Summary introduction to Wireless LTE* 4G architecture and key business implications

*: LTE: Long term evolution

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HISTORICAL EVOLUTION

ORIGINS OF WIRELESS COMMUNICATIONS: From electromagnetics to digitization and IP

- 1864: James Clark Maxwell
  - Predicts existence of radio waves
- 1886: Heinrich Rudolph Hertz
  - Demonstrates radio waves
- 1895-1901: Guglielmo Marconi
  - Demonstrates wireless communications over increasing distances
- Also in the 1890s: Nikola Tesla, Alexander Stepanovich Popov, Jagdish Chandra Bose and others, demonstrate forms of wireless communications
- Since early 1900’s: development of broadcast radio, and later TV
- World war 2: two-way radio in closed networks (esp. defense)
- 1972- : NMT development to cater for telephony for nomadic populations in Scandinavia
- 1982- : Use of digital coding, modulation and communications
- 2009: Launch of first 4G LTE commercial networks in Scandinavia

1st MOBILE RADIO TELEPHONE 1924

Courtesy of Rich Howard

WARC 2004: WIRELESS COMMUNICATIONS SPECTRUM

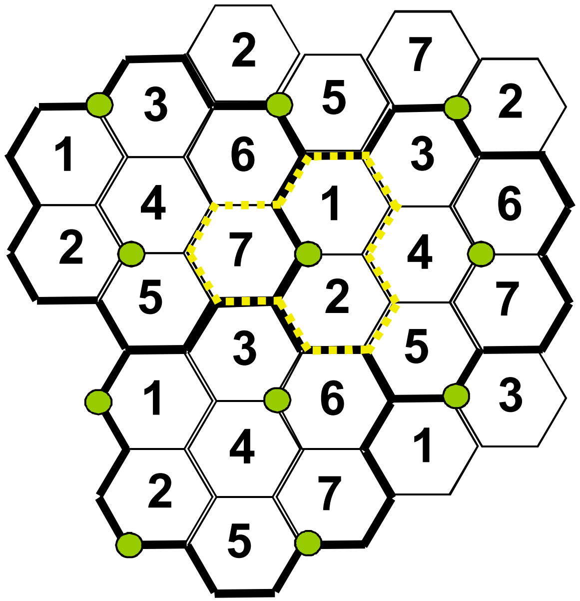
Bands	Frequencies (MHz)	Regions	GSM/ EDGE	UMTS/ 3GSM	CDMA 2000	TD-SCDMA
NMT/CDMA 450	460-493	EU, global			X	
GSM 450	450-467	EU, global	X			
GSM480	478-496	EU, global	X			
GSM 850 & CDMA 850	869-894	US	X		X	
GSM 900	925-960	EU, global	X			
DCS 1800	1805-1880	EU, global	X			
PCS 1900	1930-1990	US	X	X	X	
IMT 2000	1920-1980 & 2110-2170	EU, global		X		
China 3G	1880-1920 & 2010-2025 & 2300-2400	China				X
AWS	1710-1755 & 2110-2155	US		X	X	
700 MHz	746-764 & 776-794	US		X	X	
ITU Proposal	2500-2690	EU, global		X		

RADIO SPECTRUM (communications)

Frequency	Usage	Remarks
1 MHz-500 MHz	Government use	
450-470 MHz	NMT (disapearing) , CDMA or GSM	
470-862 MHz	Analog TV, Govt.,Digital TV or 3G : ”DIGITAL DIVIDEND” →LTE	
800 MHz	Mobitex USA	
900 MHz	GSM, Mobitex EU	
806-960 MHz	GSM 900 EU+Asia, CDMA,GSM 800 , TDMA US, PDC Japan, UWB	
960 -1710 MHz	Governement use: aircraft, GPS, satellite, radar	
1710 -1880 MHz	GSM 1800 EU , Asia and Brazil	
1880-1900 MHz	DECT	
1900-2010 MHz	CDMA, GSM 1900 , TDMA US	
1980-2010 MHz	Satellite	
1710-1770 MHz	Uplink free US	
1920-1980 MHz	Uplink EU+Asia	
2110-2170 MHz	Short range free	
2400-2483 MHz	Bluetooth, UWB	
2480-2500 MHz	Global star satellite telephony	
2500-3200 MHz	Government; 2600 MHz band for LTE ?	
3200-6000 GHz	C band and military radar	
5150-5825 MHz	WLAN	
6000-	Government	
7000-38 000 MHz	Minilink microwavelinks	

CELLULAR MOBILE TELEPHONY

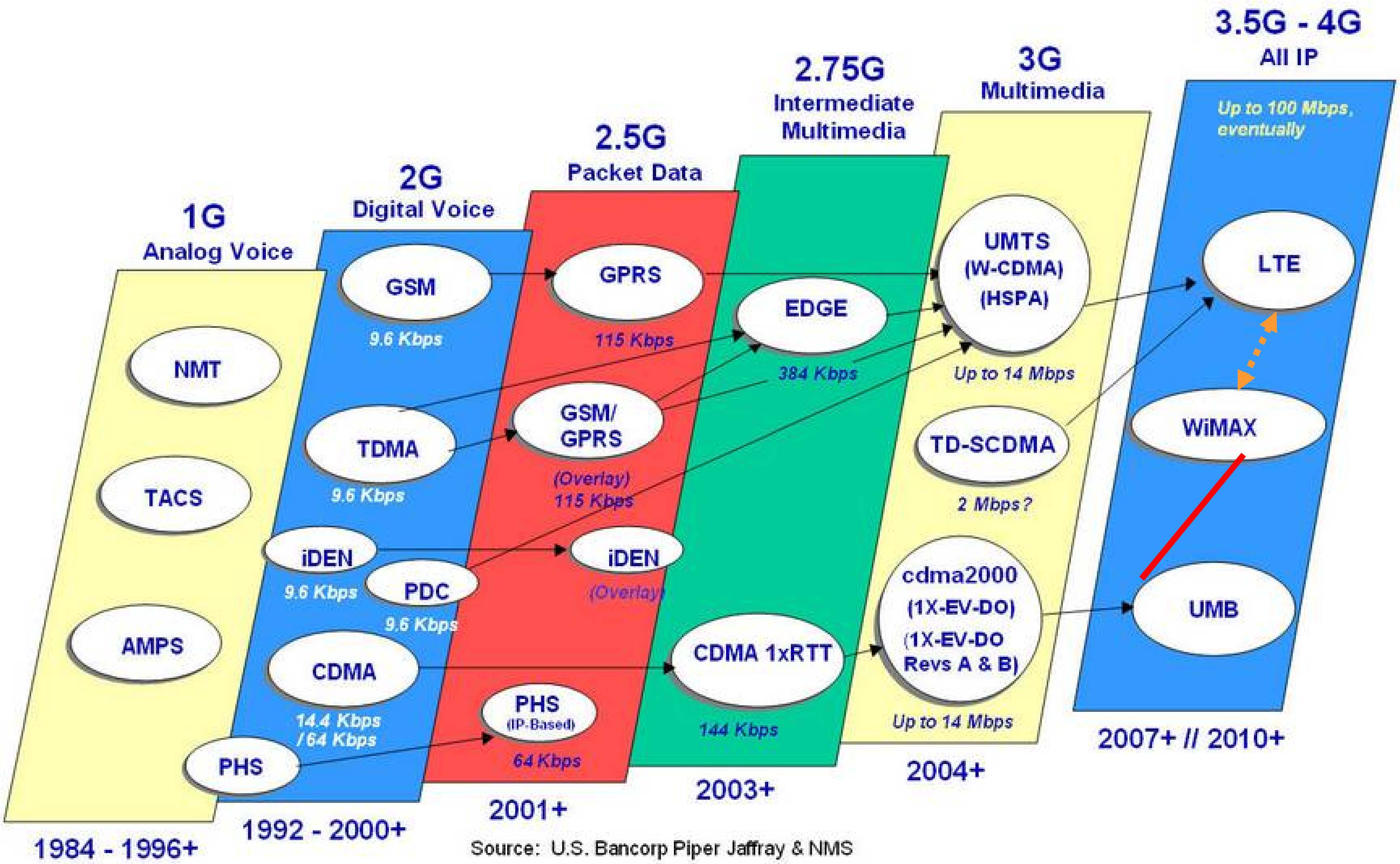
- Antenna diversity
- Cellular concept
  - Bell Labs (1957 & 1960)
- Frequency reuse
  - typically every 7 cells
- Handoff as caller moves
- Core network
  - Central Switch, HLR, handover
- Sectors improve reuse
  - every 3 cells possible



WIRELESS TECHNOLOGY GENERATIONS

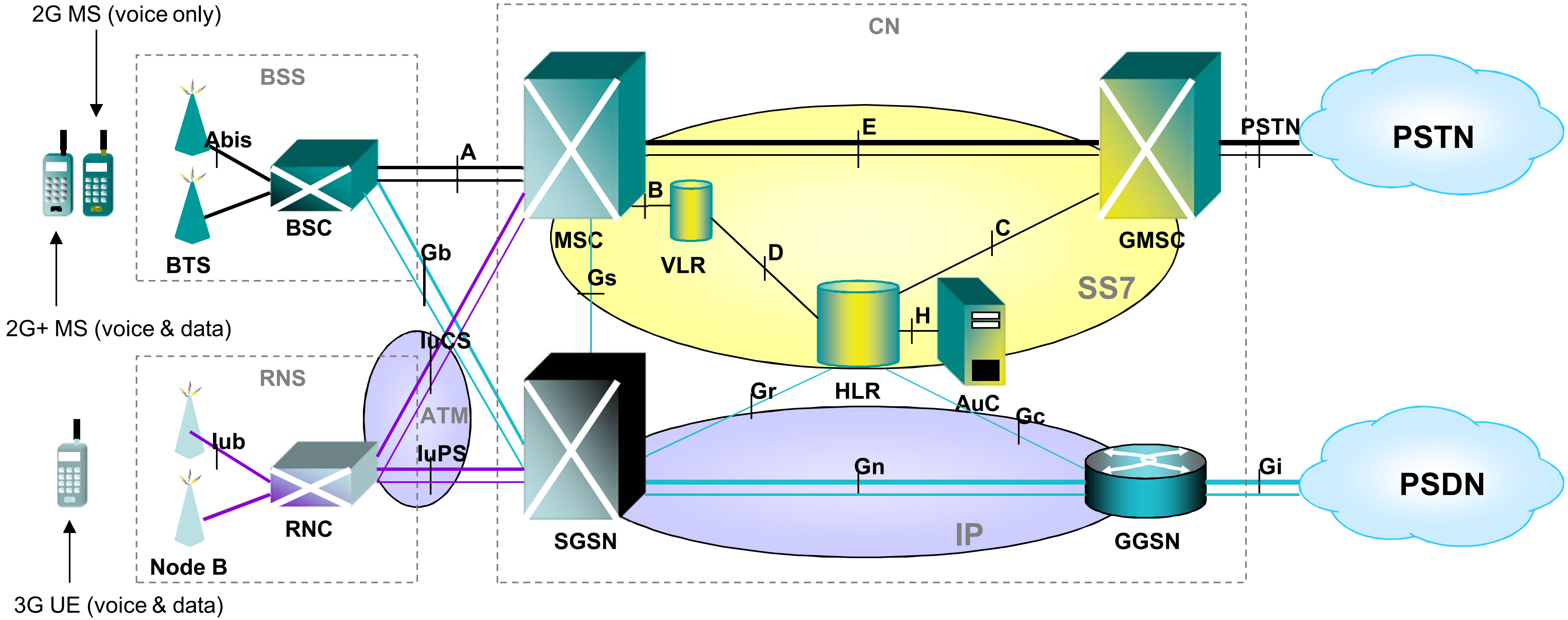
G	Key aspects	Data Rates
1	Analog	Typical 2.4 Kbps; max 22 Kbps
2	Digital – TDMA, CDMA	9.6 - 14.4 Kbps (circuit data)
2.5	GPRS – mux packets in voice timeslots	15 - 40 Kbps
3	Improved modulation, using CDMA variants	50 – 144 Kbps (1xRTT); 200 – 384 Kbps (UMTS); 500 Kbps – 2.4 Mbps (EVDO)
3.5	More modulation tweaks	2–14 Mbps (HSPA), then 28 Mbps & 42/84 Mbps HSPA+ evolution
4	New modulation (OFDMA); Multi-path (MIMO); All IP	LTE: >100 Mbps with adequate spectrum (15 or 20 MHz)

