SPE-T 2009

Advanced Radio Communications

3GPP Long-Term Evolution

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Mobile Standard Evolution

- *International Mobile Telecommunications (IMT)-2000 introduced global standard for 3G.*
- *Systems beyond IMT-2000 (IMT-Advanced) is set to introduce evolutionary path beyond 3G.*
  - *Mobile class targets 100 Mbps with high mobility and nomadic/local area class targets 1 Gbps with low mobility.*
- *3GPP and 3GPP2 are currently developing evolutionary/revolutionary systems beyond 3G.*
  - *3GPP Long Term Evolution (LTE)*
  - *3GPP2 Ultra Mobile Broadband (UMB)*
- *IEEE 802.16-based WiMAX is also evolving towards 4G through 802.16m.*

3GPP Evolution

- *Release 99 (Mar. 2000): UMTS/WCDMA*
- *Rel-5 (Mar. 2002): HSDPA*
- *Rel-6 (Mar. 2005): HSUPA*
- *Rel-7 (2007): DL MIMO, IMS (IP Multimedia Subsystem), optimized real-time services (VoIP, gaming, push-to-talk).*
- *Long Term Evolution (LTE)*
  - *3GPP work on the Evolution of the 3G Mobile System started in November 2004.*
  - *Standardized in the form of Rel-8.*
  - *Spec finalized and approved in January 2008.*
  - *Target deployment in 2010.*
  - *LTE-Advanced study phase in progress.*

LTE Requirements

- *Peak data rate*
  - *100 Mbps DL/ 50 Mbps UL within 20 MHz bandwidth.*
- *Up to 200 active users in a cell (5 MHz)*
- *Less than 5 ms user-plane latency*
- *Mobility*
  - *Optimized for 0 ~ 15 km/h.*
  - *15 ~ 120 km/h supported with high performance.*
  - *Supported up to 350 km/h or even up to 500 km/h.*
- *Enhanced multimedia broadcast multicast service (E-MBMS)*
- *Spectrum flexibility: 1.25 ~ 20 MHz*
- *Enhanced support for end-to-end QoS*

Key technologies

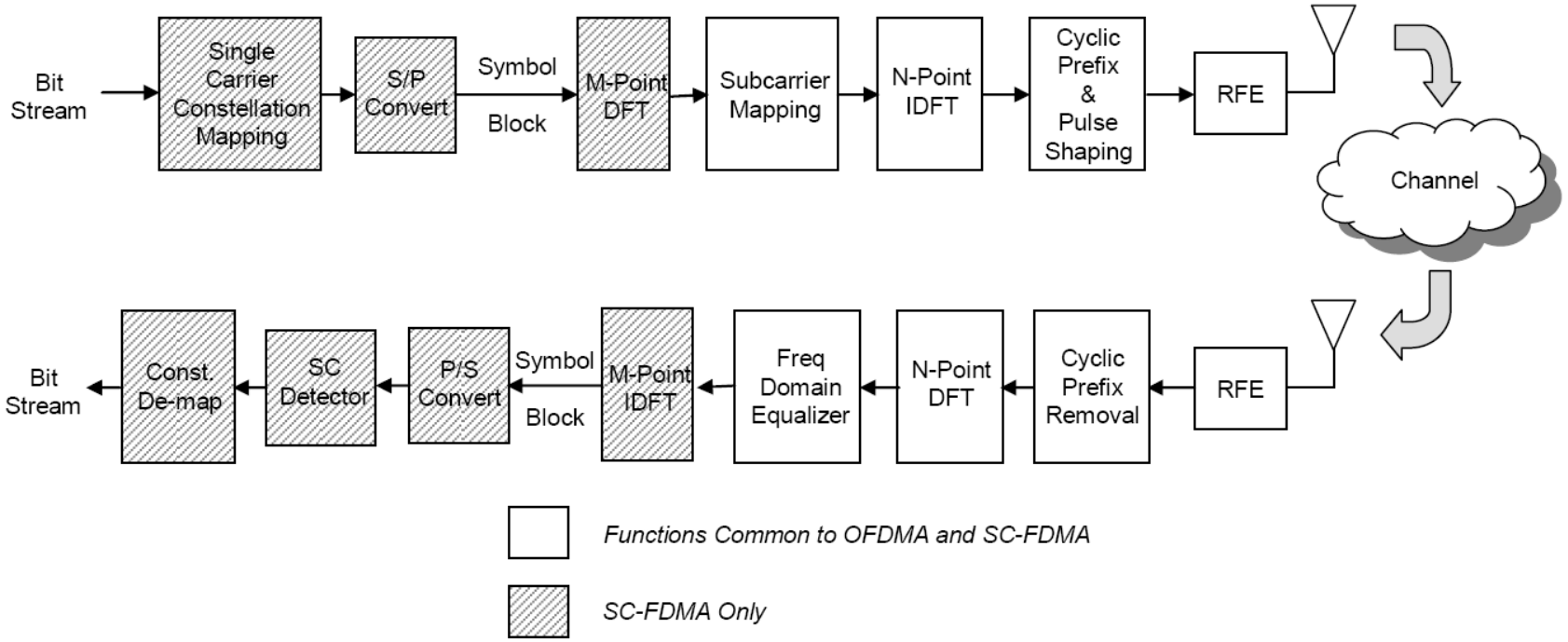
- *OFDM (Orthogonal Frequency Division Multiplexing)*
- *Frequency domain equalization*
- *SC-FDMA (Single Carrier FDMA)*
- *MIMO (Multi-Input Multi-Output)*
- *Multicarrier channel-dependent resource scheduling*
- *Fractional frequency reuse*

