MOBILE BROADBAND

UNIK4230: Mobile Communications

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Mobile Broadband

Materials used from:

1. **Nokia Networks**
2. **LTE for UMTS**. Evolution to LTE-Advanced. 2nd Edition. Harri Holma and Antti Toskala

Agenda

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- Introduction
- WCDMA/HSPA/HSPA+
- LTE
- LTE-Advanced
- Summary

Mobile broadband traffic more than doubles every year

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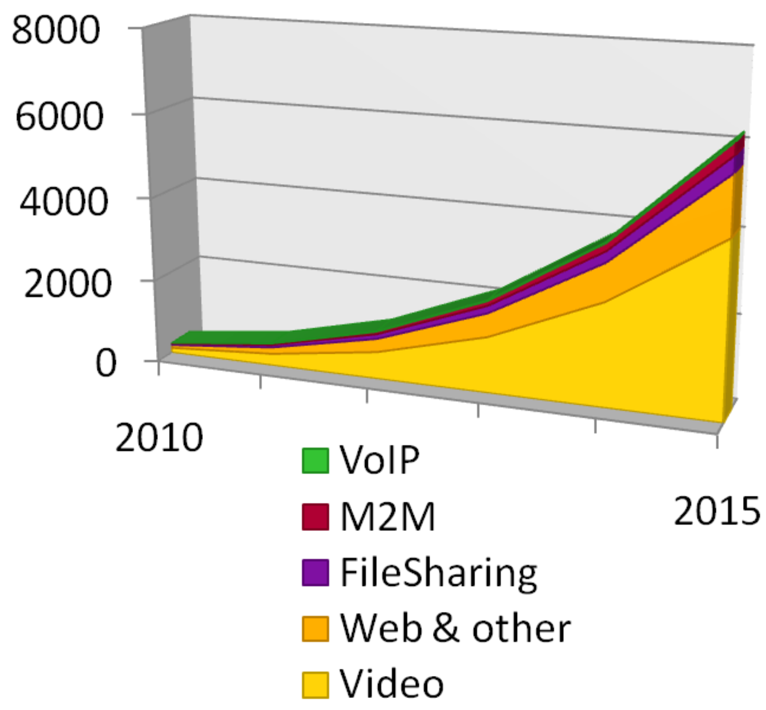
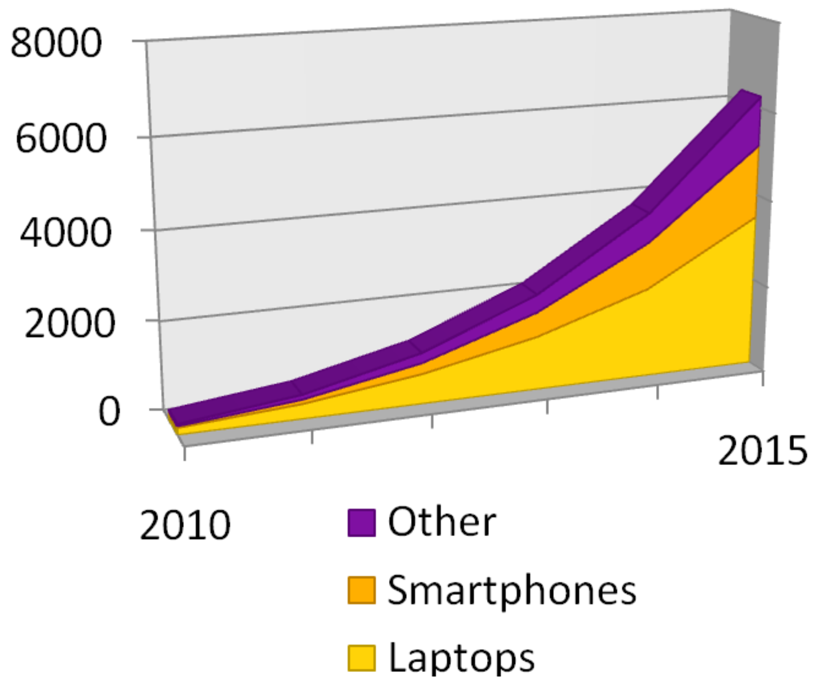
Video traffic has overtaken everything else

Mobile application traffic
Petabytes per month



Source: NSN BI, Industry analysts

Mobile data traffic
Petabytes per month



Source: NSN BI, Industry analysts

Factors impacting MBB/LTE take off & competiveness

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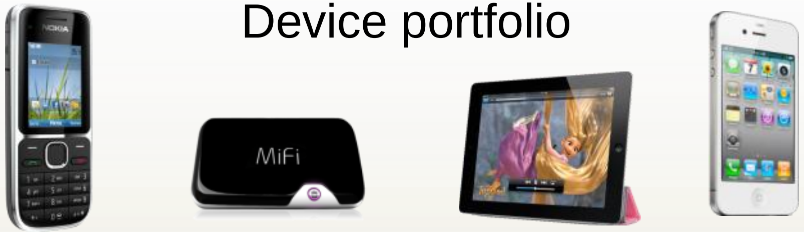
Device portfolio



