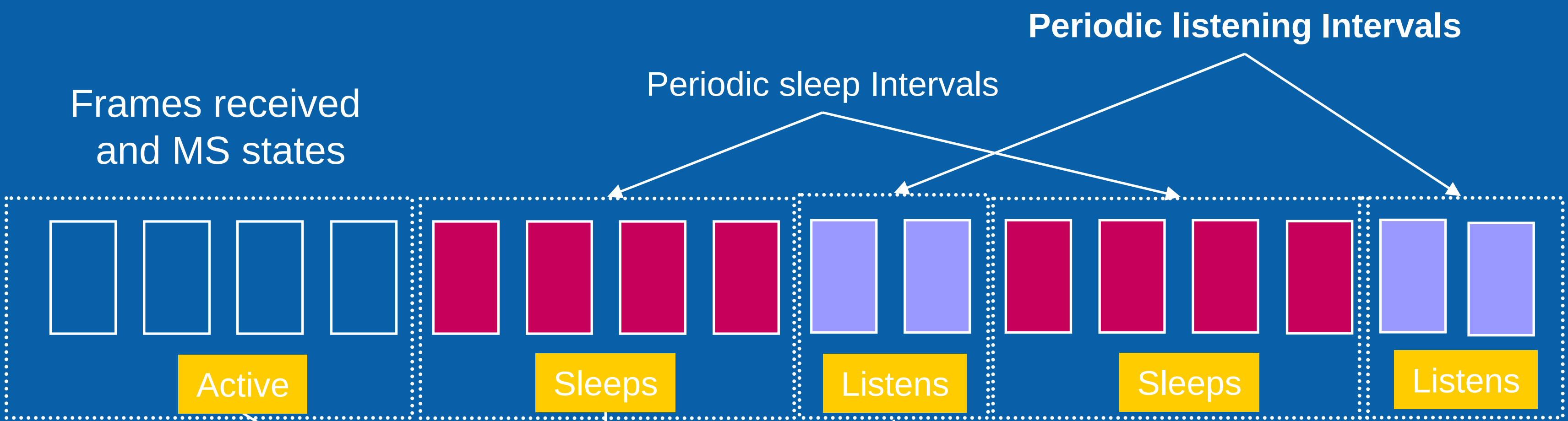


Idle Mode, Multicast/Broadcast, Paging

- MS uses special mode called "Idle Mode" to receive broadcast/multicast service without UL transmission
- MS associates to broadcast region formed by paging group
- DL traffic received but no UL transmission within broadcast region
- Cell selection may occur but no handover required (no idle mode HO support)
- MS can be paged for DL traffic alerting
- Paging controller in the network coordinates DL traffic and paging
- A SFN network and multi-BS combining is used for Multicast and Broadcast service.



