

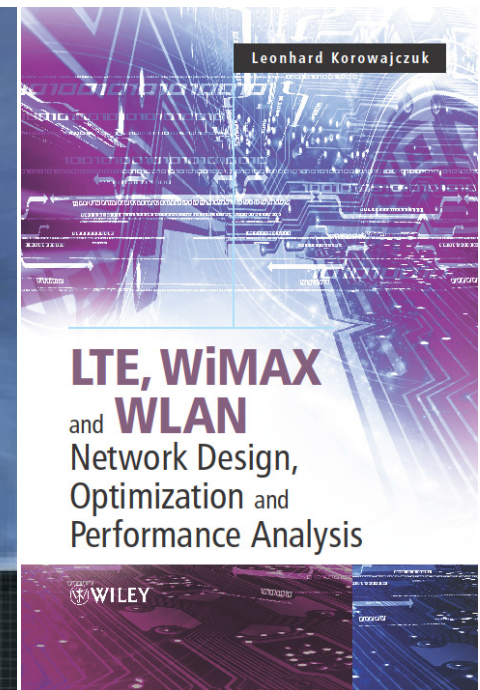
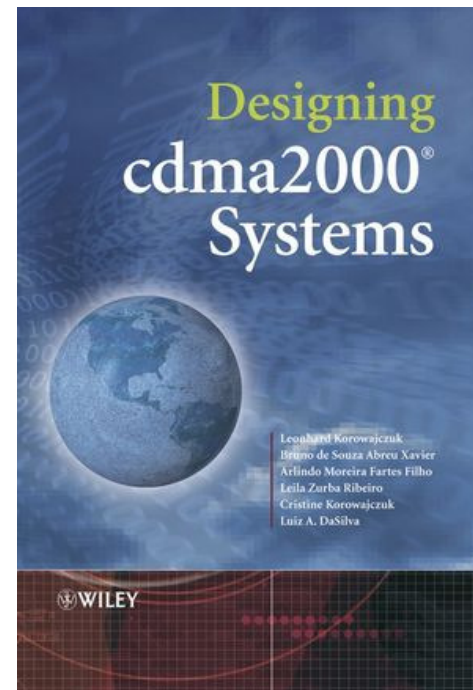
4 G Demystified

The Plain Truth about WiMAX and LTE

Biography- Leonhard Korowajczuk

- 40 plus years experience in Telecommunications R&D & Engineering (30 years in wireless)
- Designed equipments for
 - FDM
 - Switching
 - Wireless Video
 - PCM
 - Wireless
 - Energy
- Brazilian Telecom Research Center founder group
- Switching and Wireless Director at Elebra (today Alcatel Brazil)
- CTO Wireless Comsat-Plexsys (USA)
- CEO/CTO CelPlan International (USA)
- CTO Wi4Net (leader in public safety wireless video surveillance)
- Ten plus patents
- Two wireless technology books
- Hundreds of wireless designs worldwide: GSM/HSPA, cdma2000/EVDO, WiMAX, LTE, Satellite, Smart Grids

White Paper:
“Designing WiMAX Networks”
Download from
www.celplan.com



Technology and Design Training

- WiMAX Forum Certified Training
- WiMAX Forum Network Designer Boot Camp
- November 1 to 3rd
- Reston, VA

- LTE and WLAN Technology
- November 4th
- Reston, VA

Deployment of 4 G networks

- 4G is much more complex than 3 G and requires an in depth understanding of multi disciplinary subjects
- CelPlan has 20 years of expertise in the wireless industry, and have design hundreds of networks
- CelPlan provides
 - Complete portfolio of design tools (CelPlanner Suite)
 - Design services from RFP preparation to full network design
 - Specialized consulting
 - Advanced training (the only company to have published books about wireless design and technology)

LTE, WiMAX and WLAN



Network Design, Optimization and Performance Analysis

- Part A- Basic Concepts
- Part B- Technologies
- Part C- Network Design

Part A- Essential Basic Concepts for 4G

1. Business Plan
2. Data Transmission
3. Market Modeling
4. Signal Processing Fundamentals
5. RF Channel
6. RF Channel Performance Prediction
7. OFDM
8. OFDM Implementation
9. Wireless Network Core Equipment
10. Antenna and Advanced Antenna Systems
11. Radio Performance
12. Basic Mathematical Concepts

Part B- 4 G Technologies

1. Wireless LAN
2. WiMAX
3. LTE
4. Broadband Standards Comparison

Part C-Design of 4 G Wireless Networks

1. Wireless Network Design Steps
2. Wireless Market Modeling
3. Wireless Network Strategy
4. Wireless Network Design
5. Wireless Network Optimization
6. Wireless Network Performance Assessment

Webinar

- Selected topics about WiMAX and LTE
 - Objectives and Claims
 - Standards
 - Architecture
 - Technology Comparison and Real Throughput

WiMAX

WiMAX Standards

Project	Description
P802.16m	Currently in pre-draft stage. It addresses the "Advanced Air Interface" and is an amendment to projects 802.12-2004 and 802.16e-2005. This project should result in the creation of WiMAX Release 2 (WiMAX 2.0)
Draft P802.16h	Draft amendment under development, addressing "Improved Coexistence Mechanisms for License-Exempt Operation"
Draft P802.16i	Draft amendment under development, addressing "Management Plane Procedures and Services"
Draft P802.16j	Draft amendment under development, addressing "Multihop Relay Specification"
Draft P802.16Rev2	Draft under development for the IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Broadband Wireless Access Systems (this draft consolidates Standards 802.16e-2005, 802.16-2004 –including Cor1-2005, 802.16f-2005, and 802.16g-2007). When this revision is complete it will supersede Std 802.16-2004 and all related amendments and corrigenda.
Std 802.16-2004	Active standard. Revision of IEEE Std 802.16 (including 802.16-2001, 802.16c-2002, and 802.16a-2003). This standard was developed by the Task Group d under the name P802.16-REVd. The IEEE Std 802.16-2004 revision added the 2-11 GHz range and supported a fixed FFT of 256 for all bandwidths and an FFT of 2048 for the 20 MHz bandwidth, but it only targeted fixed subscribers. The shortcomings of this standard were corrected in IEEE Std. 802.16-2004/Cor1 (2005).
Std 802.16g-2007	Active amendment to 802.16, it addresses "Management Plane Procedures and Services"
Std 802.16f-2005	Active amendment to 802.16 developed by the Network Management Task Group, it addresses the "Management Information Base"
Std 802.16e-2005	Active amendment to 802.16 developed by Task Group e, it addresses "Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands" (including mobility and fast handover.) This group was working in parallel to IEEE Std. 802.16-2004 since 2002, aiming to develop a mobile version of the standard. This became IEEE Std 802.16e/Cor1 amendment and corrigendum that supports fixed and mobile communications in bands below 6 GHz.