- Smart phones, low end MBB phones
- Sticks, tablets, laptops, Mi-Fi
- Subsidizing usage of 3G/LTE devices

Content & applications

- Own applications, services from Internet
- Partnering with local brands & device vendors
- Foster country specific killer apps

Attractive bundles

- Voice, data, sms, devices, triple/quad play
- Converged fixed and mobile offering
- Content, email, navigation, security

Network capabilities

- Capacity, coverage, quality
- 6-sector, active antenna, site density, spectrum
- Small cells, offloading, traffic management

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  - **Introduction**
  - HSPA technology and evolution
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UMTS Air Interface technologies

UMTS Air interface is built based on two technological solutions

- WCDMA – FDD
- WCDMA – TDD

WCDMA – FDD is the more widely used solution

- FDD: Separate UL and DL frequency band

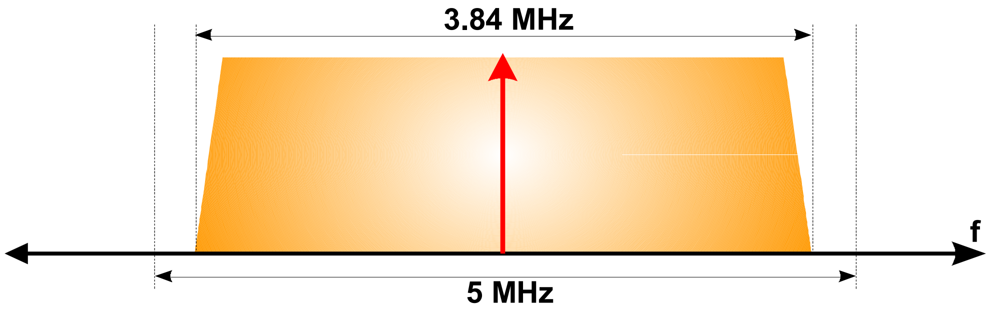
WCDMA – TDD technology is currently used in limited number of networks

- TDD: UL and DL separated by time, utilizing same frequency

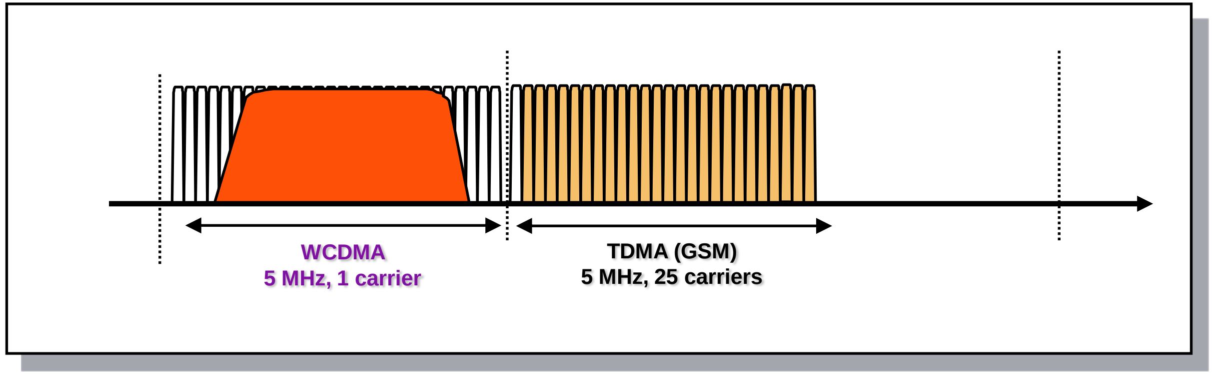
Both technologies have own dedicated frequency bands