Power Management

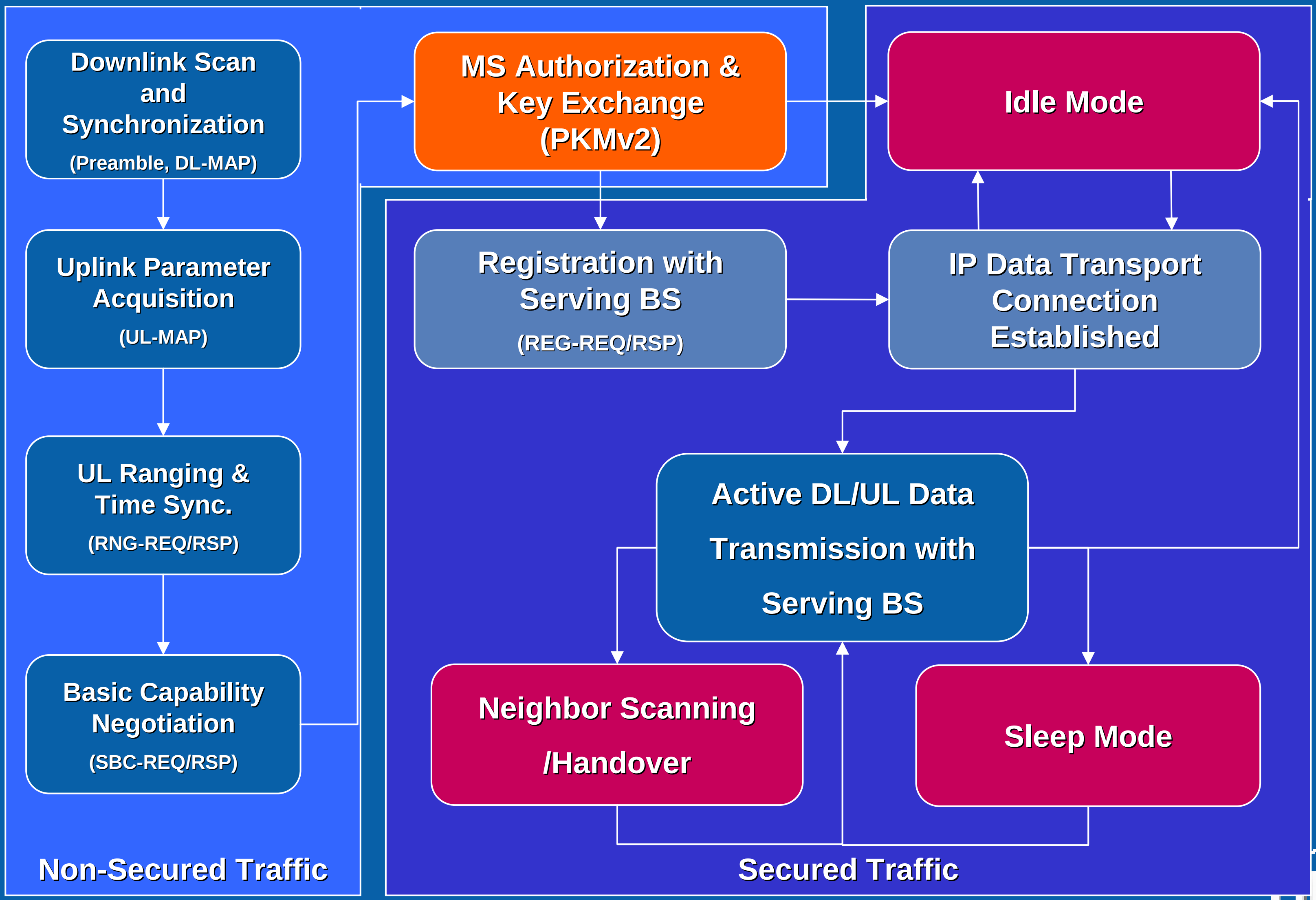


- MS Normal Tx or Rx
- MS requests BS to enter sleep mode to save power.
- Sleep mode 'start frame' is indicated.

- MS sleeps for integer # of frames called <u>sleep interval</u>.
- No MS Tx or Rx during this interval.
- Power saving classes supported provide flexible wake up methods.

- MS Listens for integer number of frames called <u>listening interval</u>.
- Paging detected in this interval.
- If Data traffic waiting on BS it is indicated.

