Mobile WiMAX Technology Overview and Evolution

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Introduction

- Mobile WiMAX is a candidate for next generation mobile network adopted or under consideration by various service providers globally.
- Mobile WiMAX technology, based on IEEE 802.16e-2005 standard, first commercialized in Korea through initial offering of WiBro services in the middle of 2006 and subsequent expansion in early 2007.
- Being deployed by Sprint by the end of 2007 early 2008 in US.
- These deployments are based on WiMAX Forum® Mobile System Release 1 profile currently being certified by WiMAX Forum.
- Mobile WiMAX is evolving to include new technology and to meet new demands.
- IEEE 802.16 TGj and TGm are currently developing Multi-hop Relay enhancements and the next generation Advanced Air Interface respectively.
- The purpose of this presentation is to familiarize the audience with an overview of the technology and different evolution projects.
- Contents are kept high level to be able to cover the technology briefly.

Agenda

- Overview of Mobile WiMAX Release 1 (IEEE 802.16e Scalable OFDMA)
- Mobile WiMAX Performance
- Mobile WiMAX Evolution
- Multihop Relay
- IEEE 802.16m Advance Air Interface
- Summary
- Additional sources

Scalable OFDMA Numerology

Parameters	Values			
System bandwidth	1.25 MHz	5 MHz	10 MHz	20 MHz
Sampling frequency (F_s) *Fs = floor(28/25 × BW/8000) × 8000*	1.4 MHz	5.6 MHz	11.2 MHz	22.4 MHz
Sample time ($1/F_s$)	714 nsec	176 nsec	89 nsec	45 nsec
FFT size (N_{FFT})	128	512	1024	2048
Subcarrier frequency spacing	10.9375 kHz			
Useful symbol time ($T_b=1/\Delta f$)	91.429 µs			
CP time ($T_g=T_b/8$) (Other values 1 /4, 1/16 and 1/32 are also supported)	11.429 µs			
OFDMA symbol time ($T_s=T_b+T_g$)	102.857 µs			

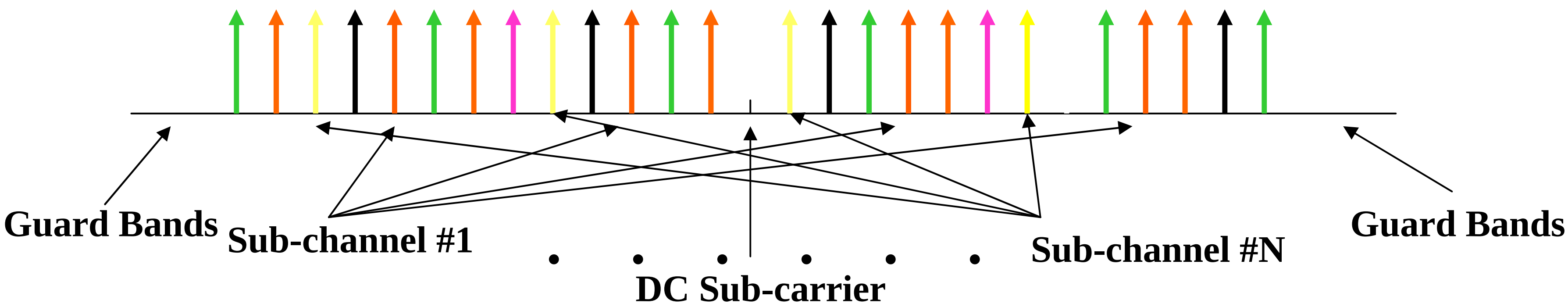
Note: Other channel BW such as 3.5, 7 and 14 MHz are supported choosing closest appropriate FFT size.

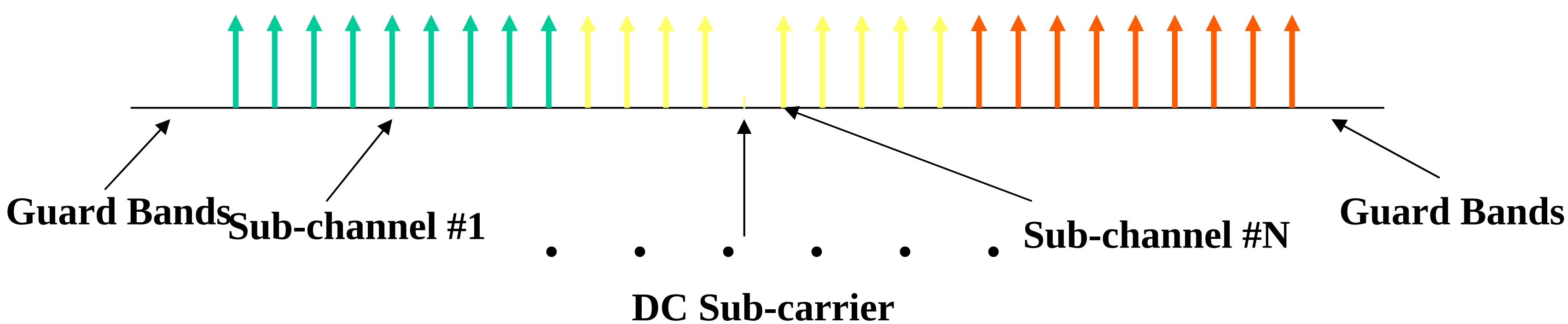
Sub-carriers and Sub-channels

- Data subcarriers: for data transmission
- Pilot subcarriers: for various estimation purposes
- Null carrier: no transmission at all, for guard bands and DC carrier.
- Active sub-carriers are divided into subsets of subcarriers called sub-channel.
  - BW/MAP allocations are done in sub-channels.
  - Downlink: Sub-channel may be intended for different (groups of) receivers.
  - Uplink: SS may be assigned one or more sub-channels, several transmitters may transmit simultaneously.
  - The sub-carriers forming one sub-channel may, but need not be adjacent.

Adjacent vs. Distributed Sub-carrier Allocation: Concept (pilots are not shown)