WIRELESS TECHNOLOGY MIGRATION



Source: U.S. Bancorp Piper Jaffray & NMS

3G release 1999 Architecture (UMTS)



BSS Base Station System

BTS Base Transceiver Station

BSC Base Station Controller

RNS Radio Network System

RNC Radio Network Controller

CN Core Network

MSC Mobile-service Switching Controller

VLR Visitor Location Register

HLR Home Location Register

AuC Authentication Server

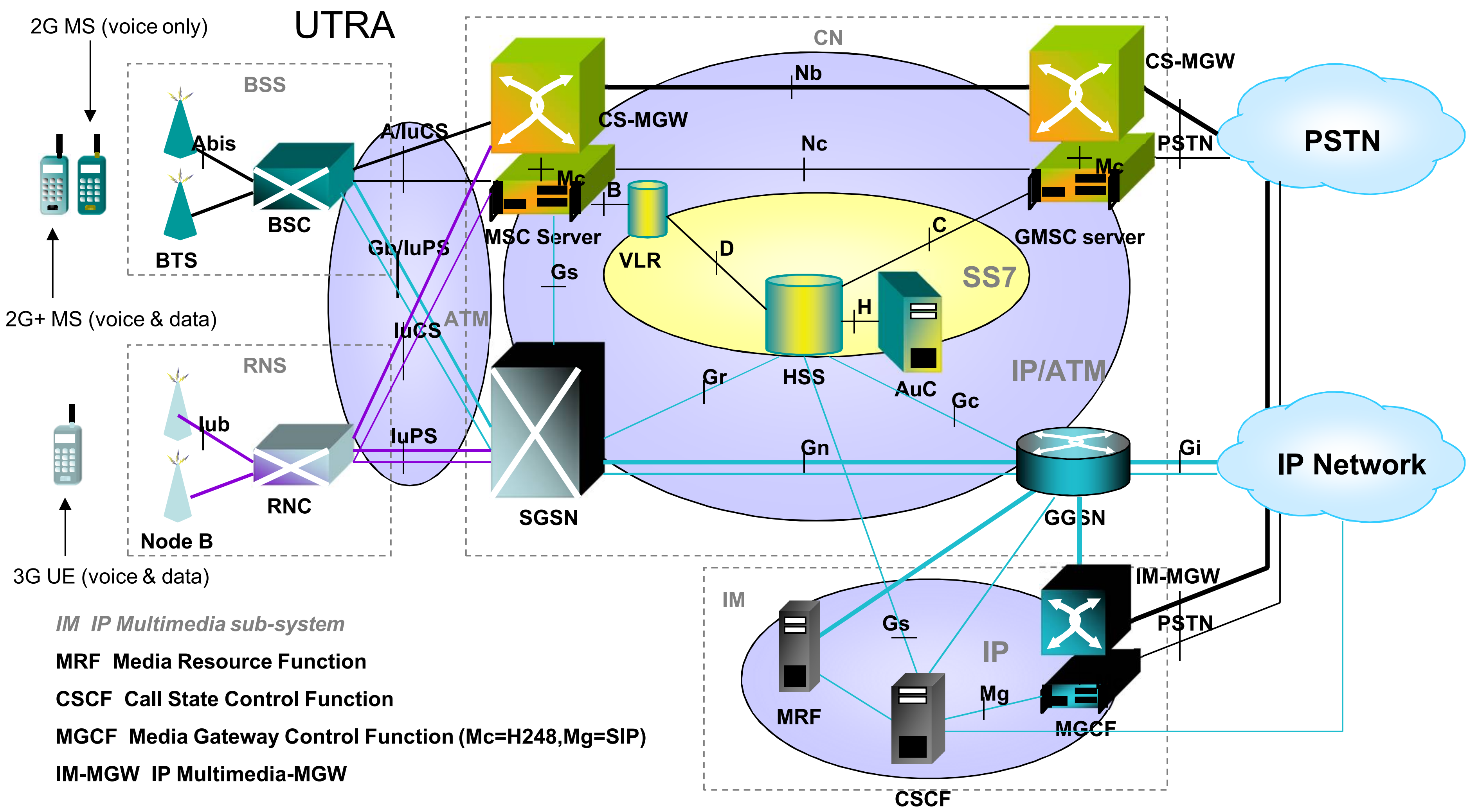
GMSC Gateway MSC

SGSN Serving GPRS Support Node

GGSN Gateway GPRS Support Node

UMTS Universal Mobile Telecommunication System

3GPP release 5 — IP Multimedia



IM IP Multimedia sub-system

MRF Media Resource Function

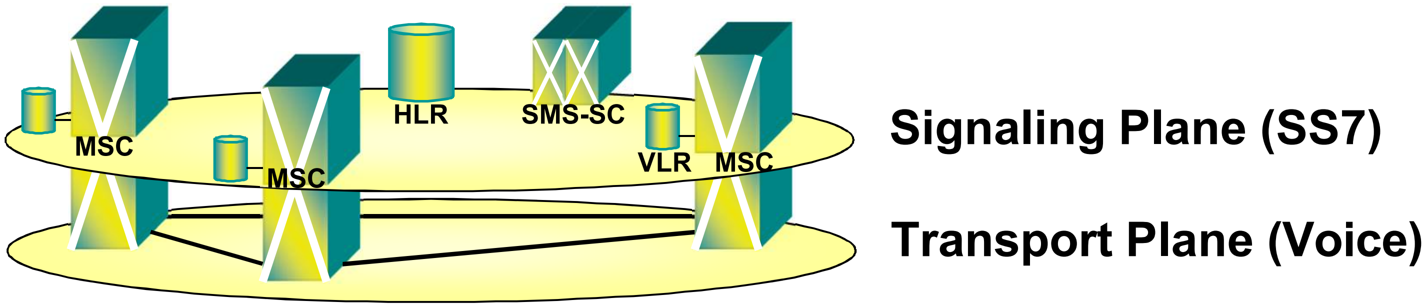
CSCF Call State Control Function

MGCF Media Gateway Control Function (Mc=H248,Mg=SIP)

IM-MGW IP Multimedia-MGW

SEPARATION OF SIGNALLING AND TRANSPORT

- Like circuit switched telephony networks, 2G/3G mobile networks have one network plane for voice circuits and another network plane for signaling
- Some elements reside only in the signaling plane
  - HLR, VLR, SMS Center, …



MAIN 3 G LIMITATIONS

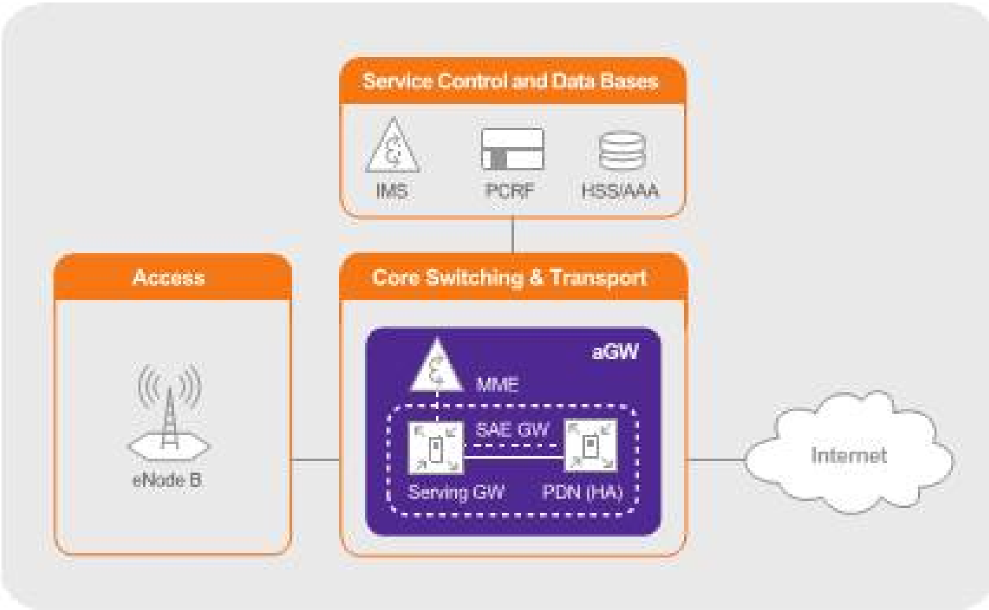
- 1. The maximum bit rates were still a factor of 10 and more behind the simultaneous state of systems like IEEE 802.11n and 802.16e/m.
- 2. The latency of user plane traffic (UMTS: >30 ms) and of resource assignment procedures (UMTS: >100 ms) is too big to handle traffic with high bit rate variance efficiently.
- 3. The UE terminal complexity for WCDMA or CDMA systems is quite high, making terminals expensive, resulting in poor performing implementations of receivers and inhibiting the implementation of other performance enhancements.

INITIAL LTE WORK (from 2002)

- LTE focus was on:
  - enhancement of the Universal Terrestrial Radio Access (UTRA)
  - optimisation of the UTRAN Network Architecture
- With HSPA (downlink and uplink), keep UTRA highly competitive for several years
- Access and bandwidth will be commodities; services are the differentiator
  - Per-session control supports per-application quality of service (QoS) and per-application billing
- Voice should “just” be one application integrated with others

LTE ARCHITECTURE and ATTRIBUTES

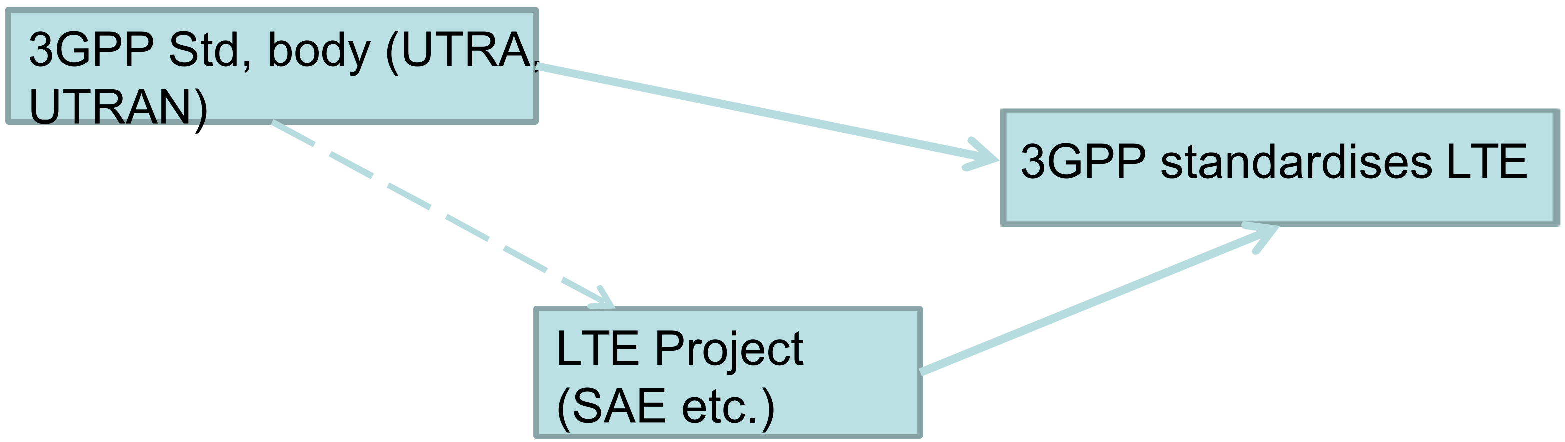
SIMPLIFIED LTE ARCHITECTURE



eNodeB: Evolved node-B
AGE: Access gateway entity
EPC: Enhanced packet core
IMS: IP Multimedia system
PCRF: Policy and charging function
HSS: Home subscriber server
MME: Mobile management entity
SAE: System architecture evolution

FROM HSPA TO 3GPP LTE and System architecture evolution (SAE)

- 3GPP (GSC 11) Work plan worked on evolving HSPA to HSPA+ with improvements (HSDPA and HSUPA) and connectivity to the SAE defined under LTE work.
- This preserved improvements for latency (protocol evolution and functional split), but had constraints in terms of support for legacy terminals and hardware changes.