WiMAX Forum

- The idea behind standards is to allow interoperability amongst operators
 - IEEE standards aim to cover all possible applications
 - 802.16 standard supports such a multitude of configuration options and features that it could lead to non-compatible networks if vendors chose different implementation options
 - Creation of the WiMAX Forum - not-for-profit organization created to divulge and further standardize WiMAX technology
- WiMAX standard defines only the physical layer (PHY) and the medium access layer (MAC), not enough to assure network inter-operability
 - WiMAX Forum creates guidelines for an end-to-end WiMAX network architecture, covering roaming and integration with other networks (WLAN and 3G)
 - Guidelines are based on IETF RFCs, IEEE standards, DOCSIS (Data Over Cable Service Interface Specification) security protocols and 3GPP IMS (3rd Generation Partnership Project- IP Multimedia Subsystem) fixed and mobile convergence protocol

WiMAX Forum

- The Forum specifies sets of minimum features (profiles) that should be supported by all vendors, making WiMAX equipment interoperable
 - These profiles define mandatory and optional parameters for implementation in base stations and CPEs
 - A certification program was established to certify equipment that fulfill requirements of each profile
 - Certification test profiles were issued in two groups:
 - wave 1 (mainly fixed stations features)
 - wave 2 (mobile station features)
 - both wave1 and wave2 certified products are already available
- WiMAX Forum organizes events called Plugfests, in which vendors can interconnect their equipment to perform interoperability tests

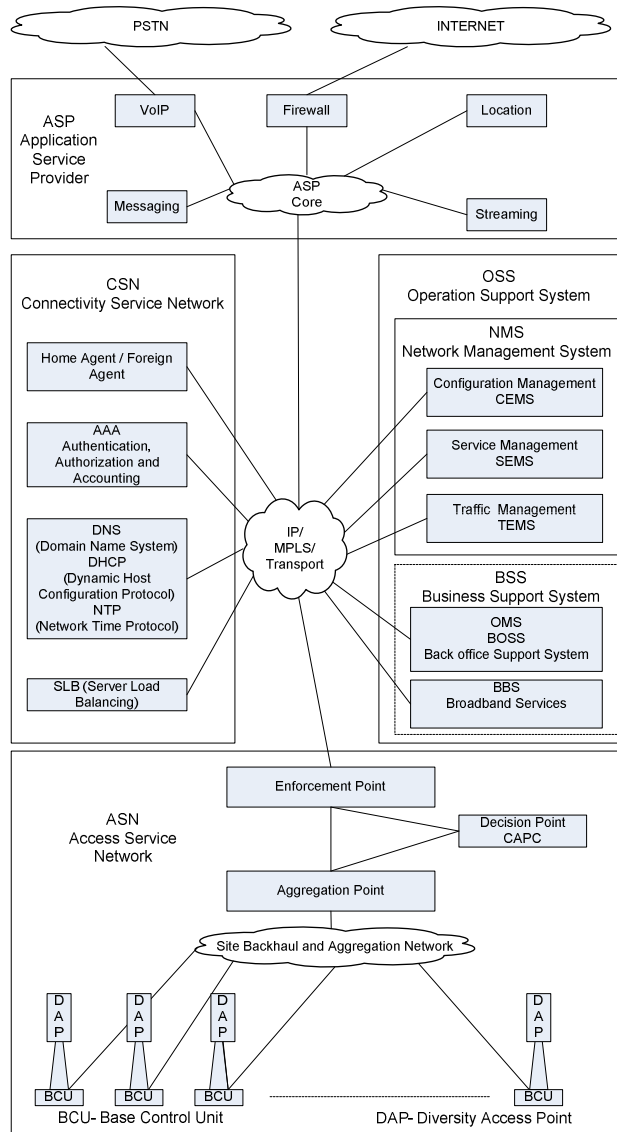
WIMAX Advantage

- Major improvements of WiMAX over traditional 3G technologies:
 - Fully packet switched (IP based)
 - Orthogonal Frequency Division Multiplexing (OFDM)
 - Time Division Duplexing (TDD)
 - Multi level adaptive modulation (up to 64QAM)
 - Stronger error correction techniques
 - Designed for Advanced Antenna Systems

WiMAX Claims

- 802.16e
 - shared rates of up to 70 Mbps;
 - cell range of 30 miles;
 - spectral efficiency of 3.7 (bit/s)/Hz
- 802.16m
 - expected to offer up to 1Gbit/s for fixed users

WiMAX Architecture



WiMAX Spectrum Efficiency

- This table shows how carrier resources are used and the percentage of resources allocated for data and for carrier overhead

Carrier Overhead	Percentage
Guard Bands	18%
Pilot DL and UL	23%
Cyclic Prefix	13%
TDD partition	5%
TDD gap	3%
OFDMA preamble and mapping	10%
Total structural overhead	72%
Available for data	28%

WiMAX Spectrum Efficiency

- There is another overhead directly related to data retrieval - data overhead
- This table shows the minimum and maximum coding overhead

Data Overhead	Minimum	Maximum
Coding	17%	50%
MAC overhead	3%	5%
HARQ	10%	15%
Total	30%	70%
Available for data	20%	8%

UMTS-LTE

Universal Mobile
Telecommunications System
Long Term Evolution

EPS- Evolved Packet System

SAE/EPC- System Architecture Evolution/ Evolved Packet Core

LTE/E-UTRAN- Long Term Evolution/ Evolved Universal
Terrestrial Radio Access Network

LTE Objectives

- Co-existence with legacy standards while evolving towards an all-IP network
- Spectral bandwidth from 1.4 to 20 MHz
- Spectral efficiency three to four times better than HSPA release 6 in the downlink (4 bit/s/Hz) and 2 to 3 times better than HSPA release 6 in the uplink (bit/s/Hz)
- Latency smaller than 5 ms for small packets
- High mobility (up to 120 km/h)
- Cell range up to 5, 30 and 100 km
- Downlink based on OFDMA (Orthogonal frequency Division Multiple Access)
- Uplink based on SC-OFDMA (Single-Carrier OFDMA)
- FDD (Frequency Division Duplex) and TDD (Time Division Duplex)
- Bandwidth scalability and multi-band operation
- A new Evolved Packet Core (EPC)
- Simplified architecture and mobility management
- Interworking with existing UTRAN (UMTS Terrestrial Radio Access Network) systems and other non 3GPP systems