WCDMA Technology

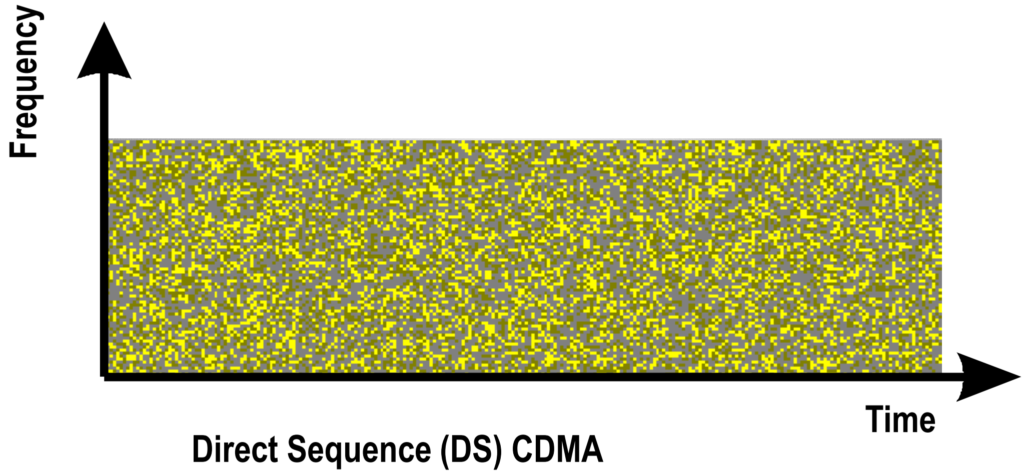
WCDMA Carrier



5+5 MHz in FDD mode
5 MHz in TDD mode

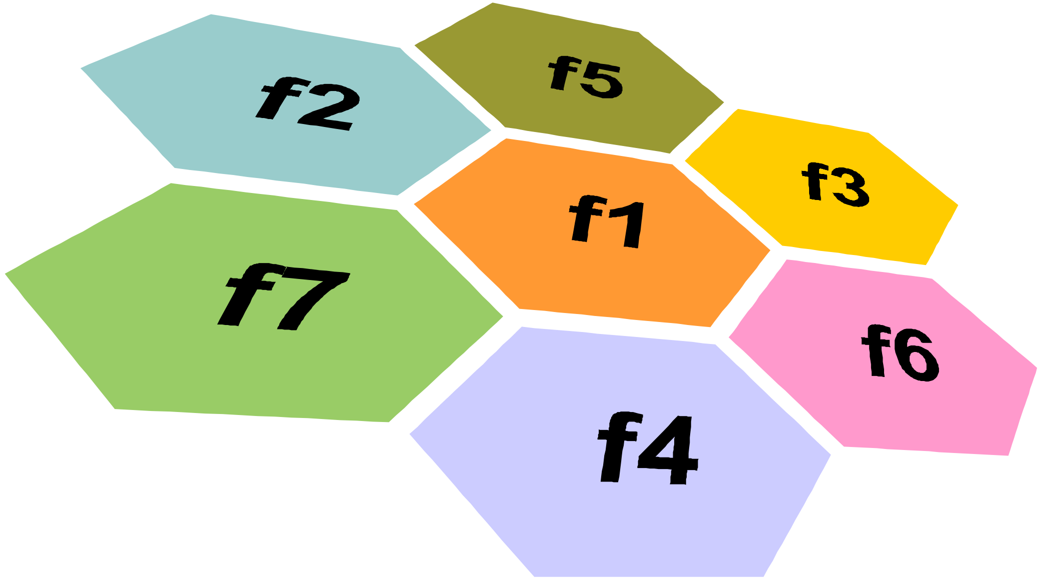