- **Distributed Sub-carrier Permutation: Mobility Support**



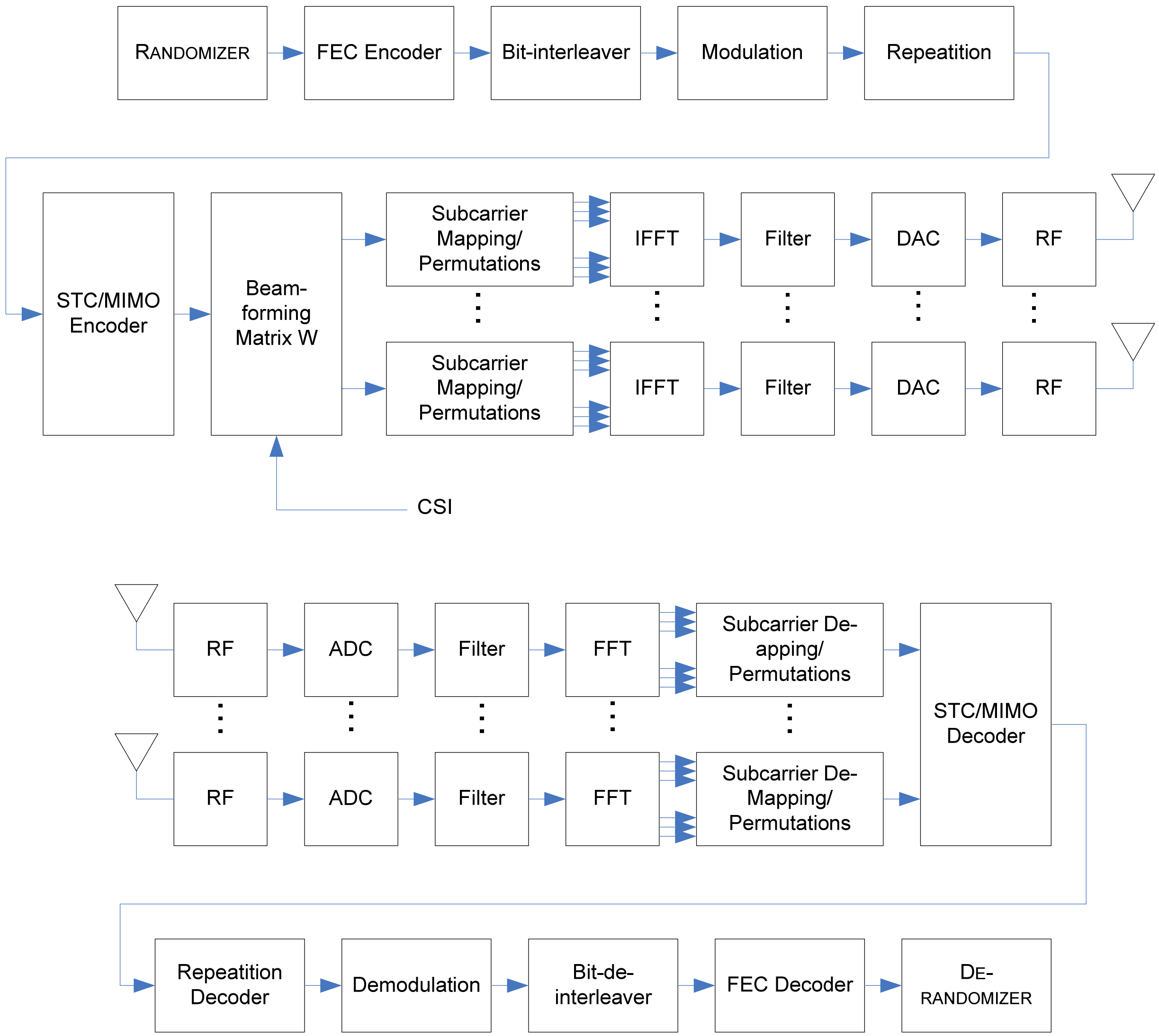


- **Adjacent Sub-carrier Permutation: AAS and Low Mobility Support**

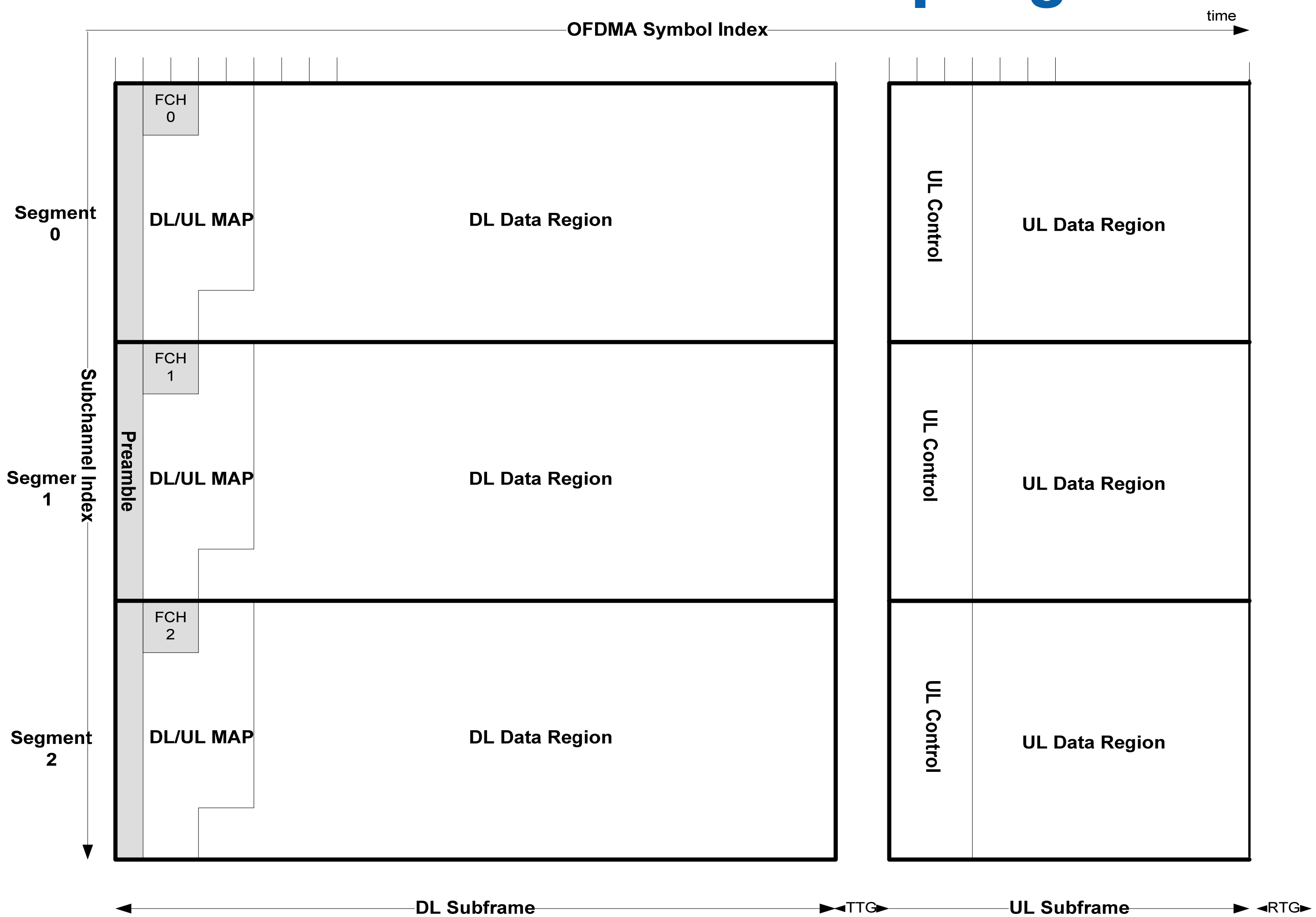
Sub carrier Allocation Modes

- Diversity permutation (FUSC/PUSC)
  - Asymmetric downlink/uplink permutation
  - Frequency diversity
  - Interference averaging
- Contiguous permutation (AMC)
  - Symmetric downlink/uplink permutation
  - Frequency coherence for loading and beamforming
  - Multiuser diversity
  - No interference averaging