LTE GOALS

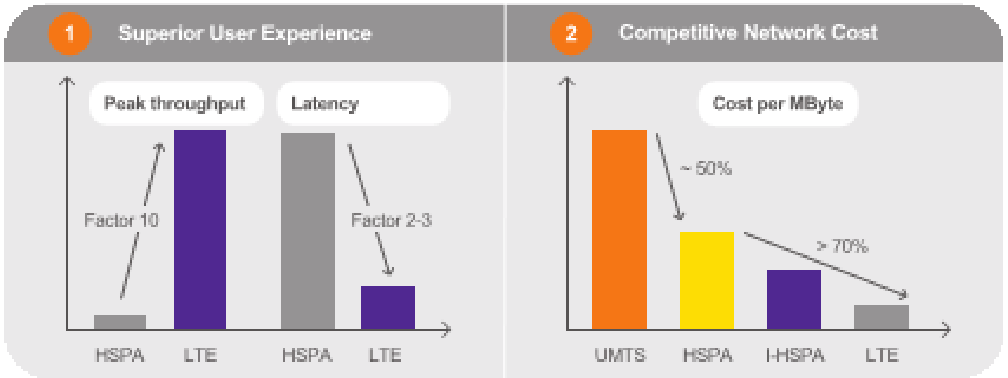
- Evolutionary ladder beyond HSPA, called Long Term Evolution /System Architecture Evolution (LTE/SAE) towards ubiquitous mobile broadband
- Make the most of scarce spectrum resources: Deployable in paired spectrum allocations with bandwidths ranging from 1.4 MHz to 20 MHz, LTE/SAE to provide up to four times the spectral efficiency of HSDPA Release 6
- Deliver peak user data rates ranging up to 173 Mbps and reduce latency as low as 10 ms
- Leverage flat all-IP network architecture
- Leverage a new air interface to significantly cut per-Mbyte costs, with later improvements: e.g. a 4x4 Multiple Input/ Multiple Output (MIMO) scheme to boost downlink rates to 326 Mbps

LTE BUSINESS GAINS

- Significantly increased peak data rates, scaled linearly according to spectrum allocation
- Instantaneous downlink peak data rate of 100Mbit/s in a 20MHz downlink spectrum (i.e. 5 bit/s/Hz)
- Instantaneous uplink peak data rate of 50Mbit/s in a 20MHz uplink spectrum (i.e. 2.5 bit/s/Hz)

- Expectations of additional 3G spectrum allocations
- Greater flexibility in frequency allocations
- No native support for circuit switching domain (e.g. voice)
- Continued cost reduction
- Keeping up with other (including unlicensed) technologies (eg. WiMAX)
- Use the growing experience with the take-up of 3G to clarify the likely requirements of users, operators and service providers in the longer term

LTE vs. HSPA USER and OPERATOR BENEFITS



WiFi OFF-LOAD

- Approx. 30-40 % of LTE usage will be from home / office
- Thus, UE must support transparent off-load to home WiFi , or to WiFi in neighboring sites (lightpoles on roads, etc.)

LTE Femtocells

- Another off-loading is via LTE eNodeB Femtocells (compliant with 3GPP Releases 8/9 and including L2/L3 stacks)
- Performances: 1 ms TTI for handover , >100 Mbps , at low power location determination with 0,5 m accuracy
- Specific functionality :automatic neighbor relations, SON, mobile load balancing , closed subscriber group options, LIPA, hybrid mobility and inbound mobility, network management for small cell networks
- Example suppliers: Tata Elxsi ; see Femto Forum
- Business concepts: 1) off-load 2) closed groups 3) social femto which combines location info with Twitter for check-in etc

HSPA /WiMAX /Early 4G COMPARISON

	Peak Data Rate (Mbps)		Access time (msec)
	Downlink	Uplink	
HSPA (today)	14 Mbps	2 Mbps	50-250 msec
HSPA (Release 7) MIMO 2x2	28 Mbps	11.6 Mbps	50-250 msec
HSPA + (MIMO, 64QAM Downlink)	42 Mbps	11.6 Mbps	50-250 msec
WiMAX Release 1.0 TDD (2:1 UL/DL ratio), 10 MHz channel	40 Mbps	10 Mbps	40 msec
LTE (Release 8), 5+5 MHz channel	43.2 Mbps	21.6 Mbps	30 msec

KEY TECHNOLOGIES

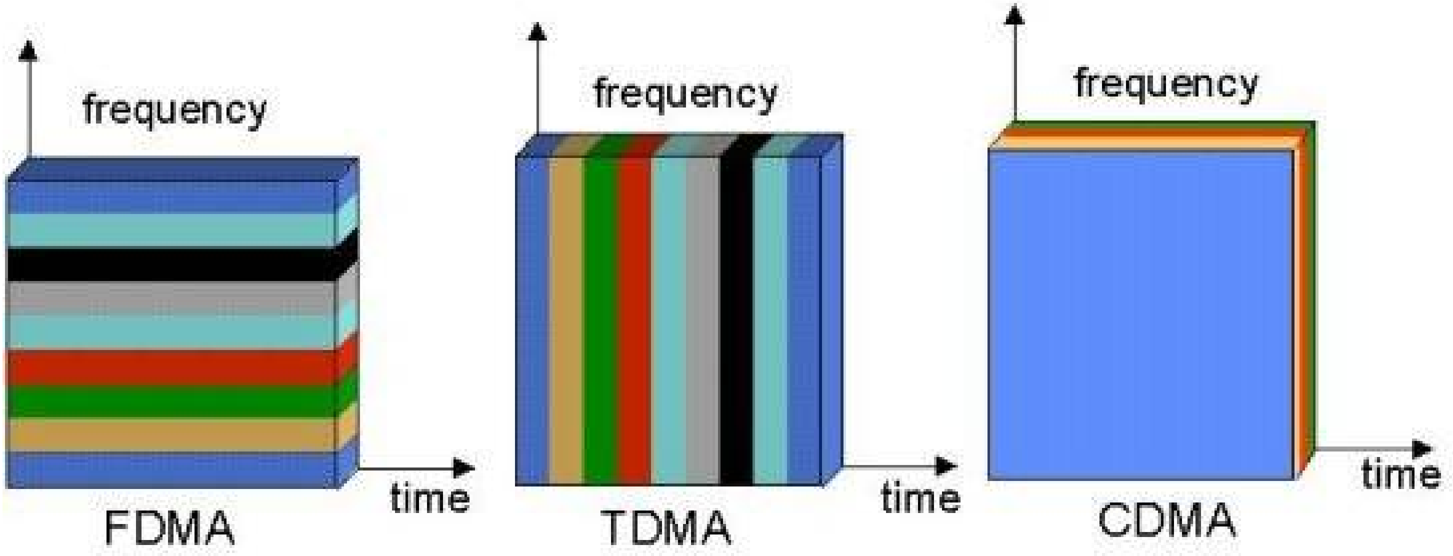
INITIAL KEY LTE DESIGN CHARACTERISTICS

- Sophisticated multiple access schemes
  - DL: OFDMA with Cyclic Prefix (CP)
  - UL: Single Carrier FDMA (SC-FDMA) with CP
- Adaptive modulation and coding
  - QPSK, 16QAM, and 64QAM
  - 1/3 coding rate, two 8-state constituent encoders, and a contention-free internal inter-leaver
- Advanced MIMO spatial multiplexing
  - (2 or 4) x (2 or 4) downlink and uplink

MAIN LTE ARCHITECTURAL ITEMS

- Modulation, coding
- System architecture (SAE and evolution)
- Evolved Node-B
- Multiple input-multiple output (MIMO) transceivers
- Other antenna techniques
- Radio links and protocols
- IP Multimedia system (IMS)
- Voice support
- Multimedia broadcast
- Transport and scheduling

1G, 2G, 3G MULTI-ACCESS TECHNOLOGIES

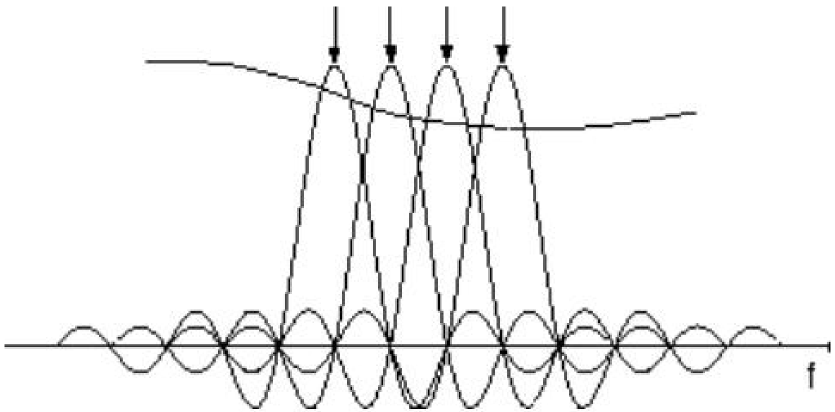


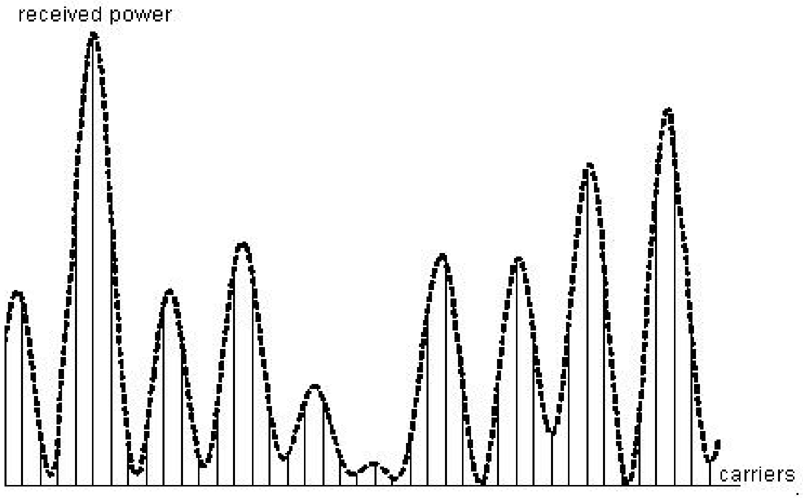
4G and future wireless systems optimize a combination of frequency, time and coding e.g. OFDMA & SC-FDMA

