Technologies and Requirements for IMT-Advanced

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Agenda

- **Standards and IMT-A Timeline**
- **LTE-Advanced Requirements and Test Environments**
- **LTE Basics and LTE Release-8 Performance**
- **LTE-A features**
  - Features necessary to meet IMT-A requirements
    - **DL MU-MIMO for Release-8/9/10**
  - Carrier Aggregation
  - Heterogeneous Networks
- **Brief overview of 802.16m**
  - Differences/similarities with LTE Release-8/9/10
- **Wireless Broadband Performance Comparison**
- **Summary**

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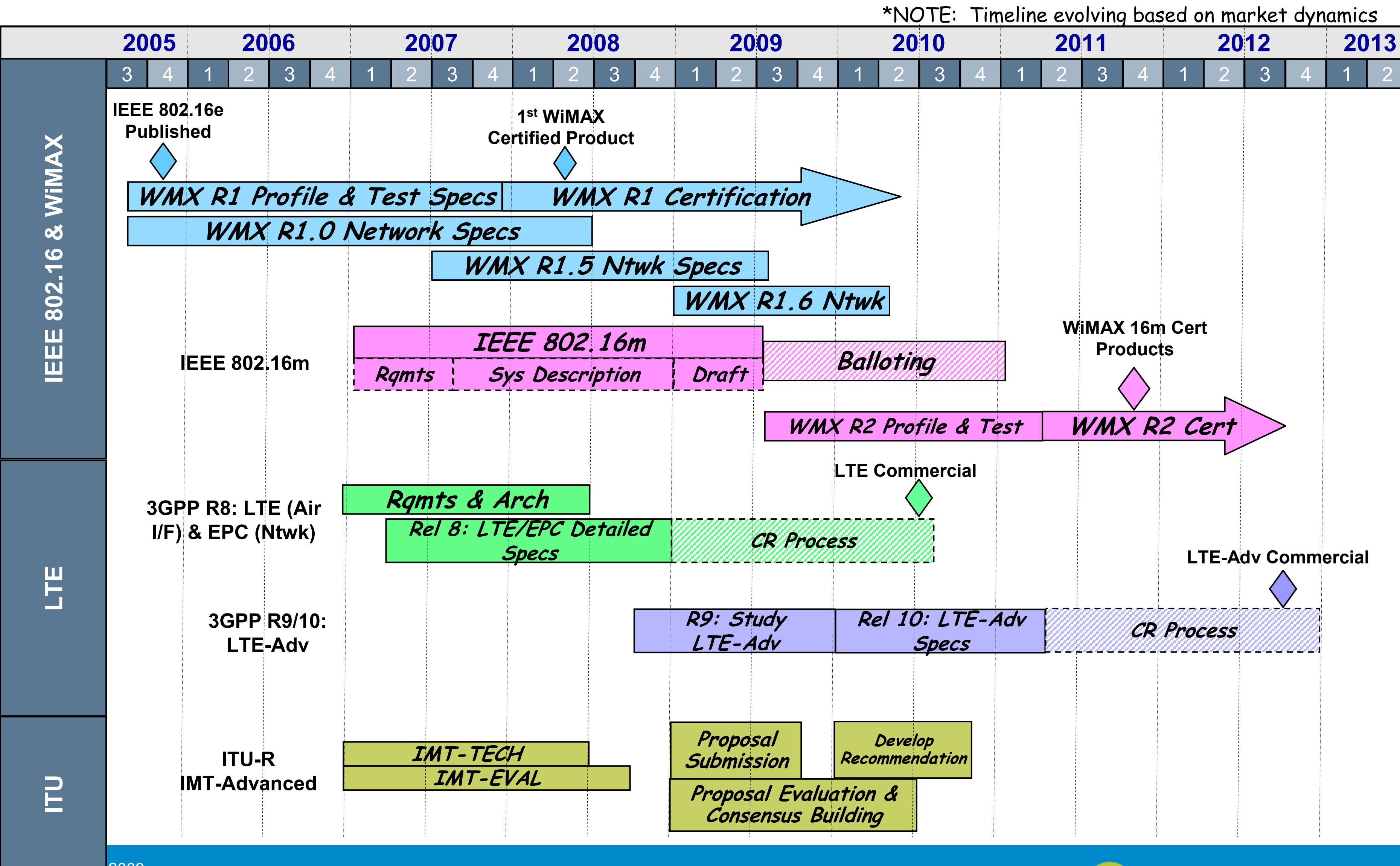
Standards and IMT-A Timeline and Requirements

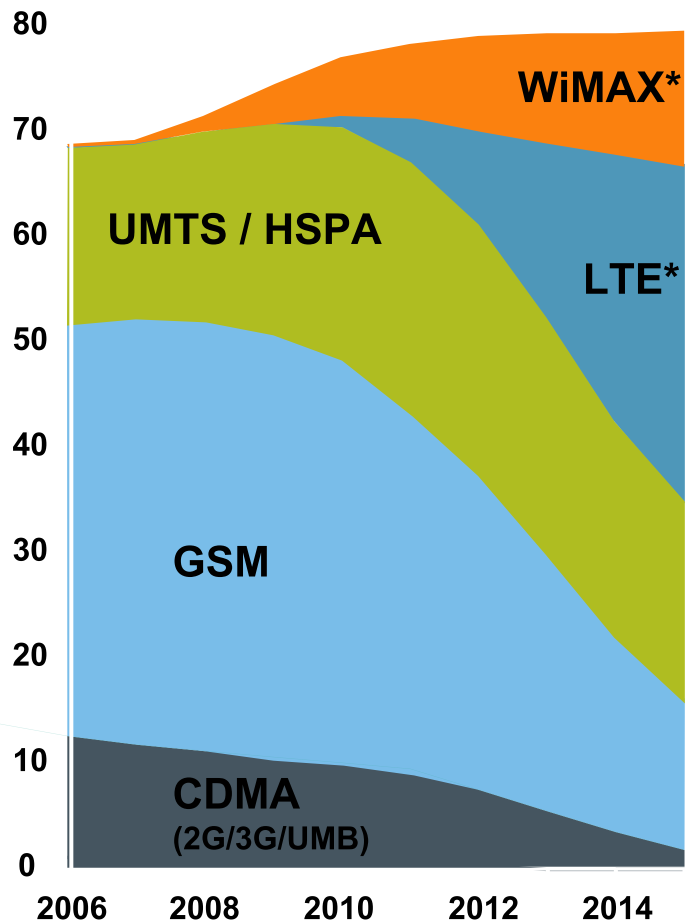
Current View of Broadband Wireless Standards Timeline



MOTOROLA

WiMAX & LTE

Two principal mobile broadband platforms for the next decade…



- All IP Networking
- OFDM Air Interface
- Light Infrastructure Design
- Advanced Antennas
- Licensed Spectrum

* Includes fixed-nomadic and mobile

IMT-Advanced Requirements

Test environment **	Cell Spectral Efficiency		Cell Edge Spectral Efficiency		Traffic Channel Link Rates**		Min VoIP capacity (Active users/sector/ MHz)
	Downlink (b/s/Hz/cell)	Uplink (b/s/Hz/cell)	Downlink (b/s/Hz/cell)	Uplink (b/s/Hz/cell)	Downlink (b/s/Hz/cell)	Uplink (b/s/Hz/cell)	
Indoor	3	2.25	0.1	0.07	1	10	50
Microcellular	2.6	1.8	0.075	0.05	0.75	30	40
Base coverage urban	2.2	1.4	0.06	0.03	0.55	120	40
High speed	1.1	0.7	0.04	0.015	0.25	350	30

Mobility Classes

	Test environments*			
	Indoor	**Microcellular**	**Base coverage urban**	**High speed**
Mobility classes supported	Stationary, pedestrian	Stationary, pedestrian, Vehicular (up to 30 km/h)	Stationary, pedestrian, vehicular	High speed vehicular, vehicular

Section 4.6 Mobility

Mobility Classes

Stationary	Pedestrian	Vehicular	High speed vehicular
0 km/h	> 0 km/h to 10 km/h	10 to 120 km/h	120 to 350 km/h

[1] ITU-R Document 5D/TEMP/89r1, Draft new Report ITU-R M.[IMT.TECH], Requirements related to technical system performance for IMT-Advanced radio interface(s) [IMT.TECH] , June 2008

IMT-A Baseline Configuration Parameters (1)

Deployment scenario for the evaluation process	Indoor hotspot	Urban micro-cell	Urban macro-cell	Rural macro-cell	Suburban macro-cell
Base station (BS) antenna height	6 m, mounted on ceiling	10 m, below rooftop	25 m, above rooftop	35 m, above rooftop	35 m, above rooftop
Number of BS antenna elements[(1)]	Up to 8 rx Up to 8 tx	Up to 8 rx Up to 8 tx	Up to 8 rx Up to 8 tx	Up to 8 rx Up to 8 tx	Up to 8 rx Up to 8 tx
Total BS transmit power	24 dBm for 40 MHz, 21 dBm for 20 MHz	41 dBm for 10 MHz, 44 dBm for 20 MHz	46 dBm for 10 MHz, 49 dBm for 20 MHz	46 dBm for 10 MHz, 49 dBm for 20 MHz	46 dBm for 10 MHz, 49 dBm for 20 MHz
User terminal (UT) power class	21 dBm	24 dBm	24 dBm	24 dBm	24 dBm
UT antenna system[(1)]	Up to 2 tx Up to 2 rx	Up to 2 tx Up to 2 rx	Up to 2 tx Up to 2 rx	Up to 2 tx Up to 2 rx	Up to 2 tx Up to 2 rx
Minimum distance between UT and serving cell[(2)]	>= 3 m	>= 10 m	>= 25 m	>= 35 m	>= 35 m
Carrier frequency (CF) for evaluation (representative of IMT bands)	3.4 GHz	2.5 GHz	2 GHz	800 MHz	Same as urban macro-cell
Outdoor to indoor building penetration loss	N.A.	See Annex 1, Table A1-2	N.A.	N.A.	20 dB
Outdoor to in-car penetration loss	N.A.	N.A.	9 dB (LN, $\sigma = 5$ dB)	9 dB (LN, $\sigma = 5$ dB)	9 dB (LN, $\sigma = 5$ dB)

(1) The number of antennas specified by proponent in the technology description template (§ 4.2.3 of Report ITU-R M.2133) should be used in the evaluations. The numbers shall be within the indicated ranges in this table.

(2) In the horizontal plane.

IMT-A Baseline Configuration Parameters (2)

Deployment scenario for the evaluation process	Indoor hotspot	Urban micro-cell	Urban macro-cell	Rural macro-cell	Suburban macro-cell
Layout(1)	Indoor floor	Hexagonal grid	Hexagonal grid	Hexagonal grid	Hexagonal grid
Inter-site distance	60 m	200 m	500 m	1 732 m	1 299 m
Channel model	Indoor hotspot model (InH)	Urban micro model (UMi)	Urban macro model (UMa)	Rural macro model (RMa)	Suburban macro model (SMa)
User distribution	Randomly and uniformly distributed over area	Randomly and uniformly distributed over area. 50% users outdoor (pedestrian users) and 50% of users indoors	Randomly and uniformly distributed over area. 100% of users outdoors in vehicles	Randomly and uniformly distributed over area. 100% of users outdoors in high speed vehicles	Randomly and uniformly distributed over area. 50% users vehicles and 50% of users indoors
User mobility model	Fixed and identical speed |*v*| of all UTs, randomly and uniformly distributed direction	Fixed and identical speed |*v*| of all UTs, randomly and uniformly distributed direction	Fixed and identical speed |*v*| of all UTs, randomly and uniformly distributed direction	Fixed and identical speed |*v*| of all UTs, randomly and uniformly distributed direction	Fixed and identical speed |*v*| of all UTs, randomly and uniformly distributed direction
UT speeds of interest	3 km/h	3 km/h	30 km/h	120 km/h	Indoor UTs: 3 km/h, outdoor UTs: 90 km/h
Inter-site interference modeling(2)	Explicitly modelled	Explicitly modelled	Explicitly modelled	Explicitly modelled	Explicitly modelled

Channel model Difference for IMT-A

LTE Basics and Performance

LTE Physical Channels

PDSCH
DL shared channel

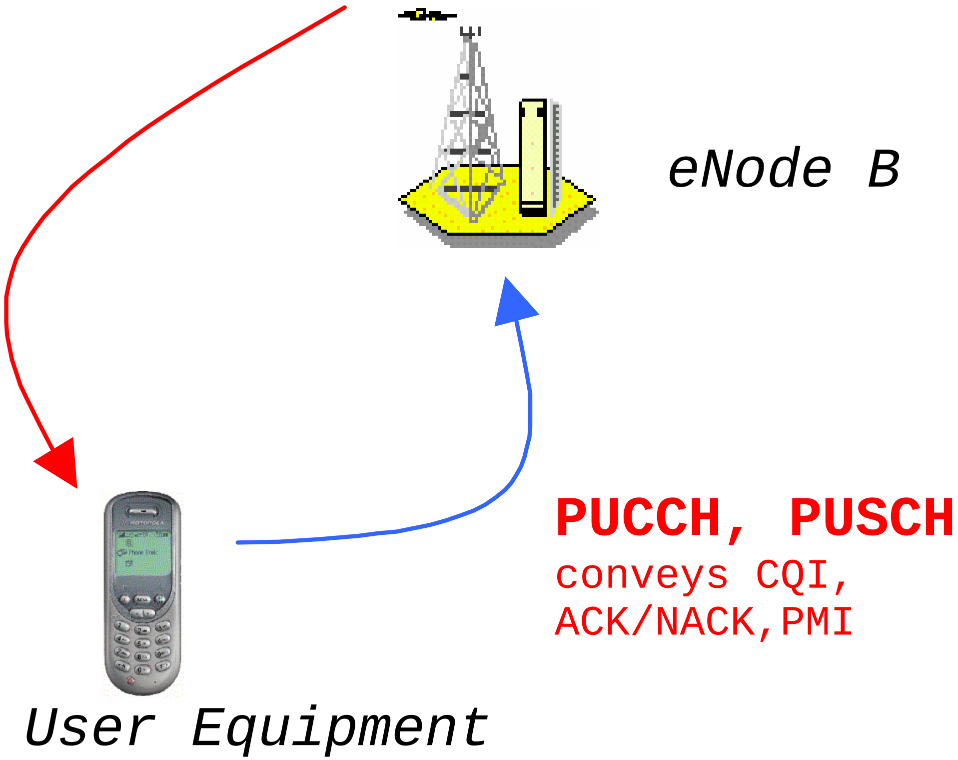
PDCCH
DL control channel

PBCH
DL Broadcast control channel

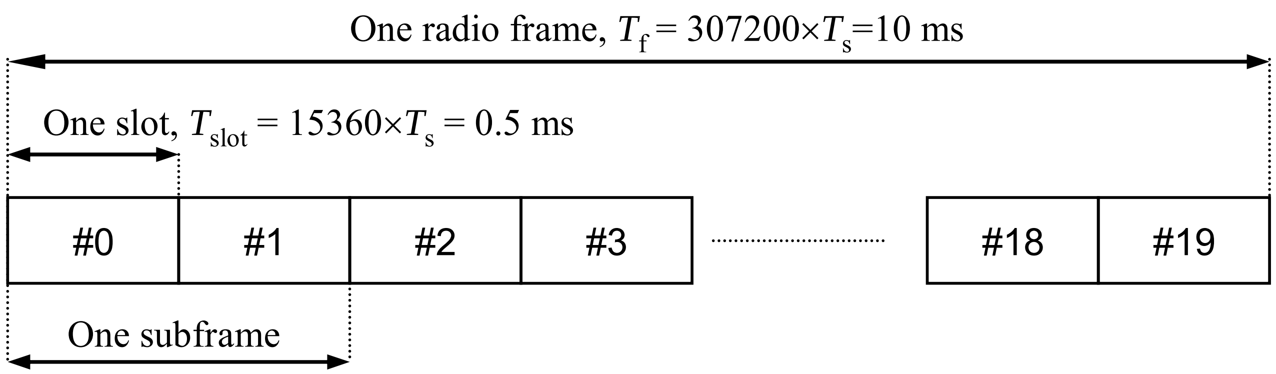
PCFICH
DL control format indicator channel