Transmit and Receive Processing of the Mobile WiMAX OFDM Signal



Sectorization / Segmentaion Through Subchannel Grouping



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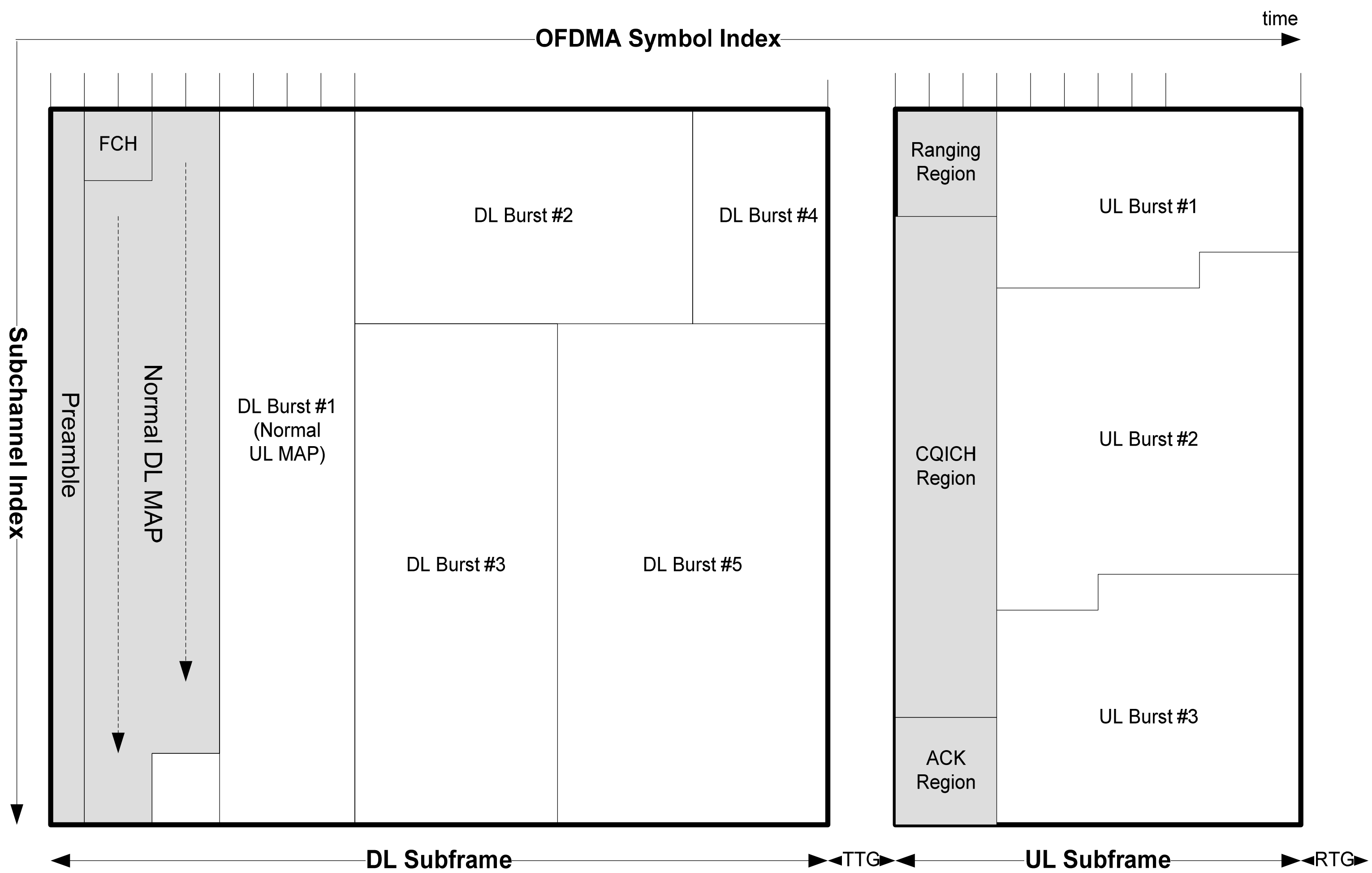
Frame Structure



Transmit Diversity and Multiple Antenna Techniques

- SBTC and MIMO/SM
  - DL 2nd , 3rd and 4th order Space Time Diversity and Spatial Multiplexing
    - OSTBC and QOSTBC used
    - DL 2x2 (2 Tx and 2 Rx) is default
  - UL 2nd order Space Time Diversity and Collaborative Special Multiplexing
    - Collaborative MIMO (SM) by two MS with single Tx antenna is default
- Beamforming
  - Support of UL Channel Sounding
  - Support of DL dedicated pilots
  - Two, four and eight Tx antenna BS considered

STBC / SM Tx Signals: Open Loop

$$A = \begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \end{bmatrix}$$

$$B = \begin{bmatrix} S_1 \\ S_2 \end{bmatrix}$$

$$A = \begin{bmatrix} S_1 & -S_2^* & 0 & 0 \\ S_2 & S_1^* & 0 & 0 \\ 0 & 0 & S_3 & -S_4^* \\ 0 & 0 & S_4 & S_3^* \end{bmatrix}$$

$$B = \begin{bmatrix} S_1 & -S_2^* & S_5 & -S_6^* \\ S_2 & S_1^* & S_6 & S_5^* \\ S_3 & -S_4^* & S_7 & -S_8^* \\ S_4 & S_3^* & S_8 & S_7^* \end{bmatrix}$$

$$C = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{bmatrix}$$

STBC/SM Tx Signals: Closed Loop

- The space time coding output can be weighted by a matrix before mapping onto transmit antennas.

$$Z = W \times X$$

  - *X* is a vector with the output from the space-time coding (per-subcarrier),
  - The matrix *W* is an weighting matrix where
  - *Z* contains the signals after weighting, i.e. the number of Beamforming antenna
  - W example for mapping of 2nd order STBC/SM into four Beamforming antenna:

$$W = \begin{bmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \\ W_{31} & W_{32} \\ W_{41} & W_{42} \end{bmatrix}$$

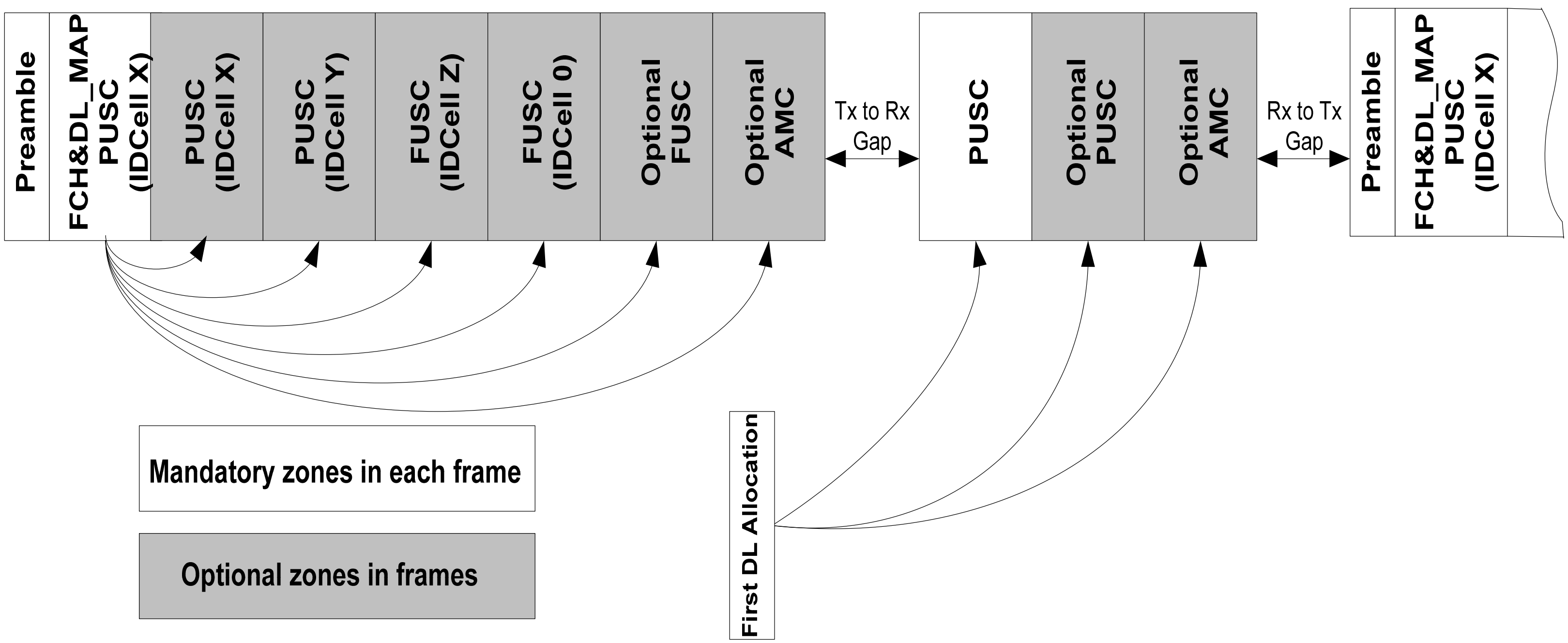
- A realization to maximize Ergodic capacity of the channel.
- Closed Loop feedback options
  - Quantized MIMO channel mapping at MS
  - Pre-coding MIMO Transmission by MS