source: Technical Overview of 3GPPLTE, HyungG.Myung

Key features

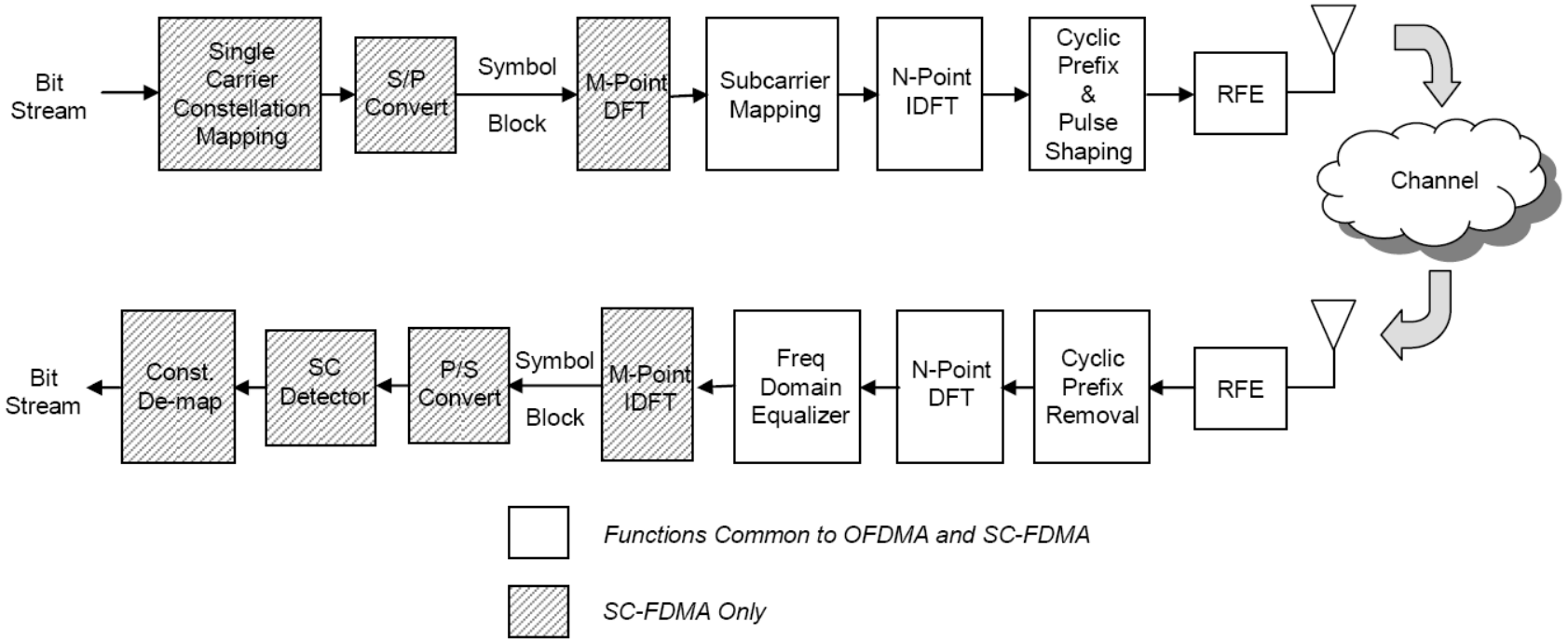
- *Single Carrier FDMA (SC-FDMA)*
  - *SC-FDMA is a new single carrier multiple access technique which has similar structure and performance to OFDMA. (Utilizes single carrier modulation and orthogonal frequency multiplexing using DFT-spreading in the transmitter and frequency domain equalization in the receiver).*
  - *A salient advantage of SC-FDMA over OFDM/OFDMA is low PAPR (Efficient transmitter and improved cell-edge performance).*
- *Multiple access scheme*
  - *DL: OFDMA with CP.*
  - *UL: Single Carrier FDMA (SC-FDMA) with CP.*
- *Adaptive modulation and coding*
  - *DL/UL modulations: QPSK, 16QAM, and 64QAM*
  - *Convolutional code and Rel-6 turbo code*
- *Advanced MIMO spatial multiplexing techniques*
  - *(2 or 4)x(2 or 4) downlink and uplink supported.*
  - *Multi-user MIMO also supported.*
- *Support for both FDD and TDD*
- *H-ARQ, mobility support, rate control, security, and etc.*

SC-FDMA



*1. **Constellation mapper**: Converts incoming bit stream to single carrier symbols (BPSK, QPSK, or 16QAM depending on channel conditions)*
*2. **Serial/parallel converter**: Formats time domain SC symbols into blocks for input to FFT*
*3. **M-point DFT**: Converts time domain SC symbol block into M discrete tones*
*4. **Subcarrier mapping**: Maps DFT output tones to specified subcarriers for transmission. SC-FDMA systems either use contiguous tones (localized) or uniformly spaced tones (distributed). The current working assumption in LTE is that localized subcarrier mapping will be used.*

SC-FDMA

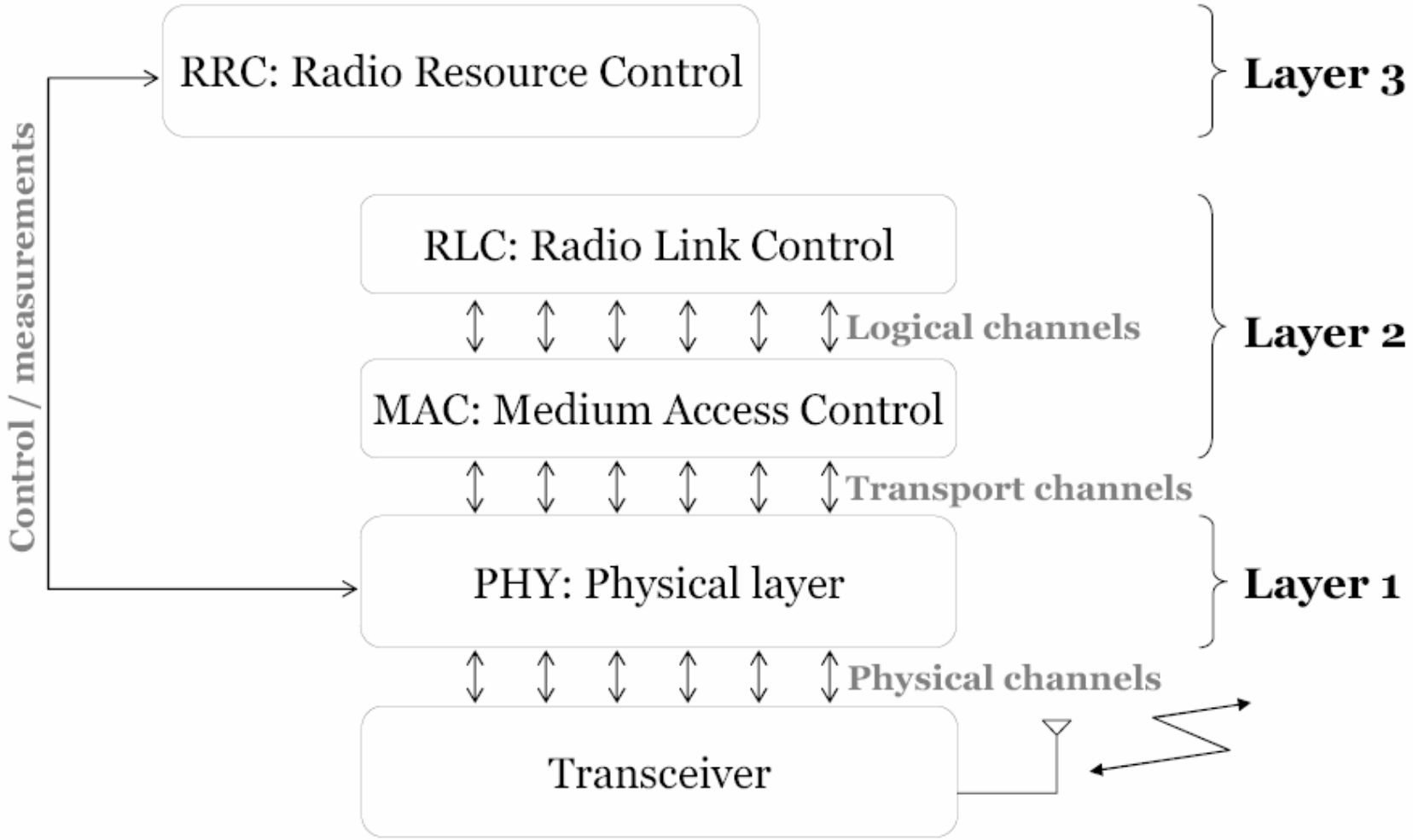


*5. **N-point IDFT**: Converts mapped subcarriers back into time domain for transmission*