Users share same time and frequency

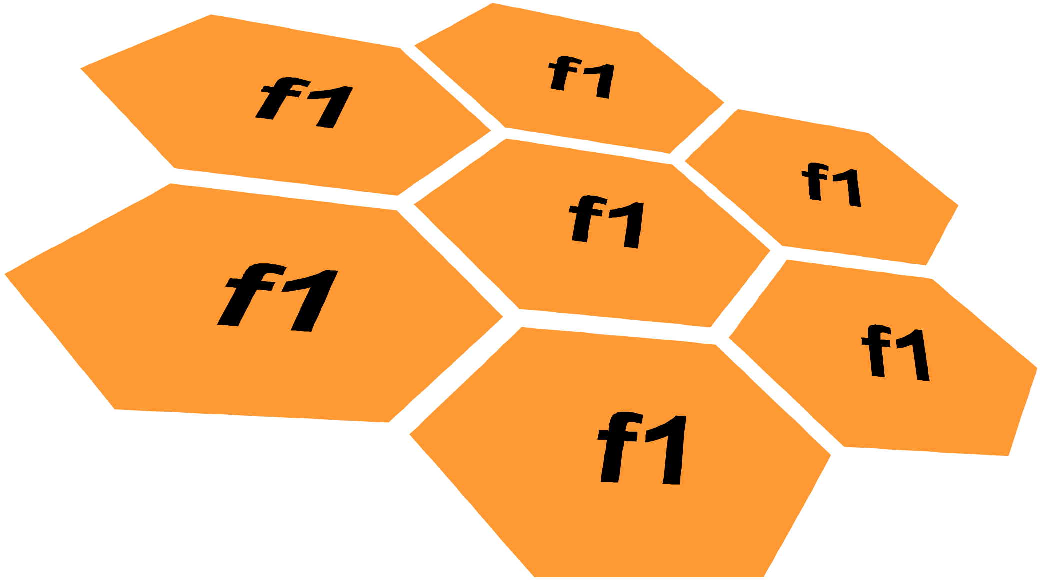


UMTS & GSM Network Planning

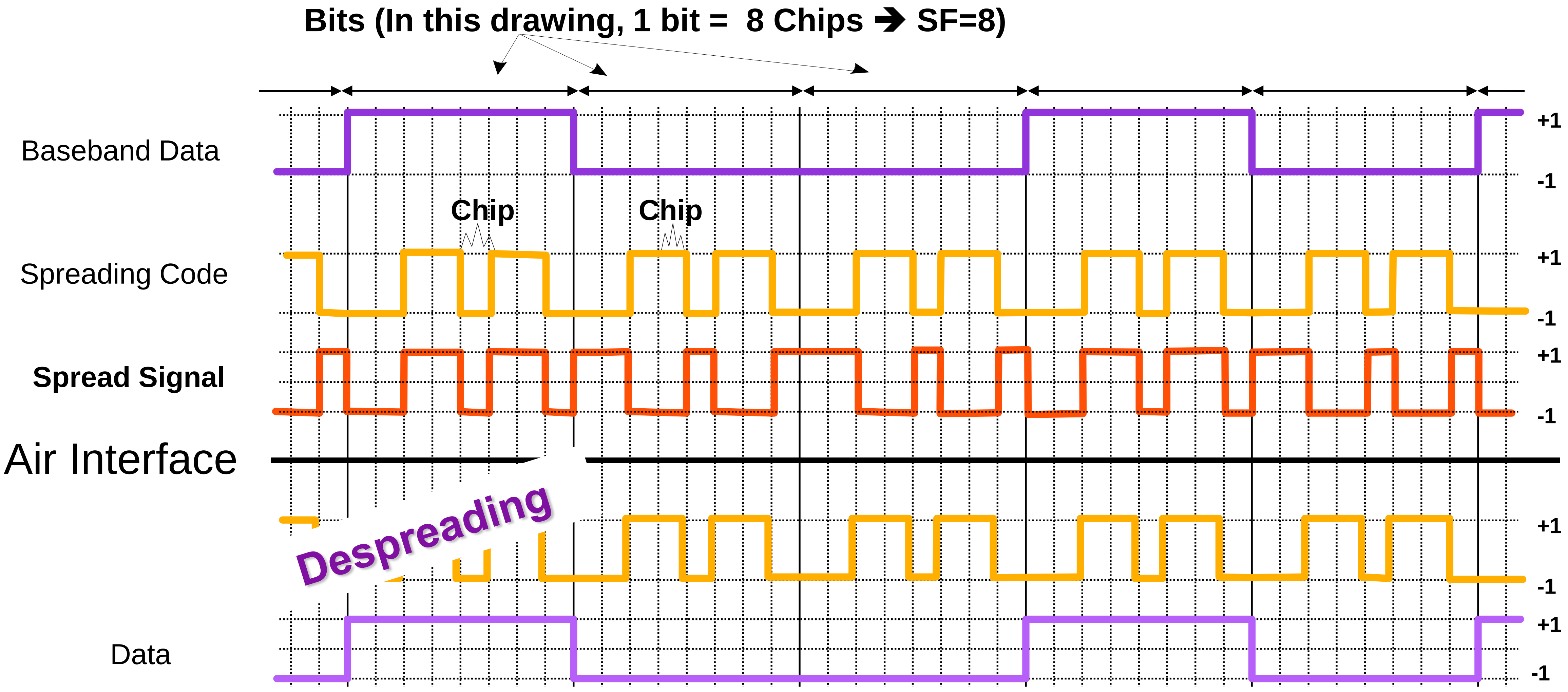
GSM900/1800:



3G (WCDMA):