Forward Error Correction and Modulation and Coding Schemes

- Convolutional Encoding
  - Used in DL Frame Control Header
- Convolutional Turbo Code (CTC)
  - Default for DL and UL
- Block Turbo Code (BTC)
  - Optional
- Low Density Turbo Codes (LDPC)
  - Optional
- HARQ
  - Chase Combining (default)
  - Incremental Redundancy (enhanced)

Modulation	Code Rate
QPSK	1 / 2
QPSK	3 / 4
16 QAM	1 / 2
16 QAM	3 / 4
64 QAM	1 / 2
64 QAM	2 / 3
64 QAM	3 / 4
64 QAM	5 / 6

Support for Multiple Usage Models through Zone Switching



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Zone Switching

To switch subcarrier allocation modes, reuse factors and multiple antenna techniques

Zone Switching in DL

- Subcarrier allocation mode
  - Diversity: PUSC, FUSC, OFUSC
  - Adjacent: AMC
- Reuse factor
  - Segmented
  - All subchannels
- Multiple antenna techniques
  - MIMO: 2nd, 3rd or 4th order, Matrix A, B or C
  - Beamforming: Broadcast or dedicated pilots

Zone Switching in UL

- Subcarrier allocation mode
  - Diversity: PUSC, OPUSC
  - Adjacent: AMC
- Reuse factor
  - Segmented
  - All subchannels
- Multiple antenna techniques
  - MIMO: Single and dual transmission, collaborative and non-collaborative
  - Beamforming: UL subchannel rotation disabled/enabled

Mobile WiMAX System: MAC Features

MAC Feature	Description
Convergence Sub-layer	PHS and IPv4
	IPv6 and ROHC
QoS	BS initiated service flow
	MS initiated service flow
ARQ	MAC ARQ
Data Delivery Services	UGS, BE, ERT-VR
	RT-VR, NRT-VR
Request Grant Mechanism	Request Grant Mechanism
Hand over initiation	HO initiated by MS
	HO initiated by BS

Mobile WiMAX System: MAC Features (cont'd)

MAC Feature	Description
Handover	Neighbor Advertisement
	Scanning and Association
	HO Optimization
	CID & SAID Update (Connection & Security IDs)
Power saving Modes	Sleep
	Idle
Supported Cryptographic Suites	No data encryption, no data authentication & 3-DES, 128
	CCM-Mode 128-bit AES, CCM-Mode, AES Key Wrap with 128-bit key
Security	PKMv2 (Privacy Key Managements)
	CMAC (Message Authentication Code)
MBS	Multi BS MBS

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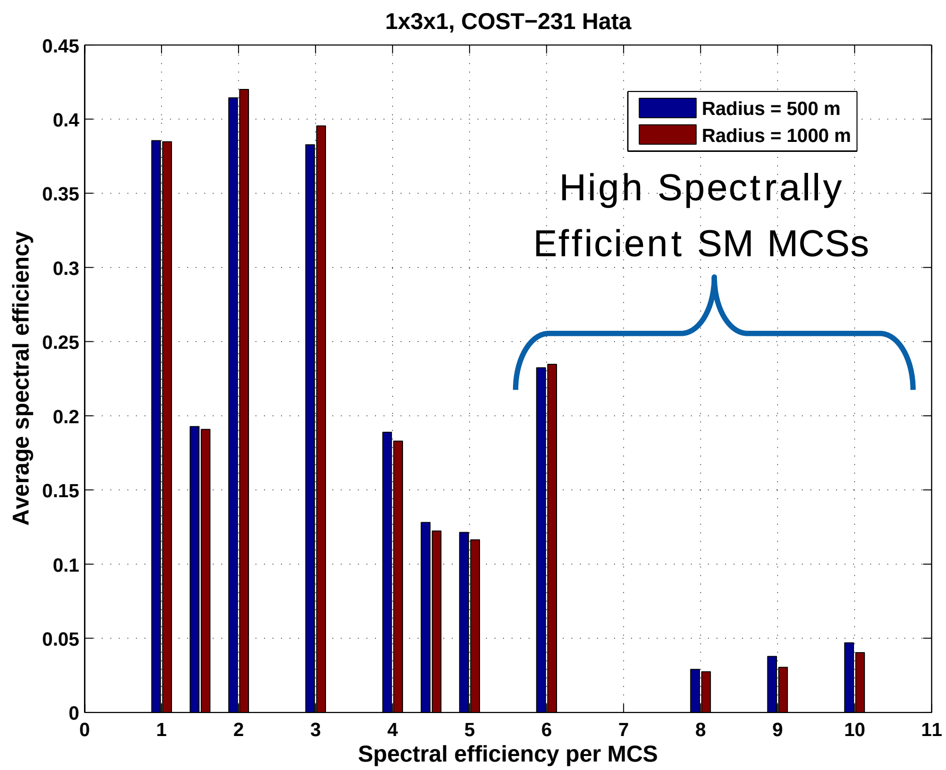
System-level performance evaluation of Mobile WiMAX Release 1: Methodology

- Using the 1xEV-DV methodology adopted by 3GPP/3GPP2
- Downlink considerations
  - Adaptive MIMO switching (AMS) between STBC and SM (2x2)
  - Use of suboptimal MLD for MIMO SM stream decoding
- Uplink considerations
  - Collaborative (virtual) MIMO transmission (2nd order)
  - Realistic power control over all sectors of the 19-cell network
- Modeling/Scheduling
  - Realistic MIMO channel modeling for both useful and interfering signals
  - Realistic PHY abstraction and link adaptation
  - User scheduling according to the proportional-fair approach
  - Chase-combining HARQ
  - CQI feedback delay