ITU Spectral Efficiency Objectives (bit/s/Hz)				
	Downlink		Uplink	
ITU Scenario	LTE	LTE- A	LTE	LTE- A
Indoor Hotspot	3.0	5.0	2.3	4.0
Urban Micro	2.6	3.1	1.8	2.2
Urban Macro	2.2	2.8	1.4	1.8
Rural Macro	1.1	2.6	0.7	2.0

LTE Marketing Claims

	Channel Bandwidth (MHz)	Downlink Throughput (Mbit/s)	Uplink Throughput (Mbit/s)	Symbol duration (μs)	Maximum multipath delay spread (m)
HSDPA	5	14.4	0.384	0.26	781
HSUPA	5	14.4	5.75	0.26	781
HSPA+	5	26	11.5	0.26	781
LTE	20	300	75	66.67	5,000

- Reuse of 1
- Self Organizing Networks (SON)

Standardization

- General format 3GPP TS SS.NNN vR.XX.YY
- Specifications are aggregated into Releases (Rel)
 - Stage 1: The desired service is described from the user’s point of view
 - Stage 2: A logical analysis is done, breaking the problem in functional elements and information flows
 - Stage 3: Documentation of the functionality and protocols

3 GPP Standard	Release date	Commercial introduction	Main Technology Introduced
Rel-99	March-00	2003	UMTS
Rel-4	Mar-01	none	
Rel-5	Oct-02	2006	HSDPA, IMS
Rel-6	Dec-04	2007	HSUPA
Rel-7	Dec-06	2009	HSPA+
Rel-8	Dec-08	2011 (forecast)	LTE, EPC, IMS+
Rel-9	Dec-09	2012 (forecast)	LTE TDD, MBMS
Rel-10	Mar-11	2013 (forecast)	LTE-A, SON
Rel-11	Dec-12	2015 (forecast)	TBD

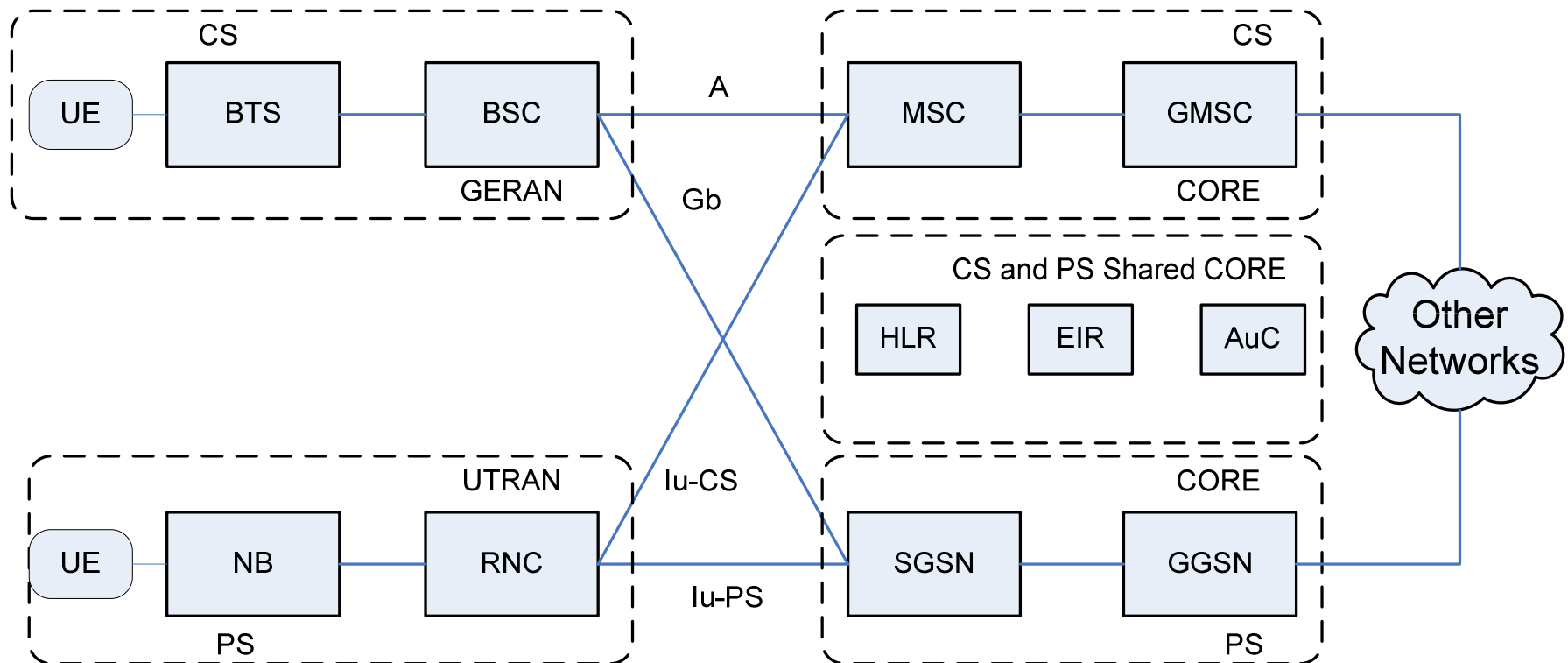
Releases

- Release 8 (December 2008)
 - LTE Radio Access Modes
 - Transmission Bandwidth
 - Peak data rates
- Release 9 (December 2009)
 - Release 9 includes small enhancements, MBMS (Multimedia Broadcast Multicast services) and SON (Self Organizing Networks) was published December 2009
 - SON (Self Organizing Networks)
 - MBMS (Multimedia Broadcast/ Multicast Service)
 - Multi RAT (Radio Access Technology) Internetworking and System Reselection
 - Inter RAT Handover