CDMA principle - Chips & Bits & Symbols



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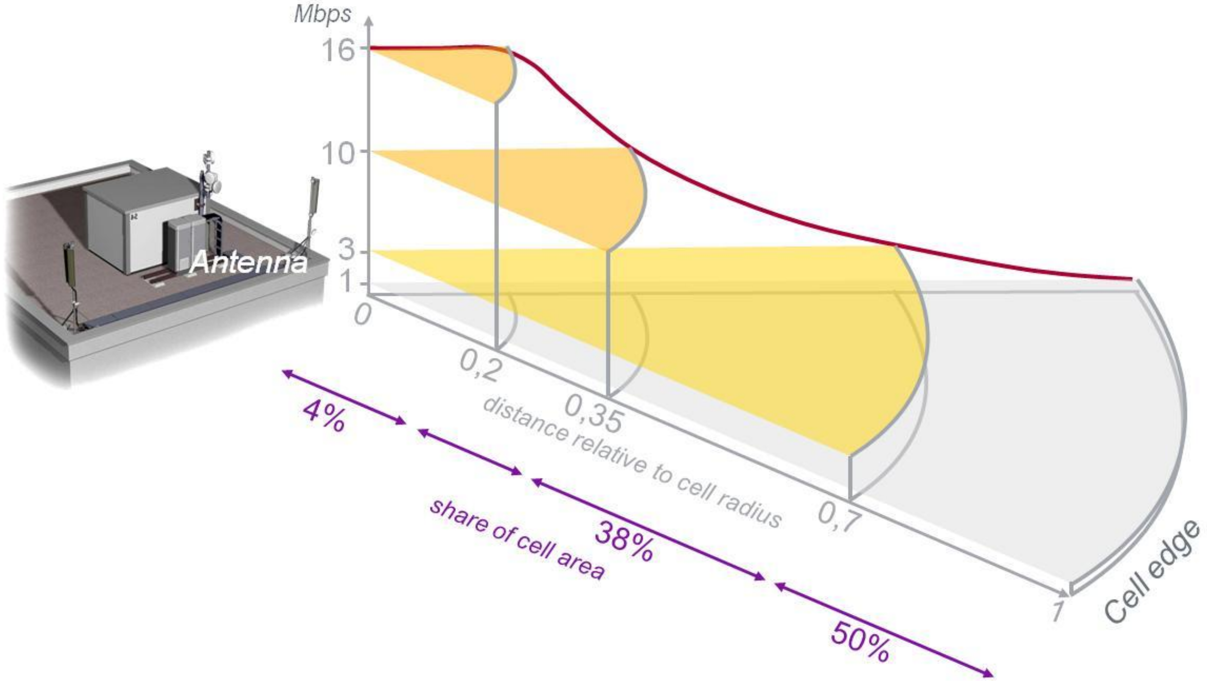
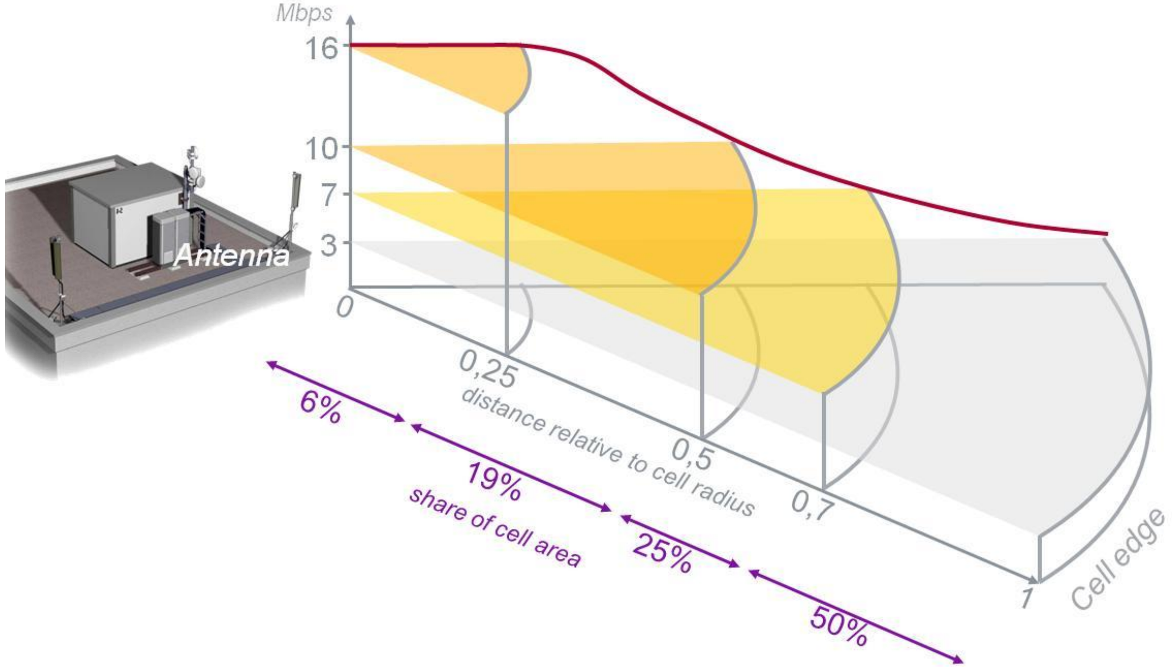
HSPA+ radio performance basics

- HSDPA peak rate depends on adaptive modulation, coding and UE category
- BTS selects modulation and coding based on reported signal quality (affected by e.g. distance from BTS, load in neighboring cells and UE performance)



HIGH LOAD neighboring cells
64 QAM, no MIMO, no DC-HSPA



LOW LOAD neighboring cells
64 QAM, no MIMO, no DC-HSPA

Dual Cell HSDPA and HSUPA

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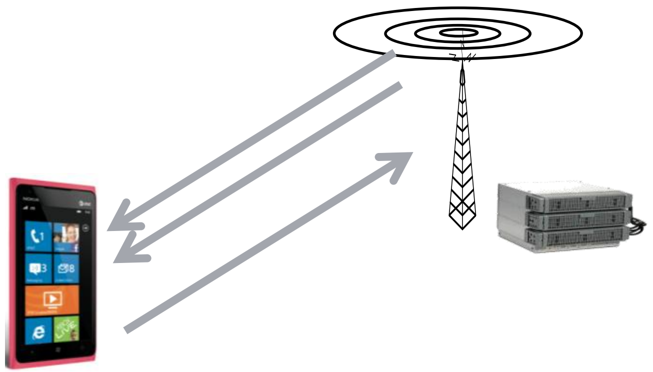
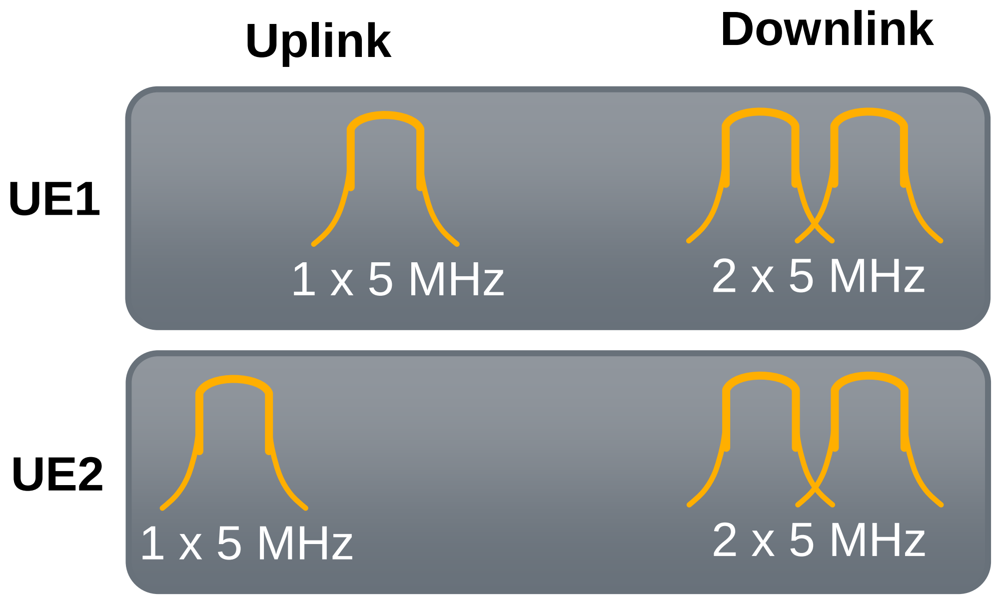
- DC-HSDPA is a Release 8 enhancement. It provides a method to aggregate two adjacent carriers in the downlink.