System Level Simulation (SLS) framework

- Network model: Cells, sectors, reuse
- DL/UL link budget: Power, antennas, noise figure
- Channel model:
  - Long-term characteristics (slow fading)
  - Short-term characteristics (fast fading)
  - Spatial characteristics (MIMO model)
- Air interface model: OFDMA, PUSC permutation, frame, resource blocks
- Interference model: Characteristics of interfering signals, loading
- HARQ parameters: Method, type, CQI feedback delay
- Scheduler: Resource allocation, latency time scale, target PER
- Performance statistics: SINR statistics, user throughput distribution (outage), normalized throughput distribution (fairness), MCS selection probability, aggregate sector throughput, spectral efficiency

Adaptive MIMO Switching average SE per MCS



Spectral Efficiency per MCS	
1	1xQPSK 1/2
1.5	1xQPSK 3/4
2	1x16QAM 1/2 2xQPSK 1/2
3	1x16QAM 3/4 1x64QAM 1/2 2xQPSK 3/4
4	1x64QAM 2/3 2x16QAM 1/2
4.5	1x64QAM 3/4
5	1x64QAM 5/6
6	2x16QAM 3/4 2x64QAM 1/2
8	2x64QAM 2/3
9	2x64QAM 3/4
10	2x64QAM 5/6

- The selection of spatial multiplexing modes with spectral efficiency greater than 5 bits/s/Hz leads to a dramatic increase of the overall spectral efficiency
- No appreciable difference between 500 m and 1000 m BS-BS radius with respect to MCS selection probability

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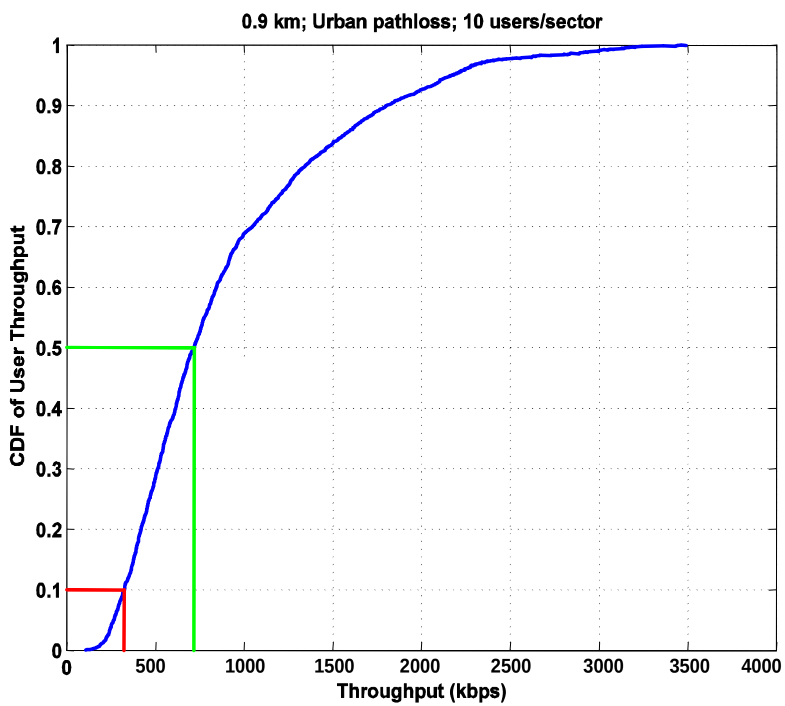
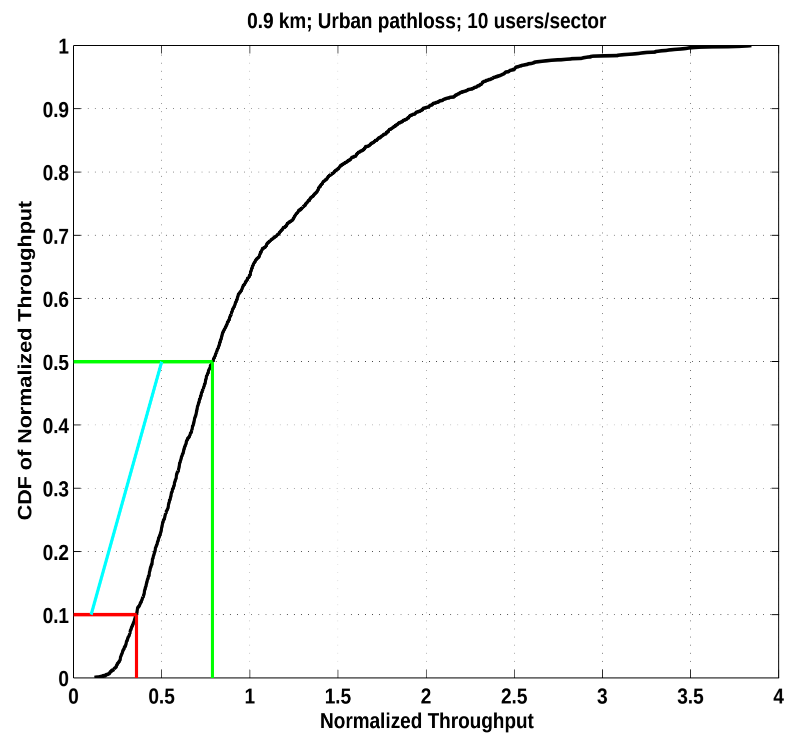
User throughput and normalized user throughputs (A measure for proportional fairness)



CDF of user throughput for BS-to-BS separation of 0.9 km



CDF of the normalized user throughput for BS-to-BS separation of 0.9 km

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DL user and aggregate throughput with Adaptive MIMO Switching

Value	10 users/sector 10 MHz	20 users/sector 10 MHz
10th Percentile (Outage)	320 Kbps	175 Kbps
50th Percentile (Median)	720 Kbps	392 Kbps

System Configuration	Aggregate DL Sector Throughput (Mbps)	DL Spectral Efficiency (b/s/Hz/cell site)
Reuse-1 SIMO	7.37	3.42
Reuse-1 MIMO (2x2)	10.65	4.95
Reuse-3 MIMO (segmented/non-segmented)	6.5 / 19.32	3.02 / 2.99

Most SE Option

45% Increase vs. SIMO

Lower SE vs. R-1

0.65 x R-1

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UL SIMO vs. Collaborative MIMO: Aggregate sector throughput and spectral efficiency

ITU Vehicular model

Cell radius 1.6 km

Parameter	SIMO	MIMO
Aggregate sector throughput	1.87 Mbps	2.33 Mbps
Spectral efficiency	0.59 b/s/Hz/sector	0.73 b/s/Hz/sector

Collaborative MIMO over SIMO spectral efficiency increase is 24%.

Mobile WiMAX voice capacity: 10MHz TDD, Reuse 1, Mix Mobility, VAF 0.4

Codec	VoIP Capacity (users/sector)	95th Percentile of LT FER (%)	Users below target system outage (%)
AMR (12.2 Kbps)	195	2.05	2.9
G.729 (8 Kbps)	220	1.1	2.3

- Performance targets for VoIP Capacity:
  - 95th percentile of Long Term FER <3%
  - System Outage < 3%
- VoIP capacity (G.729, 8 Kbps) satisfying performance targets: 220 users/sector
  - G.729 (8Kbps) has smaller payload than AMR (12.2Kbps) but capacity increase is limited by increased control overhead. Further optimization is possible for G.729 simulation.
- VoIP capacity (AMR 12.2 Kbps) satisfying performance targets: 195 users/sector

Wave 2 enhancements position Mobile WiMAX as a highly competitive solution for Mobile Broadband. In particular, multiple antenna enhancements can achieve additional 40-50% capacity in DL and 25% in UL over SIMO. Further gain is achievable through optimized operational scenarios.