PHICH
HARQ indicator channel

PMCH
DL multicast chanel

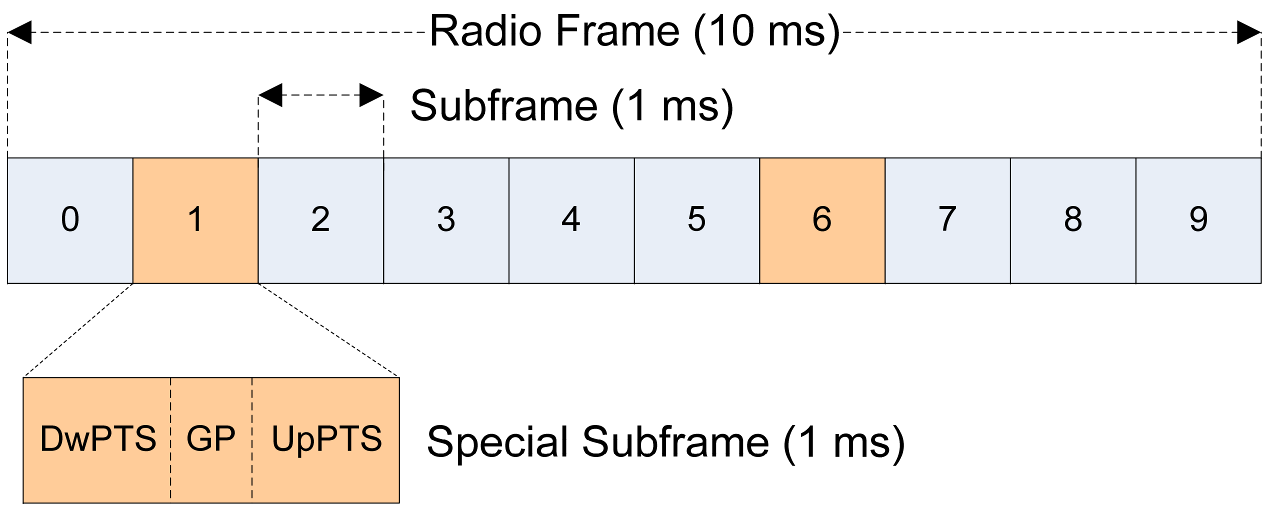


DL Frame Structure – Type 1 (FDD)



- Each radio frame is 10ms long and consists of 20 slots of length 0.5ms, numbered from 0 to 19.
- A subframe is defined as two consecutive slots.
- For FDD, 10 subframes are available for downlink transmission and 10 subframes are available for uplink transmissions in each 10 ms interval. Uplink and downlink transmissions are separated in the frequency domain.
- In half-duplex FDD operation, the UE cannot transmit and receive at the same time.

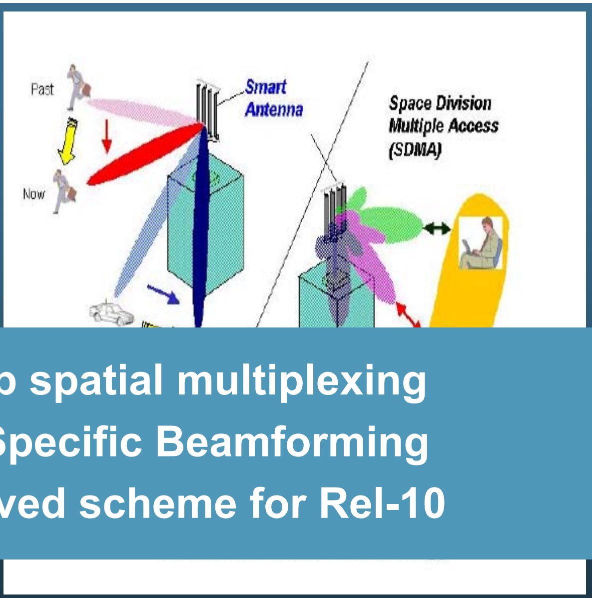
LTE TDD Frame Structure



- Each radio frame consists of two half-frames of length 5ms each.
- Each half-frame consists of eight slots of length 0.5ms and three special fields, DwPTS, GP, and UpPTS.
- The lengths of DwPTS and UpPTS are configurable subject to the total length of DwPTS, GP and UpPTS being equal to 1ms.
- Sub-frames 0 and 5 are always downlink sub-frames
- Two switching point periodicities are supported - 5ms or 10ms switching

LTE MAS Features

	Channels /Signals	MIMO/Diversity Schemes	Comments
DL Data Channel	PDSCH	Open loop spatial multiplexing Closed loop spatial multiplexing Multi-user MIMO UE Specific RS Beam-forming	Large Delay CDD/SFBC SU-MIMO MU-MIMO Applicable > 4 Antennas
	PDCCH		SFBC
	PCFICH		SFBC
UL Control Channels	PUCCH	Receiver Diversity	MRC
	PRACH		MRC



FDD : 2 Tx, 2RX -> Tx Diversity, Open and closed loop spatial multiplexing

TDD: 4Tx, 8RX (mainly for CMCC)-> Additionally UE Specific Beamforming

MU-MIMO Rel-8 scheme is inferior to SU-MIMO, Improved scheme for Rel-10

Downlink MIMO Schemes	Tx Mode	Precoding	Antenna Reqts eNB	Antenna Reqts UE	Preferred UE	Antenna Geometry	Standard Support
Single Input Single Output (SISO)	1	None	1	1,2	All speeds	Uncorr	R8
Open Loop Transmit Diversity	2	SFBC/FSTD for 2 and 4 Tx antenna	2,4		>30kph		
Open Loop Spatial Multiplexing	3	Large Delay CDD					
Closed Loop Spatial Multiplexing	4, 6	SU-MIMO			<30kph	Corr/Uncorr	
Multi-User MIMO (MU-MIMO)	5	Subset of Codebook used for SU-MIMO				Corr	
UE Specific RS based Beamforming	7	None	4,8		<60kph	Corr	

Rel-8 DL Performance with ITU Configurations (FB)

2x2 SU-MIMO with cross poles (FDD)

Environ.	Sect Tput (Mbps)	Sect SE (bps/Hz/cell)	5% UE (Mbps)	5% UE SE (bps/Hz/cell)	IMT-A Sector SE (bps/Hz/cell)	IMT-A 5% UE SE (bps/Hz/cell)
Case1_2D	17.429	1.74	0.382	0.038	NA	NA
Case1_3D	22.578	2.26	0.462	0.046	NA	NA
RMa	14.110	1.41	0.307	0.031	1.1	0.04
UMa	11.472	1.15	0.218	0.022	2.2	0.06
UMi	20.484	2.05	0.610	0.061	2.6	0.075
InH	43.67	4.36	1.466	0.146	3	0.1

4x2 SU-MIMO with cross poles (FDD)

Environ.	Sect Tput (Mbps)	Sect SE (bps/Hz/cell)	5% UE (Mbps)	5% UE SE (bps/Hz/cell)	IMT-A Sector SE (bps/Hz/cell)	IMT-A 5% UE SE (bps/Hz/cell)
Case1_2D	21.725	2.17	0.490	0.049	NA	NA
Case1_3D	27.843	2.78	0.568	0.057	NA	NA
RMa	18.117	1.81	0.434	0.043	1.1	0.04
UMa	15.569	1.56	0.321	0.032	2.2	0.06
UMi	24.295	2.43	0.710	0.071	2.6	0.075
InH	NA	NA	NA	NA	3	0.1

Total Overhead: 31.6% (L=3)

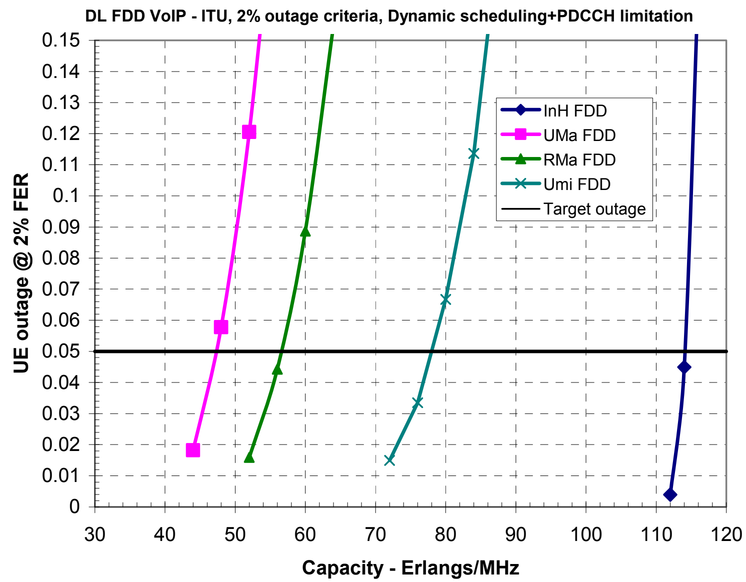
Release-8 LTE DL with 4 Tx antenna does not meet the UMa and UMi requirements

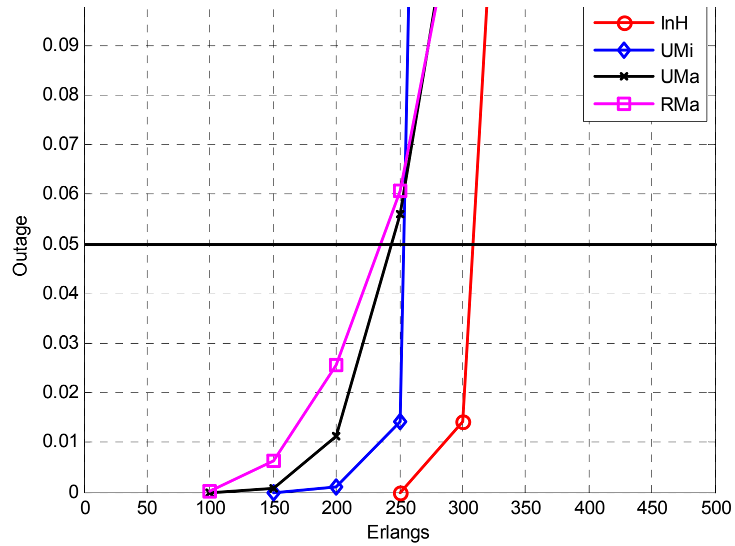
Rel-8 DL/UL Performance with ITU Configs (VoIP)

Case	IMT-A Requirements (VoIP users/MHz)	VoIP Capacity		IMT-A Requirements Met?
		Downlink (4x2)	Uplink (1x4)	
InH	50	112	60	Yes
UMi	40	74	50	Yes
UMa	40	44	42	Yes
RMa	30	54	36	Yes

VoIP capacity met without using SPS and using Release-8 features only with 4Tx and 4RX at eNodeB

VoIP Codec	AMR 12.2
Packet size	VoIP – 41 bytes including overhead SID – 15 bytes including overhead
One-way delay budget	50 ms
Outage criteria	User is in outage if 2% or more of the packets are lost or discarded
VoIP capacity definition	Number of supported users at 2% and 5% outage





Rel-8 UL Performance with ITU Configs (FB)

Antenna: linear array 0.5λ separation							
Case		IMT-A Requirements	FDD		TDD		IMT-A Requirements Met?
			1x4	1x8	1x4	1x8	
InH	Cell spectral efficiency (bps/Hz/cell)	2.250	2.970	3.364	2.920	3.341	Yes
	Cell edge user spectral efficiency (bps/hz)	0.070	0.203	0.246	0.193	0.242	Yes
UMi	Cell spectral efficiency (bps/Hz/cell)	1.800	1.904	2.413	1.891	2.407	Yes
	Cell edge user spectral efficiency (bps/hz)	0.050	0.057	0.074	0.056	0.073	Yes
UMa	Cell spectral efficiency (bps/Hz/cell)	1.400	1.487	2.015	1.480	2.010	Yes
	Cell edge user spectral efficiency (bps/hz)	0.030	0.060	0.083	0.059	0.083	Yes
RMa	Cell spectral efficiency (bps/Hz/cell)	0.700	1.600	2.110	1.594	2.098	Yes
	Cell edge user spectral efficiency (bps/hz)	0.015	0.054	0.072	0.054	0.071	Yes

Release-8 LTE UL with 4 Rx antenna meets the IMT-A requirements

How to meet IMT-A Target for DL

- **Need new features to meet UMi/UMa IMT-A target for DL**
- **Motorola prefers simplest technology possible for LTE-A to meet this requirements**
- **This technology will be available in LTE Rel-9/10**

Technologies for LTE-A

Technologies for LTE-A

- Technologies for LTE-A (3GPP Release-10)
  - Support of wider bandwidth
  - Uplink spatial multiplexing
  - Downlink spatial multiplexing
  - Coordinated multiple point transmission and reception (COMP)
  - Heterogeneous Network (Relays, Femto cells, Pico cells etc.)
  - Mobility enhancement

- Release-9 Technologies
  - Dual Layer Beamforming
  - OTDOA based positioning

Technologies required to meet DL IMT-A Target

DL MU-MIMO for LTE-A

- **MU-MIMO Operation**
  - Using covariance matrix and CQI information e NB scheduler
    - **Schedules a PDSCH transmission using SU or MU-MIMO**
- **Classes of MU-MIMO techniques**
  - Non-coordinated MU MIMO with long term spatial correlation
  - Non-coordinated MU MIMO with short term spatial correlation
  - Coordinated MU MIMO with long term spatial correlation
  - Coordinated MU MIMO with short term spatial correlation
- **Feedback modes**
  - Explicit channel feedback
    - **Short term co-variance feedback (wideband or narrowband)**
    - **Statistical Covariance Feedback - very long term**
  - Implicit channel feedback
    - **PMI as in Release-8**
- **RS Design**
- **PDCCH Design**

Preferred

CoMP

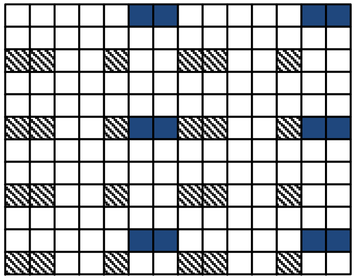
Existing MU-MIMO Rel-8

- **Semi-static MU-MIMO transmission mode**
- **1 layer of UE specific reference signals**
- **CQI/PMI/RI feedback similar to SU-MIMO**
- **4-bit codebook based feedback**
- **UE cannot suppress cross-talk due to MU-MIMO**
- **Possible MU-MIMO algorithm**
  - eNodeB pairs users with orthogonal rank-1 vectors
  - eNodeB chooses best user-pair, predicts MCS
  - UE cannot suppress cross-talk due to MU-MIMO
  - No gains with respect to SU-MIMO