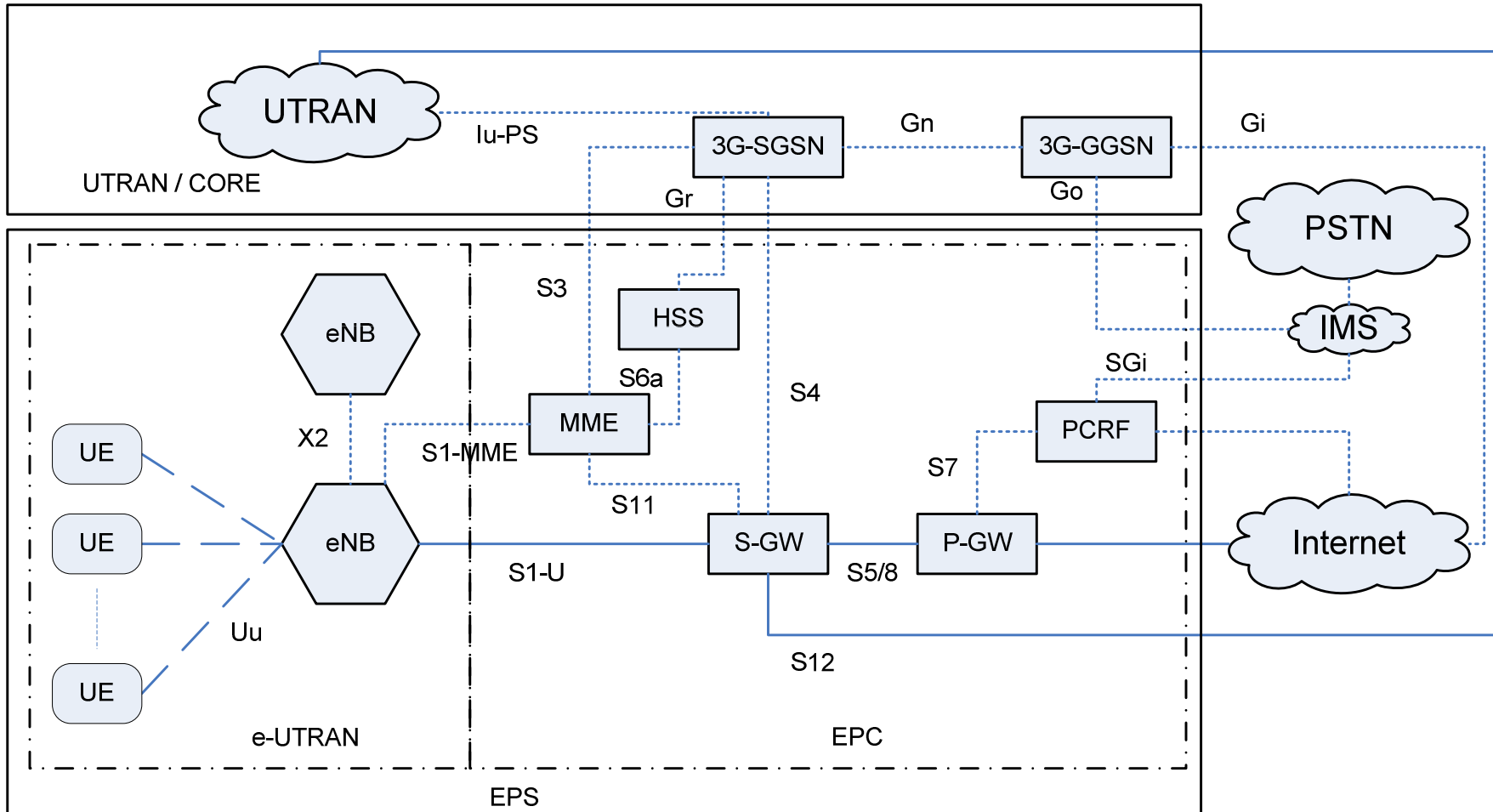
Releases

- **Release 10 (March 2011)**
 - Backward compatible with LTE
 - Bandwidth extension (up to five 20 MHz carriers)
 - Spectrum aggregation (aggregation of non-contiguous channels, even from different bands)
 - MIMO enhancements
 - Uplink spatial multiplexing (up to 4 layers)
 - Downlink spatial multiplexing (up to 8 layers)
 - Enhanced downlink multi-user MIMO
 - Combined non-code-book-based beam-forming and spatial multiplexing
 - Relay techniques (coverage extension and data rate, multi-frequency repeater like function)
 - Creates new cell and self backhauled to donor cell
 - Coordinated multipoint reception and transmission
 - Scheduling coordination
 - Joint transmission and reception
 - Reduces inter-cell interference and improves signal strength
- **Release 11 (December 2012)**
 - Advanced IP Interconnection of Services
 - System Improvements to Machine Type Communications
 - Network provided location information for IMS