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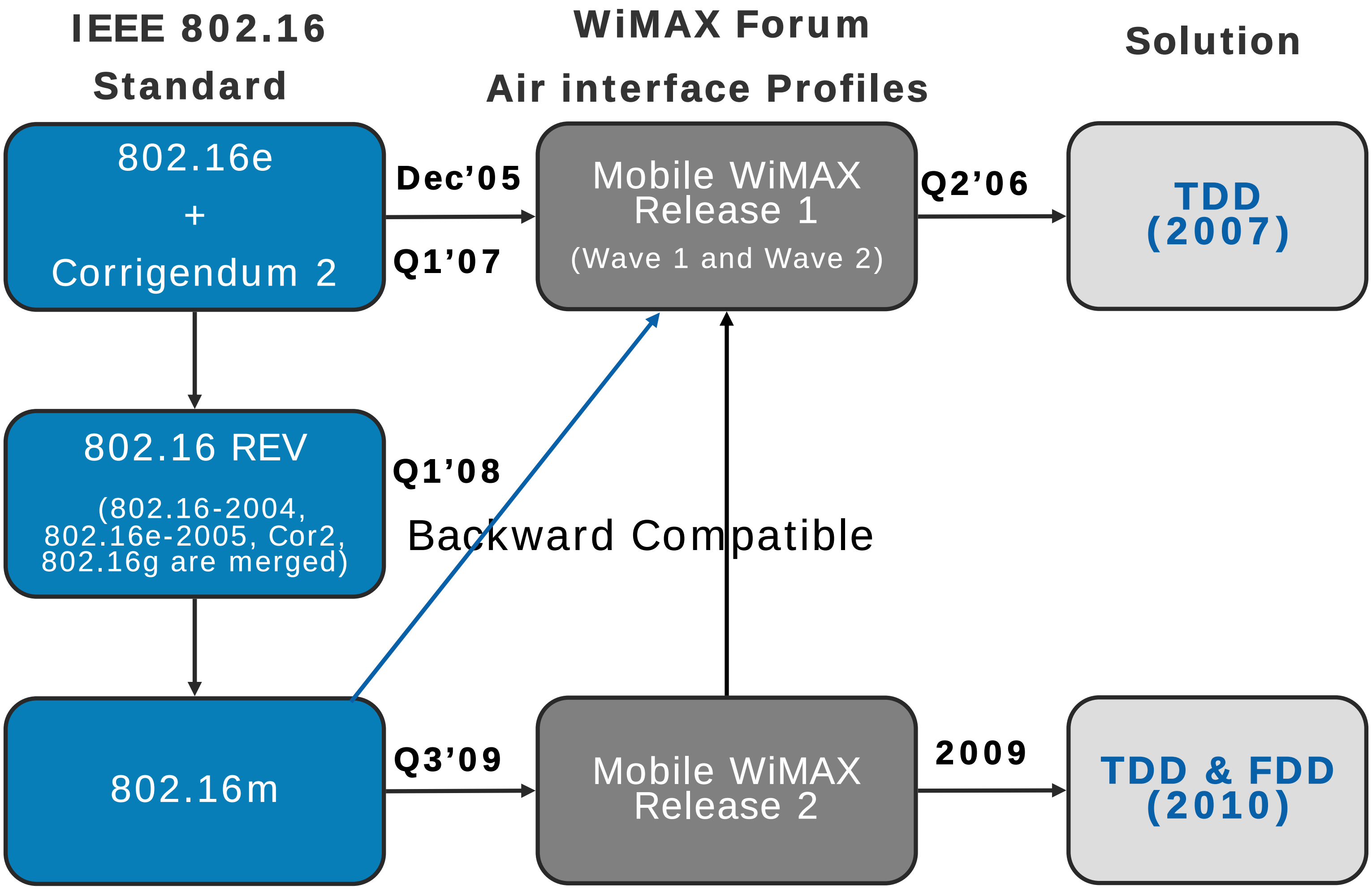
Mobile WiMAX Evolution

- Mobile WiMAX Release 1 is being commercialized by WiMAX Forum®
- IEEE 802.16 Standard continues evolving through various major enhancements including Multihop Relay and Advance Air Interface 802.16m considered for Mobile WiMAX Release 2.

IEEE 802.16 / Mobile WiMAX evolution



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Mobile Multihop Relay project: Purposes and scopes

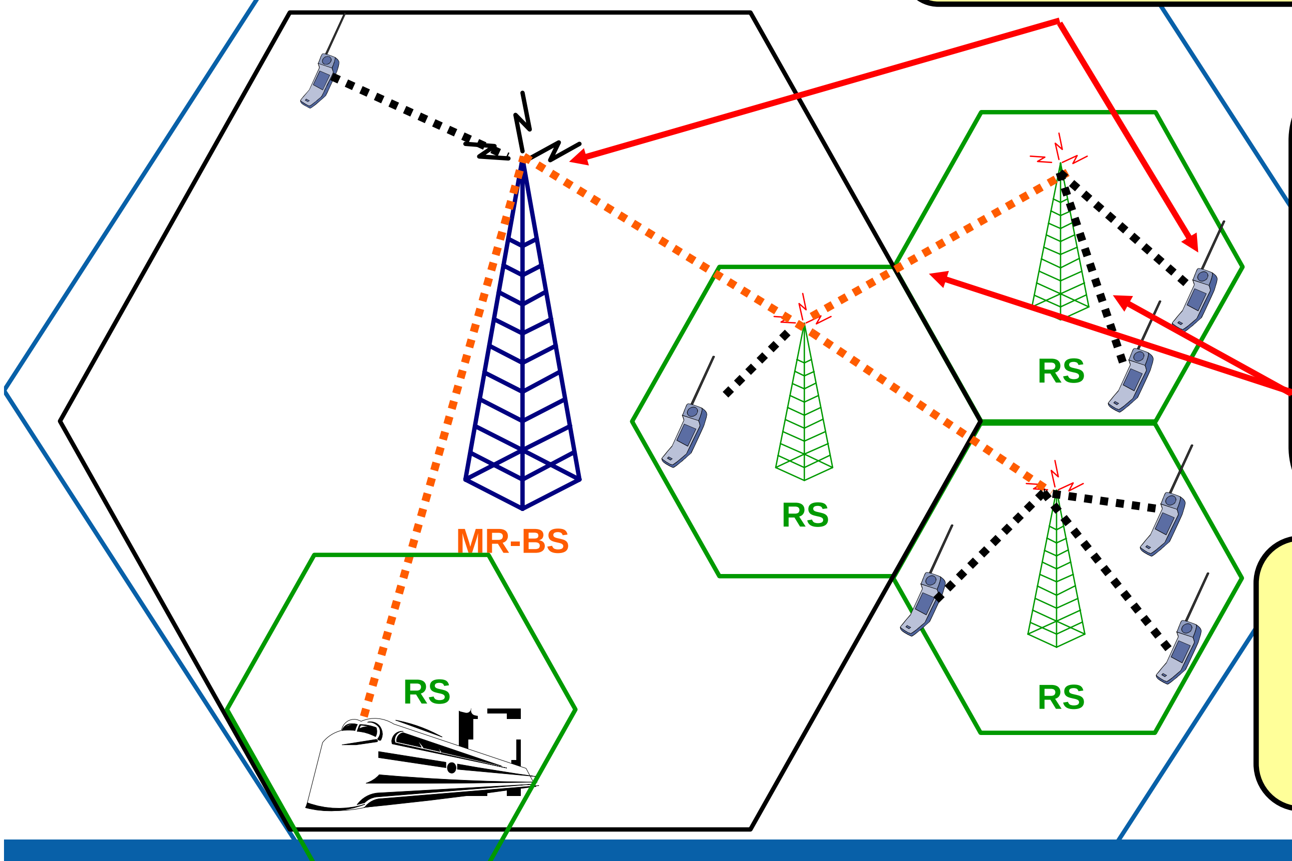
- OFDMA PHY and MAC enhancements to IEEE Std 802.16,
- Licensed bands to enable the operation of Relay Stations,
- Subscriber station specifications are not changed,
- Specifying 802.16 multihop relay capabilities and functionalities of interoperable relay stations and base stations,
- Amendment is to enhance coverage, throughput and system capacity of 802.16 networks,
- Control functions may be centralized at the Base Station or distributed among the Relay Stations with central coordination from the Base Station.