Network Entry and Connection Management

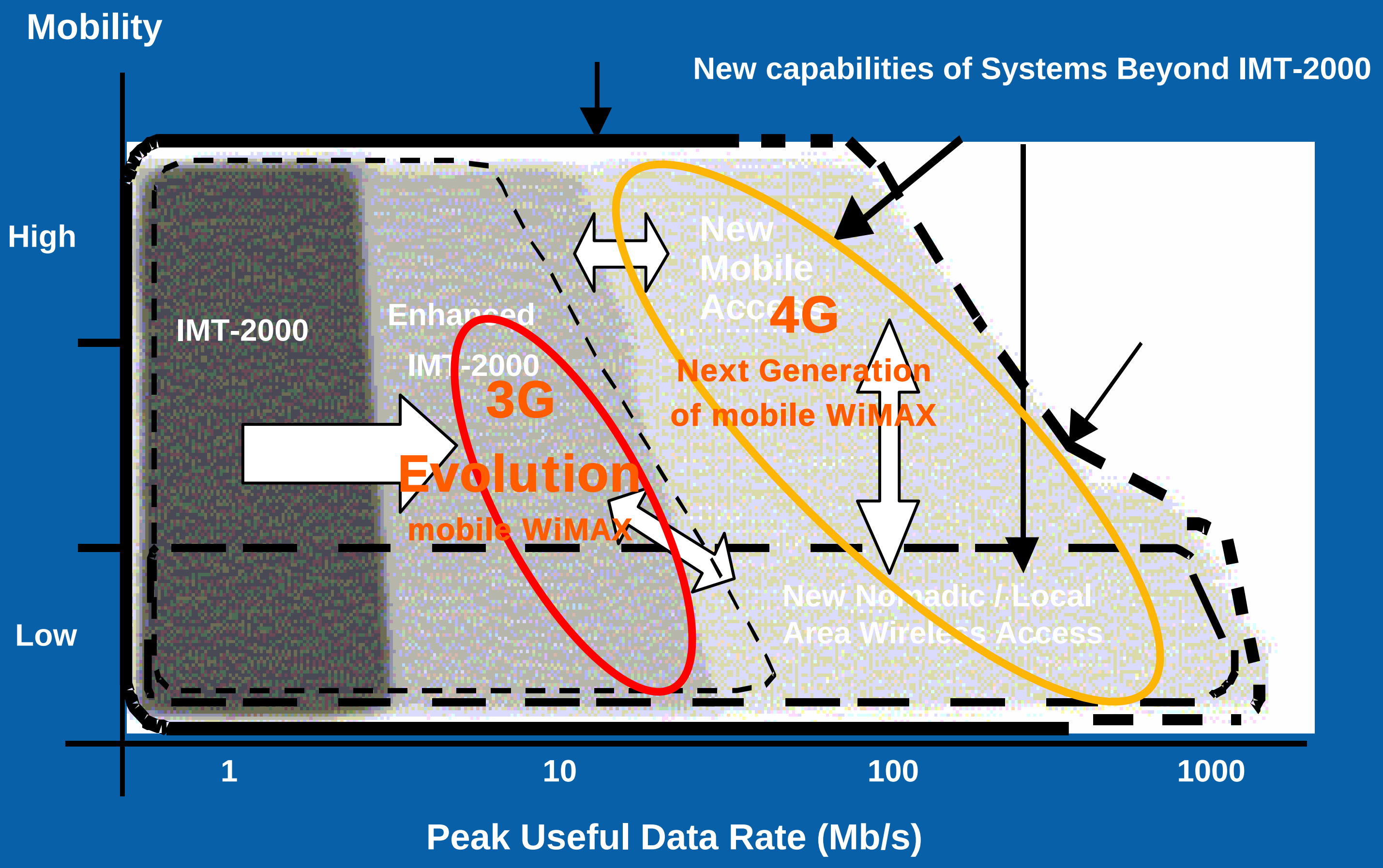


Performance of mobile WiMAX

DL/UL Ratio			1:0	3:1	2:1	3:2	1:1	0:1
User Peak Rate (Mbps)	SIMO (1x2)	DL	31.68	23.04	20.16	18.72	15.84	0
		UL	0	4.03	5.04	6.05	7.06	14.11
	MIMO (2x2)	DL	63.36	46.08	40.32	37.44	31.68	0
		UL	0	4.03	5.04	6.05	7.06	14.11
Sector Peak Rate (Mbps)	SIMO (1x2)	DL	31.68	23.04	20.16	18.72	15.84	0
		UL	0	4.03	5.04	6.05	7.06	14.11
	MIMO (2x2)	DL	63.36	46.08	40.32	37.44	31.68	0
		UL	0	8.06	10.08	12.10	14.12	28.22