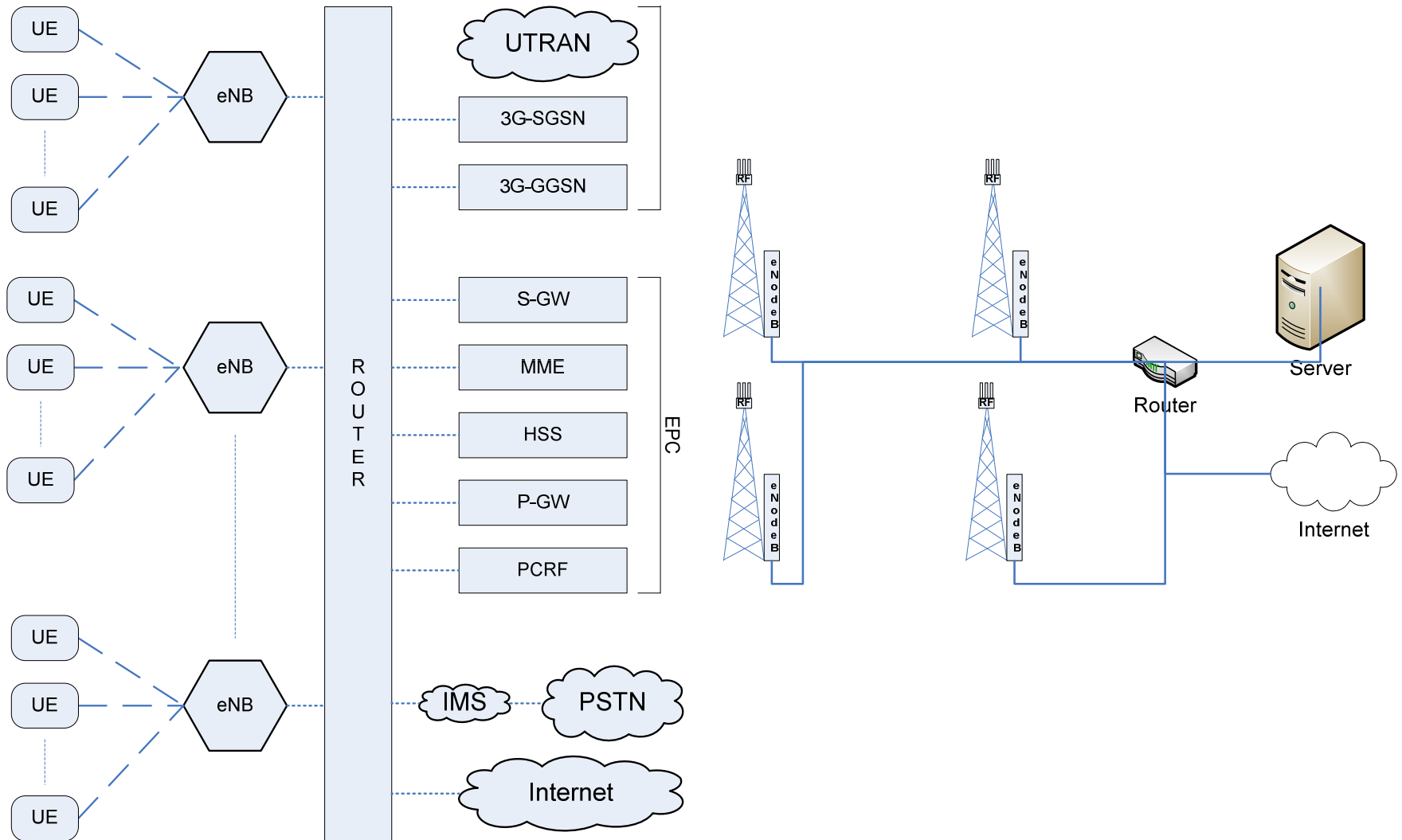
GSM and UMTS Architecture



EPS (LTE) Architecture

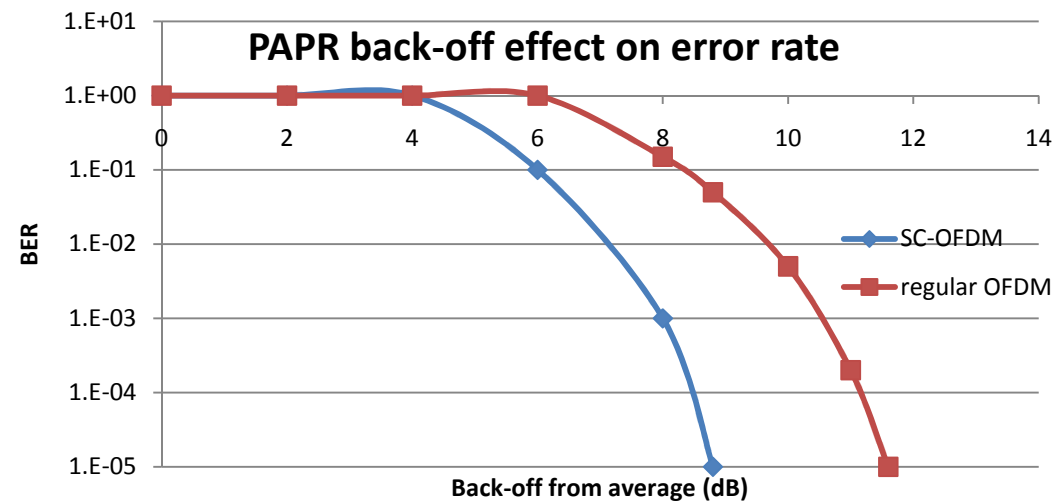


LTE Architecture

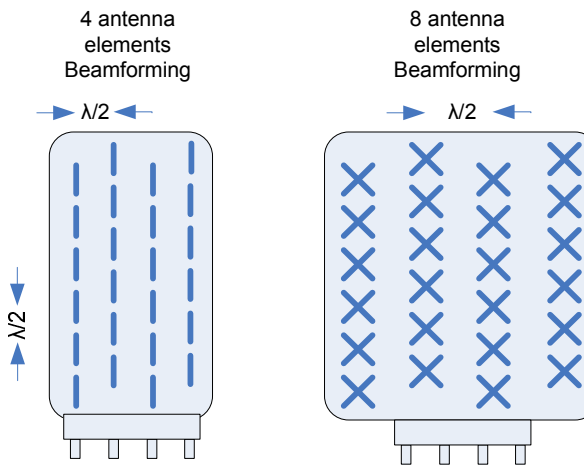
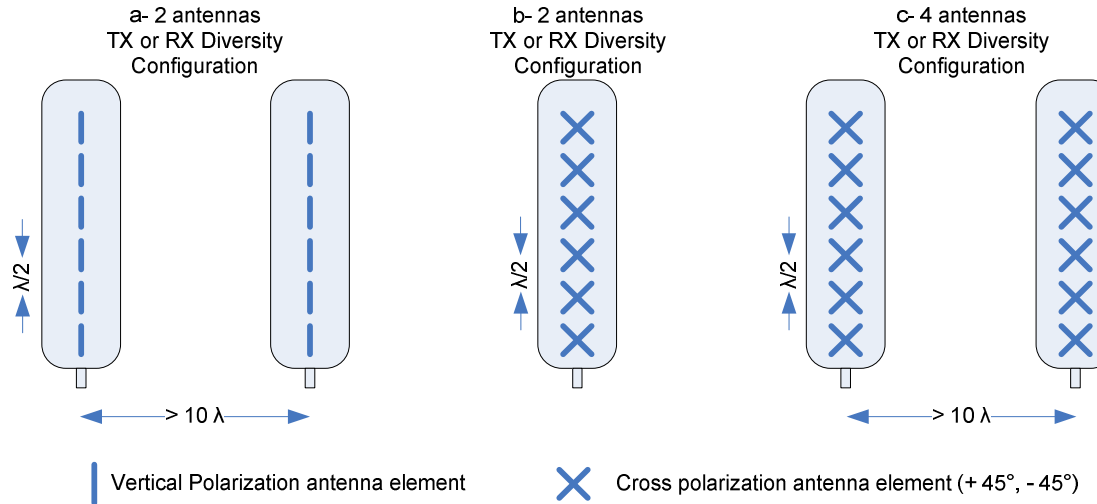