What is Mobile Multihop Relay (MR)? Is not Mesh, more than wireless backhaul!

Fixed/Portable, Mobile and Client Based Relay Stations are considered

Data communications between BS and MS – no direct communication of data between MS;

Control of cell is centrally coordinated by BS



Tree-like structure,

BS-MS communications traverse zero or more backhaul links and an access link,

Redundant routs are possible

Backhaul and access links can share radio resources

Control is distributed between BS and RSs

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Coverage, Capacity, and QoS enhancement relative to conventional Cellular deployments

- Current deployments suffer from …
  - Low SINR at cell edge
  - Coverage holes due to shadowing
  - Out-of-range clusters of users
  - Non-uniformly distributed traffic load (e.g. hot spots)
  - Limited spectrum and/or insufficient wire-line capacity
- Reducing cell size improves conditions, but issues are…
  - Limited availability of wire-line infrastructure in developing markets
  - Limited access to traditional cell site locations
  - Prohibitive installation and operating costs (backhaul is large fraction)
- Providing fault tolerant service is difficult and expensive
  - Redundant equipment, backhaul, backup power at cell sites is costly

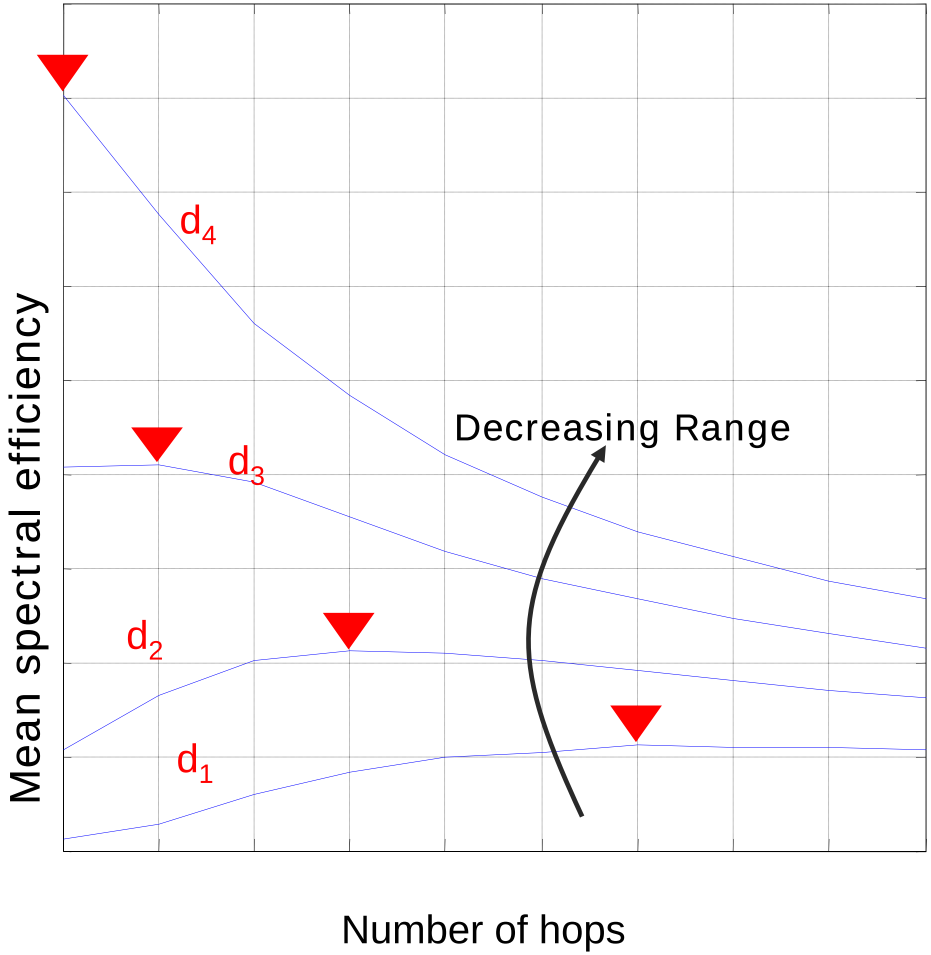
Key MR technology areas

- Frame structure
  - Critical to enabling flexible and efficient radio resource usage
- Scheduling structure and algorithms
  - Key to high efficiency
- Frequency assignment and reuse
  - Improves interference mitigation and efficiency
- Routing structure and algorithms
  - Enables load balancing and fault tolerance
  - Enhances efficiency
- Mobility management
  - Critical to support hit-less handover and mobile RS

Frame structure options

- In-band Relay – access and relay links share a channel
  - Non-transparent Relay –**RS does transmit preamble and MAPs**
    - Supports both Centralized and Distributed control
    - Mainly targeting coverage enhancement
  - Transparent Relay – **RS does not transmit preamble or MAPs**
    - Supports both Centralized control
    - Mainly targeting capacity enhancement
- Out-of-band Relay – Relay links operate on a separate channel

Trade off space: throughput, range, and number of hops



- For any given range there exists an **optimal hop number** that maximizes end-to-end throughput
- Optimal number of hops increases for longer ranges
- Other considerations such as latency limits for applications such as voice limit the number of hops that can be deployed in practice.