- Enables transmission of 2 adjacent carriers of 10MHz bandwidth to single terminal.

- The main reason behind DC-HSDPA, i.e. multi-carrier, is to improve resource utilization and therefore increase spectrum efficiency. This is achieved by having joint resource allocation, as well as load balancing across both carriers.



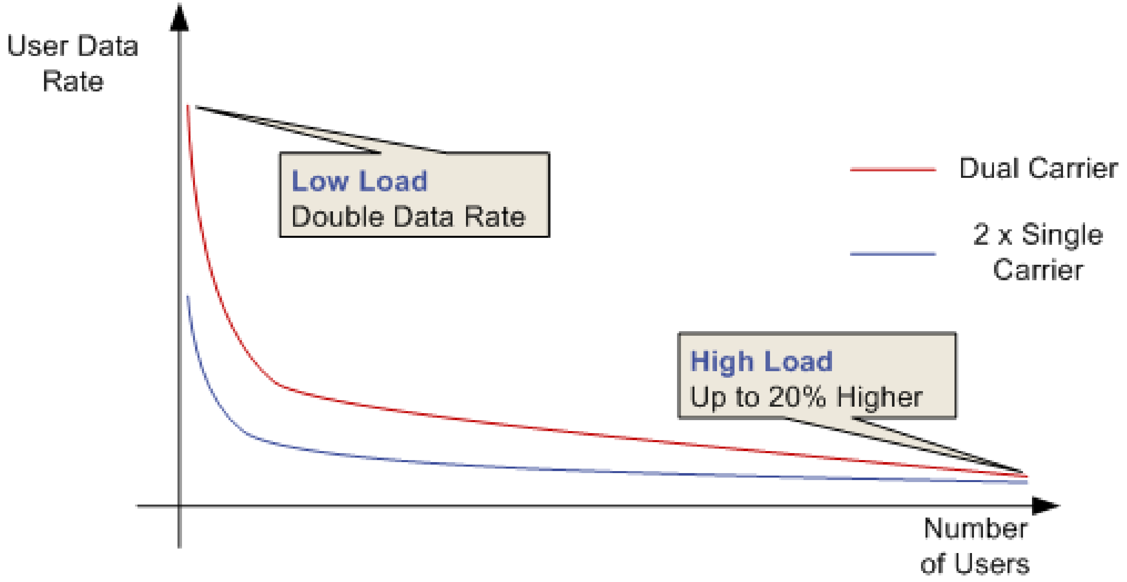


Downlink DC HSDPA concept

Dual Cell HSDPA and HSUPA

- DC-HSDPA can double data rate at low loading because the user can access the capacity of two carriers instead of just one. The relative benefit decreases when loading increases.

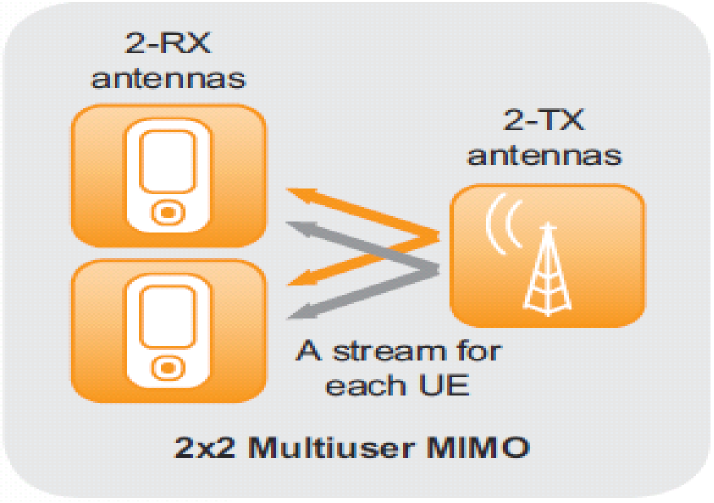
- There is still some capacity benefits at high load due to frequency domain scheduling and dynamic load balancing between carriers (if both carrier is not 100% loaded at all time).