*6. **Cyclic prefix and pulse shaping**: Cyclic prefix is pre-pended to the composite SC-FDMA symbol to provide multipath immunity in the same manner as described for OFDM. As in the case of OFDM, pulse shaping is employed to prevent spectral regrowth.*

*7. **RFE:** Converts digital signal to analog and upconvert to RF for transmission*

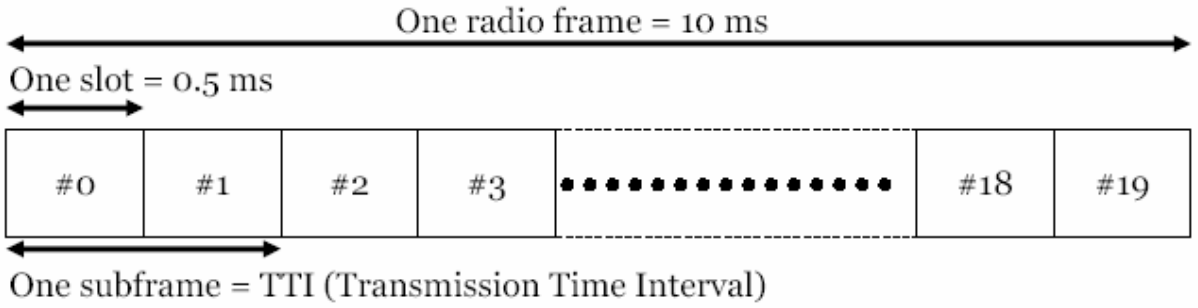
Protocole Architecture



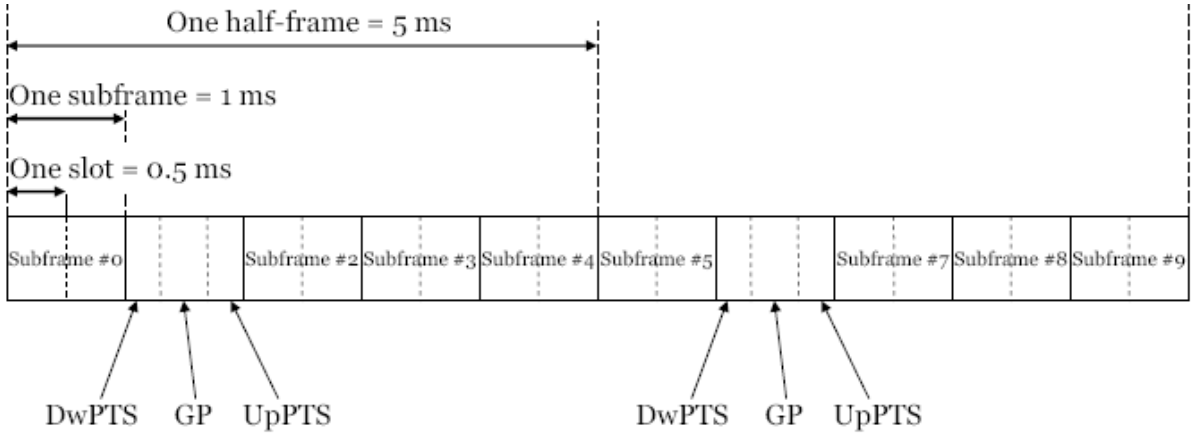
Frame Structure

- *Two radio frame structures defined.*
  - *Frame structure type 1 (FS1): FDD.*
  - *Frame structure type 2 (FS2): TDD.*
- *A radio frame has duration of 10 ms.*
- *A resource block (RB) spans 12 subcarriers over a slot duration of 0.5 ms. One subcarrier has bandwidth of 15 kHz, thus 180 kHz per RB.*