SC-OFDMA or DFT-S-OFDMA

- WiMAX requires a large PAPR (Peak to Average Power Ratio)
- LTE resorted to DFT-S-OFDM (Discrete Fourier Transform Spread OFDM) to reduce PAPR
- This implied in fixing a minimum size Resource Block
- PAPR was reduced by 2 to 3 dB
- Throughput inefficiency was increased

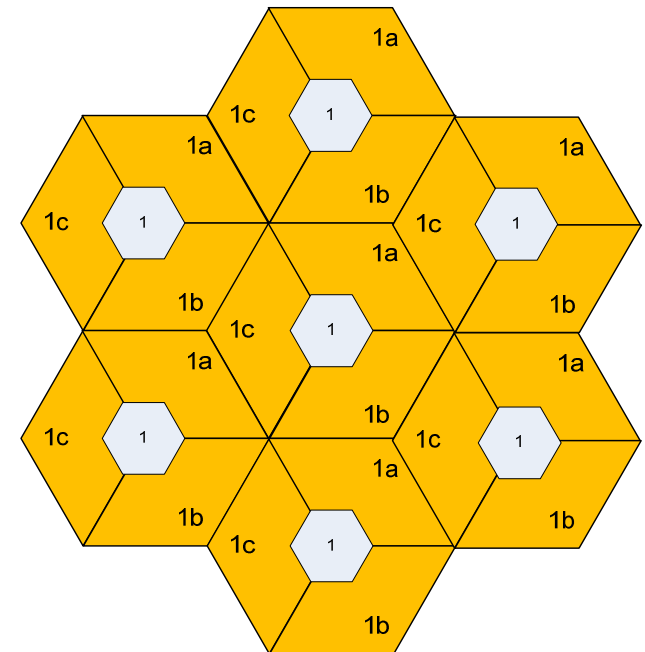
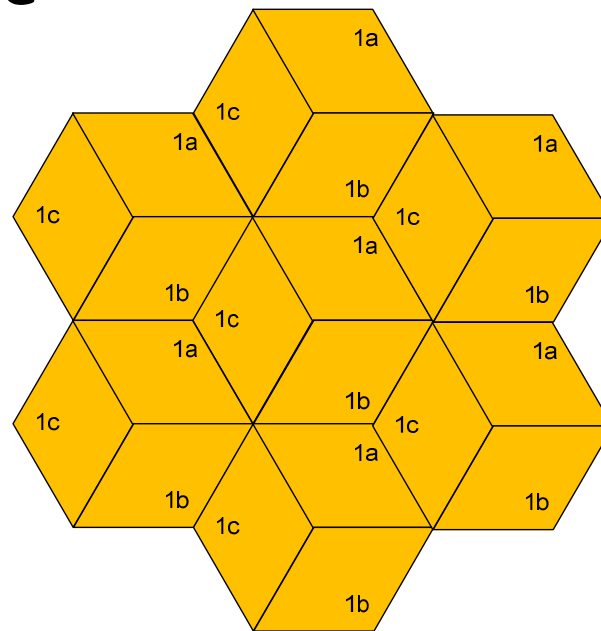


Multiple Antennas in LTE



Resource Planning in LTE

- Full Reuse
- Hard Reuse
- Fractional Reuse
- Soft Reuse



Self-Organizing Network (SON)

- Self Configuration
 - Plug and play detection of the eNB by the gateways and vice versa
 - Self configuration of RF transport
 - Physical Cell ID (PCI) determination
 - Automatic Neighbor Relations (ANR)
 - Tracking Area Planning
- Network Operation
 - Auto inventory
 - Automated Software upgrade
 - Self testing and self healing
- Network Optimization
 - Load Balancing
 - Handover Parameters Optimization
 - RF Plan Optimization
 - Interference Control
 - Energy Savings

WiMAX, LTE Real Performance

Cyclic Prefix

Table 15.6. WiMAX Scalable and LTE Cyclic Prefix

	WiMAX 802.16e-2005 Scalable OFDM				LTE 3GPP TS 36.104						LTE 3GPP TS 36.104					
	OFDMA				OFDMA						OFDMA					
											MBSFN					
Channel Bandwidth (MHz)	1.3	5.0	10.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0
Cyclic Prefix																
Reduced= nominal 1/32 (3.125%) of symbol duration	0.03125										0.0352					
Duration (μs)	2.9										4.7					
Duration (time units)	4										144					
Duration (time units- first frame symbol- LTE only)											160					
Multipath mitigation distance (km)	0.9										1.4					
Maximum Number of OFDM symbols per second (Msymbol/s)	0.011				0.015						0.007					
Normal= nominal 1/16 (6.25%) of symbol duration	0.0625				0.0703											
Duration (μs)	5.7				4.7											
Duration (time units)	8				144											
Duration (time units- first frame symbol- LTE only)					160											
Multipath mitigation distance (km)	1.7				1.4											
Maximum Number of OFDM symbols per second (Msymbol/s)	0.010				0.014											
Large= nominal 1/8 (12.5%) of symbol duration	0.125															
Duration (μs)	11.4															
Duration (time units)	16															
Multipath mitigation distance (km)	3.4															
Maximum Number of OFDM symbols per second (Msymbol/s)	0.010															
Extended= nominal 1/4 (25%) of symbol duration	0.25				0.25						0.25					
Duration (μs)	22.9				16.7						33.3					
Duration (time units)	32				512						1024					
Multipath mitigation distance (km)	6.9				5.0						10.0					
Maximum Number of OFDM symbols per second (Msymbol/s)	0.009				0.012						0.006					