MU-MIMO for Rel-9 1/2

- **2 streams of UE specific reference signals**
  - –CDM of 2 streams
  - –Same overhead as Rel-8 1 stream UE specific RS
  - –Enables cross-talk suppression with transparent MU-MIMO

- **A single transmission mode for rank-1, rank-2, MU-rank-1**
  - –Dynamic transition between SU and MU
  - –Dynamic transition among rank-1, rank-2



- **Downlink control signal**
  - –No signaling to indicate the presence of co-scheduled UEs

MU-MIMO for Rel-9 2/2

- **No PMI feedback**
  - UE always feeds back one CQI based on transmit diversity
  - UE does not feed back rank indicator
  - MCS/rank determined by the eNodeB
  - UE not aware of SU or MU transmission during feedback
- **PMI feedback (2Tx)**
  - CQI/PMI/RI feedback (same as 2Tx spatial mux mode)
- **In TDD, SRS transmission can be used for estimating covariance matrix for MU-MIMO**
  - Zero-forcing based MU-MIMO for 2 rank-1 users
  - In FDD translation of UL covariance to DL covariance may be possible for some situations
- **Codebook based feedback with CRS is inefficient**

MU-MIMO for Rel-10

- **UE specific reference signals extended to 8 streams**
  - Support more than 2 users for MU-MIMO
  - Support multi-stream MU-MIMO
- **CSI-RS (midamble) for CQI estimation**
  - Reduce CRS overhead
- **Novel feedback method for FDD/TDD**
  - Covariance feedback
  - High resolution PMI feedback

DL Reference Signals (RS)

- **New RS design to support LTE-A**
- **RS design goals**
  - UE specific demodulation reference signals (DRS) up to 8 streams, extension from 2 stream DRS for Rel-9
  - A low overhead CSI-RS (Channel State Information RS) supporting up to 8Tx antennas (0.96% for 8Tx) is to be used that is non-UE specific to enable channel information feedback
- **Estimates of RS overhead**
  - **CSI-RS overhead of 1/840=0.12% per antenna port (8 antenna ports = 0.96%)**
    - **Example:**
      - Time density: 1 symbol every 10ms per antenna port: 1/140
      - Frequency density: 1 subcarrier every 6 sub-carriers per antenna port: 1/6
  - **DM-RS**
    - **Rank 1 transmission: 12 REs per RB (same overhead as Rel-8)**
    - **Rank 2 transmission: 12 REs per RB**
    - **Rank 3-8 transmissions: max 24 REs (total) per RB**

Rel-9/10 DL Performance with ITU Configurations (FB)

4x2 MU-MIMO with cross poles (FDD)

Environ.	# ctrl channel Symbols	Sect Tput (Mbps)	Sect SE (bps/Hz/cell)	5% UE (Mbps)	5% UE SE (bps/Hz/cell)	IMT-A Sector SE (bps/Hz/cell)	IMT-A 5% UE SE (bps/Hz/cell)
UMa - narrow	3	24.834	2.48	0.633	0.063	2.2	0.06
UMa - wide	3	23.571	2.36	0.602	0.060	2.2	0.06
UMa - narrow	2	27.588	2.76	0.679	0.068	2.2	0.06
UMi - narrow	3	26.403	2.64	0.752	0.075	2.6	0.075
UMi - wide	3	25.192	2.52	0.699	0.070	2.6	0.075
UMi - narrow	2	29.293	2.93	0.820	0.082	2.6	0.075
RMa - narrow	3	29.370	2.94	0.771	0.077	1.1	0.04
RMa - wide	3	29.052	2.90	0.762	0.076	1.1	0.04
RMa - narrow	2	32.599	3.26	0.870	0.087	1.1	0.04

Release-9/10 LTE DL with 4 Tx antenna does meets the UMa and UMi requirements

Total Overhead: 28.78% (L=3), 24.50%(L=2)

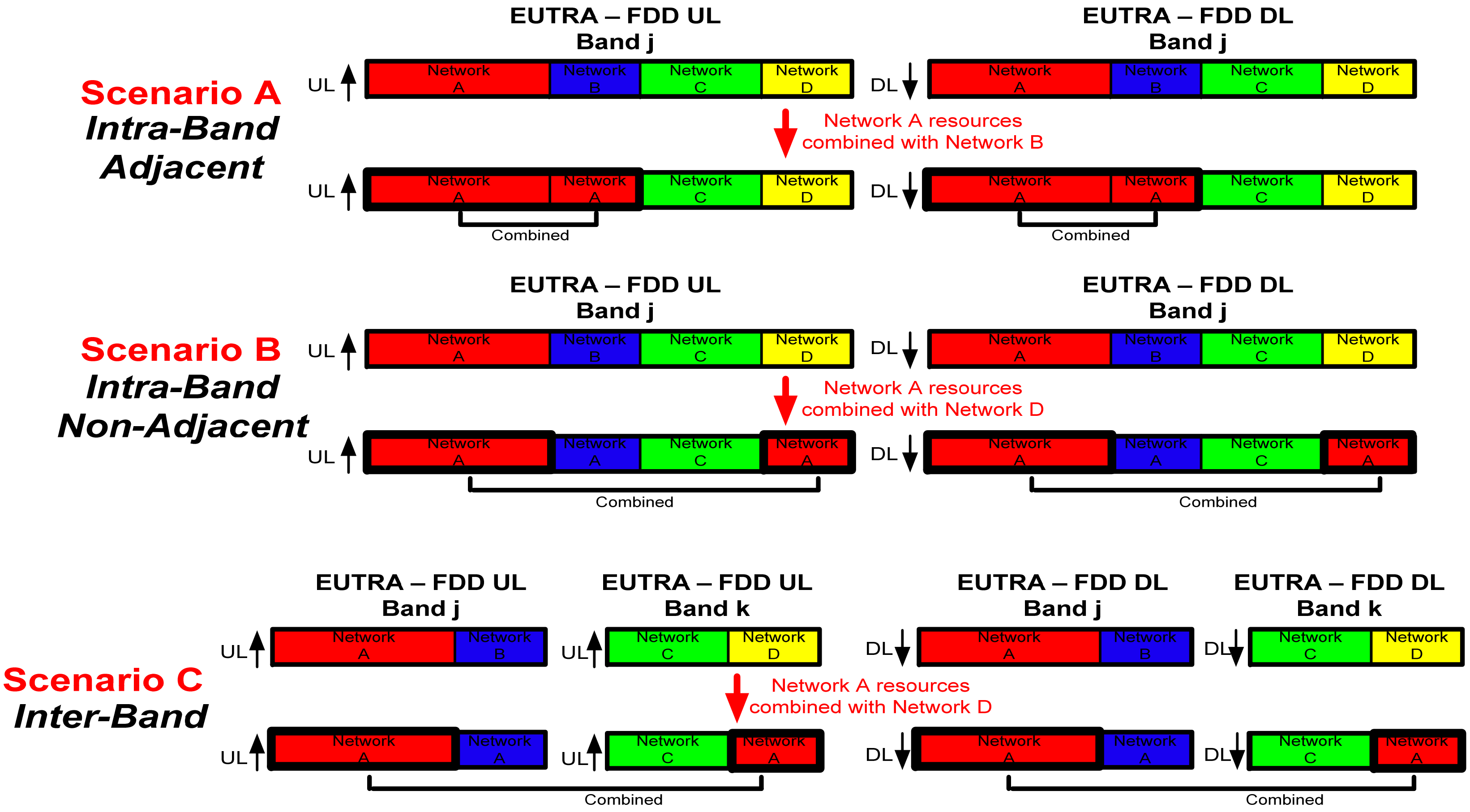
Performance of schemes based on DRS

Configuration	Avg Cell Tput Mbps	Avg UE Tput Mbps	5% Edge UE Tput Mbps	% MU-MIMO	% SU-MIMO Rank 1	% SU-MIMO Rank 2	% First Try Success
UMa SU-MIMO rank 1	17.322	1.732	0.625		100.00%		73.20%
UMa SU-MIMO rank 1 & 2	18.837	1.884	0.605		91.20%	8.80%	72.40%
UMa MU-MIMO, SU-MIMO rank 1	22.283	2.228	0.736	56.60%	43.50%		76.60%
UMa MU-MIMO, SU-MIMO rank 1 & 2	23.244	2.324	0.67	61.50%	36.80%	1.80%	75.90%
UMa SU-MIMO rank 1 & 2 codebook	15.31	1.531	0.646		77.78%	22.22%	74.54%

- **Goal is to reduce total overhead by reducing the number of common reference symbol (CRS) and having unified multiple antenna schemes based on DRS**
- **Performance of various schemes showed using UE specific DRS**
  - Results may be slightly different because of different scheduler settings
- **TDD**
  - Use SRS
- **FDD**
  - Quantization scheme for transmitting spatial correlation under study

Carrier Aggregation

Spectrum Aggregation Scenarios – FDD



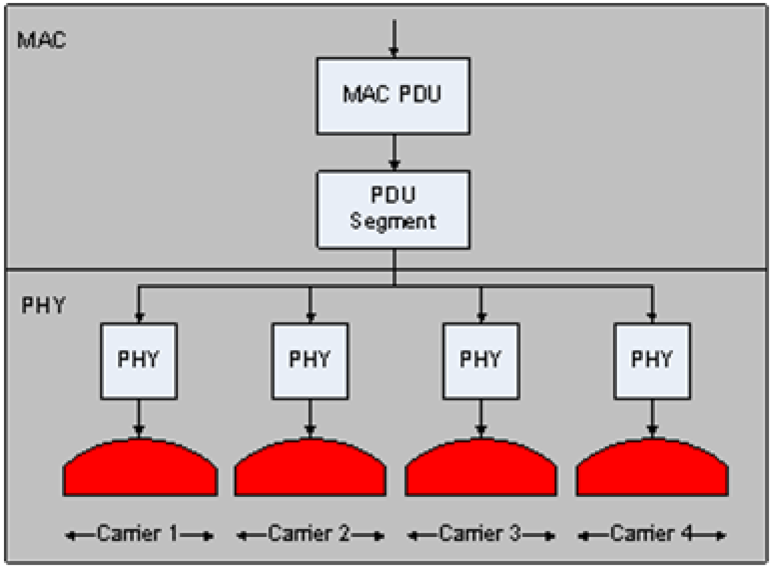
Notes: Additional TDD scenarios can be identified but not shown here

Spectrum Aggregation Scenarios

Deployment Scenario		*Carrier Aggregation*
FDD	**Contiguous single band, UL: 40 MHz DL: 80 MHz**	**UL: 2x20 MHz (3.5 GHz) DL: 4x20 MHz (3.5 GHz)**
	Non-contiguous multiple bands, UL: 40 MHz DL: 40 MHz	**UL: 10 MHz (1.8 GHz) + 10 MHz (2.1 GHz) + 20 MHz (2.6 GHz) DL: 10 MHz (1.8 GHz) + 10 MHz (2.1 GHz) + 20 MHz (2.6 GHz)**
TDD	**Contiguous single band, 100 MHz**	**5x20 MHz (2.3 GHz)**
	Non-contiguous single band, 80 MHz	**2x20 MHz (2.6 GHz) + 2x20 MHz (2.6 GHz)**

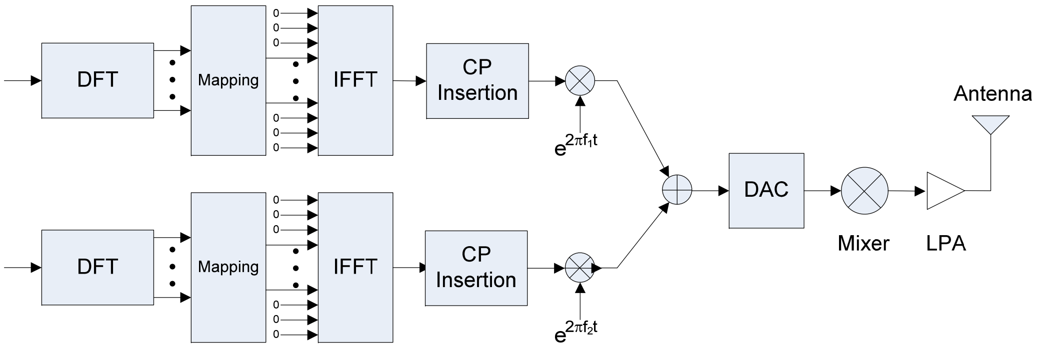
- **Spectrum aggregation scenarios outlined in RAN4**
- **Existing and new bands**

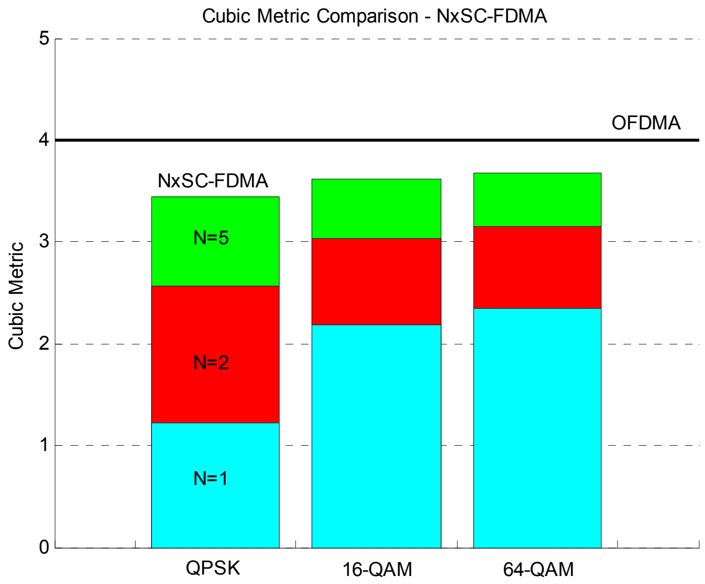
Carrier Aggregation Overview (1)



- **Aggregation of data streams at the MAC layer:**
  - Multi-codeword (MCW) transmission on per carrier basis
  - Selection of AMC, HARQ and MIMO schemes on per-carrier basis
  - Same numerology, soft-buffer size, transport block size as LTE Release-8.
  - Multiple HARQ processes needs to be supported for a single user with multiple A/N.
  - eNode-B has to monitor multiple CQI reports from carriers being aggregated.
- **Not a spectral efficiency enhancing feature**

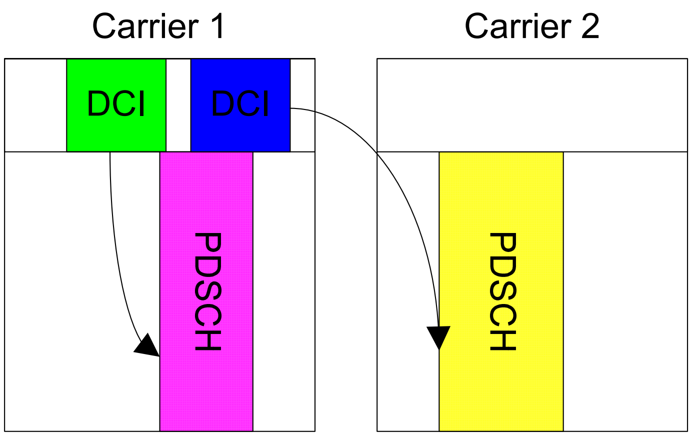
Carrier Aggregation Overview (2)





- **Uplink**:
  - N x SC-FDMA
  - Substantial increase in cubic metric when transmitting on multiple uplink carriers
  - Multi-carrier transmission will generally be restricted to UEs in good channel conditions, there should be no loss of coverage for those users.