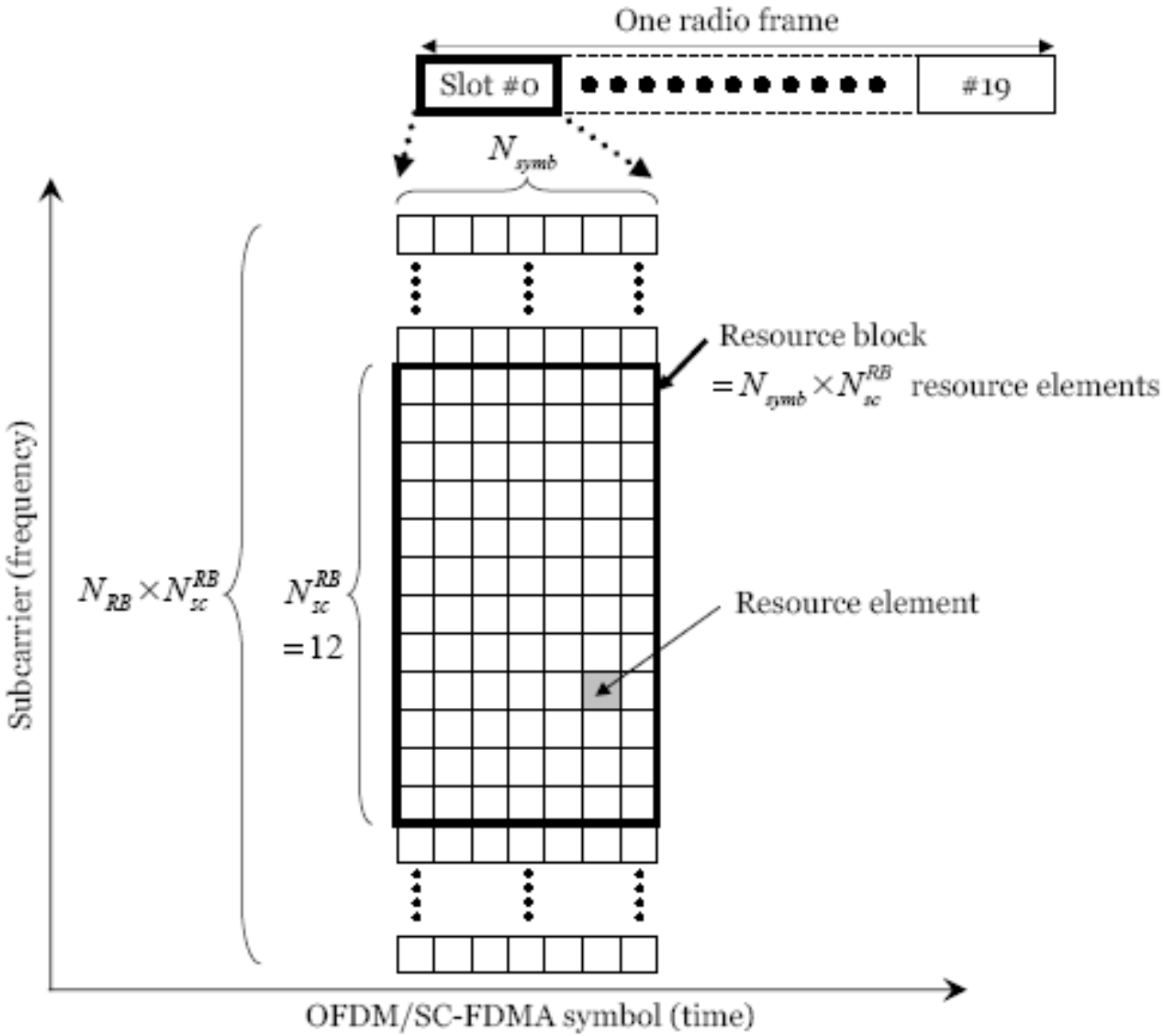
FDD Frame



TDD Frame



Resource Grid

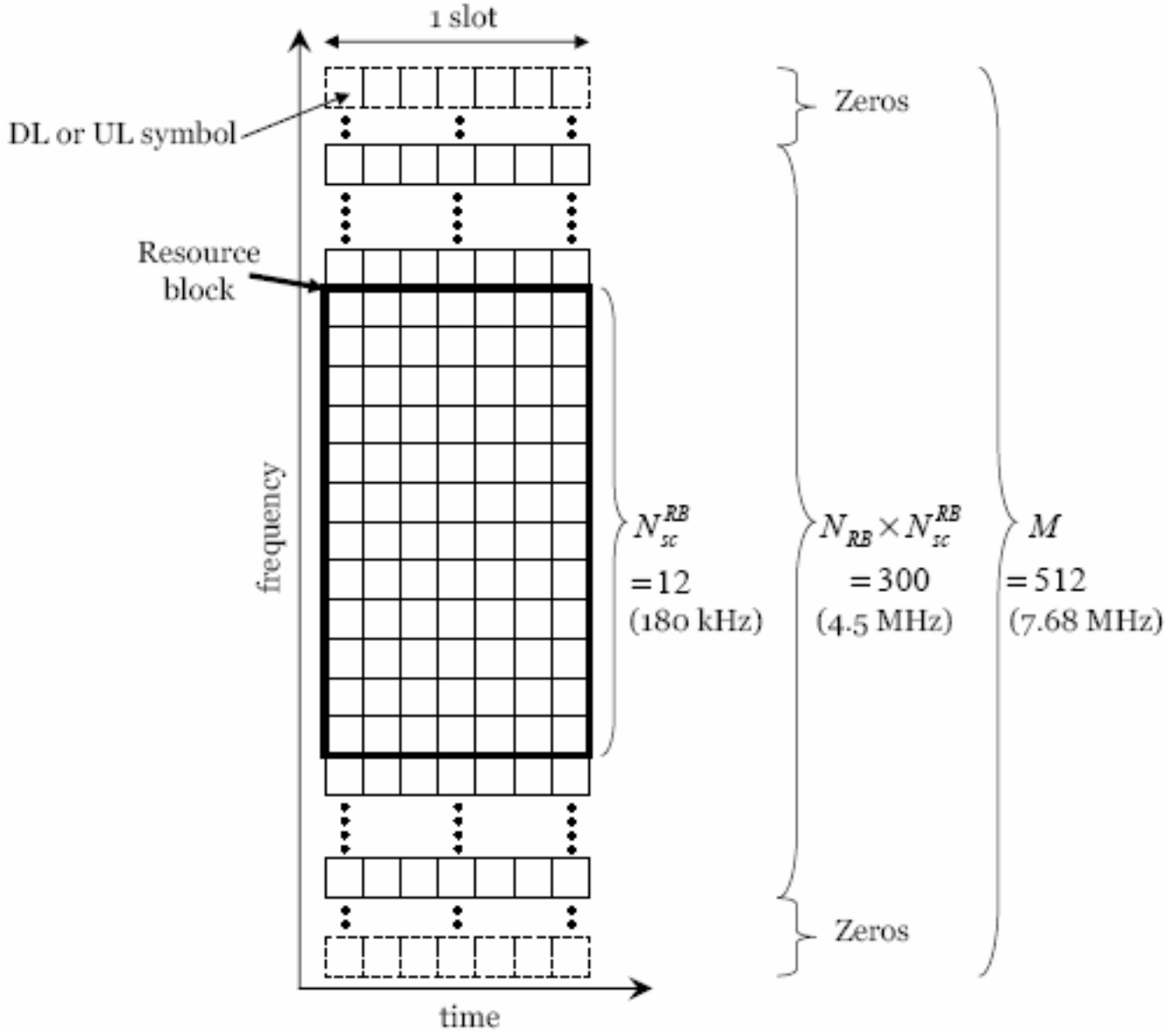


Some Values

Configuration	N_{symb}
Normal CP	7
Extended CP	6
Extended CP (Δf = 7.5 kHz)†	3

Channel bandwidth [MHz]	1.4	3	5	10	15	20
Number of resource blocks (N_{RB})	6	15	25	50	75	100
Number of occupied subcarriers	72	180	300	600	900	1200
IDFT(Tx)/DFT(Rx) size	128	256	512	1024	1536	2048
Sample rate [MHz]	1.92	3.84	7.68	15.36	23.04	30.72
Samples per slot	960	1920	3840	7680	11520	15360

Bandwidth Management



LTE-WiMAX comparison

source WiMAX Forum

LTE versus WiMAX

- *HSPA+: Next step in 3GPP Migration Path*
- *Mobile WiMAX Rel 1.5 and HSPA+*
- *3GPP Long Term Evolution (LTE)*
- *LTE Peak User Performance & Mobile WiMAX Rel 1.5*
- *Mobile WiMAX Rel 2.0*
- *Timeline Comparison*
- *Migration Path Options for Today's Mobile Operators*
- *Summary and Conclusion*

3GPP HSPA Rel-6

- *FDD 2x5 MHz Channel BW*
- *Downlink:*
- *QPSK/16QAM*
- *(1x2) SIMO*
- *14 Mbps Peak*

- *Uplink:*
- *BPSK/QPSK*
- *(1x2) SIMO*
- *5.8 Mbps Peak*
- *Availability: 2007*

Mobile WiMAX Rel 1.0 (TDD, 10 MHz Channel BW) has higher peak rate & 2x to 3x greater DL[1] sector throughput than HSPA Rel-6

1. Throughput advantage depends on ratio of DL to UL traffic see white paper: "Mobile WiMAX – Part II: A Comparative Analysis", available on WiMAX Forum website for a more detailed analysis..