Modulation Schemes

Table 15.9. WiMAX Scalable and LTE Modulation Schemes

	WiMAX 802.16e-2005 Scalable OFDM				LTE 3GPP TS 36.104						LTE 3GPP TS 36.104					
	OFDMA				OFDMA						OFDMA					
Modulation Schemes											MBSFN					
Channel Bandwidth (MHz)	1.3	5.0	10.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0
Nominal Coding Scheme (Extended CP, DL)	Air Data Rate (Mbit/s)				Air Data Rate (Mbit/s)						Air Data Rate (Mbit/s)					
	RSCC, BTC, CTC, LDPC				CRC, RSCC, CTC						CRC, RSCC, CTC					
BPSK 1/2	0.3	1.6	3.2	6.3	0.4	1.0	1.7	3.4	5.1	6.8	0.4	1.0	1.7	3.4	5.1	6.8
BPSK 3/4																
QPSK 1/2	0.6	3.2	6.3	12.6	0.8	2.0	3.4	6.8	10.2	13.6	0.8	2.0	3.4	6.8	10.2	13.6
QPSK 2/3	0.8	4.2	8.4	16.8	1.1	2.7	4.5	9.1	13.6	18.1	1.1	2.7	4.5	9.1	13.6	18.1
QPSK 3/4	0.9	4.7	9.5	18.9	1.2	3.0	5.1	10.2	15.3	20.4	1.2	3.1	5.1	10.2	15.3	20.4
16QAM 1/2	1.3	6.3	12.6	25.2	1.6	4.1	6.8	13.6	20.4	27.2	1.6	4.1	6.8	13.6	20.4	27.2
16QAM 3/5	1.5	7.6	15.1	30.3	1.9	4.9	8.1	16.3	24.5	32.6	1.9	4.9	8.1	16.3	24.5	32.6
16 QAM 3/4	1.9	9.5	18.9	37.8	2.4	6.1	10.2	20.4	30.6	40.8	2.4	6.1	10.2	20.4	30.6	40.8
16QAM 4/5	2.0	10.1	20.2	40.3	2.6	6.5	10.8	21.7	32.6	43.5	2.6	6.5	10.9	21.7	32.6	43.5
64QAM 2/3	2.5	12.6	25.2	50.4	3.2	8.1	13.6	27.2	40.8	54.4	3.2	8.1	13.6	27.2	40.8	54.4
64QAM 3/4	2.8	14.2	28.4	56.7	3.6	9.1	15.2	30.5	45.8	61.1	3.6	9.2	15.3	30.6	45.9	61.2
64QAM 5/6	3.1	15.8	31.5	63.0	4.0	10.1	16.9	33.9	50.9	67.9	4.1	10.2	17.0	34.0	51.0	68.0

Framing Characteristics

Table 15.11. WiMAX Scalable and LTE Framing

Framing	WiMAX 802.16e-2005 Scalable OFDM				LTE 3GPP TS 36.104						LTE 3GPP TS 36.104					
	OFDMA				OFDMA						OFDMA					
Channel Bandwidth (MHz)	1.3	5.0	10.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0
Duplex	TDD				FDD						FDD MBSFN					
Frame duration (ms)	2, 2.5, 4, 5, 8, 10, 12.5, 20				10						10					
TDD sub-frame duration (ms)	flexible				5, 10						5, 10					
Sub-frame duration (ms)					1						1					
Slot duration (ms)					0.5						0.5					
Example	$T_f=10$ ms, CP=0.25, TTG/GP=180 μ s, RTG=0 μ s, DL/UL usage ratio= 0.51, PUSC				$T_f=10$ ms, CP=0.25, TTG/GP= 180 μ s, RTG=0 μ s, DL/UL usage ratio= 0.5						$T_f=10$ ms, CP=0.25, TTG/GP= 180 μ s, RTG=0 μ s, DL/UL usage ratio= 0.5					
DL TDD ratio DL/(DL+UL)					0.25, 0.38, 0.5, 0.75, 0.78, 0.89						0.25, 0.38, 0.5, 0.75, 0.78, 0.89					
OFDM Symbol total duration	114.3				83.3						166.7					
OFDM Symbols per frame- DL+UL	85				108						54					
Total symbols per second (Msymbol/s)	0.7	3.6	7.1	14.3	0.8	1.9	3.2	6.5	9.7	13.0	0.8	1.9	3.2	6.5	9.7	13.0
Reference symbols (pilots) as % of total symbols- DL	14.3%				5.6%						11.1%					
Average control symbols as % of total symbols-DL	6.9%				16.7%						16.7%					
Reference symbols (pilots) as % of total symbols- UL	33.3%				16.7%						33.3%					
Average control symbols as % of total symbols-UL	4.6%				8.3%						8.3%					
TDD transition	1.8%				5.0%						5.0%					
FEC overhead	20.0%				20.0%						20.0%					
Wireless layer MAC overhead	5.0%				5.0%						5.0%					
Total data Symbols per second- DL+UL (Msymbol/s)	0.4	2.0	4.0	7.9	0.5	1.1	1.9	3.8	5.6	7.5	0.4	1.0	1.6	3.2	4.8	6.4

Framing

Framing	WiMAX 802.16e-2005 Scalable OFDM				LTE 3GPP TS 36.104						LTE 3GPP TS 36.104					
	OFDMA				OFDMA						OFDMA					
Channel Bandwidth (MHz)	1.3	5.0	10.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0
Duplex	TDD				FDD						FDD MBSFN					
Frame duration (ms)	2, 2.5, 4, 5, 8, 10, 12.5, 20				10						10					
TDD sub-frame duration (ms)	flexible				5, 10						5, 10					
Sub-frame duration (ms)					1						1					
Slot duration (ms)					0.5						0.5					
Example	$T_f=10$ ms, CP=0.25, TTG/GP=180 μ s, RTG=0 μ s, DL/UL usage ratio=0.51, PUSC				$T_f=10$ ms, CP=0.25, TTG/GP=180 μ s, RTG=0 μ s, DL/UL usage ratio=0.5						$T_f=10$ ms, CP=0.25, TTG/GP=180 μ s, RTG=0 μ s, DL/UL usage ratio=0.5					
DL TDD ratio DL/(DL+UL)					0.25, 0.38, 0.5, 0.75, 0.78, 0.89						0.25, 0.38, 0.5, 0.75, 0.78, 0.89					
OFDM Symbol total duration	114.3				83.3						166.7					
OFDM Symbols per frame-DL+UL	85				108						54					
Total symbols per second (Msymbol/s)	0.7	3.6	7.1	14.3	0.8	1.9	3.2	6.5	9.7	13.0	0.8	1.9	3.2	6.5	9.7	13.0
Reference symbols (pilots) as % of total symbols-DL	14.3%				5.6%						11.1%					
Average control symbols as % of total symbols-DL	6.9%				16.7%						16.7%					
Reference symbols (pilots) as % of total symbols-UL	33.3%				16.7%						33.3%					
Average control symbols as % of total symbols-UL	4.6%				8.3%						8.3%					
TDD transition	1.8%				5.0%						5.0%					
FEC overhead	20.0%				20.0%						20.0%					
Wireless layer MAC overhead	5.0%				5.0%						5.0%					
Total data Symbols per second-DL+UL (Msymbol/s)	0.4	2.0	4.0	7.9	0.5	1.1	1.9	3.8	5.6	7.5	0.4	1.0	1.6	3.2	4.8	6.4
Maximum data capacity-DL+ UL (Mbit/s)	2.4	11.9	23.7	47.4	2.7	6.8	11.3	22.6	33.9	45.1	2.3	5.8	9.6	19.3	28.9	38.6
Spectral Efficiency TDD (bits/Hz)																
Maximum DL	2.1	2.6	2.6	2.6	2.2	2.5	2.5	2.5	2.5	2.5	2.0	2.3	2.3	2.3	2.3	2.3
Average DL	0.7	0.9	0.9	0.9	0.7	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.8
Maximum UL	1.7	2.0	2.0	2.0	2.1	2.4	2.4	2.4	2.4	2.4	1.9	2.2	2.2	2.2	2.2	2.2
Average UL	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.6	0.7	0.7	0.7	0.7	0.7