Carrier Aggregation : DL Control Channel Design

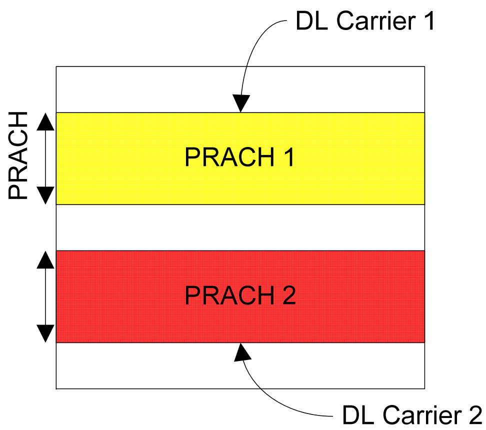


- **PDCCH: Separate grant for each component carrier based on DCI format (s) for single carrier**
  - An additional carrier indicator field (CIF) of 0-3 bits allows for cross-carrier scheduling
  - Presence of CIF is configured via higher-layer signalling
  - Limiting the number of blind decodings is desirable
- **PCFICH: Independent configuration on each component carrier**
- **PHICH:**
  - PHICH is transmitted on the same DL carrier as the UL scheduling assignment
  - PHICH resource index selection is done per Rel-8 LTE as a baseline
    - **FFS whether additional parameters such as carrier index should be included in the resource selection.**

Carrier Aggregation : UL Control Channel Design

- **PUCCH:**
  - Control signalling to support up to 5 downlink component carriers
  - ACK/NACK and CQI/PMI/RI reported for each downlink component carrier
  - Limited ACK/NACK transmission (e.g. ACK/NACK bundling) may be needed in case of power limitation
  - Scheduling request is per UE (one request for all uplink component carrier)

- **PRACH:**
  - RACH procedure is the same as Rel-8
  - For asymmetric downlink-heavy aggregation, several PRACHs may be mapped in the same UL carrier as shown below -



LTE Heterogeneous Networks

What is Heterogeneous Networks

- **Heterogeneous Deployments**
  - Low power nodes are placed throughout a macro cell layout
- **Types of low power nodes**
  - Femto Cells
  - Pico Cells
  - Distributed Antenna Systems
    - **Outdoor, Indoor, RRH**
  - **Relays**
    - Subject of discussion
- **Characteristics**
  - Gives rise to high interference conditions
  - ICIC and CoMP techniques can be critical
  - Operation in low geometry environments

Type of Nodes	LPA Power	Number of Tx/Rx Antennas	Backhaul Type	Comments
Micro cell nodes	30 dBm – 10 MHz carrier	2/2 or 4/4	X2	Open to all UEs; placed outdoors
RRH nodes	30 dBm – 10 MHz carrier	2/2 or 4/4	Several μs latency to macro	Open to all UEs; placed indoors or outdoors
Pico cell nodes	30 dBm – 10 MHz carrier	2/2 or 4/4	X2	Open to all UEs; placed indoors or outdoors
Femto cell nodes	20 dBm – 10 MHz carrier	2/2 or 4/4	Home broadband	Closed subscriber group, placed indoors
Relays	30 dBm – 10MHz carrier	2/2 or 4/4	Out-of-band or In-band	Open to all UEs; placed outdoors

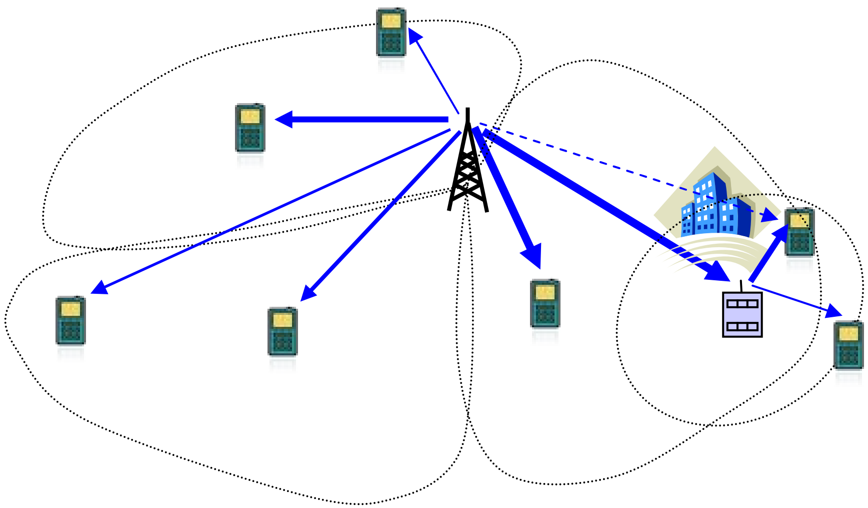
Overview of Relays

- **Relays are a feature for LTE-A**
  - Used to improve sector throughput, coverage, and cell-edge throughput
  - Provide coverage in new areas
  - Relays may operate at layer 1, layer 2, or layer 3
- **Repeaters and L1 Relays operate at layer 1**
  - Repeater
    - **Can offer coverage extension for eNodeBs by amplifying and forwarding received waveform**
    - **Cannot distinguish between signal and interference/noise**
  - L1 Relay
    - **Is a smart repeater that regenerates and amplifies only the relevant parts of the received signal based on the subset of users targeted by the relay**
- **Relays are connected to RAN via a donor macro-cell**
  - Backhaul Connection
    - **In-band: eNodeB-to-relay link shares the same band with direct eNodeB-to-UE links within cell**
    - **Out-of-band: eNodeB-to-relay link doesn't share the same band with direct eNodeB-to-UE links**
  - UE Perspective
    - **Transparent: UE is not aware of whether or not it communicates with the network via relay**
    - **Non-transparent: UE is aware of whether or not it communicates with the network via relay**

Comparison of L1/L2/L3 Relays

- **L1 relay**
  - Amplifies and forwards the signal at physical layer
  - Can be advanced repeater (with physical layer processing or power control)
  - Noise is amplified but less delay than L2/L3 relays
- **L2 relay**
  - Decodes and forwards re-encoded data at layer 2 (MAC/RLC/PDCP PDUs)
  - No noise amplification with precise decoding but delay introduced
  - Can have a unique physical layer cell identity
  - Independent link adaptation on each hop possible
  - ARQ protocols can either operate per-hop or end-to-end
  - Scheduling at relay node independent of the eNodeB may be possible
- **L3 relay**
  - Forwards IP packets on layer 3 (IP layer)
  - All LTE protocols operate per-hop
  - Has full functionality of eNodeB
  - Can be viewed as a regular eNodeB with wireless backhauling (i.e., self-backhauling)
  - User-plane protocol stack is similar to eNodeB but differences exist in control-plane protocol stack

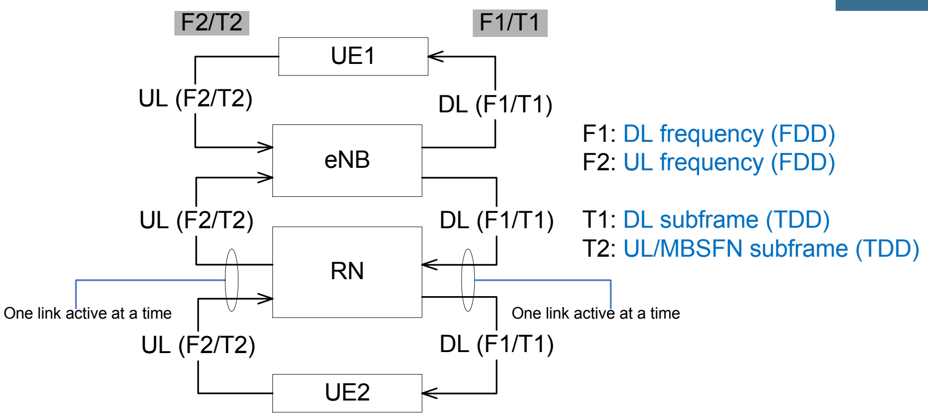
Functional Aspects of Type 1 Relay

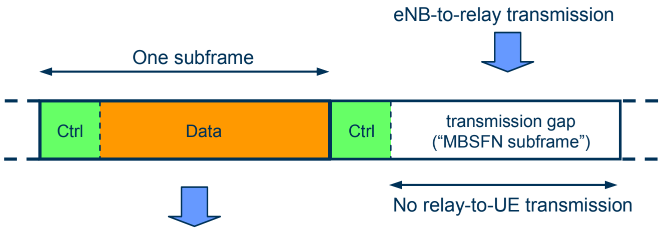


- UE can attach to strong relay rather than weak eNodeB
- SFN implies that relay-cell uses same resources as macro-cell
- Relay improves throughput to relay-cell UEs but introduces more interference to macro-cell UEs
- Resources for backhaul can either be in-band (and orthogonal to access resources) or out-of-band
- In-band backhaul reduces resources for macro-cell UEs
- Relays provide gain when there is a net improvement in sector-throughput or edge-throughput

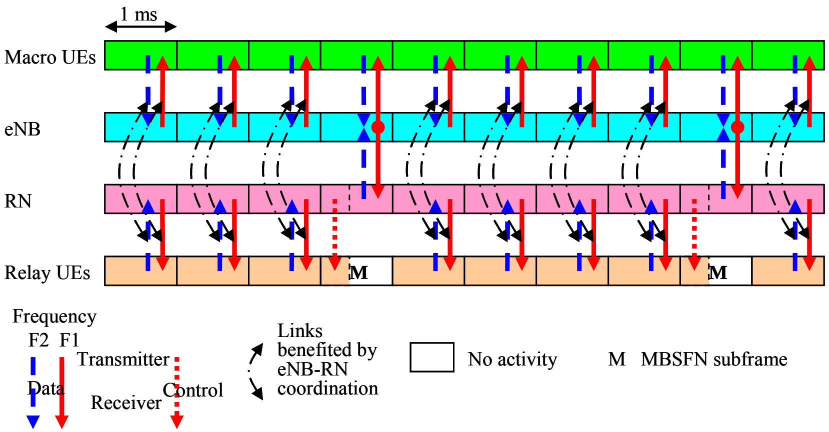
Access-Backhaul Partition for Type 1 Relays

- **For a type 1 FDD relay**
  - TDM access-backhaul
  - Access split is as follows
    - **eNB →RN is in DL frequency**
    - **RN →eNB is in UL frequency**
    - **eNB →RN and RN →UE links are TDM (only one active at a time)**
    - **RN → eNB and UE →RN links are TDM (only one active at a time)**
  - Use of UL frequency for eNB →RN communication is FFS
- **MBSFN subframes can be used to time-multiplex eNB-RN and RN-UE links**
  - No access traffic in relay-cells during MBSFN subframes

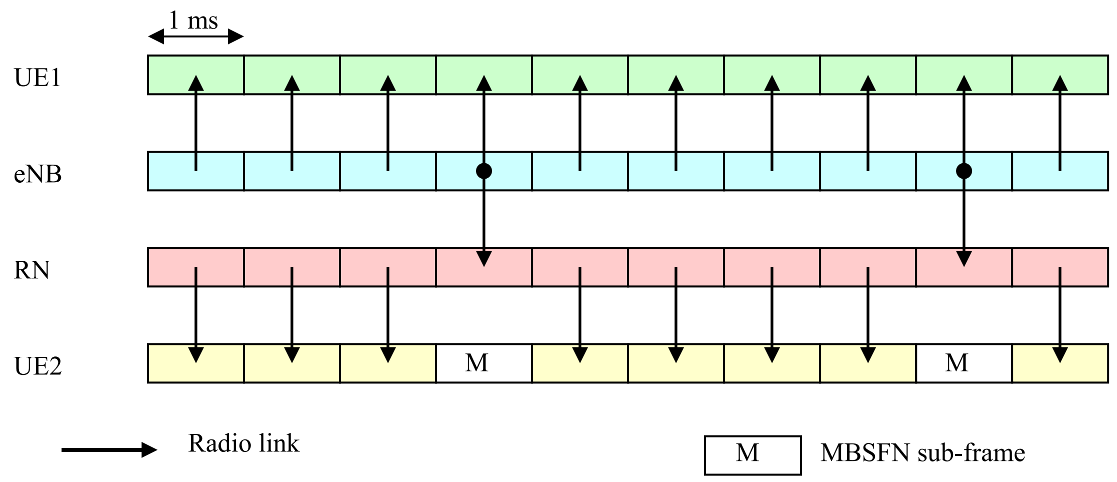




Relay-to-UE communication using normal subframes (left) and eNodeB-to-relay communication using MBSFN subframes (right)



Sub-Frame Utilization for Access and Backhaul

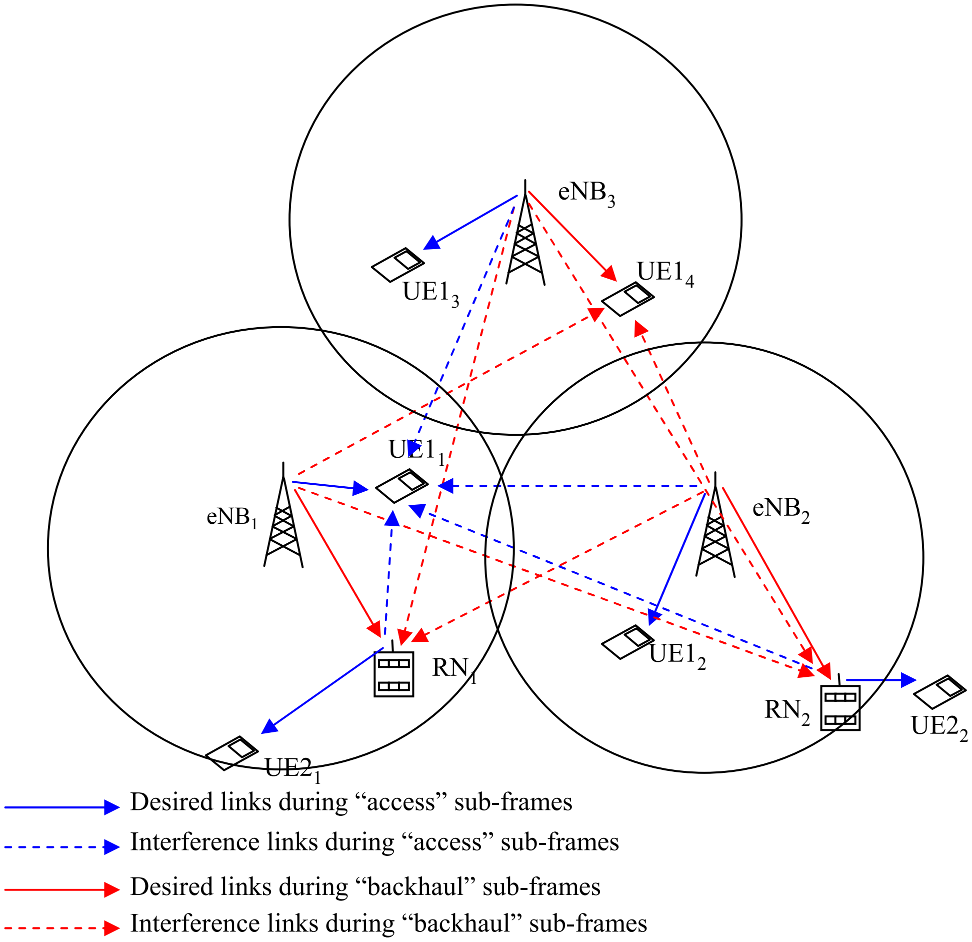


- **Time-orthogonal "access sub-frames" and "backhaul sub-frames"**
- **Network-wide uniform configuration of backhaul sub-frames**
  - Fixed number of backhaul sub-frames every frame
  - Reserved exclusively for backhaul traffic
  - When there are no RNs in a cell, these sub-frames are used for access