HSPA+ (HSPA Rel-7 and Rel-8)

The Next Step in 3GPP Evolution

FDD 2x5 MHz Channel BW – as in Rel-6

HSPA Rel-7 Enhancements[1] (Availability: late 2008)

- *64QAM in DL with (1x2) SIMO or …*
- *16QAM in DL with (2x2) MIMO*
- *16QAM in UL*
- *Higher VoIP Capacity*

HSPA Rel-8 Enhancements (Expected availability: 2009)

- *Simultaneous DL support for (2x2) MIMO + 64QAM*
- *Higher order MIMO & UL MIMO being considered[2]*

1. Ref: "Release 7 HSPA+ for Mobile Broadband Evolution", Qualcomm Inc. December 2007
2. In UMTS white paper "Towards Global Mobile Broadband, February 2008", (2x2) MIMO in UL is part of Release 8, other sources indicates it is only being considered

Mobile WiMAX and HSPA+

Parameter	HSPA[1]			WiMAX	
	Rel-7		Rel-8	Rel 1.5	
Frequency	2000 MHz			2500 MHz	
Duplex	FDD			FDD	TDD
Channel BW	2 x 5 MHz			2 x 5 MHz	10 MHz
BS Antenna	(1x2) SIMO	(2x2) MIMO		(2x2) MIMO	
MS Antenna	(1x2) SIMO			(1x2) SIMO	
DL Mod-Coding[2]	64QAM-5/6	16QAM-3/4	64QAM-5/6	64QAM-5/6	64QAM-5/6
UL Mod-Coding[2]	16QAM-3/4			64QAM-5/6	64QAM-5/6
DL Peak User Rate	17.5 Mbps	21 Mbps	35 Mbps	36 Mbps	48 Mbps[3]
UL Peak User Rate	8.3 Mbps	8.3 Mbps	8.3 Mbps	17 Mbps	24 Mbps[4]

1. *Source: "Release 7 HSPA+ for Mobile Broadband Evolution", Qualcomm Inc. December 2007*
2. *Results for unity coding are often reported for HSPA, code rate used in table is considered more realistic for actual deployments and provides a more direct comparison to Mobile WiMAX*
3. *Assumes DL/UL ratio 3:1*
4. *Assumes DL/UL ratio 1:3*

Diapositive 18

dag1 Add 10 MHz TDD for WiMAX

Doug Gray; 30/01/2009

Summary: Mobile WiMAX & HSPA+

- *Mobile WiMAX Rel 1.5 has comparable peak DL performance for the same Modulation, Coding, and Channel BW as HSPA Rel-8*
- *Mobile WiMAX Rel 1.5 has >2 times better peak UL performance*
- *HSPA+ is constrained to 2 x 5 MHz channels in traditional 3G spectrum assignments*
- *Mobile WiMAX Rel 1.5 supports channel BWs up to 20 MHz, FDD and TDD, and has planned profiles in 700, 1700, 2300, 2500, & 3500 MHz frequency bands*
- *Mobile WiMAX provides a flat all-IP e2e network*

3GPP Long Term Evolution

- *3GPP (LTE) is Adopting:*
  - *OFDMA in DL with 64QAM*
  - *All IP e2e Network*
  - *Channel BWs up to 20 MHz*
  - *Both TDD and FDD profiles*
  - *Flexible Access Network*
  - *Advanced Antenna Technologies*
  - *UL: Single-Carrier FDMA (SC-FDMA), (64QAM optional)*
- *LTE is adopting technology & features already available with Mobile WiMAX*
  - *Can expect similar long-term performance benefits and trade-offs*

LTE: Not a Simple 3G Upgrade

- *LTE Represents a Major Upgrade from CDMA-Based HSPA (or EV-DO)*
  - *No longer a "simple" SW upgrade:*
    - *CDMA to OFDMA, represent different technologies*
    - *Circuit switched to IP e2e network*
  - *Also requires new spectrum to take full advantage of wider channel BWs and …*
  - *Requires dual-mode user devices for seamless internetwork connectivity*

LTE Projections & Mobile WiMAX

FDD 2 x 20 MHz Channel BW

Parameter	Reported LTE Results				WiMAX Rel 1.5	
	Motorola[1]		T-Mobile[2]	Qual-comm[3]		
BS Antenna	2x2	4x4	2x4	4x2	2x2	4x4
Channel BW	2 x 20 MHz				2 x 20 MHz	
Mod-Code Rate	64QAM-5/6		64QAM-5/6	64QAM-?	64QAM-5/6	
DL Peak User Rate	117 Mbps	226 Mbps	144 Mbps	277 Mbps	144.6 Mbps	289 Mbps
MS Antenna			1x2	1x2	1x2	
Mod-Code Rate			64QAM[4]-?	16QAM[4]-?	64QAM-5/6	
UL Peak User Rate	?	?	50.4 Mbps	75 Mbps	69.1 Mbps	

1. Motorola website, "LTE In Depth" , Reference does not show UL peak rate projections
2. "Trials–Ensuring Success for Innovation", Joachim Horn, T-Mobile, NGMN Conference presentation, June 25-27,2008
3. "3GPP Long-Term Evolution (LTE)", Qualcomm, January 2008
4. 64QAM is optional for UL in LTE specification, 16QAM is mandatory

Other Key Parameter Comparisons

Parameter	LTE	Mobile WiMAX Rel 1.5
Duplex	FDD and TDD	FDD and TDD
Frequency Band for Performance Analysis	2000 MHz	2500 MHz
Channel BW	Up to 20 MHz	Up to 20 MHz
Downlink	OFDMA	OFDMA
Uplink	SC-FDMA	OFDMA
DL Spectral Efficiency[1]	1.57 bps/Hz/Sector (2x2) MIMO[2]	1.59 bps/Hz/Sector (2x2) MIMO
UL Spectral Efficiency[1]	0.64 bps/Hz/Sector (1x2) SIMO[2]	0.99 bps/Hz/Sector (1x2) SIMO
Mobility Support	Target: Up to 350 km/hr	Up to 120 km/hr
Frame Size	1 millisec	5 millisec
HARQ	Incremental Redundancy	Chase Combining
Link Budget	Typically limited by Mobile Device	Typically limited by Mobile Device
Advanced Antenna Support	DL: 2x2, 2x4, 4x2, 4x4 UL: 1x2, 1x4, 2x2, 2x4	DL: 2x2, 2x4, 4x2, 4x4 UL: 1x2, 1x4, 2x2, 2x4