Resource Blocks

Table 15.13. WiMAX Scalable and LTE Resource Blocks

	WiMAX 802.16e-2005 Scalable OFDM				LTE 3GPP TS 36.104						LTE 3GPP TS 36.104					
	OFDMA				OFDMA						OFDMA					
Channel Bandwidth (MHz)	1.3	5.0	10.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0
Resource Blocks (sub-channel)	PUSC-DL										MBSFN					
Resource Block subcarriers	14	14	14	14	12	12	12	12	12	12	24	24	24	24	24	24
Resource Block Bandwidth (kHz)	153.1	153.1	153.1	153.1	180						180					
Resource Block Symbols	4	4	4	4	6	6	6	6	6	6	6	6	6	6	6	6
Resource Block slots					1	1	1	1	1	1	1	1	1	1	1	1
Number of Resource blocks in bandwidth	8	32	65	130	6	15	25	50	75	100	6	15	25	50	75	100
Number of Resource Blocks per frame	27	27	27	27	20	20	20	20	20	20	20	20	20	20	20	20
Total Resource Blocks	216	864	1755	3510	120	300	500	1000	1500	2000	120	300	500	1000	1500	2000
Reference signal symbols per resource block	8	8	8	8	4	4	4	4	4	4	8	8	8	8	8	8
Data symbols per resource block	48	48	48	48	68	68	68	68	68	68	136	136	136	136	136	136

Maximum Throughput and Spectral Efficiency

Table 15.17. WiMAX Scalable and LTE Maximum Throughput and Spectral Efficiency

Throughput and Spectral Efficiency	WiMAX 802.16e-2005 Scalable OFDM				LTE 3GPP TS 36.104						LTE 3GPP TS 36.104					
	OFDMA				OFDMA						OFDMA					
Channel Bandwidth (MHz)	1.3	5.0	10.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0	1.4	3.0	5.0	10.0	15.0	20.0
	TDD				FDD						MBSFN FDD					
Frame duration (ms)	2, 2.5, 4, 5, 8, 10, 12.5, 20				10						10					
Sub-frame duration (ms)					1						1					
Slot duration (ms)					0.5						0.5					
Example	Tf=10 ms, CP=25%, 64QAM 5/6, PUSC				Tf=10 ms, CP=25%, 64QAM 5/6						Tf=10 ms, CP=25%, 64QAM 5/6					
OFDM Symbol total duration	114.3				83.3						166.7					
OFDM symbols per slot					6						3					
OFDM Symbols per frame	87				120						60					
Total symbols per second (Msymbol/s)	0.7	3.7	7.3	14.6	0.9	2.2	3.6	7.2	10.8	14.4	0.9	2.2	3.6	7.2	10.8	14.4
Reference symbols (pilots) as % of total symbols-DL	14.3%				5.6%						11.1%					
Average control symbols as % of total symbols-DL	6.9%				16.7%						16.7%					
Reference symbols (pilots) as % of total symbols-UL	33.3%				16.7%						33.3%					
Average control symbols as % of total symbols-UL	4.6%				8.3%						8.3%					
FEC overhead	20.0%				20.0%						20.0%					
Wireless layer MAC overhead	5.0%				5.0%						5.0%					
Total data symbols per second- DL (Msymbol/s)	0.4	2.2	4.3	8.6	0.5	1.3	2.1	4.2	6.3	8.4	0.5	1.2	2.0	3.9	5.9	7.8
Maximum data capacity- DL (Mbit/s)	2.6	13.0	25.9	51.9	3.0	7.6	12.6	25.2	37.8	50.4	2.8	7.0	11.7	23.4	35.1	46.8
Total data symbols per second- UL (Msymbol/s)	0.3	1.7	3.4	6.8	0.5	1.2	2.0	4.1	6.1	8.1	0.4	1.1	1.8	3.6	5.5	7.3
Maximum data capacity- UL (Mbit/s)	2.1	10.2	20.4	40.8	2.9	7.3	12.2	24.3	36.5	48.6	2.6	6.6	10.9	21.8	32.8	43.7
Spectral Efficiency FDD (bits/Hz)																
Maximum DL	2.1	2.6	2.6	2.6	2.2	2.5	2.5	2.5	2.5	2.5	2.0	2.3	2.3	2.3	2.3	2.3
Average DL	0.7	0.9	0.9	0.9	0.7	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.8
Maximum UL	1.7	2.0	2.0	2.0	2.1	2.4	2.4	2.4	2.4	2.4	1.9	2.2	2.2	2.2	2.2	2.2
Average UL	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.6	0.7	0.7	0.7	0.7	0.7

Pilot and Control to Data Symbol Ratio

Table 15.18. Pilot to data or symbol ratio

Pilot to data or Symbol ratio	P/D	P/S	P/S
LTE DL (2/36)	0.0588235	0.0555556	5.6%
LTE UL (1/6)	0.2	0.1666667	16.7%
FUSC	0.108	0.0974729	9.7%
OFUSC/AMC DL	0.125	0.1111111	11.1%
PUSC	0.167	0.143102	14.3%
PUSC UL	0.5	0.3333333	33.3%
OPUSC UL	0.125	0.1111111	11.1%
AMC UL	0.125	0.1111111	11.1%
WLAN	0.0833333	0.0754717	7.5%

Table 15.19. Control to Total Symbols ratio

Control to total Symbols ratio		
WiMAX OFDM DL	0.045977	4.6%
WiMAX OFDM UL	0.0344828	3.4%
WiMAX OFDMA DL	0.0689655	6.9%
WiMAX OFDMA UL	0.045977	4.6%
LTE DL	0.1666667	16.7%
LTE UL	0.0833333	8.3%