For 10 MHz channel, 5 ms frame, PUSC sub-channel, 44 data OFDM symbols
DL 64QAM 5/6 CTC x 1 and UL 16QAM CTC 3/4 x1

Next Generation of mobile WiMAX



Back up

mobile WiMAX MS
Certification Profiles

Band Class		1	2	3	4	5
Frequency Range		2.3-2.4 GHz	2.305-2.320 GHz	2.496-2.690 GHz	3.3-3.4 GHz	3.4-3.8 GHz
Duplex		TDD	TDD	TDD	TDD	TDD
Channel Bandwidth	5 MHz	●	●	●	●	●
	7 MHz				●	●
	8.75 MHz	●				
	10 MHz	●	●	●	●	●

mobile WiMAX MS
Release 1 PHY Profile and Certification

Release 1 PHY Profile		Wave 1*	Wave 2	Comments
DL Subcarrier Allocation	PUSC	●	●	
	PUSC w/ All Subchannels	●	●	
	FUSC	●	●	
	AMC 2x3		●	Required in Wave 1 for Band Class 3
UL Subcarrier Allocation	PUSC	●	●	
	AMC 2x3		●	Required in Wave 1 for Band Class 3
Ranging & Bandwidth Request	Initial Ranging	●	●	
	Handoff Ranging	●	●	
	Periodic Ranging	●	●	
	Bandwidth Request	●	●	
Fast-Feedback	6-bit	●	●	
Channel Coding	Repetition	●	●	
	Randomization	●	●	
	Convolutional Coding (CC)	●	●	
	Convolutional Turbo Coding (CTC)	●	●	
	Interleaving	●	●	
H-ARQ	Chase Combining	●	●	Wave 1 waiver on required buffer size
Synchronization	BS Time/Freq Synchronization	N/A	N/A	
	BS-BS Freq Synchronization	N/A	N/A	
	MSS Synchronization	●	●	
Power Control	Closed-loop Power Control	●	●	
	Open-loop Power Control	●	●	

● Full Support ◓ Partial Support

mobile WiMAX MS

Release 1 PHY Profile and Certification

Release 1 PHY Profile		Wave 1*	Wave 2	Comments
CINR Measurement	Physical CINR using Preamble	●	●	
	Physical CINR using Pilots	●	●	
	Effective CINR using Pilots		●	Required in Wave 1 for Band Class 3
	RSSI Measurement	●	●	
Modulation	DL QPSK	●	●	
	DL 16-QAM	●	●	
	DL 64-QAM	●	●	
	UL QPSK	●	●	
	UL 16-QAM	●	●	
MAP Support	Normal MAP	●	●	
	Compressed MAP	●	●	
	Sub-DL-UL MAP	●	●	
MIMO (IO-MIMO for BS)	2nd Order Matrix A/B		●	Required in Wave 1 for Band Class 3
	Collaborative Spatial Multiplexing		●	Required in Wave 1 for Band Class 3
	Fast Feedback on DL		●	Required in Wave 1 for Band Class 3
	Mode Selection Feedback w/ 6-bits		●	Required in Wave 1 for Band Class 3
	MIMO DL-UL Chase		●	Required in Wave 1 for Band Class 3
AAS/BF (IO-BF for BS)	PUSC w/ Dedicated Pilots		●	Required in Wave 1 for Band Class 3
	AMC 2x3 w/ Dedicated Pilots		●	Required in Wave 1 for Band Class 3
	UL Sounding 1 (Type A)		●	Required in Wave 1 for Band Class 3
	UL Sounding 2		●	Required in Wave 1 for Band Class 3
	CINR Measurement (Group Indication)		●	PUSC, Required in Wave 1 for Band Class 3
	MIMO Permutation Feedback Cycle		●	Required in Wave 1 for Band Class 3