Channel and Antenna Models for In-Band Backhaul

- **Backhaul link model is based on relay site planning**
  - Optimized (5 dB path loss bonus) or non-optimized (0 dB bonus) relay-site planning
- **Two antenna models for backhaul**
  - Based on single (omni) or two (omni/directional) antenna sets at relay
- **Combinations present different models for backhaul link**
  - Non-optimized relay-site + omni antenna (Backhaul A)
  - Optimized relay-site + omni antenna (Backhaul B)
  - Non-optimized relay-site + directional antenna (Backhaul C)
  - Optimized relay-site + directional antenna (Backhaul D)
  - Allow for different cost models
- **The shadowing standard deviation is different for eNodeB-UE, eNodeB-RN (backhaul), and RN-UE links**

Interference Model



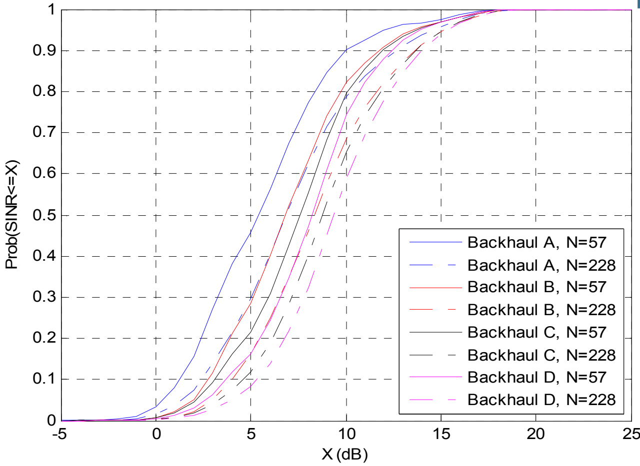
- **Macro-cells and relay-cells reuse access sub-frames causing mutual interference**
  - Interference at UEs from other eNodeBs and RNs
  - No interference from RNs with backhaul bottlenecks
- **Backhaul sub-frames are used exclusively for backhaul unless there are no relays in cell**
  - Interference at RNs (and UEs) from eNodeBs only (not RNs)

Simulation Setup

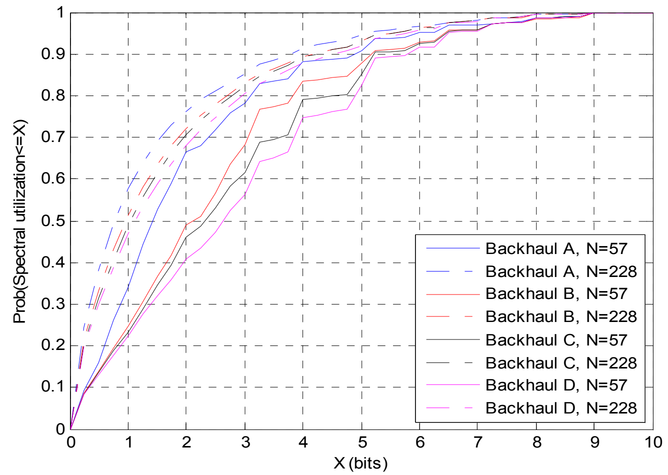
- **Two-ring, 19-macro-cell, 3-sectored site hexagonal grid system layout**
- **DS Case 1 and DS Case 3**
- **57 or 228 relays randomly dropped with uniform spatial prob. density**
- **1425 UEs randomly dropped with uniform spatial prob. density**
- **Ideal out-of-band (OOB) backhaul with unlimited capacity and four in-band (IB) backhaul models are considered**
- **1, 2, 4, or 6 backhaul sub-frames per frame (SFpF)**
  - Increase in the available backhaul capacity at the expense of macro-cell capacity
- **Constraint implemented to ensure that relay-cell throughput does not exceed the corresponding backhaul throughput**
- **Aggregate sector throughput is sum of macro-cell and relay-cell throughputs**
- **Backhaul link quality can be evaluated via SINR, spectral utilization (mod. order × code rate × rank × fraction of sub-carriers allocated to link) and average throughput of active backhaul links**

Simulation Results for DS Case 1

Scenario	Backhaul model with relays	Average macro-cell throughput per sector (Mbps)		Average relay throughput per sector (Mbps)		Average aggregate throughput per sector (Mbps)		5th percentile UE throughput (kbps)		Average throughput of active backhaul links (kbps)	
		N=57	N=228	N=57	N=228	N=57	N=228	N=57	N=228	N=57	N=228
No relays	N/A	31.026		N/A		31.026		223.57		N/A	
OOB Backhaul	Ideal	30.874	29.920	14.950	55.603	45.823	85.523	237.35	315.77	N/A	N/A
Relays with 1 IB backhaul SFpF	Backhaul A	29.832	29.733	0.900	2.297	30.732	32.030	159.32	33.89	1230.68	816.68
	Backhaul B	29.796	29.657	1.146	2.738	30.942	32.396	179.73	55.83	1571.59	973.83
	Backhaul C	29.793	29.652	1.241	2.847	31.035	32.499	185.43	67.01	1705.99	1012.73
	Backhaul D	29.773	29.634	1.334	3.022	31.107	32.656	188.58	75.90	1833.57	1074.75
Relays with 2 IB backhaul SFpF	Backhaul A	27.966	26.073	1.816	4.853	29.783	30.926	175.65	56.24	2484.62	1725.81
	Backhaul B	27.887	25.959	2.310	5.722	30.196	31.681	185.05	96.92	3168.46	2035.75
	Backhaul C	27.865	25.943	2.497	5.918	30.362	31.861	192.67	113.38	3432.59	2105.72
	Backhaul D	27.850	25.915	2.687	6.266	30.537	32.181	193.22	129.50	3696.31	2229.28
Relays with 4 IB backhaul SFpF	Backhaul A	24.501	20.001	3.430	9.458	27.931	29.459	155.53	100.76	4960.05	3518.53
	Backhaul B	24.432	19.880	4.367	11.153	28.799	31.033	164.82	136.22	6320.21	4123.37
	Backhaul C	24.414	19.878	4.735	11.531	29.149	31.409	166.67	151.89	6867.86	4248.90
	Backhaul D	24.389	19.832	5.115	12.204	29.504	32.036	166.49	156.11	7409.16	4479.48
Relays with 8 IB backhaul SFpF	Backhaul A	20.874	13.638	4.769	12.981	25.642	26.619	110.14	97.62	7196.73	5049.18
	Backhaul B	20.808	13.549	6.051	15.363	26.859	28.912	113.27	114.66	9154.72	5920.97
	Backhaul C	20.804	13.546	6.571	15.946	27.374	29.492	112.75	119.27	9970.40	6097.26
	Backhaul D	20.773	13.512	7.081	16.924	27.854	30.436	113.09	120.72	10754.1	6443.72



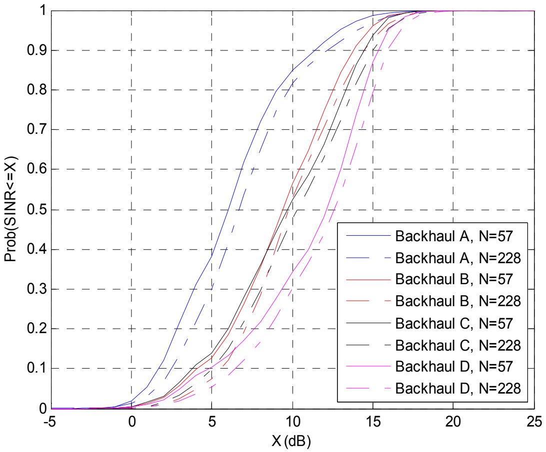
CDF of SINR



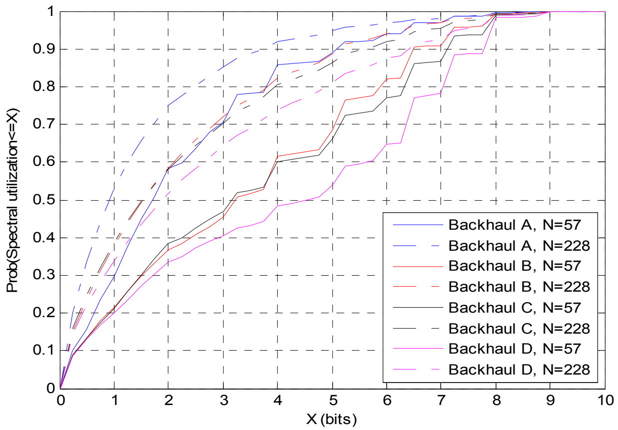
CDF of Spectral Utilization

Simulation Results for DS Case 3

Scenario	Backhaul model with relays	Average macro-cell throughput per sector (Mbps)		Average relay throughput per sector (Mbps)		Average aggregate throughput per sector (Mbps)		5th percentile UE throughput (kbps)		Average throughput of active backhaul links (kbps)	
		N=57	N=228	N=57	N=228	N=57	N=228	N=57	N=228	N=57	N=228
No relays	N/A	30.153		N/A		30.153		185.42		N/A	
OOB Backhaul	Ideal	30.838	30.659	12.482	44.783	43.320	75.442	215.22	248.38	N/A	N/A
Relays with 1 IB backhaul SFpF	Backhaul A	29.545	28.858	0.881	2.053	30.426	30.911	185.90	131.70	1375.65	894.90
	Backhaul B	29.512	28.786	1.385	3.079	30.897	31.865	194.87	173.99	2165.13	1341.44
	Backhaul C	29.513	28.783	1.416	3.161	30.929	31.944	195.07	172.43	2213.47	1376.88
	Backhaul D	29.490	28.748	1.669	3.719	31.159	32.467	198.17	182.08	2611.32	1619.81
Relays with 2 IB backhaul SFpF	Backhaul A	27.970	25.879	1.769	4.296	29.739	30.175	182.26	153.21	2763.66	1873.38
	Backhaul B	27.925	25.756	2.776	6.348	30.701	32.104	186.09	182.65	4344.01	2770.23
	Backhaul C	27.933	25.762	2.839	6.490	30.772	32.252	187.10	179.70	4442.46	2831.55
	Backhaul D	27.901	25.725	3.343	7.598	31.245	33.318	186.81	186.52	5236.44	3319.01
Relays with 4 IB backhaul SFpF	Backhaul A	24.916	20.297	3.389	8.280	28.305	28.577	157.48	143.25	5498.78	3784.10
	Backhaul B	24.868	20.179	5.192	12.139	30.060	32.317	160.30	154.11	8654.33	5544.48
	Backhaul C	24.864	20.170	5.287	12.514	30.151	32.684	159.49	151.02	8856.32	5685.44
	Backhaul D	24.843	20.126	6.149	14.561	30.991	34.686	161.60	150.28	10447.5	6646.07
Relays with 8 IB backhaul SFpF	Backhaul A	21.673	14.374	4.677	11.496	26.349	25.870	110.86	100.16	8064.42	5460.47
	Backhaul B	21.630	14.279	6.859	16.728	28.489	31.007	112.49	99.22	12372.1	7937.08
	Backhaul C	21.628	14.276	6.906	16.959	28.534	31.235	112.12	99.59	12442.7	8046.53
	Backhaul D	21.614	14.238	7.653	19.322	29.267	33.560	111.70	99.08	14186.9	9183.99



CDF of SINR



CDF of Spectral Utilization

Observations on DL System Performance (1)

- **Large gains in sector throughput and 5th percentile throughput are realized with OOB backhaul, particularly with a large number of RNs**
  - ~176% in DS Case 1 and ~150% in DS Case 3 with 228 RNs
- **Generally, performance with IB backhaul is in the order Backhaul D > Backhaul C > Backhaul B > Backhaul A**
  - Non-optimized relay-site planning with directional antenna is superior to optimized relay-site planning and omnidirectional antenna
- **Performance with even the best IB backhaul model (Backhaul D) is greatly inferior to OOB backhaul**
  - Backhaul link is the bottleneck that limits throughput gains in relay cells
  - Large backhaul capacity is required to meet relay-cell capacity requirements
  - Backhaul capacity comes at the expense of donor macro-cell capacity

Observations on DL System Performance (2)

- **Moderate sector throughput performance gains (peak gain of ~15% with 228 RNs) are observed in DS Case 3**
  - Gains realized because backhaul-constrained relay throughput in sector outweighs loss of donor macro-cell throughput due to backhaul allocation
  - Higher interference in DS Case 1 on backhaul and access links leads to poorer performance and only small gains (peak gain of ~5% with 228 RNs)

- **Drop in 5th percentile throughput experienced in DS Case 1**
  - Due to increased macro-cell-edge interference and backhaul limitation
  - Some gains are observed in DS Case 3 when adequate capacity is available to macro-cell UEs

- **Number of backhaul SFpF required for peak sector throughput performance may be different than that required for peak 5th percentile throughput performance**
  - Increasing backhaul capacity may improve sector throughput but reduces capacity available to donor-macro-cell UEs, including edge UEs

Challenge: Improvement of Backhaul Link Quality

- **It is important to have good in-band backhaul link quality to realize meaningful performance benefits of relays**
  - Poor backhaul links become bottlenecks
  - Backhaul link SE should be at least 5 bps/Hz for good relay performance
- **Relays are most beneficial in locations with poor link quality**
  - Backhaul link quality is also likely to be poor
- **Poor cell-edge performance with smaller cells**
  - SINR degradation at cell edges
- **Performance with out-of-band backhaul is good under "ideal" conditions**
  - Same challenges as for in-band backhaul
  - Additional spectrum is required
- **Need techniques to improve backhaul link and cell-edge performance**
  - Directional antennas alone are not sufficient
  - Interference coordination and mitigation techniques are desirable