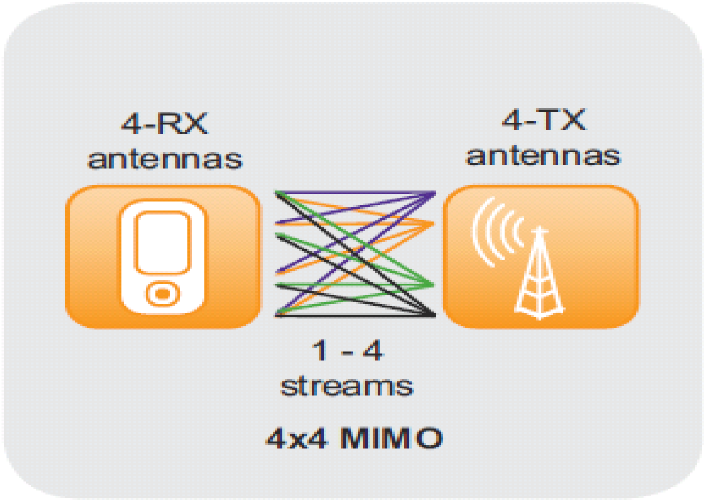
MIMO Evolution

- Multi-antenna transmission and reception increases
  - peak data rates,
  - cell throughput and
  - cell edge data rates

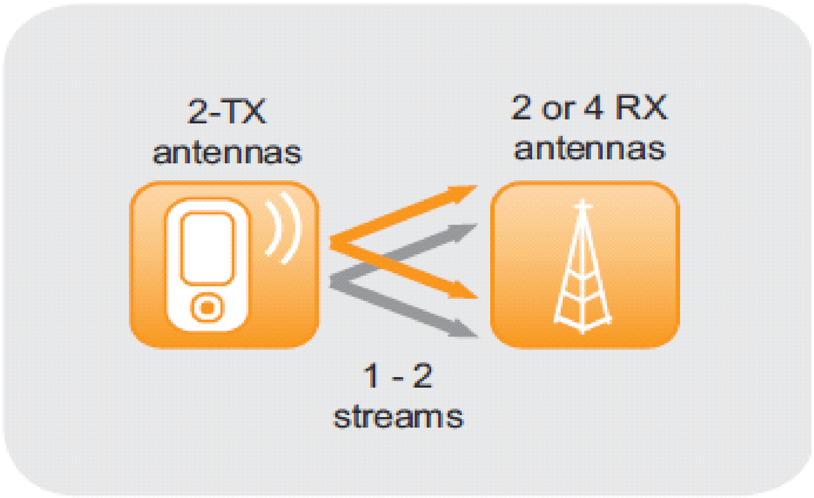
Downlink Multiuser MIMO



Downlink 4x4 MIMO



Uplink 2x2 MIMO



Dual Cell vs MIMO

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	Dual Carrier	MIMO
Peak Rate	42Mbps	42Mbps
Improvement in Spectral Efficiency	20% - Due to improved scheduling in the frequency domain and increased trunking gain.	10% - Since two antennas.
Data Rate Improvement	The gain is similar all over the cell area.	Largest gain close to Node B.
Node B RF Requirements	Single Power Amplifier per sector.	Needs two Power Amplifiers per sector.
UE RF Requirements	Possible with 1 antenna terminal.	2 antennas required.

Multicarrier HSPA Evolution

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3GPP Release 7:

UE can receive and transmit on single 5 MHz carrier

3GPP Release 8-9:

UE can receive and transmit two adjacent 5 MHz carriers

3GPP Release 10:

UE can receive four 5 MHz carriers

Uplink **Downlink**

Multiband HSPA Evolution

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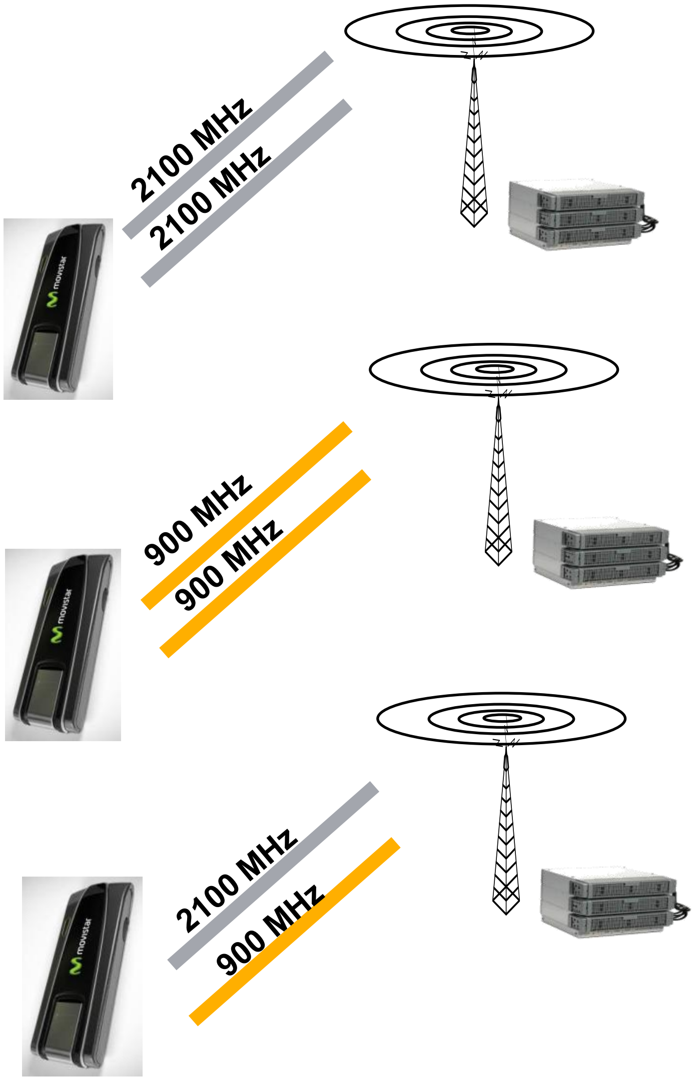
3GPP Release 7:
UE can receive and transmit on single band