FDMA: frequency domain multiple access
TDMA: time domain multiple access
CDMA: code domain multiple access

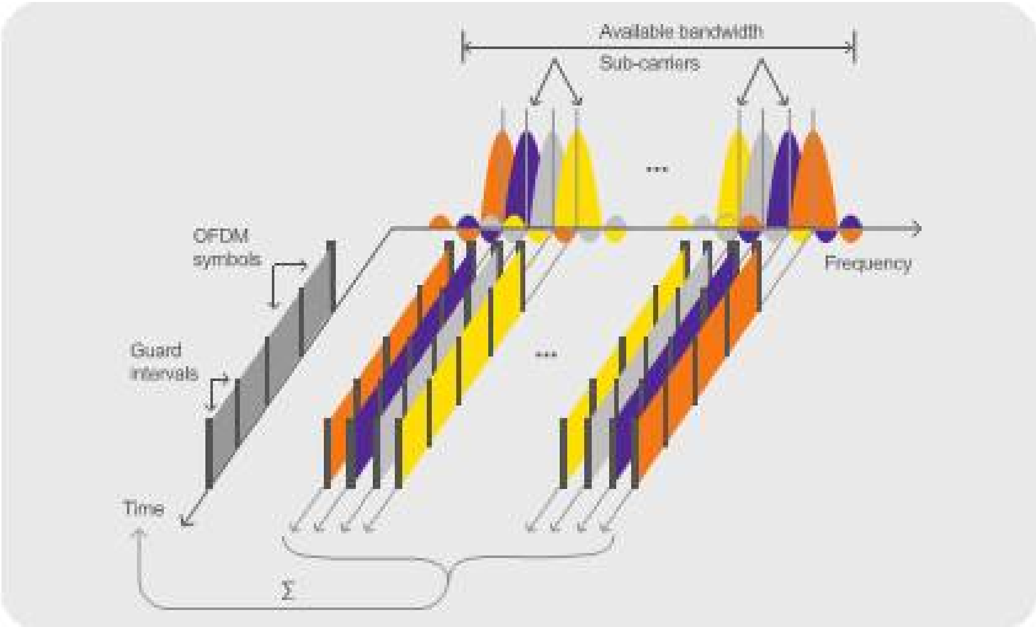
OFDM: ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

- Many closely-spaced sub-carriers, chosen to be orthogonal, thus eliminating inter-carrier interference
- Varies bits per sub-carrier based on instantaneous received power



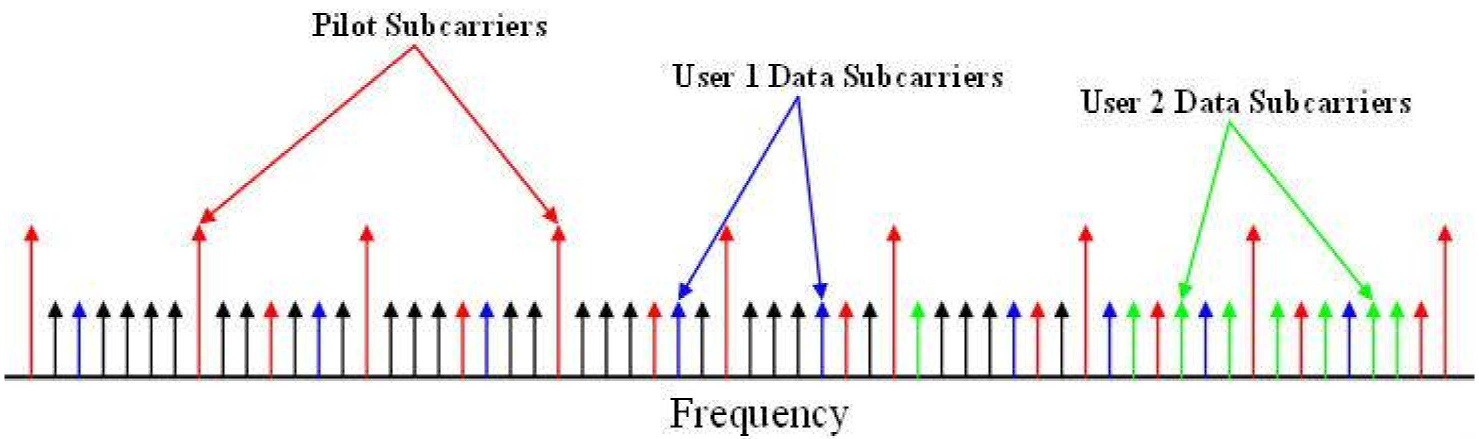


LTE OFDM MULTIPLEXING



STATISTICAL MULTIPLEXING (in OFDMA)

- Dynamically allocates user data to sub-carriers based on instantaneous data rates and varying sub-carrier capacities
- Highly efficient use of spectrum
- Robust against fading, e.g. for mobile operation

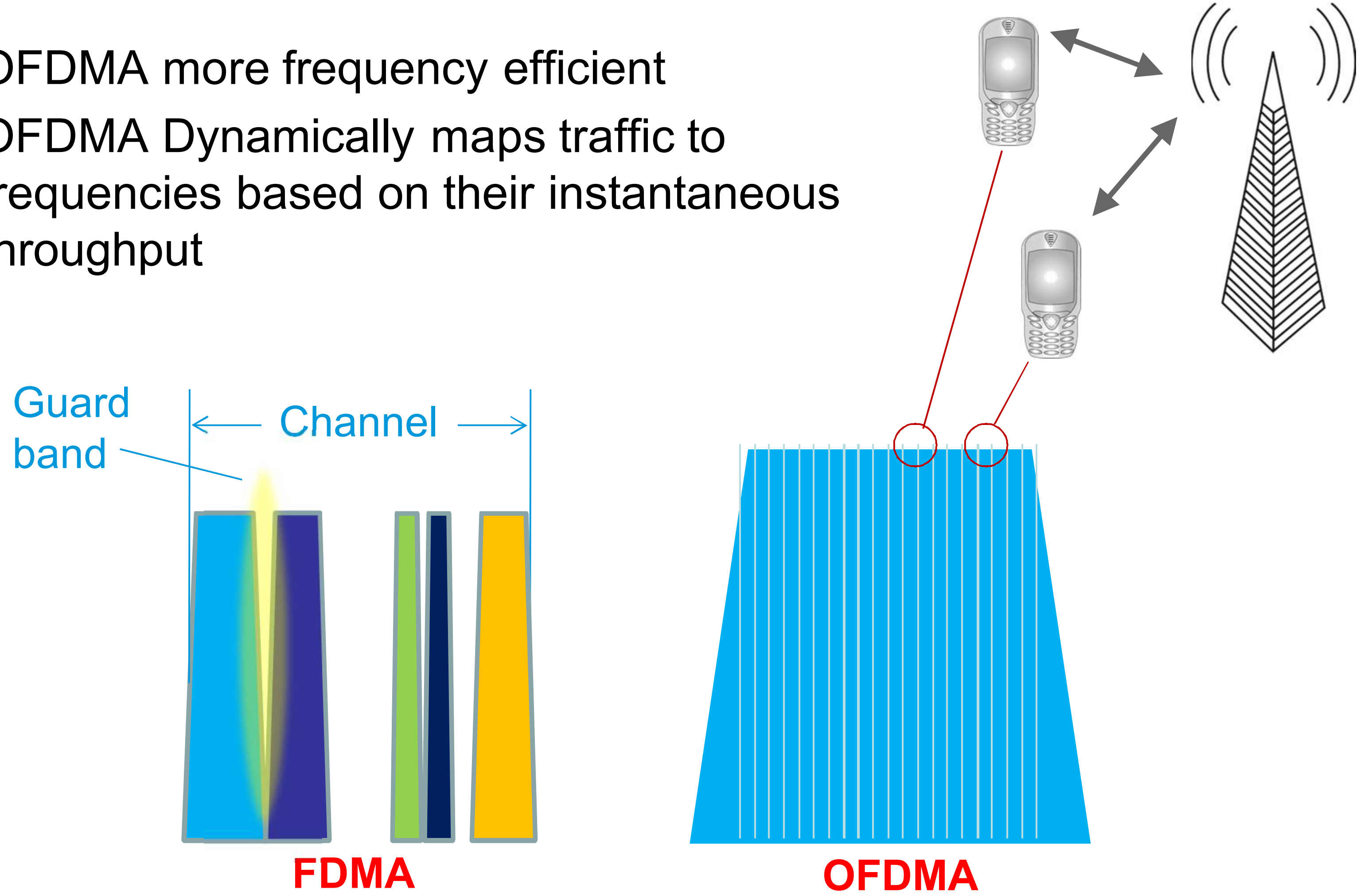


OFDMA (ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS)

- Orthogonal Frequency Division Multiple Access
  – Supercedes CDMA used in all 3G variants
- OFDMA = Orthogonal Frequency Division Multiplexing (OFDM) plus statistical multiplexing
  – Optimization of time, frequency & code multiplexing
- OFDMA already deployed in 802.11a & 802.11g
  – Took Wi-Fi from 11 Mbps to 54 Mbps & beyond

FREQUENCY DOMAIN FDMA vs. ORTHOGONAL FREQUENCY DOMAIN OFDMA MULTIPLE ACCESS

- OFDMA more frequency efficient
- OFDMA Dynamically maps traffic to frequencies based on their instantaneous throughput



SC-FDMA: SINGLE CARRIER FREQUENCY DIVISION MULTIPLE ACCESS

- Single carrier multiple access
  - Used for LTE uplinks
  - Being considered for 802.16m uplink
- Similar structure and performance to OFDMA
  - Single carrier modulation with DFT-spread orthogonal frequency multiplexing and FD equalization
- Lower Peak to Average Power Ratio (PAPR)
  - Improves cell-edge performance
  - Transmit efficiency conserves handset battery life

UPLINK PARAMETERS (incl. TD SCDMA framing)

Uplink Parameters

Transmission BW		1.25 MHz	2.5 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Timeslot duration		0.675 ms					
Sub-carrier spacing		15 kHz					
Sampling frequency		1.92 MHz (1/2 × 3.84 MHz)	3.84 MHz	7.68 MHz (2 × 3.84 MHz)	15.36 MHz (4 × 3.84 MHz)	23.04 MHz (6 × 3.84 MHz)	30.72 MHz (8 × 3.84 MHz)
FFT size		128	256	512	1024	1536	2048
Number of occupied sub-carriers†, ††		76	151	301	601	901	1201
Number of OFDM symbols per Timeslot (Short/Long CP)		9/8					
CP length (μs/samples)	Short	7.29/14	7.29/28	7.29/56	7.29/112	7.29/168	7.29/224
	Long	16.67/32	16.67/64	16.67/128	16.67/256	16.67/384	16.67/512
Timeslot Interval (samples)	Short	18	36	72	144	216	288
	Long	16	32	64	128	192	256