Overview of 802.16m

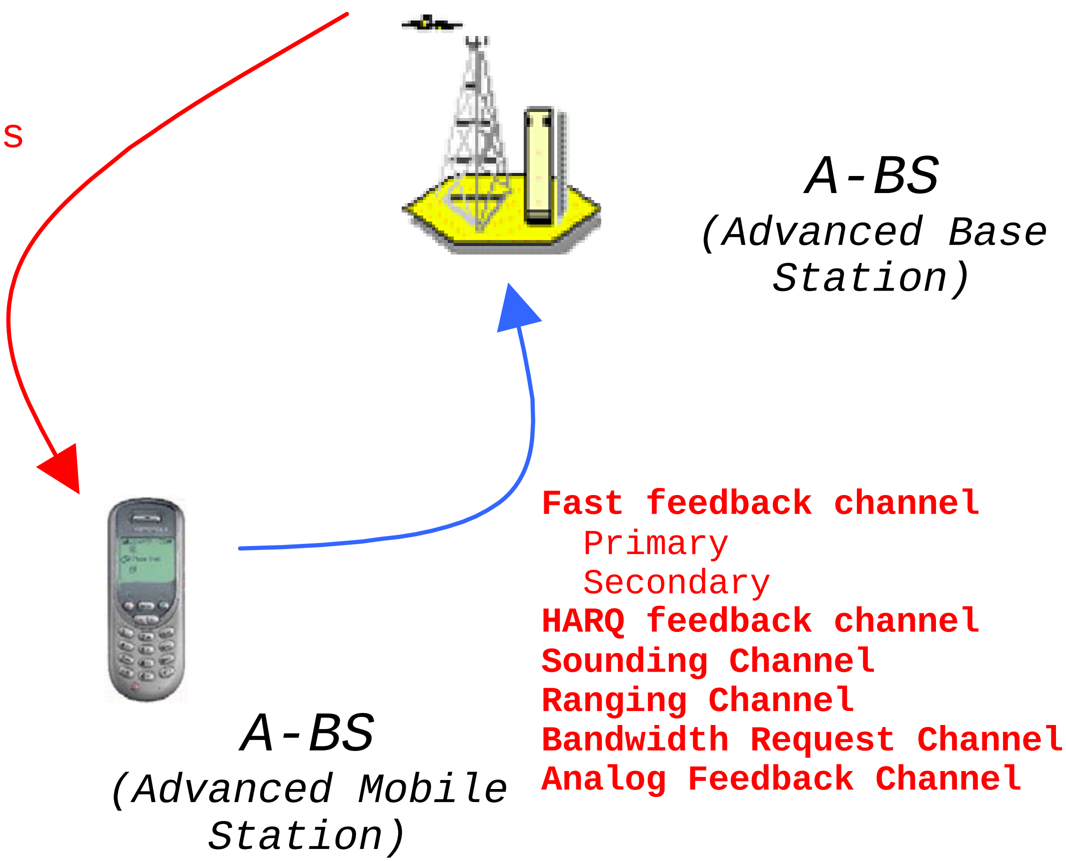
802.16m Physical Channels

PRU
Physical Resource Units

SFH
Super-Frame Header

A-Preamble
Advanced Preamble

A-MAP
Advanced MAP



Fast feedback channel
- Primary
- Secondary

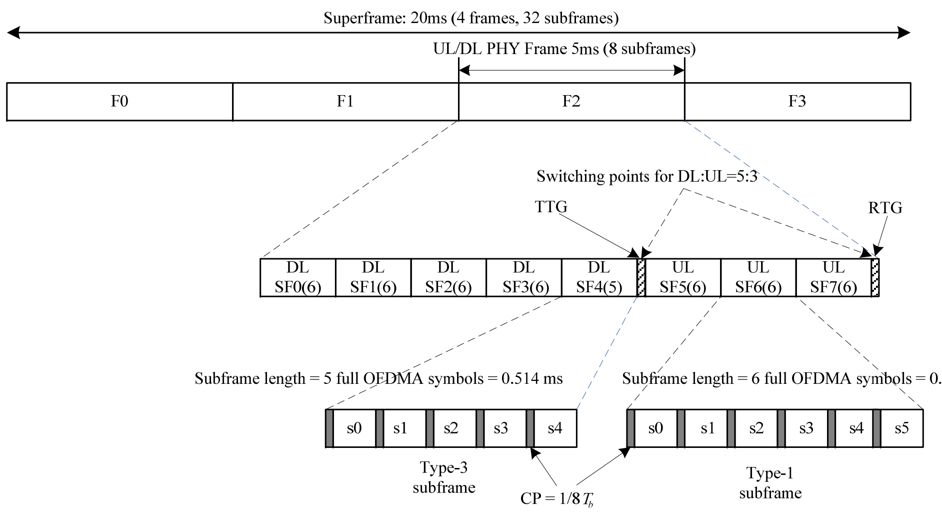
HARQ feedback channel
Sounding Channel
Ranging Channel
Bandwidth Request Channel
Analog Feedback Channel

The Benefits of IEEE 802.16m

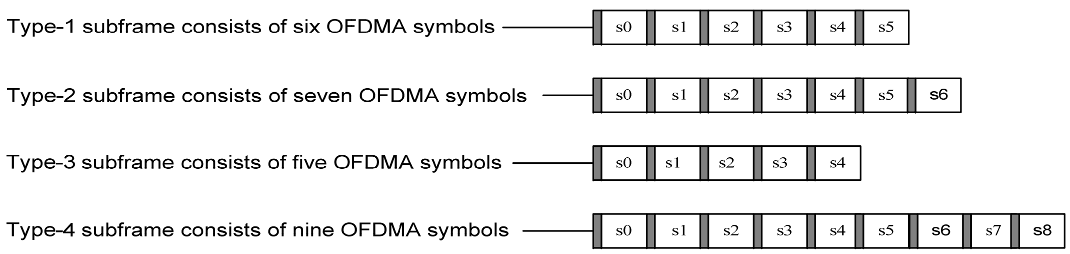
- **Low-cost evolution from 802.16e emphasizing backwards compatibility**
  - Necessary and achievable goal having minimal impact on the system performance
    - **Over 90% of the time-frequency resources available for advanced design**
  - May be disabled for “green field” deployments
- **Improved spectral efficiency (at least 50% improvement over 16e)**
  - Improved multi-antenna technologies
    - **New pilot structures and permutations allow for more efficient implementation**
  - Link adaptation enhancements for improved MCS selection
  - Incremental redundancy optimized for frequency selective operation
  - Interference coordination for improved SNR
- **Improved control channel performance**
  - Allows improved cell-edge coverage and extended range
  - Overhead reduced with respect to legacy 16e constructs
  - VoIP capacity improvement
- **Improved latency**
  - HARQ retransmission with 5 ms
- **Optimized handover**
  - Reduced interruption times
  - Improved reliability
- **More efficient paging**
  - Hierarchical paging to reduced paging load
  - Cascaded paging to maintain low-latency
- **Increased operational bandwidths**
  - Hybrid multi-carrier operation allows backwards compatibility with 16e technology while providing efficient IMT-Advanced performance
- **Native femto cell support**
  - New pre-ambles that identify femto cells
- **Security/Enhanced privacy**

802.16m Frame Structure & Bandwidths

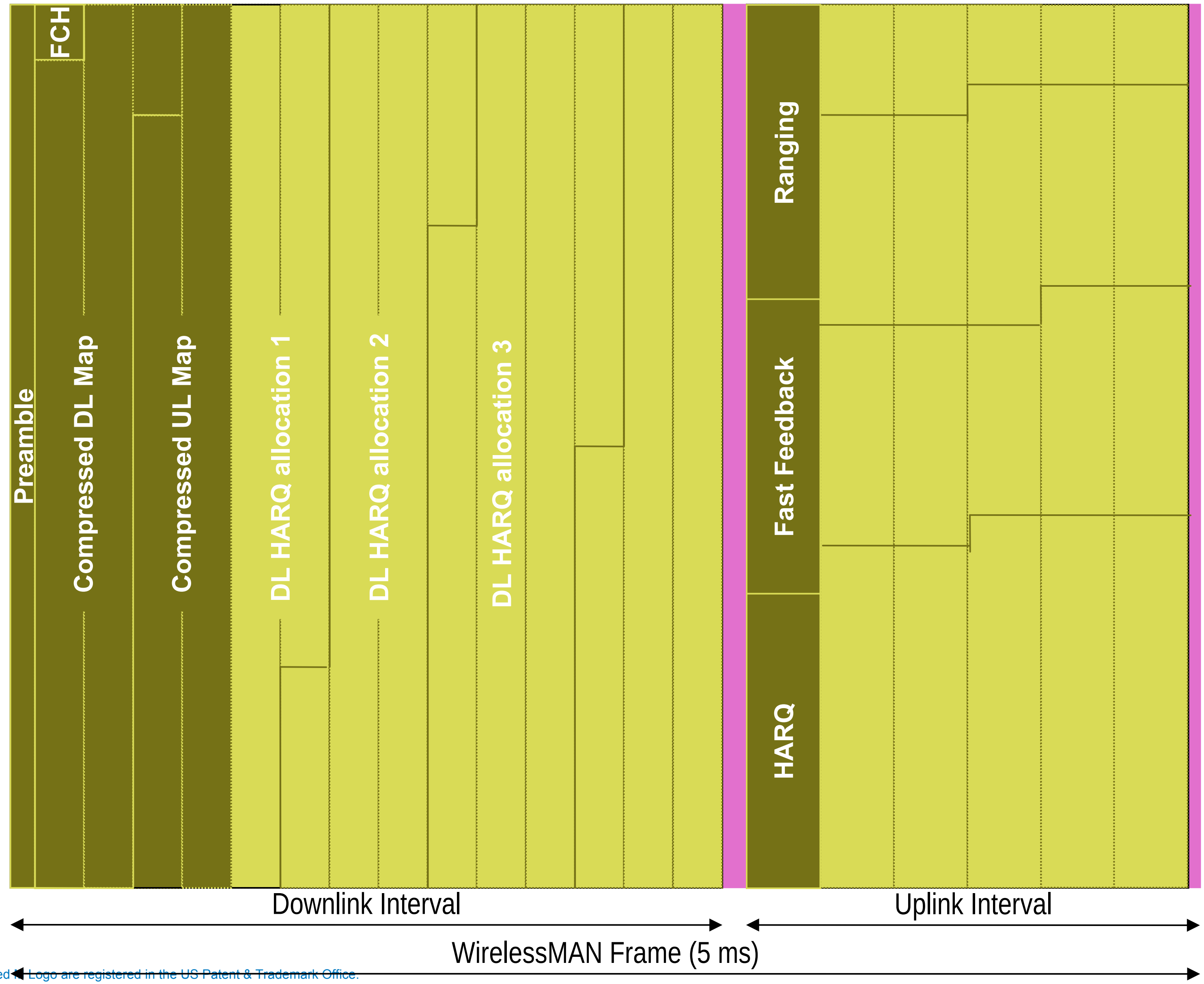
- **Supports same OFDM parameter as WiMAX R1.0**
  - 1/8 Tu prefix as in 16e
  - OFDM multiple access scheme for both DL and UL
- **20 ms Super-Frame Structure**
  - Groups four 16e frames to form a super-frame
  - System acquisition opportunities every super-frame
- **0.617 ms Sub-Frame Structure**
  - 8 sub-frames per 16e frame
  - LTE-like structure
  - Grouping of 6 OFDMA symbols
- **PRU (18 subcarriers) based resource blocks**



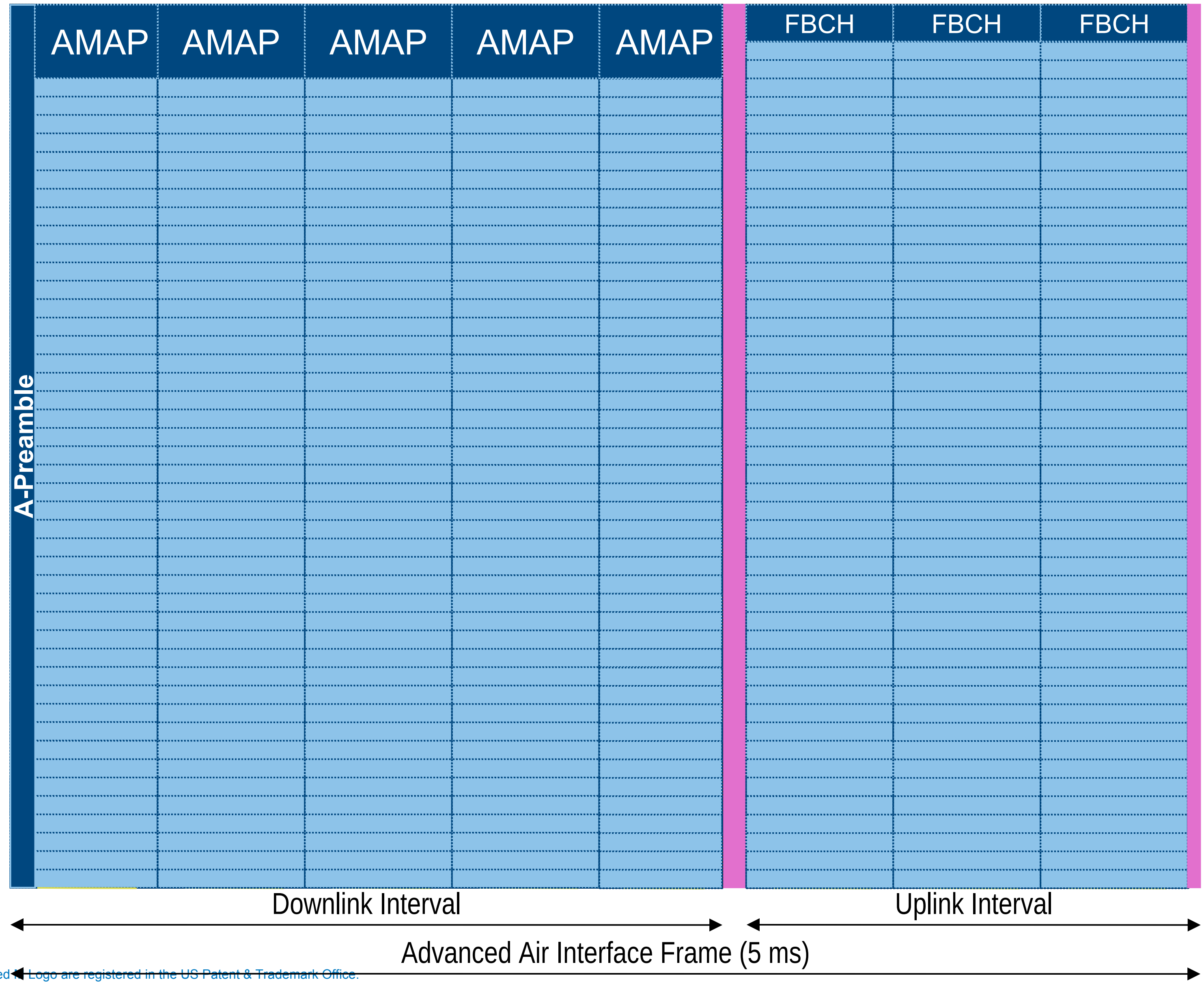
Frame structure with Type-1 and Type-3 subframes in TDD mode for 5, 10, and 20 MHz channel bandwidths (CP=1/8 T_b)