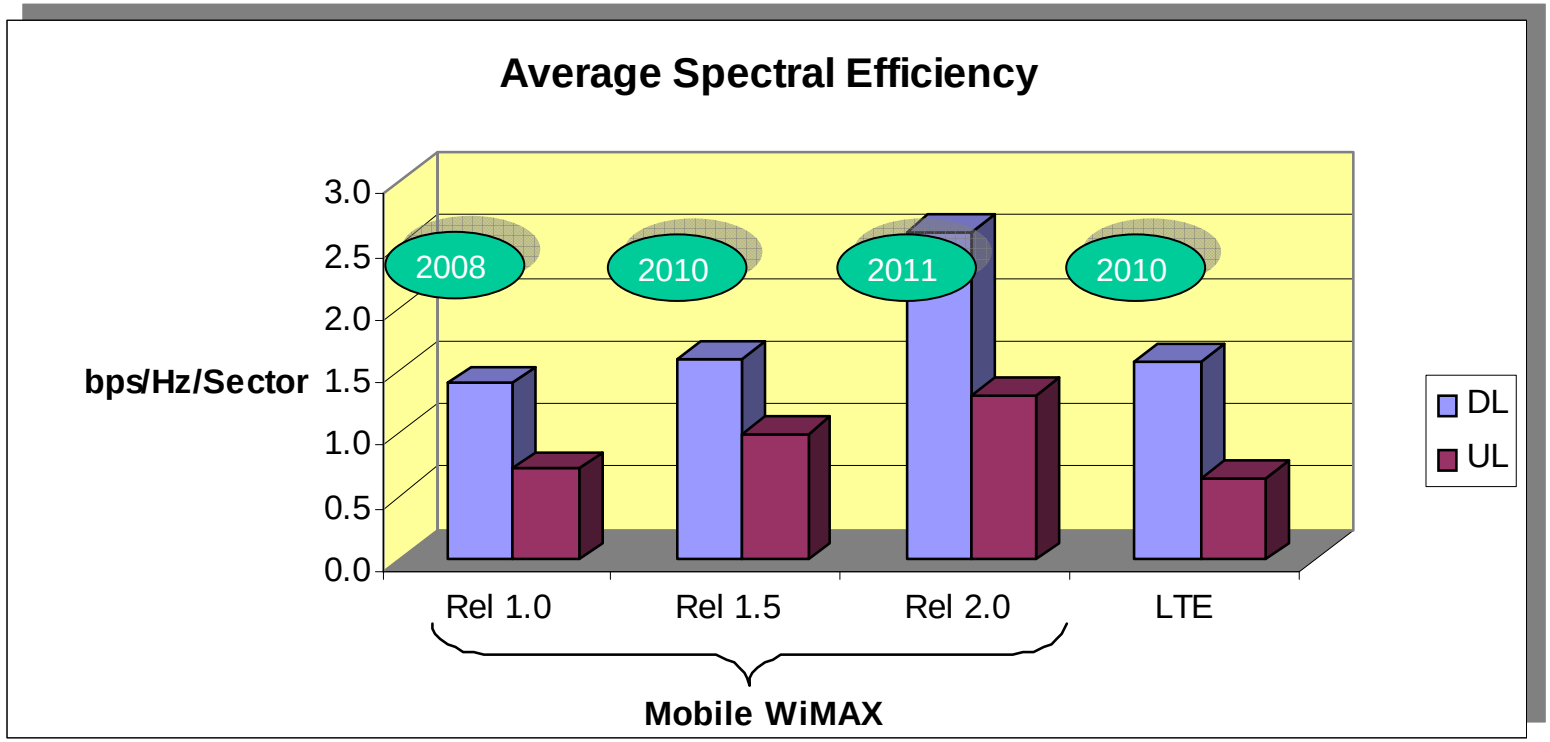
1. Spectral efficiency is based on NGMN Alliance recommended evaluation methodology

2. Reference for LTE Spectral Efficiency: Motorola website, "LTE in Depth".

Further Performance Enhancements Planned for Mobile WiMAX Rel 2.0

- *Release 2.0 is based on the IEEE 802.16m System Requirements Document*
- *802.16m Mirrors IMT-Advanced Requirements*
  - *Key Performance Targets are:*
    - *Increased DL peak channel & user data rate*
    - *Increased UL peak channel & user data rate*
    - *2x DL spectral efficiency of Release 1.0 (2.6 bps/Hz)*
    - *2x cell-edge DL user throughput of Release 1.0 (0.09 bps/Hz)*
    - *2x UL spectral efficiency of Release 1.0 (1.3 bps/Hz)*
    - *2x cell-edge UL user throughput of Release 1.0 (0.05 bps/Hz)*
    - *Reduction of the connection setup, RAN delay, & handover interruption time*
    - *>60 concurrent sessions per MHz per sector for the AMR 12.2 kbps speech codec*
    - *Multi-Carrier support for contiguous or non-contiguous channels (up to 100 MHz operating BW with band aggregation)*
    - *Mobility support up to 500 km/hr*
- *Mobile WiMAX Rel 2.0 is backwards compatible with Rel 1.5 and Rel 1.0*