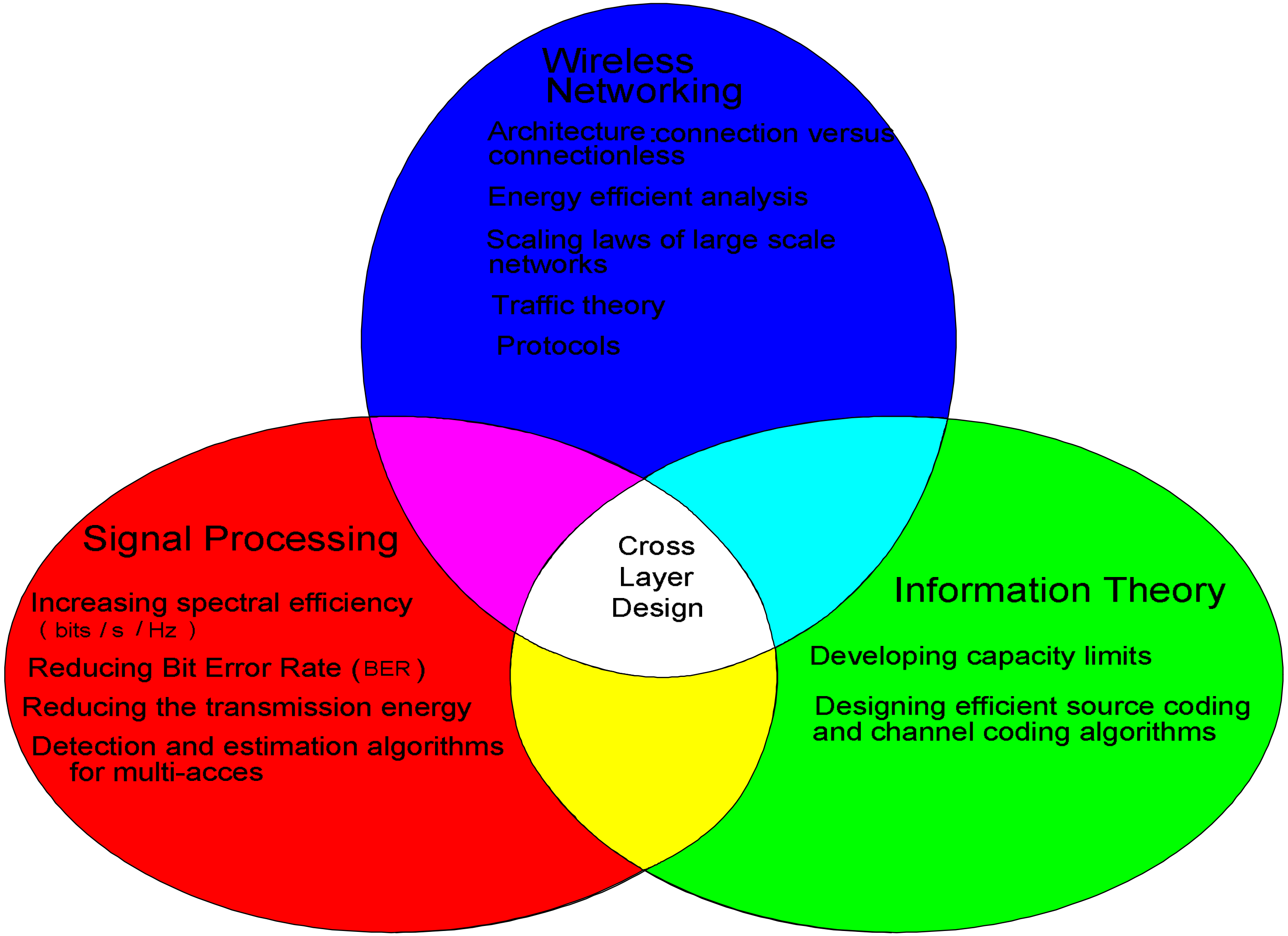
DOWNLINK OFDMA PARAMETERS

OFDMA

Transmission BW		1.25 MHz	2.5 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Sub-frame duration		0.5 ms					
Sub-carrier spacing		15 kHz					
Sampling frequency		1.92 MHz (1/2 × 3.84 MHz)	3.84 MHz	7.68 MHz (2 × 3.84 MHz)	15.36 MHz (4 × 3.84 MHz)	23.04 MHz (6 × 3.84 MHz)	30.72 MHz (8 × 3.84 MHz)
FFT size		128	256	512	1024	1536	2048
Number of occupied sub-carriers†, ††		76	151	301	601	901	1201
Number of OFDM symbols per sub frame (Short/Long CP)		7/6					
CP length (μs/samples)	Short	(4.69/9) × 6, (5.21/10) × 1*	(4.69/18) × 6, (5.21/20) × 1	(4.69/36) × 6, (5.21/40) × 1	(4.69/72) × 6, (5.21/80) × 1	(4.69/108) × 6, (5.21/120) × 1	(4.69/144) × 6, (5.21/160) ×1
	Long	(16.67/32)	(16.67/64)	(16.67/128)	(16.67/256)	(16.67/384)	(16.67/512)

SYSTEM ARCHITECTURE EVOLUTION (SAE) and CORE NETWORKS (EPC Evolved packet core)

DESIGN ARCHITECTURAL TECHNIQUES



CLD as an intersection of different disciplines

INITIAL System architecture evolution (SAE)

SAE focus was on:

- enhancement of Packet Switched technology to cope with rapid growth in IP traffic
  - higher data rates
  - lower latency
  - packet optimised system
- through
  - fully IP based network
  - simplified network architecture
  - distributed control

LTE / SAE CORE NETWORK ARCHITECTURE (EPC)

- LTE/SAE architecture is driven by the goal to optimize the system for packet data transfer supported by a packet core network
- No circuit switched components in IMS/PDN; if circuit switched applications are required, they must be implemented via IP
- New approach in the inter-connection between radio access network and core network
- The core network provides access networks and performs a number of core network related functions (e.g. QoS, security, mobility and terminal context management) for idle (camped) and active LTE-UE terminals
- The Radio access network (RAN) performs all radio interface related functions
- Non-3GPP access : the EPC will be prepared also to be used by non-3GPP access networks (e.g. LAN, WLAN, WiMAX, etc.); this will provide true convergence of different packet radio access system

SYSTEM ARCHITECTURE EVOLUTION (SAE)

- Achieving mobility within the Evolved Access System
- Implications of using the evolved access system on existing and new frequency bands
- Adding support for non-3GPP access systems
- Inter-system Mobility with the Evolved Access System
- Roaming issues, including identifying the roaming interfaces
- Inter-access-system mobility
- Policy Control & Charging
- User Equipment (Terminal) discovers Access Systems and corresponding radio cells; implications of various solutions on User Equipment, e.g. on battery life
- Implications for seamless coverage with diverse Access Systems
- Migration scenarios

LTE’s System Architecture Evolution (SAE)

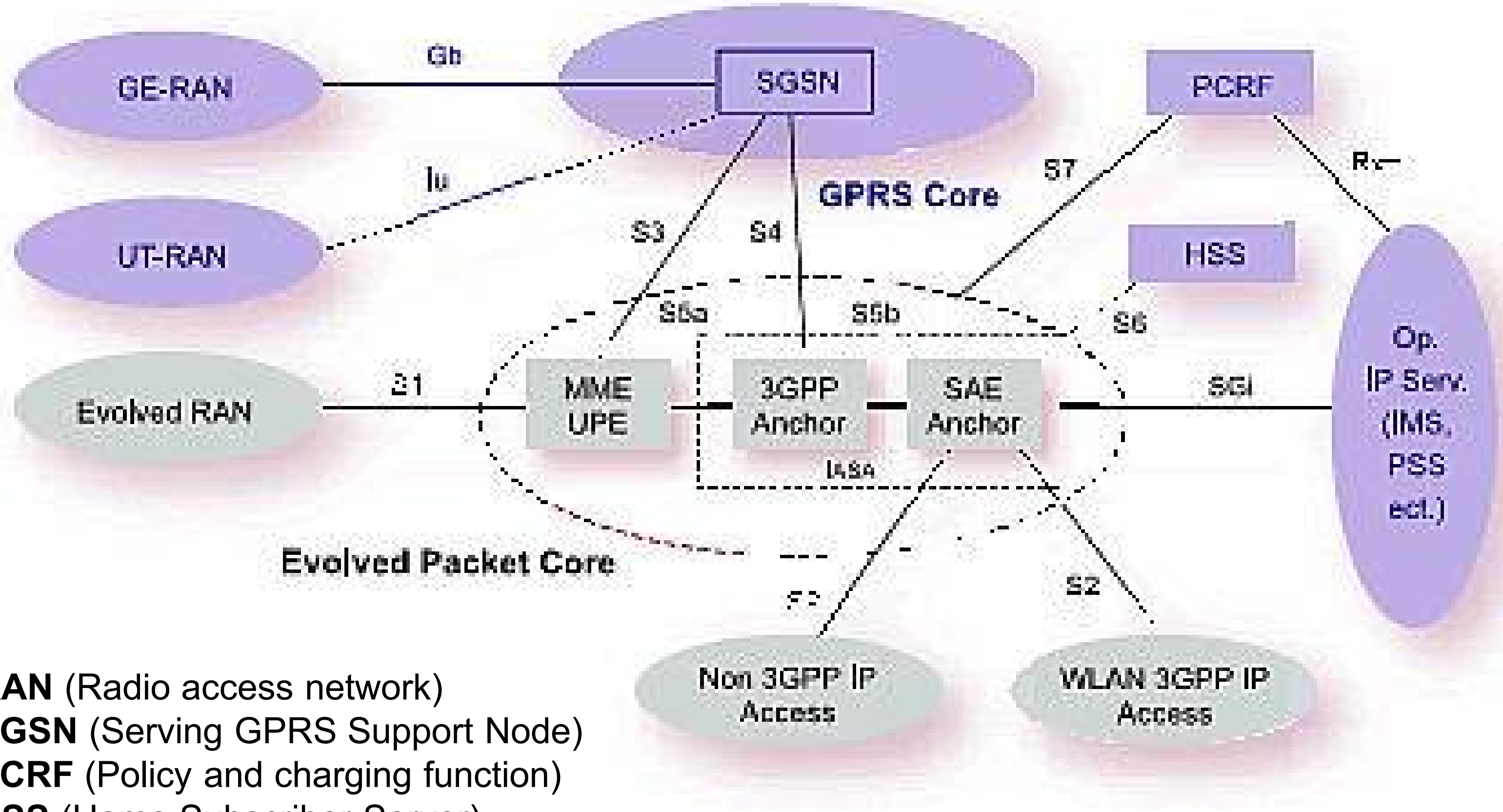


Diagram by Huawei

RAN (Radio access network)
SGSN (Serving GPRS Support Node)
PCRF (Policy and charging function)
HSS (Home Subscriber Server)
MME (Mobility Management Entity)
SAE (System Architecture Evolution)

CORE NETWORK EVOLUTION

- In addition to IP Multimedia system (IMS) available in 3G, equivalent Circuit switching Services may be provided in LTE by IMS core, since Circuit switching domain is not supported in LTE
- Mobility Management Entity and User Plan Entity might be collocated in the Access Gateway entity
- Reduced number of nodes in the evolved packet core may be achieved compared to 3G to provide connectivity to IMS

PHYSICAL LAYER

- It provides the basic bit transmission functionality over air.
- The physical layer is driven by OFDMA in the downlink and SC-FDMA in the
- uplink.
- Physical channels are dynamically mapped to the available resources