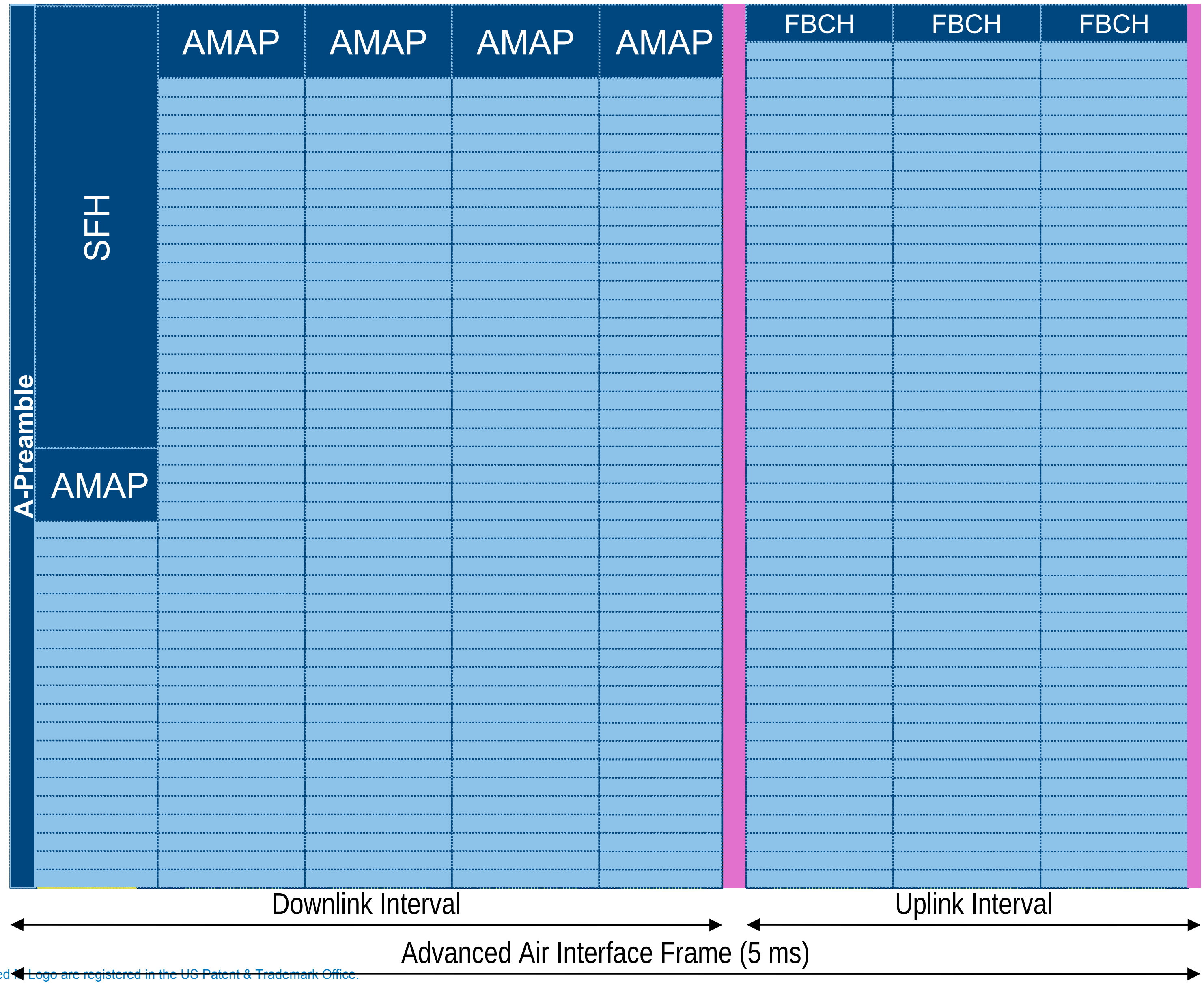
IEEE 802.16e Frame



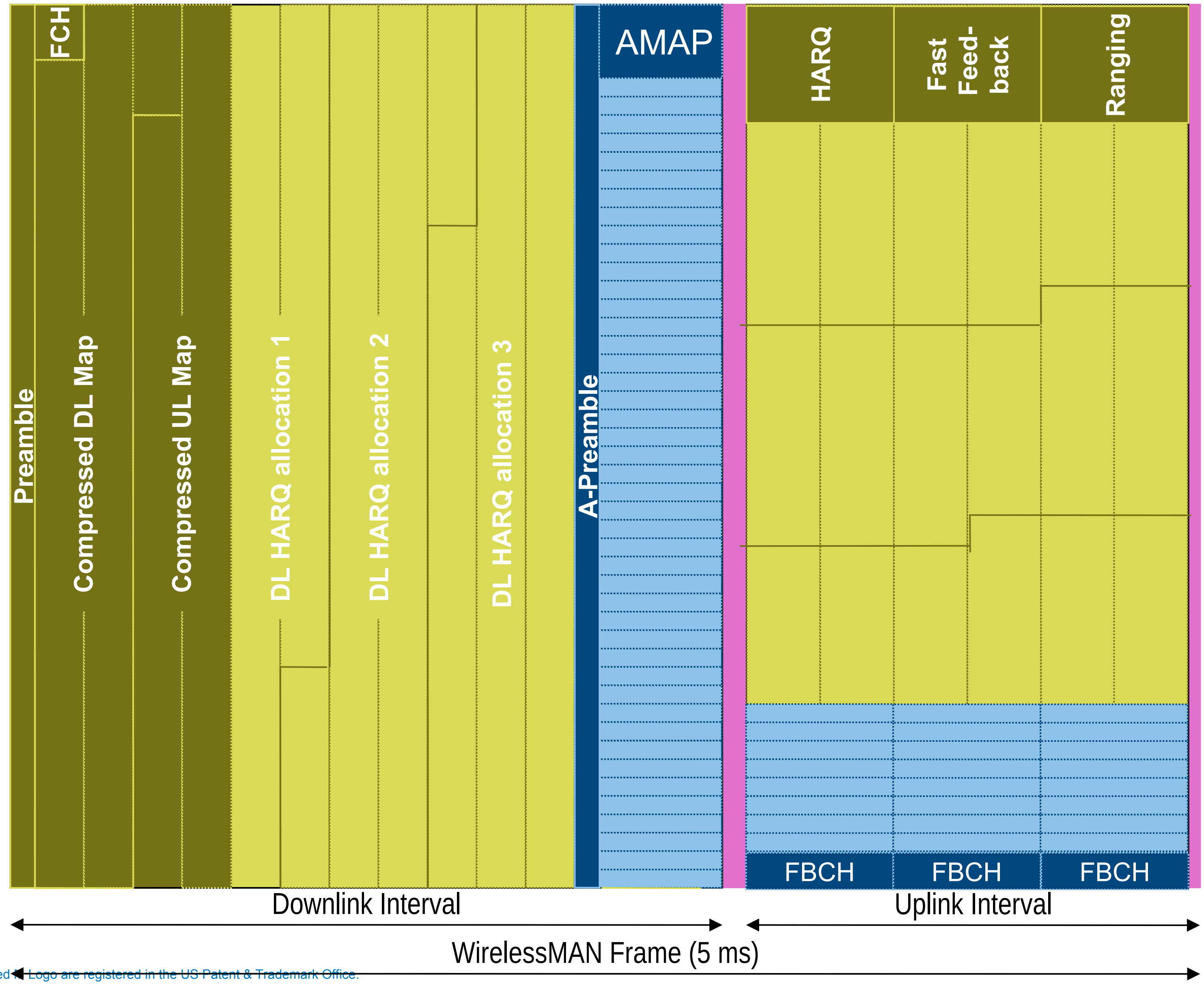
IEEE 802.16m Frame



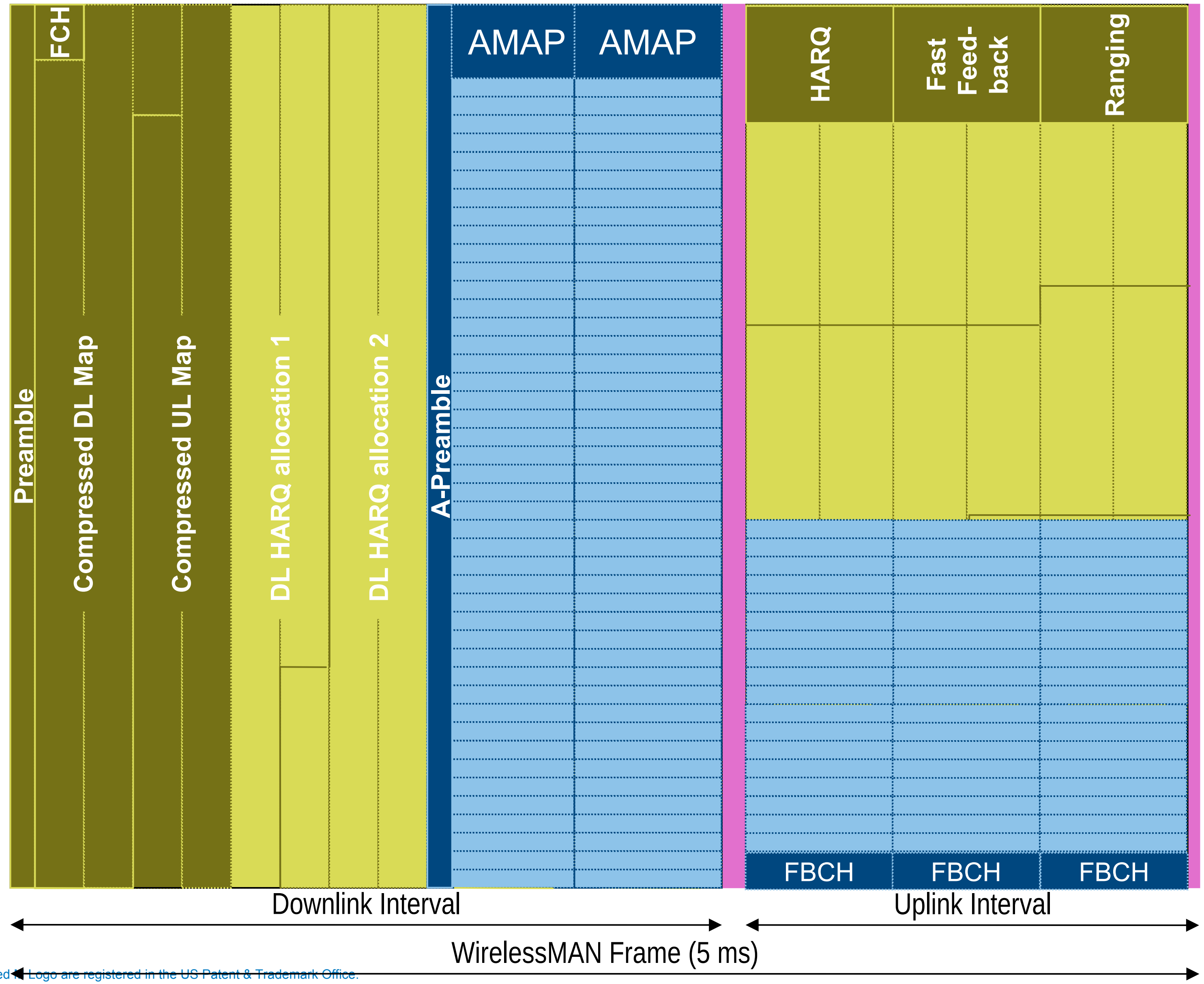
IEEE 802.16m Frame with SFH (like DCD)



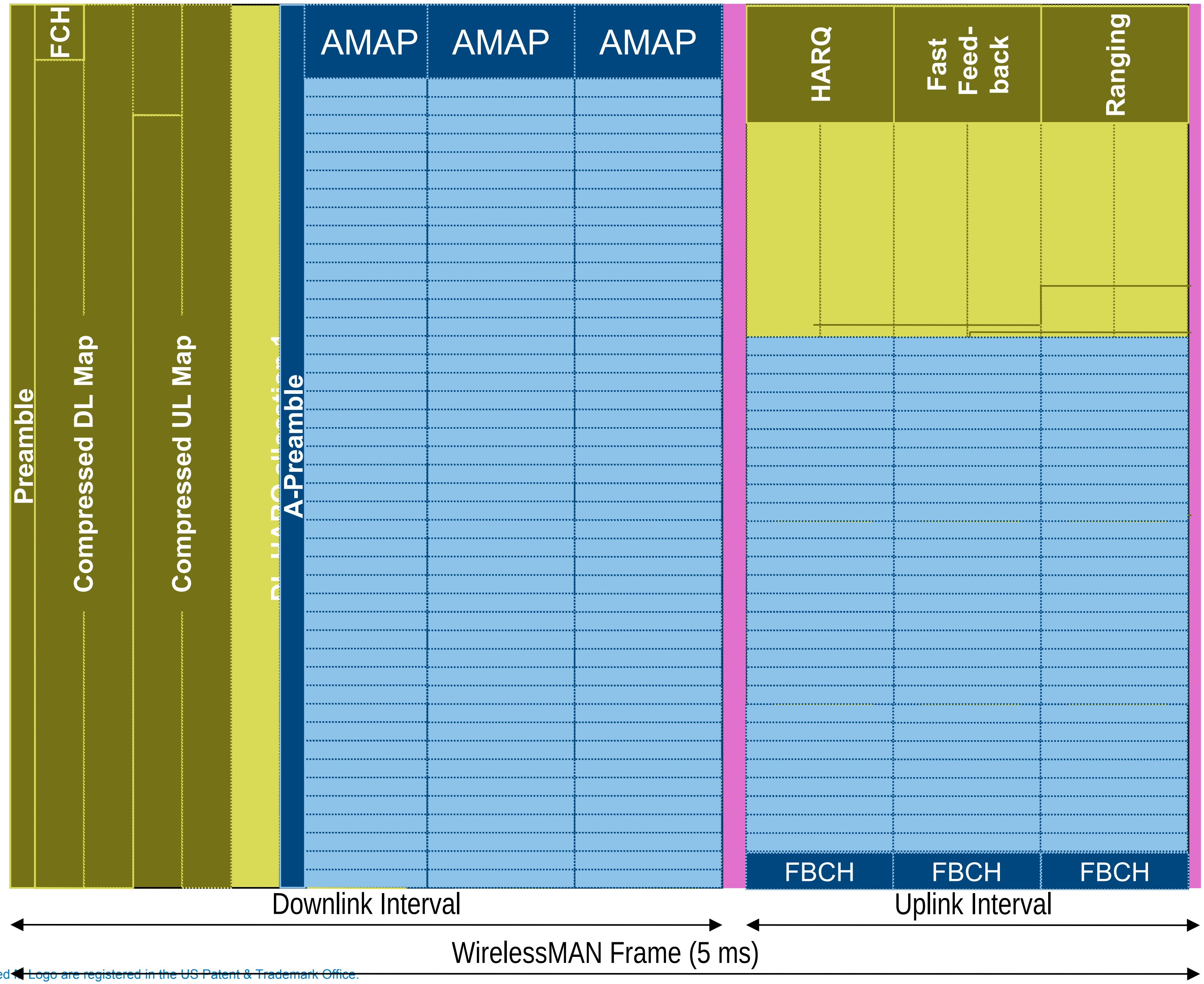
Mixed Mode (one 16m subframe)