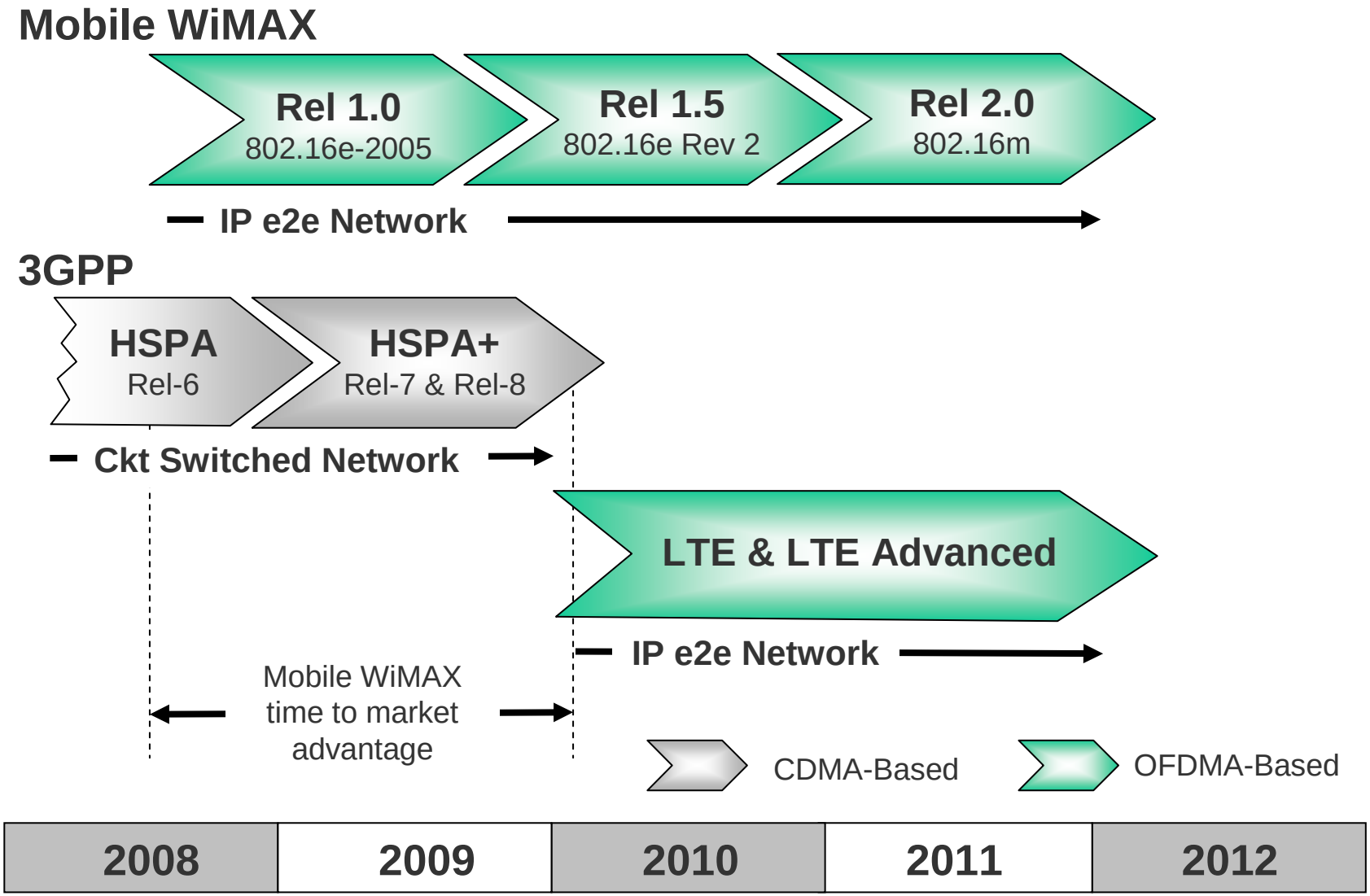
Spectral Efficiency Enhancements for Mobile WiMAX



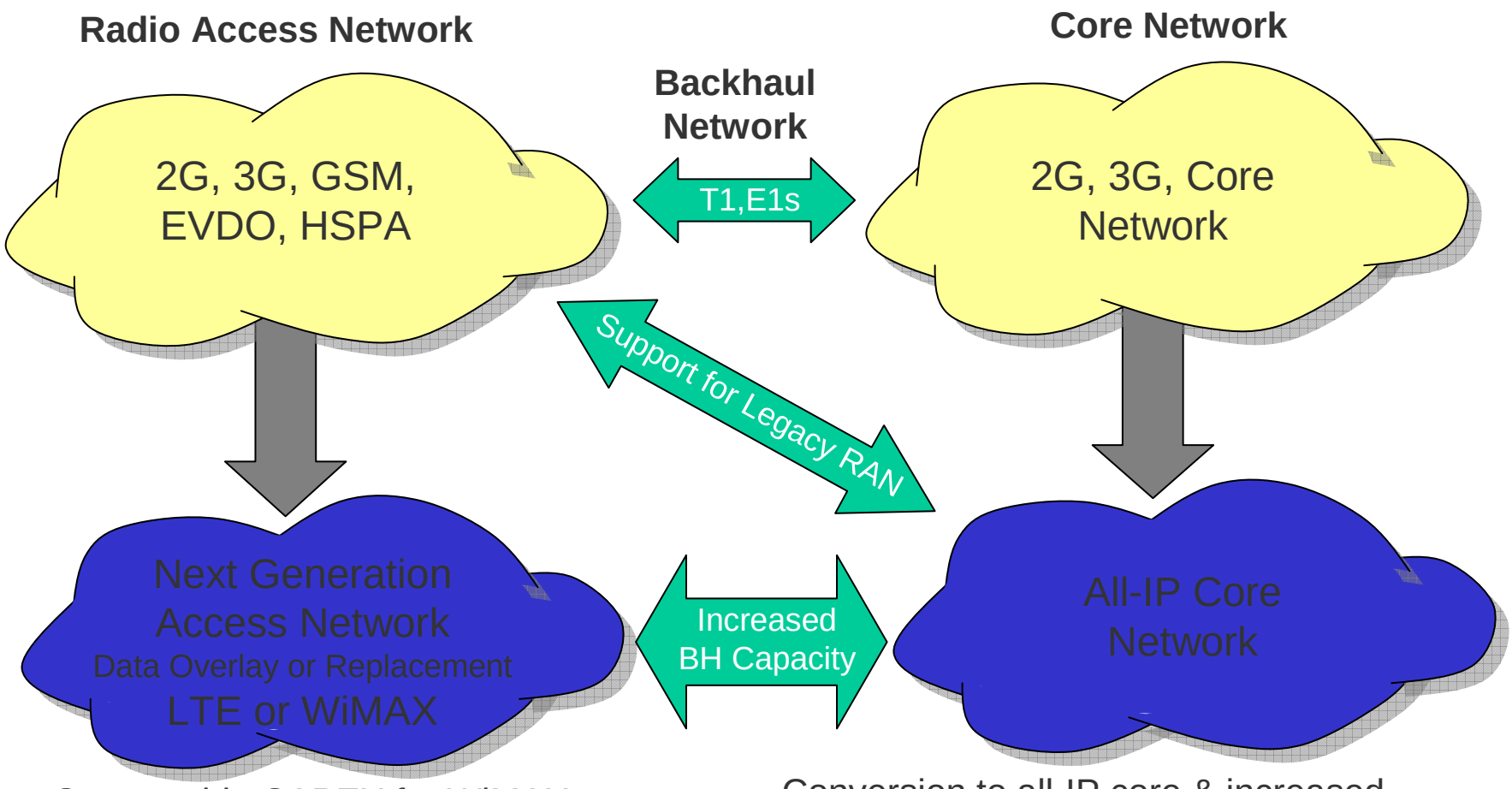
Spectral efficiency has an impact on the business case

- ✓ *Lowers deployment cost per Megabit*
- ✓ *Adds channel capacity to support new value-added services for increased operator revenues*