  (ph physical resource blocks and antenna ports).
- To higher layers the physical layer offers its data transmission functionality via transport channels.
- Like in UMTS, a transport channel is a block oriented transmission service with certain characteristics regarding bit rates, delay, collision risk and reliability.
- In contrast to 3G WCDMA or even 2G GSM there are no dedicated transport or physical channels anymore, as all resource mapping is dynamically driven by the scheduler

EVOLVED Node-B (eNodeB)

- No Radio Network controller (RNC) is needed anymore: eNodeB is the only network element defined as part of the radio access network UTRAN ; it is a Node-B/RNC combination (from 3G)
- eNodeB-B's take over all radio management functionality; this will make radio management faster and hopefully the network architecture simpler
- It terminates the complete radio interface incl. the physical layer, and: Access Layer Security: ciphering , integrity protection on the radio interface , Mobile management entity (MME) Selection at Attach of the UE
- It includes old Node-B functions such as: Measurements Collection and evaluation , Dynamic Resource Allocation (Scheduler) , IP Header Compression/ de-compression
- It can carry out the management for cells not attached to the same eNode-B via an inter-eNodeB interface X2; this makes possible to coordinate inter-eNode-B handovers without direct involvement of the EPC
- An eNode-B can handle several cells.
- It enables efficient inter-cell radio : User Data Routing to the SAE GW, Transmission of Paging Message coming from MME , Transmission of Broadcast Info(System info, MBMS)

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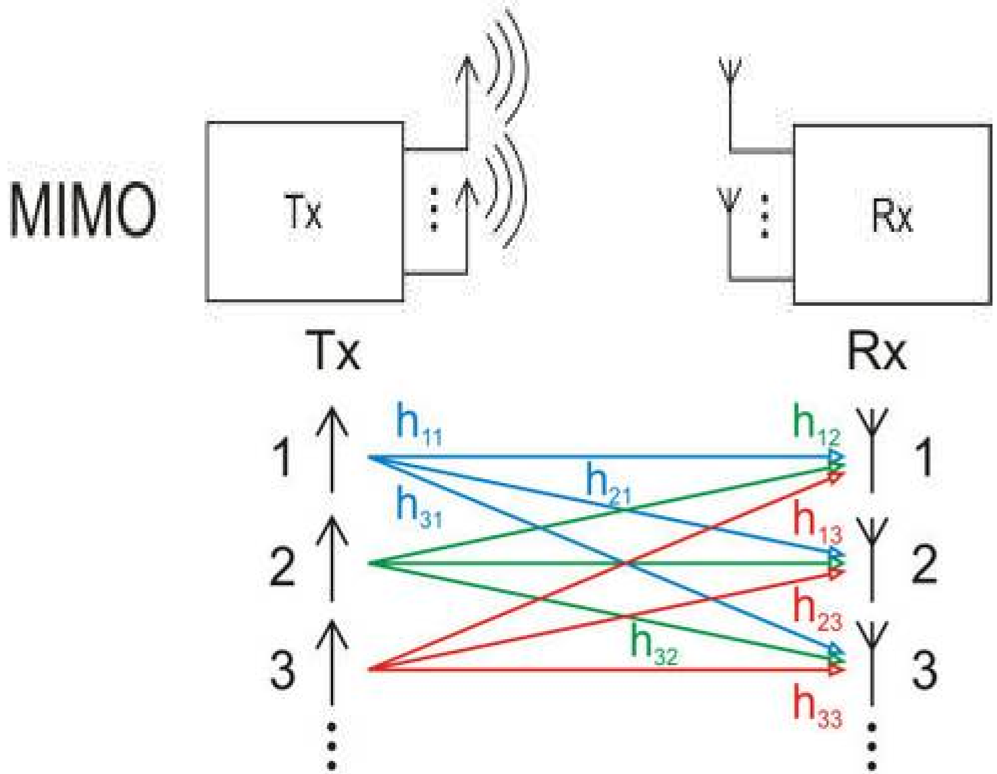
MULTIPLE INPUT-MULTIPLE OUTPUT (MIMO)

- Multiple Input Multiple Output smart antenna technology
- Multiple paths improve link reliability and increase spectral efficiency (bps per Hz), range and directionality



MIMO (Multiple Input Multiple Output) RADIO TRANSCEIVER

- LTE supports MIMO as the base option, with multiple transmitter and receiver antennas in a same eNode-B.
- Up to four antennas can be used by a single LTE cell (gain: spatial multiplexing)
- MIMO is considered to be the core technology to increase spectral efficiency.

ADVANCED ANTENNA TECHNIQUES

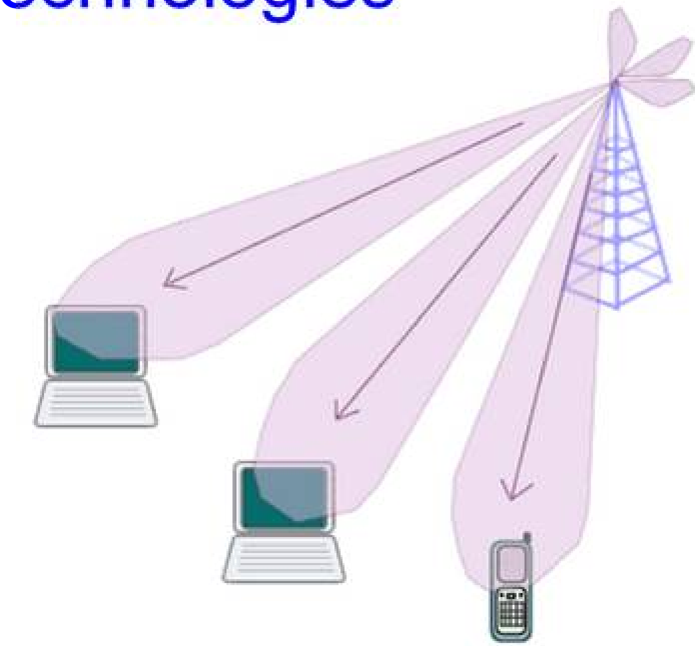
- Single data stream / user
- Beam-forming for coverage, longer battery life
- Spatial Division Multiple Access (SDMA): Multiple users in same radio resource
- Multiple data stream / user Diversity : link robustness
- Spatial multiplexing : spectral efficiency, high data rate support

MIMO BEAMFORMING

- Enhances signal reception through directional array gain, while individual antenna has omni-directional gain
- Extends cell coverage
- Suppresses interference in space domain
- Enhances system capacity
- Prolongs battery life
- Provides angular information for user tracking

SPATIAL DIVISION MULTIPLEXING (SDMA)
Smart Antenna Technologies

- Beamforming
  - Use multiple antennas to spatially shape the beam
- Spatial Multiplexing a.k.a. Collaborative MIMO
  - Multiple streams transmitted
  - Multi-antenna receivers separate the streams to achieve higher throughput
  - On uplink, multiple single-antenna stations can transmit simultaneously
- Space-Time Codes
  - Transmit diversity such as Alamouti code, reduces fading



2x2 Collaborative MIMO give 2x peak data rate by transmitting two data streams

MULTIPATH ENVIRONMENTS

LTE RADIO PROTOCOLS

- They are quite similar to the WCDMA protocol stack of UMTS.

- The protocol stack defines three layers: the physical layer (layer 1), data link and access layer (layer 2) , layer 3 (hosting the AS, the NAS control protocols as well and the application level)

LAYER 3 RADIO PROTOCOLS

- PDCP (Packet Data Convergence Protocol)
  - Each radio bearer also uses one PDCP instance.
  - PDCP is responsible for header compression (ROHC: RObust Header Compression; RFC 3095) and ciphering/deciphering.
  - Obviously header compression makes sense for IP datagram's, but not for signaling. Thus the PDCP entities for signaling radio bearers will usually do ciphering/deciphering only.
- RRC (Radio Resource Control)
  - RRC is the access stratum specific control protocol for EUTRAN.
  - It provides the required messages for channel management, measurement control and reporting
- NAS Protocols
  - The NAS protocol is running between UE and MME and thus must be transparently transferred via Evolved UTRAN (EUTRAN).
  - It sits on top of RRC, which provides the required carrier messages for Network attached storage (NAS) transfer

RADIO LINK CONTROL (RLC)

- There is a one to one relationship between each Radio Bearer and each RLC instance
- RLC can enhance the radio bearer with ARQ (Automatic Retransmission on reQuest) using sequence numbered data frames and status reports to trigger retransmission.
- The second functionality of RLC is the segmentation and reassembly that divides higher layer data or concatenates higher layer data into data chunks suitable for transport over transport channels which allow only a certain set of transport block sizes.

LTE’s IP MULTIMEDIA SYSTEM (IMS) / Value Proposition

- Generate new revenue from new services
  - Per-session control allows IMS to guarantee QoS for each IP session, and enables differential billing for applications & content
- Reduce capital spending
  - Converge all services on common infrastructure
  - Focus limited resources on core competencies

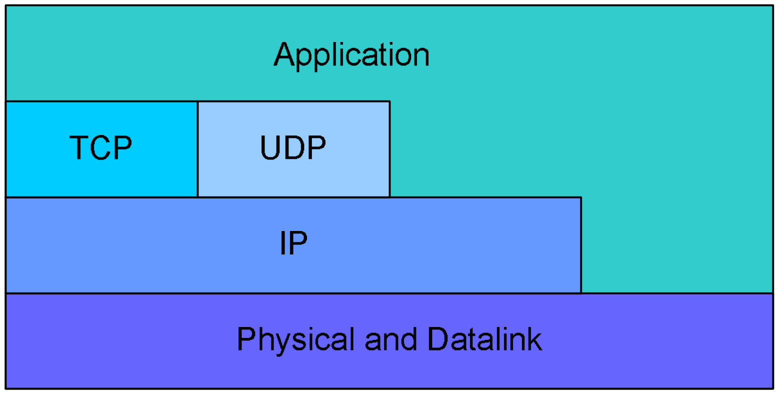
- To date, mobile operators have had no incentive to deploy IMS for voice services

PROTOCOLS

- In the OSI model, each layer communicates only with the adjacent layer above and the adjacent layer below by Protocols
- LTE services rely on mostly ISO/ITU approved IP protocols from IETF and/or other fora; TCP supported but still causing problems

- The traditional approach has been to treat the layers as different entities

- Example: TCP/IP protocols
- NB: the drawing gives protocols BETWEEN layers



TCP/IP and UDP in a network

LTE VOICE by Circuit Switched fallback

- Circuit Switched Fallback (CSFB) enables mobile operators to provide voice services alongside their LTE network in the absence of IMS.
- LTE registered mobile devices ‘fall back’ to a 2G/3G domain to send/receive voice calls. CSFB saves time & CAPEX so operators can focus on meeting data requirements with their LTE deployments.
- VOIP interworking necessary

- Note: CSFB standard TS 23.272 allows network operators to carry voice traffic over existing GERAN/UTRAN networks from multi-mode LTE UE devices. This very practical goal is realized by a clever innovation: network awareness in the MME. Where overlapping networks exist, the MME may carry maps of UTRAN TAs (Tracking Areas) to LTE LAs (Location Areas) that allow the UE to utilize circuit switched services all managed from the MME in conjunction with the Mobile switching center. If no VoIP services are available, the UE is instructed to access the alternate network for voice calls.