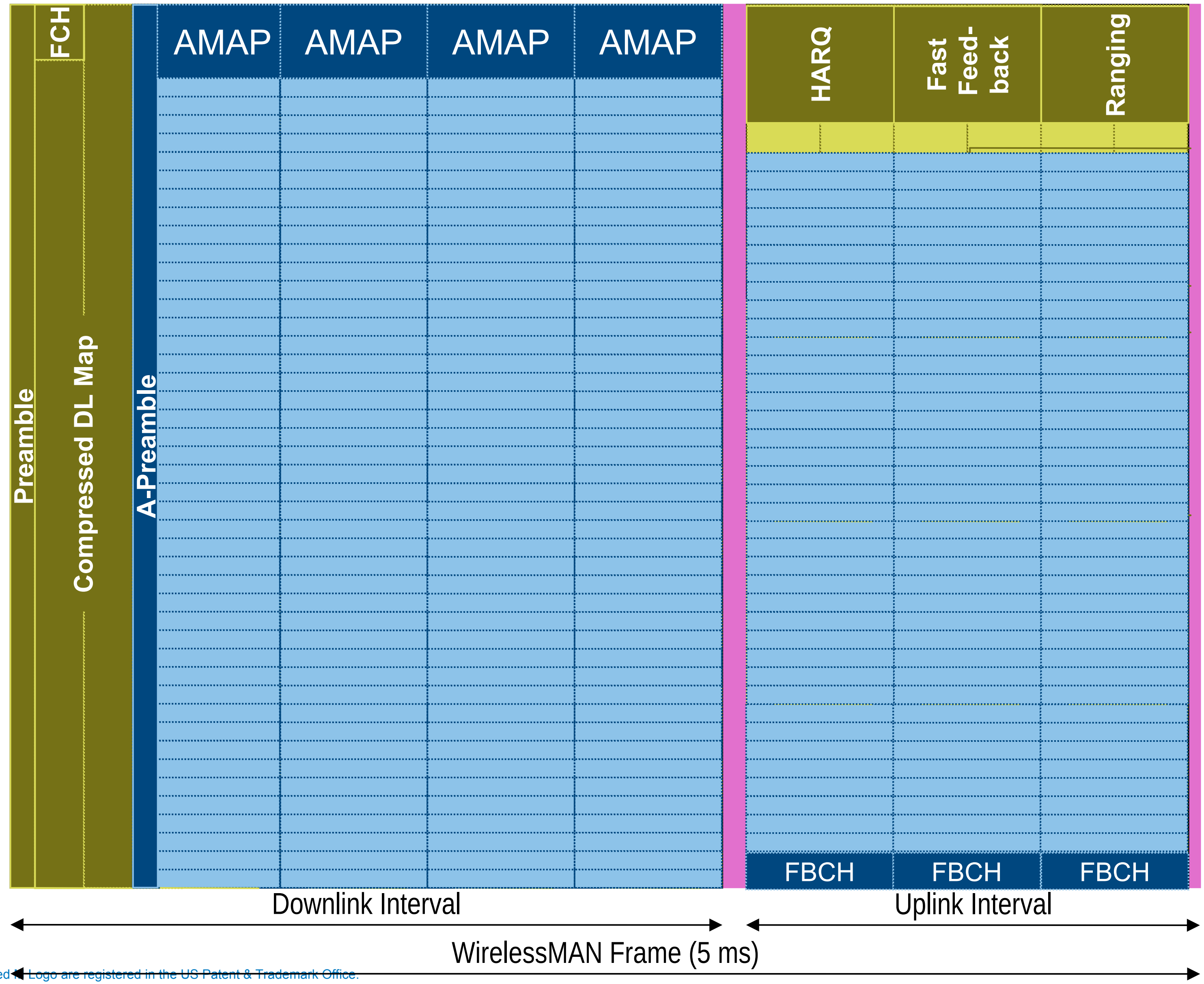
Mixed Mode (two 16m subframes)



Mixed Mode (three 16m subframes)

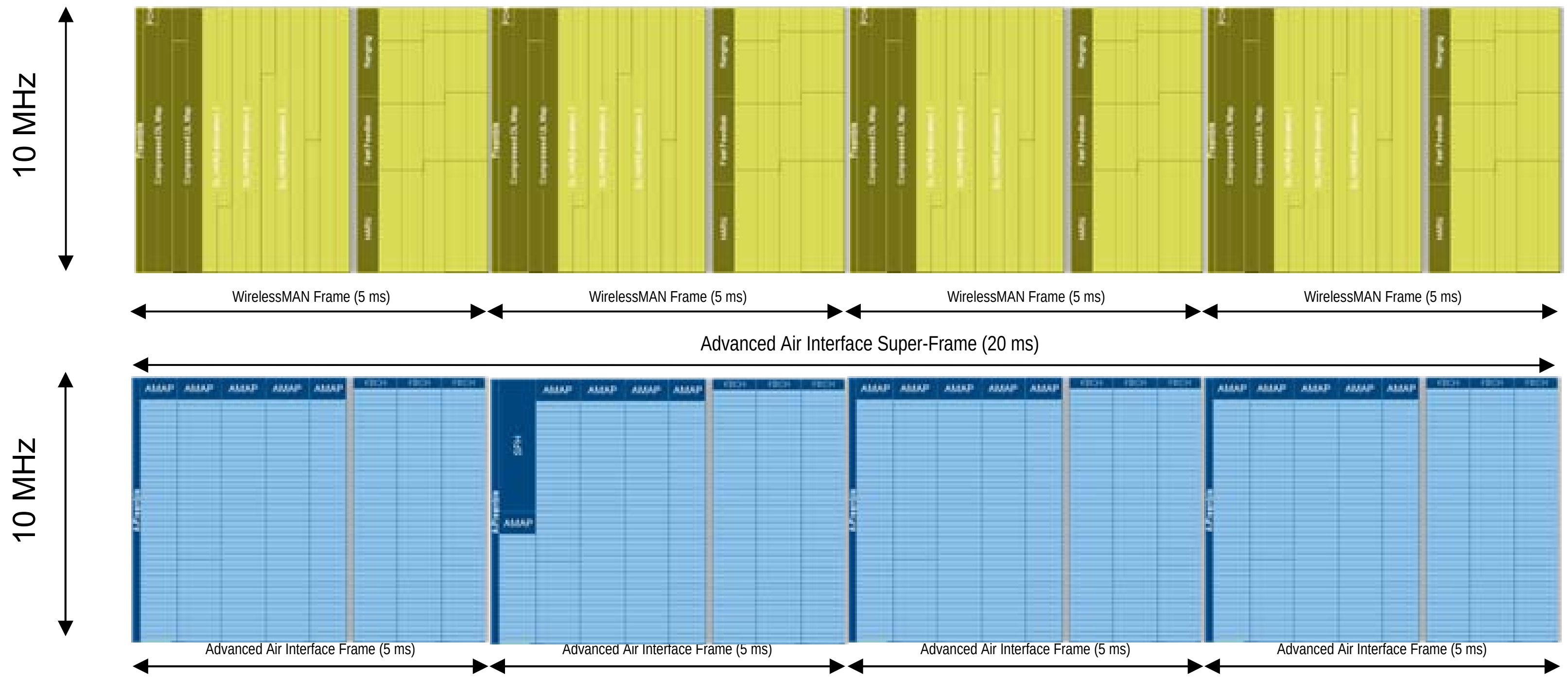


Mixed Mode (four 16m subframes)



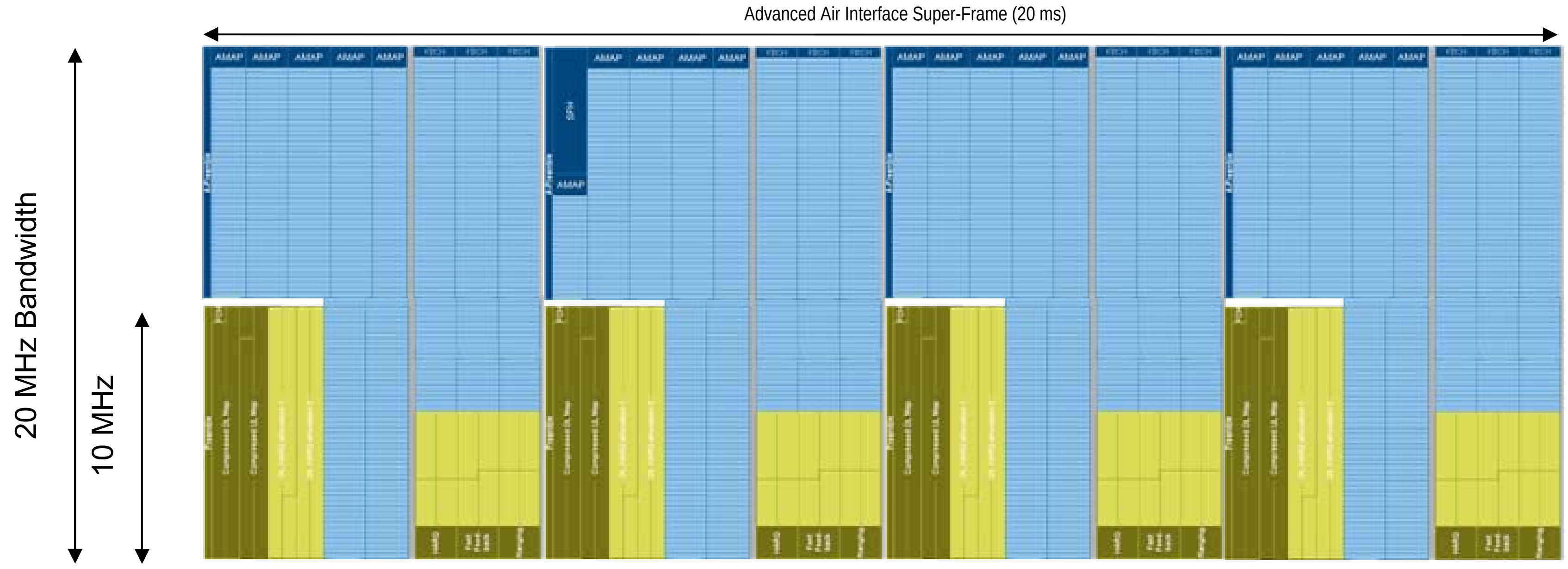
Globecom 2009

Super-Frame Structure
Co-existence in adjacent cells (and/or carriers)



- **Identical uplink and interval desirable for co-existence**
  - No base to mobile interference
- **Common numerology enables seamless co-existence**

Multicarrier Coexistence
20 MHz 16m Frame with 10 MHz 16e Frame



- **Similar to LTE-Advanced IEEE 802.16m supports Multicarrier**
  - Competition between 16m and LTE may force 20 MHz carriers
  - Maximum 16e bandwidth of 10 MHz requires creative solutions

802.16m vs. LTE Rel-8

Features	LTE Rel-8	802.16m
Multiple Access Scheme	DL: OFDMA, UL: SC-OFDMA	DL:OFDMA, UL: OFDMA
Basi...	...KHz sub-carrier spacing, 14 ...: 12subx7symb	0.617ms subframes, 11 KHz sub-carrier spacing, 6 sym/subframes, PRU: 18subx6symb
	...ed pilots	FDM, common and dedicated pilots
DL...	...dedicated control channel	FDM/TDM hierarchical structure, Per user dedicated control channel
DL MIMO Schemes	Open loop and Closed Loop Spatial Multipl... MIMO, RS based Beamfor...	...losed Loop Spatial Multiplexing, MU- ...Beamforming
Number of codewords, CQI and A/N for DL	2 codewords, per stream...	...I and A/N
Cell Search	Two step cell search proce... SCH	...edure using PA-Preamble and ...equence length and type different ...rom LTE
DL Sub-channelization	Locali...	...istributed, Additional FFR zone
UL Pilot Structu...		
UL Powe...		...ontrol
UL MI...		
UL Cont...		...er
HARQ		
Backward Compatibility		...2.16e subframes, ...DM/FDM multiplexing of WiMAX and 802.16m

DL MU-MIMO provide a capacity gain for 4 Tx x 2 Rx configurations. 16m & LTE Rel 10 provide this gain

Difference in sub-frame and symbol timing complicate co-existence and preclude concurrent operation between LTE and .16e

Similar PHY layer features sets for LTE Rel-8 and 802.16m provide similar performance for 2 Tx x 2 Rx system configurations

Comparable DL MIMO Modes in LTE R8 and 802.16m

MIMO Technology	IEEE 802.16m	LTE R8
SISO / SIMO	**No Explicit SISO / SIMO Mode [Minimum number of BS TX antennas is 2]**	TX Mode 1
Open Loop TX Diversity	MIMO Mode 0 **[SFBC w/ RP]** MIMO Mode 5 **[CDR]**	TX Mode 2 **[SFBC w/ FSTD]**
Open Loop SU-MIMO	MIMO Mode 1 **[Rank 1 & SM w/ RP]**	TX Mode 3 **[SM w/large delay CDD]**
Closed-Loop SU-MIMO [Codebook-based]	MIMO Mode 2 **[Rank 1 & SM w/AP]**	TX Mode 4, 6 **[Rank 1 and SM]**
Closed-Loop SU-MIMO [UL Sounding-based]	MIMO Mode 2 **[Rank 1 & SM w/AP]**	TX Mode 7 **[UE Specific BF (Rank 1 only)]**
Closed-Loop MU-MIMO	MIMO Mode 4 **[codebook & sounding-based]**	TX Mode 5 **[codebook-based only]**
Open-Loop MU-MIMO	MIMO Mode 3 **[Fixed precoding]**	**No equivalent version**

SFBC = Space-Frequency Block Coding

SM = Spatial Multiplexing (Rank>1)

CDD = Cyclic Delay Diversity

AP = Adaptive Precoding

RP = Random (non-adaptive) Precoding

BF = Beamforming

CDR = Conjugate Data Repetition

FSTD = Frequency Shift Transmit Diversity

Wireless Broadband Performance Comparison

Wireless Broadband Performance Comparison

Parameter		WiMAX (1x3x1)	WiMAX (1x3x3)	802.16m (1x3x1)	802.16m (1x3x3)	LTE (Rel-8) (1x3x1)	LTE (Rel-8) (1x3x3)	LTE-A (Rel-10) (1x3x1)	LTE-A (Rel-10) (1x3x3)
Spectrum usage (MHz)		10 T… c…	3 x 10	10	3x10 TDD …40 DL/UL	10 TDD Conf-1	3x10 TDD Conf-1	10 TDD Conf-1	3x10 TDD Conf-1
Access Technology					…DMA	DL…			DL: OFDMA …L: SC-FDMA
Antenna Configuration (Tx/Rx)	DL	2x2	2…	2x2	2x2				2x2
	UL	1x2	1x2	1x2	1x2	1x2			1x2
DL Peak Rate (Mbps) (Sustained)		32	32	44	44	41.8	41.8	41.8	41.8
DL Sector Throughput (Mbps)		5.8	15.3	-	-	9.5	20.2	9.5	20.2
DL 5% Throughput (Mbps)		0.11	0.39			0.244	0.597	0.244	0.597
DL SE (bps/Hz/Sector)		1.0	0.85			1.67	1.18	1.67	1.18
DL 5% SE (bps/Hz/Sector)		0.018	0.021			0.0427	0.034	0.0427	0.034
UL Peak Rate (Mbps) (Sustained)		5	5	26	26	14.6	14.6	29.2	29.2
UL Sector Throughput (Mbps)		1.5	3.3			3	4.8	3	4.8
UL Spectral Efficiency (bps/Hz/Sector)		0.39	0.29			0.76	0.41	0.76	0.41

IEEE 802.16m will boost WiMAX performance making it comparable to LTE Rel 8 for a 2x2 configuration

Performance is similar with a 2x2 configuration for LTE and LTE-A

3x

2x

IEEE 802.16m 1x3x1 will be 50% more spectrally efficient than 1x3x3 (similar to LTE)

Assumptions: NGMN Case-1, Full Buffer, 500m inter-site distance, 3km/hr, MMSE receivers, 20 dB penetration loss

Summary

- **Both LTE and WiMAX has an evolution path**
  - LTE Rel-8, Rel-9 and Rel-10
  - WiMAX 1.x, 802.16m, 802.16m+
- **802.16m features similar to LTE Rel-8**
- **LTE Rel-8 UL and DL generally meets the IMT-A requirements**
  - Except for 2 DL scenarios
  - Un-coordinated MU-MIMO required to meet the DL IMT-A targets
  - 802.16m also meets IMT-A requirements