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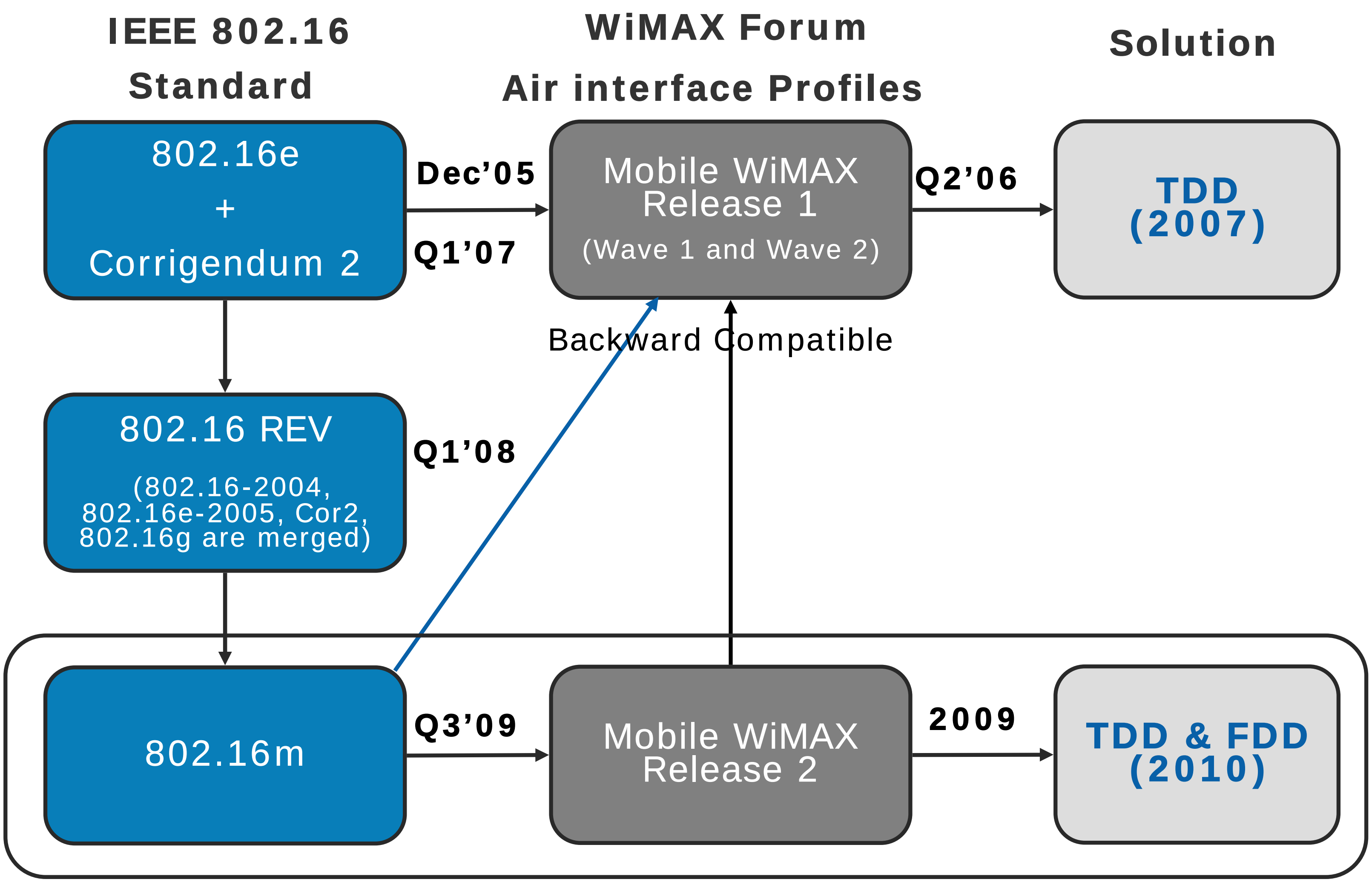
IEEE 802.16 / Mobile WiMAX evolution (revisited)



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Advanced Air Interface project: Purposes and scopes from 802.16m PAR

- 802.16m amends the IEEE 802.16 WirelessMAN-OFDMA specification to provide an advanced air interface for operation in **licensed bands**.
- It meets the cellular layer requirements of **IMT-Advanced next generation mobile networks**.
- **This amendment provides continuing support for legacy WirelessMAN-OFDMA equipment.**
- The project seek to develop an advanced IEEE 802.16 air interface by working cooperatively with ITU-R and its members.
- Some of the specific requirements that this amendment will target are:
  - 100 Mbit/s - high mobility
  - Frequency bands - licensed mobile bands below 6 GHz
  - Target cell size- Micro and Macro-cells as defined in Table 7-15 of Report ITU-R M.207

802.16m Advance Air Interface Requirements

Feature	IEEE 802.16m
RF Bands	Below 6 GHz, licensed
Duplexing Modes	TDD and FDD/HFDD
Channel Bandwidths	5, 10, 20, others optional BWs
Peak Data Rates (per sector)	DL: > 130 Mbps UL: > 56 Mbps (20 MHz)
Mobility	Up to 350 km/hr
Latency	Link-Layer Access: <10ms Handoff: <50ms
MIMO Configuration	DL: 2x2, 2x4, 4x2, 4x4 MIMO UL: 1x2, 1x4, 2x2, 2x4 MIMO
Spectral efficiency (per sector)	Peak: DL > 6.5 bps/Hz UL > 2.8 bps/Hz
Coverage (km)	< 5 km: Optimized 5-30 km: Graceful degradation 30-100 km: Functional, coverage limited
Number of VoIP Active Users	> 75 users/sector/FDD MHz > 37 users/sector/TDD MHz

802.16m / Mobile WiMAX R2 Candidate Targets

Feature	Mobile WiMAX R1* (802.16e)	Mobile WiMAX R2 (802.16m) (Expected Performance)
RF Bands	2.3 GHz, 2.5GHz, 3.3-3.8GHz	2.3 GHz, 2.5GHz, 3.3-3.8GHz, IMT-Advanced bands
Duplexing Modes	TDD	TDD, FDD/HFDD
Channel Bandwidths	5, 3.5, 7, 8.75, 10 MHz	5, 10, 20, 40 MHz
Peak Data Rates (per sector)	DL: 64 Mbps (2x2) UL: 28 Mbps (2x2 collaborative MIMO) (10 MHz)	DL: > 350 Mbps (4x4) UL: > 200 Mbps (2x4) (20 MHz)
Mobility	Up to 60-120 km/hr	Up to 350 km/hr
Latency	Link-Layer Access: ~20ms Handoff: ~35-50ms	Link-Layer Access: <10ms Handoff: <20ms
MIMO Configuration	DL: 2x2 MIMO UL: 1x2 MIMO	DL: 2x2, 2x4, 4x2, 4x4 MIMO UL: 1x2, 1x4, 2x2, 2x4 MIMO
Spectral efficiency (per sector)	Peak: DL 6.4 bps/Hz, UL 2.8 bps/Hz Sustained: DL 1.7 bps/Hz, UL 0.78 bps/Hz	Peak: DL > 17.5 bps/Hz UL > 10 bps/Hz Sustained: DL > 2.5 bps/Hz, UL > 1.16 bps/Hz
Coverage (km)	1/5/30 km	1/5/30km (Optimal performance at 5km)
Number of VoIP Active Users	~ 50 users/sector/FDD MHz ~ 25 users/sector/TDD MHz	> 100 users/sector/FDD MHz > 50 users/sector/TDD MHz

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Summary

- Mobile WiMAX is a globally defined standard currently undergoing trial and interoperability.
- Release 1.0 advanced features position Mobile WiMAX as a highly competitive solution for Mobile Broadband. In particular, multiple antenna enhancements can achieve additional 40-50% capacity in DL and 25% in UL over SIMO. Further gain is achievable through optimized operational scenarios.
- MR technology provides opportunities to enhance Coverage, Capacity, and QoS of Mobile WiMAX performance relative to conventional Cellular deployments.
- IEEE 802.16m Advanced Air Interface project targets the cellular layer requirements of IMT-Advanced next generation mobile networks.

Additional sources of information on this topic

More web based info:

- –http://www.wimaxforum.org
- –http://www.wimaxforum.org/technology/documents/
- –http://www.wimaxforum.org/technology/downloads/
- –http://www.ieee802.org/16/

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