VOICE OVER LTE

- VoLTE 3GPP standard may be added to IMS (with EPC / Policy control / Multimedia telephony) , along with enriched multimedia services
- MSF / GSMA VoLTE interoperability event, Vodafone, Düsseldorf, Sept 2011
- Question is whether operators can generate incremental revenues with high-definition branded voice services
- This would require the Evolved packet system (EPC) to expose network QoS to third parties via standardized API's , to allow applications to move from best effort on default bearers to guaranteed QoS class
- Competitive approaches to VoLTE: Circuit switched fall-back (CSFB), GAN , VoLGA

MULTIMEDIA BROADCAST MULTICAST SERVICES (MBMS)

- MBMS (Multimedia Broadcast Multicast Services) is an essential part of LTE. The so-called e-MBMS is therefore an integral part of LTE.
- In LTE, MBMS transmissions may be performed as single-cell transmission or as multi-cell transmission. In case of multi-cell transmission, the cells and content are synchronized to enable for the terminal to soft-combine the energy from multiple transmissions.
- The superimposed signal looks like multipath to the terminal. This concept is also known as Single Frequency Network (SFN).
- The E-UTRAN can configure which cells are part of an SFN for transmission of an MBMS service. The MBMS traffic can share the same carrier with the unicast traffic or be sent on a separate carrier.
- For MBMS traffic, an extended cyclic prefix is provided. In case of sub-frames carrying MBMS SFN data, specific reference signals are used. MBMS data is carried on the MBMS traffic channel (MTCH) as logical channel.

QoS AND CONFIGURATION

- QoS awareness

– The scheduler must handle and distinguish different quality of service classes; otherwise real time services would not be possible via EUTRAN

– The system provides the possibility for differentiated service

- Self configuration

– Currently under investigation

– Possibility to let eNodeB 's configure themselves

- It will not completely substitute the manual configuration and optimization.

TRANSPORT AND SCHEDULING

- IP transport layer

– Enhanced UTRAN (EUTRAN) exclusively uses IP as transport layer

- UL/DL resource scheduling

– In UMTS physical resources are either shared or dedicated

– eNode B handles all physical resource via a scheduler and assigns them dynamically to users and channels; this provides greater flexibility than the older system

--Frequency domain scheduling uses those resource blocks that are not faded; not possible in CDMA based system

BACKHAUL TRANSPORT NETWORKS

- Backhaul traffic load from/to an eNode B goes up an order of magnitude (x 10); typical number : 100-200 Mbps/eNode-B
- eNode B spatial density may have to go up x 1,5- 2,5 to deliver expected user experience
- TDM radio systems cannot handle this traffic
- ROADM Fiber links are therefore preferred, if available in eNodeB
- If not, improved microwave with >1 Gbps packet microwave (also for aggregation), with narrow 7-14 MHz backhaul channel allocations
- Operators must secure eventually backhaul microwave spectrum, with associated costs (about 50 % of LTE microwave backhaul)
- Improved ring and mesh topologies connecting eNode-B’s with one another , with multiplexing, increases effective network capacity by x 4

LTE OPERATIONAL PERFORMANCE

LTE PERFORMANCE

- Radio performance, coverage and effect of frequency band
- Data rates and peak data rates
- Spectral efficiency
- Network latency
- VoIP capacity

LTE RADIO PERFORMANCE (I)

- Data Rates:

– Instantaneous downlink peak data p rate of 100Mbit/s in a 20MHz downlink spectrum (i.e. 5 bit/s/Hz)

– Instantaneous uplink peak data rate of 50Mbit/s in a 20MHz uplink spectrum (i.e. 2.5 bit/s/Hz)

- Cell size:

– 5 km - optimal size

– 30km sizes with reasonable performance

– up to 100 km cell sizes supported with acceptable performance

- Cell capacity

– up to 200 active users per cell(5 MHz) (i.e., 200 active data clients)

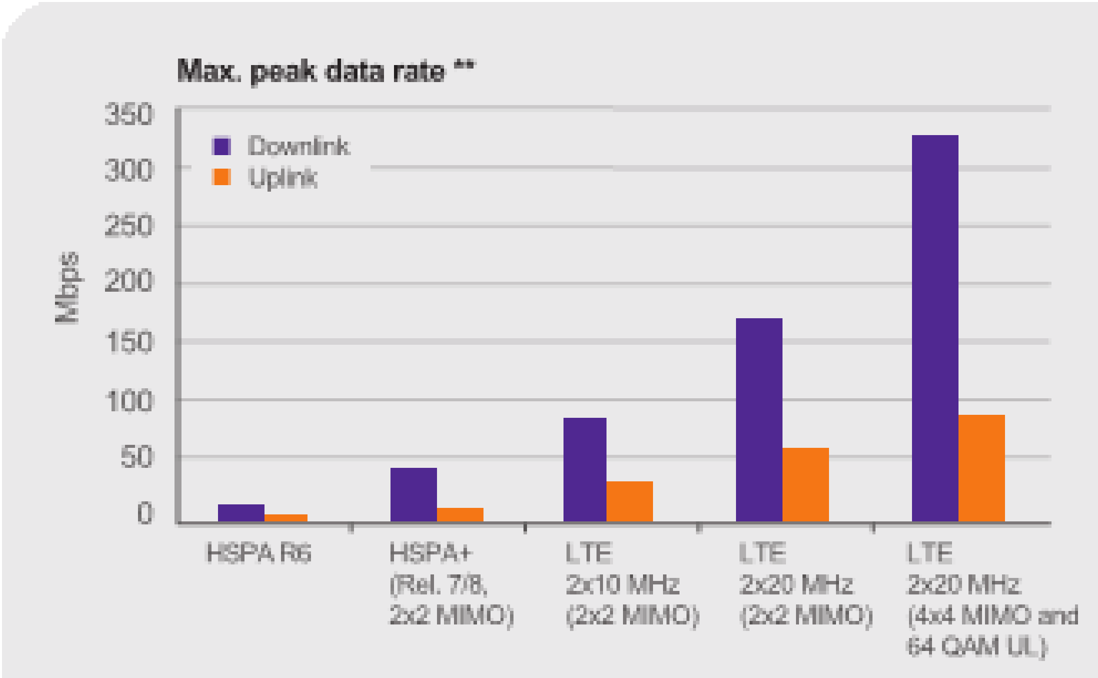
LTE RADIO PERFORMANCE (II)

- Mobility
  – Optimized for low mobility (0-15km/h) but supports high speed
- Latency
  – user plane < 5ms
  – control plane < 50 ms
- Improved spectrum efficiency
- Improved broadcasting
- IP-optimized
- Scalable bandwidth of 20, 15, 10, 5, 3 and 1.4MHz
- Coexistence with legacy standards

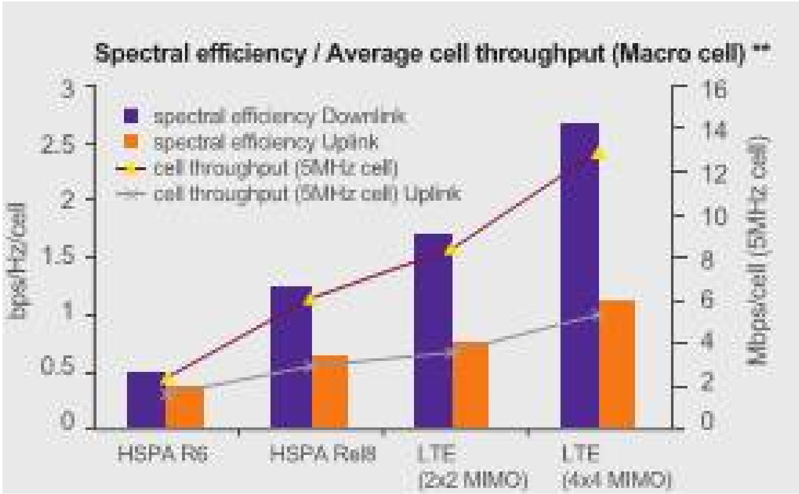
INDOOR and SMALL CELL USE OF LTE

- Need to use low frequency 700-800 MHz LTE bands, as 2,6 GHz LTE would not work well
- Need for users to be able to mark traffic as low priority, so it gets shifted to off-peak delivery in return for reduced charges (due to decaying mobile data margins and excess peak data demand)
- Indoor femtocell networks and WiFi to offload macro networks, as well as signalling functions
- Exploit indoor the MIMO and beam forming capabilities

LTE PEAK DATA RATE EVOLUTION

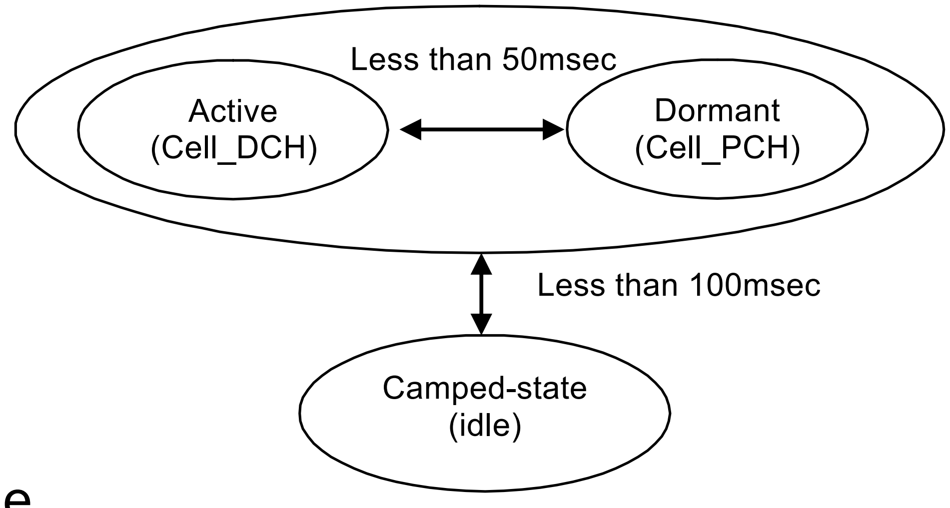


LTE SPECTRAL EFFICIENCY bps/ Hz / cell and CELL THROUGHPUT Mbps / cell (5MHz)



LTE LATENCY ISSUE

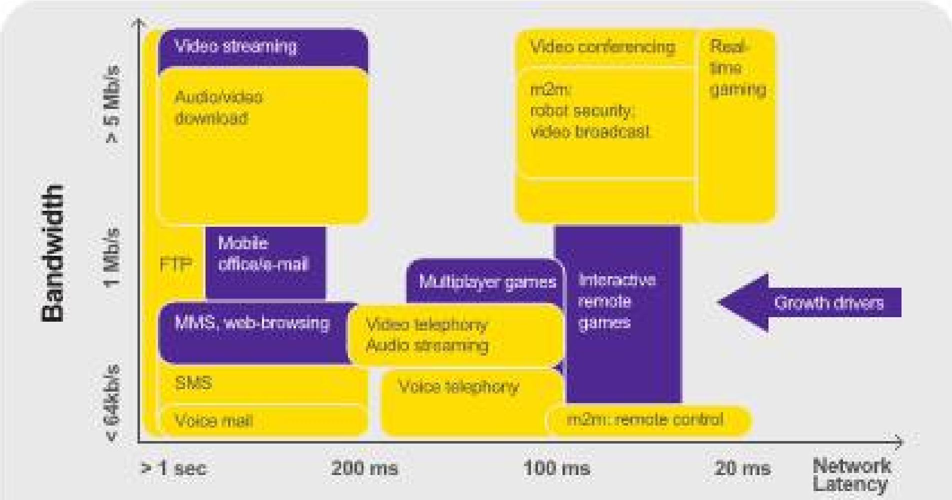
– Control-plane
  - Significant reductions in transition times from idle or dormant states to active state