3GPP & Mobile WiMAX Timeline



Upgrade Path for Existing Operators



Comparable CAPEX for WiMAX today or LTE in 2+ years. Both require new spectrum

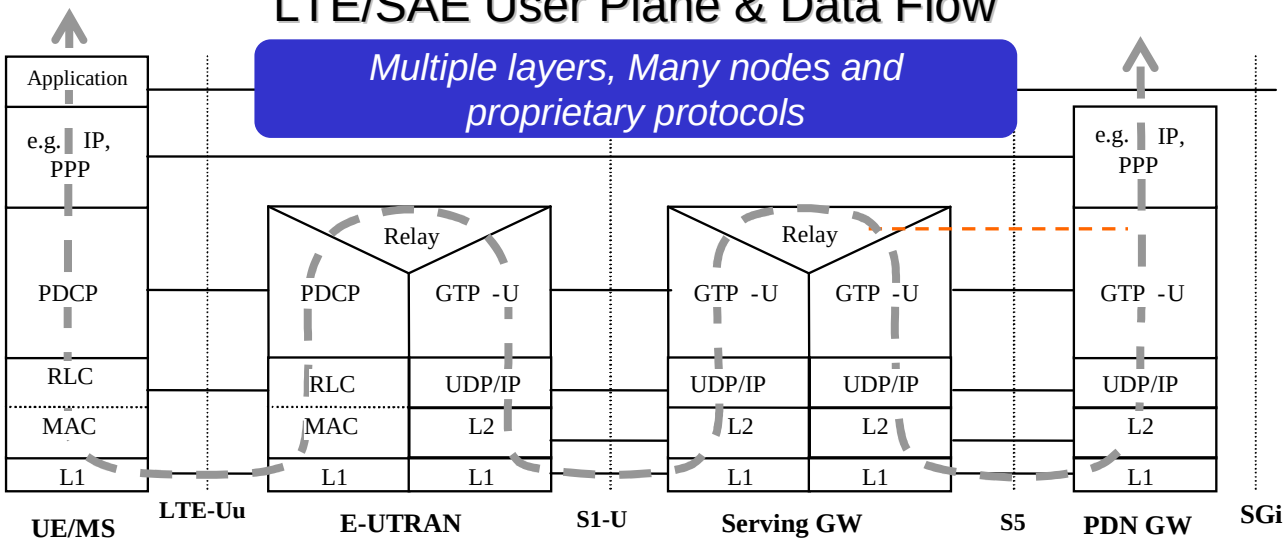
Conversion to all-IP core & increased backhaul capacity required in either case

Other Deployment Considerations

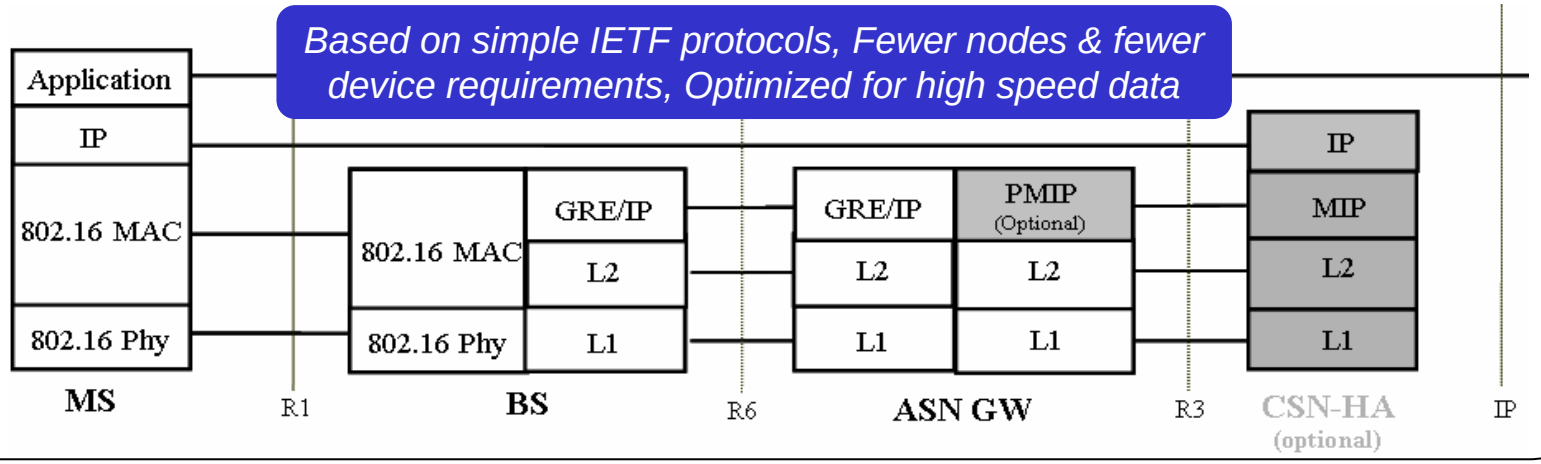
- *Mobile WiMAX has significant time-to-market advantage*
  - *100+ Certified client devices by year-end 2008*
  - *1000+ Certified client devices expected by 2011*
  - *WiMAX Rel 1.0 being deployed today, LTE specification not expected until end of 2008*
- *WiMAX has friendly Intellectual Property Environment*
  - *IPR distributed amongst many companies, not just a few*
  - *Open patent alliance established*
  - *Lower costs for WiMAX/WiFi client devices*
- *Mobile WiMAX provides a simple, all-IP flat network, with all IETF protocols*
  - *LTE network is a more complex multi-layer network burdened with proprietary 3G cellular protocols*

Comparing the End-to-End Network

LTE/SAE User Plane & Data Flow



Mobile WiMAX User Plane & Data Flow



Source: LTE/SAE: 3GPP, Mobile WiMAX: WiMAX Forum Network Specification Release 1.0

Summary and Conclusion

Mobile WiMAX and LTE are both accepted as candidates to meet IMT-Advanced performance goals
IMT-Advanced specifications not yet fully defined
IEEE 802.16m will mirror IMT-Advanced requirements
Mobile WiMAX Rel 1.5 and LTE have comparable performance
Both use OFDMA in the DL with higher order modulation and coding
Peak performance is similar for same modulation and code rate
Both support FDD and TDD with channel BWs up to 20 MHz
Both support higher order MIMO antenna solutions
Both offer reduced latency
But Mobile WiMAX has ~2 year time lead and a…
A flat e2e network architecture optimized for high speed data

Summary and Conclusion (ctd)

Throughput & spectral efficiency target for Mobile WiMAX Rel 2.0 will further enhance key performance parameters
Mobile WiMAX Rel 2.0 is backwards compatible with Rel 1.0 & Rel 1.5
Comparable investment to upgrade 2G/3G network to LTE or Mobile WiMAX
New spectrum required for either LTE or WiMAX to support wider channel BW
Multi-Band/Multi-Mode subscriber devices required in either case for internetwork connectivity and global roaming
Upgrade to Mobile WiMAX provides operators a significant time-to-market advantage