– User-plane
  - Radio access network latency below less than 5 ms in unloaded condition (i.e. single user with single data stream) for small IP packet

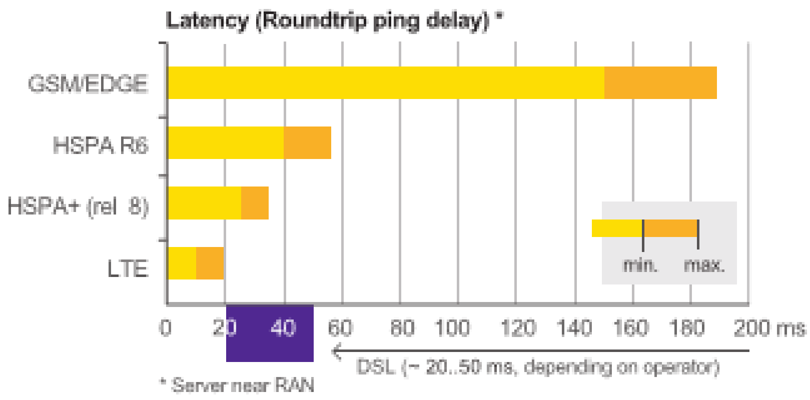
Latency also being addressed in SAE

BANDWIDTH vs. NETWORK LATENCY

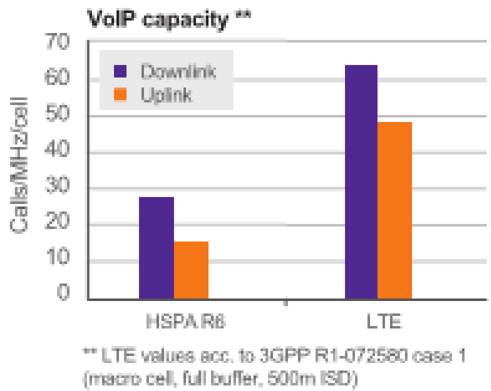


Source: IST-2003-507581 WINNER, D1.3 version 1.0, Final usage scenarios. 30/06/2005;
„Parameters for Tele-traffic Characterization in enhanced UMTS2", University of Beira, Portugal, 2003

HSPA / LTE LATENCY



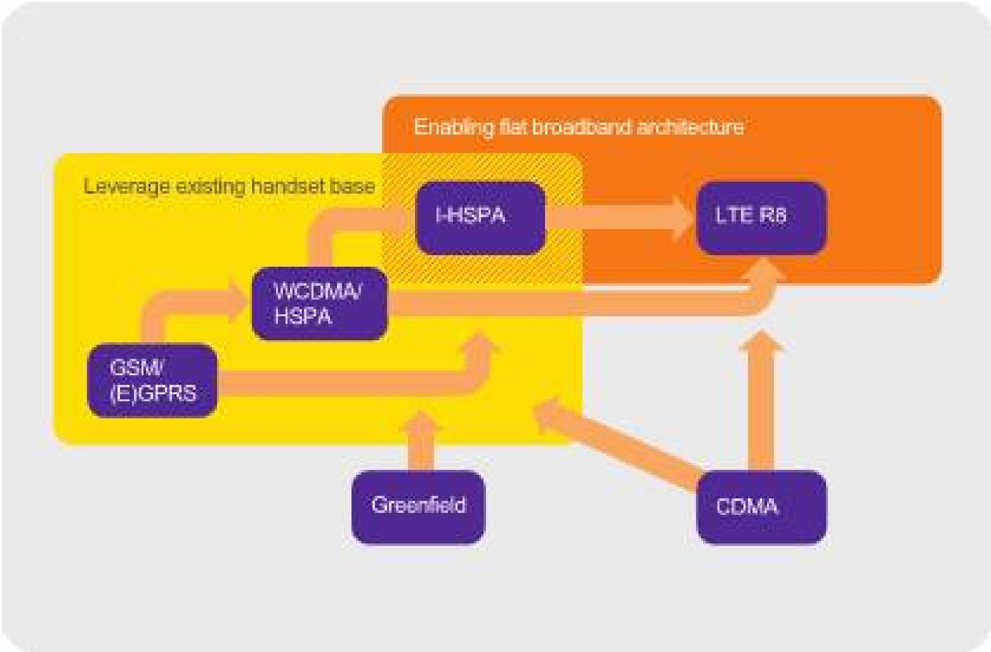
LTE VoIP CAPACITY (calls / MHz / cell (5MHz))



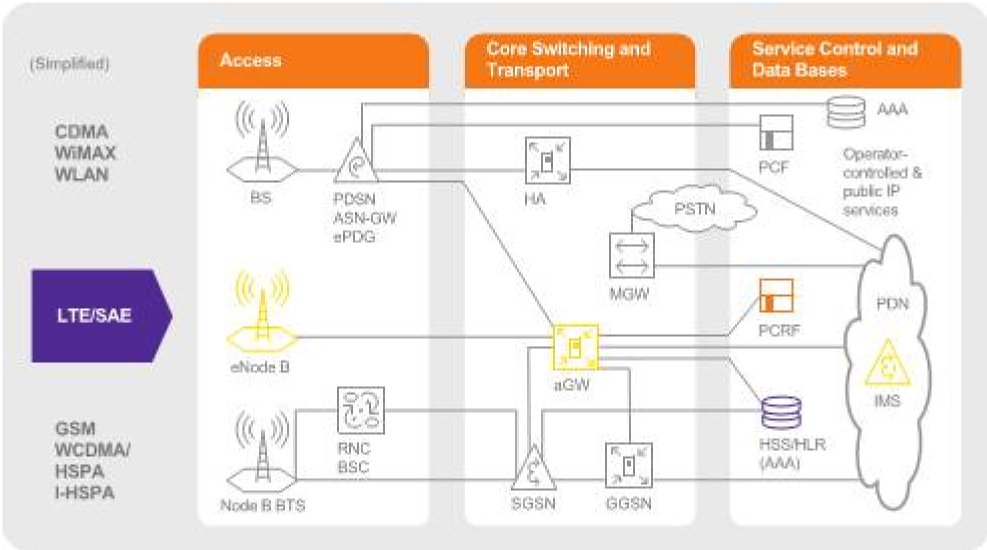
COMPLIANCE of TERMINALS

- Operators need to ensure LTE terminals can meet their own network requirements in an efficient manner
- GCF (Global certification forum) and PTCRB (PCS Type certification review board) tests
- TTCN scripts mandated for ETSI conformance tests

MIGRATION PATHS TOWARDS LTE R8

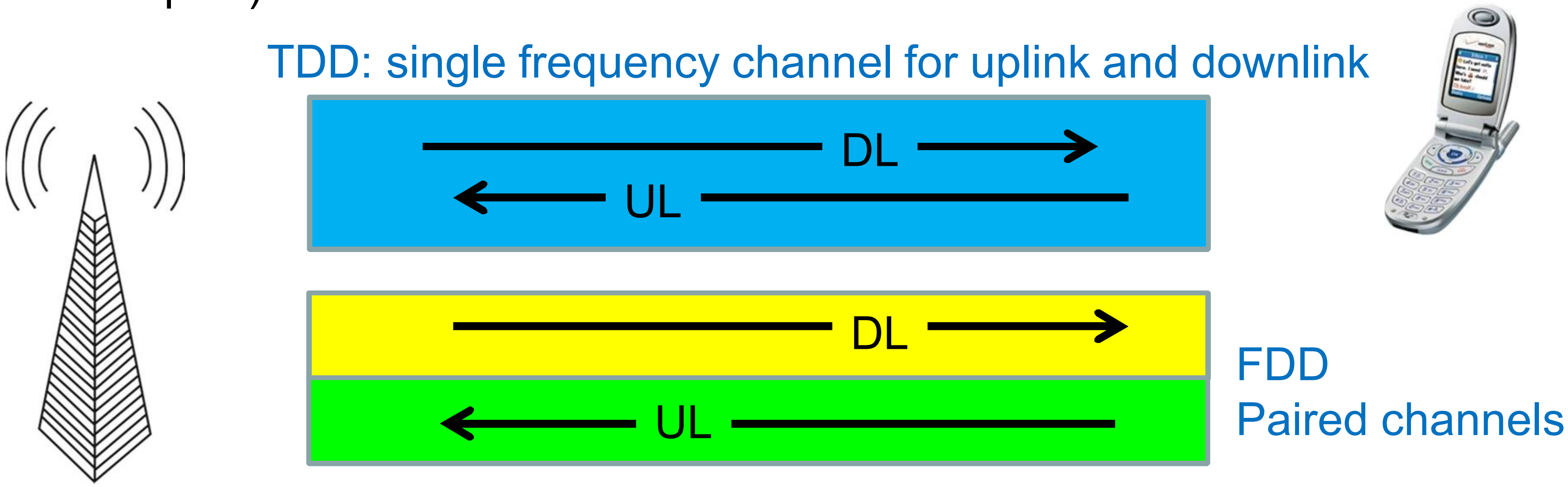


MIGRATION PATHS TOWARDS LTE R8 (II)



COMMON FEATURES of WiMAX and LTE

- OFDMA (Orthogonal Frequency Division Multiple Access) and MIMO
- Users are allocated a slice in time and frequency
- Flexible, dynamic per user resource allocation
- Base station scheduler for uplink and downlink resource allocation
  - Resource allocation information conveyed on a frame-by frame basis
- Support for TDD (time division duplex) and FDD (frequency division duplex)



Differences

Carriers are able to set requirements for LTE through organizations like NGMN and ETSI, but cannot do this as easily at the IEEE-based 802.16

LTE backhaul is, at least partially, designed to support legacy services while WiMAX assumes greenfield deployments

LATER LTE and SAE EVOLUTION

- No more macro-diversity
  - No soft handover required
- Security
  - Control Plane
    - Ciphering and Integrity provided by eNode B (BTS)
    - RLC and MAC provided directly in the eNode B
  - User plane
    - Ciphering and integrity in the eAccess Gateway functionality

ABBREVIATIONS

- 3GPP Third Generation Partnership Project
- AMC Advanced mezzanine card
- ATCA Advanced TCA
- ATL Application transport layer
- AUM Auxiliary unit module
- BB Baseband
- CBU Cello basic unit
- CP-OFDM Cyclic-prefix orthogonal frequency-division multiplexing
- CPP Cello processor platform
- DPD Digital pre-distortion
- DSP Digital signal processor
- eNB Evolved Node-B
- FDMA Frequency-division multiple access
- FFT Fast Fourier Transform
- FTP File transfer protocol
- FU Filter unit
- GPS Global positioning system
- I2C Intelligent interface controller
- IFFT Inverse FFT
- IO Input-output
- IP Internet protocol
- L1, L2 Layer-1, layer-2
- LTE Long-term evolution of third-generation cellular systems
- LTU Local timing unit

MAC Media access control
MCPA Multicarrier power amplifier
MIMO Multiple input, multiple output
MP Main processor
MTU Main timing unit
OAM Operation, administration and maintenance
PA Power amplifier
PEC Processor element cluster
RAS Radio and antenna subsystem
RBS Radio base station
RF Radio frequency
RLC Radio link controller
RUIF Radio unit interface
RX Receiver
RXIF Receiver interface
RXRF1 Receiver RF1
RXRF2 Receiver RF2
SIMO Single input, multiple output
SISO Single input, single output
TCA Telecom computing architecture
TCP Transport control protocol
TOR Transmit observation receiver
TRX Transceiver
TX Transmitter
UE User equipment
VoIP Voice over IP