3GPP Release 9:
UE can receive on two bands

3GPP Release 10:
UE can receive on two bands and up to four carriers

nsn

DC-HSPA on 2100, 900 and 2100+900 MHz (dual-band DC)



- DC-HSPA 42 Mbit/s device available currently in the market can support aggregation of two HSPA-carriers on the 2100 MHz band
- Technology-wise DC-HSPA on 900 MHz could be done but typically not included to the early devices/ chipset due lack of operator demand
  (not many operators that can free 900 for two HSPA-carriers)
- Devices capable for dual-band DC-HSPA 42 Mbit/s are expected earliest year 2013

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Motivation and Targets for LTE

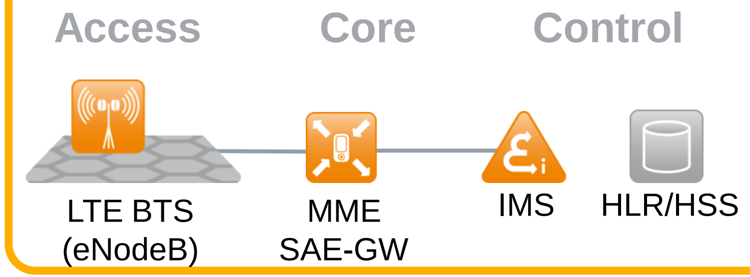
- Spectral efficiency 2 to 4 times more than with HSPA Rel-6
- Peak rates exceed 100 Mbps in downlink and 50 Mbps in uplink (which is 10 times more than HSPA Rel-6)
- Enable a round trip time of < 10 ms
- Packet switched optimized
- High level of mobility and security
- Optimized terminal power efficiency
- Frequency flexibility with allocations from below 1.5 MHz up to 20 MHz

Basic Concepts / Architecture

LTE / SAE introduces the mechanism to fulfill the requirements of a next generation mobile network

Flat Overall Architecture

- 2-node architecture
- IP routable transport architecture

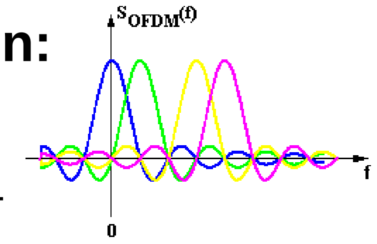


Improved Radio Principles

- peak data rates [Mbps] 173 DL , 58 UL
- Scalable BW: 1.4, 3, 5, 10, 15, 20 MHz
- Short latency: 10 – 20 ms

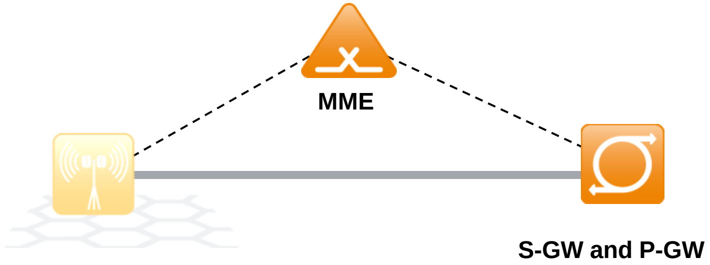
RF Modulation:

- OFDMA in DL
- SC-FDMA in UL



New Core Architecture

- Simplified Protocol Stack
- Simple, more efficient QoS
- UMTS backward compatible security



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LTE spectrum & ecosystem

LTE FDD

- **Early FDD LTE ecosystem (commercial networks)**
  - → **2600** (Europe, APAC)
  - → **2100** (Japan)
  - → **1900 PCS** (US)
  - → **1800** (GSM refarming)
  - → **1700/2100 AWS** (NAM incl. Canada)
  - → **850** (South Korea)
  - → **800 Digital Dividend** (Europe, MEA)
  - → **Upper 700 MHz, C** (Verizon)
  - → **Lower 700 MHz, B/C** (AT&T)

TD-LTE

- **Early TD-LTE ecosystem mainly building on**
  - → **2300** (MEA, India, China, APAC, Russia)
  - → **2600** (China, LatAM, Europe)

LTE FDD

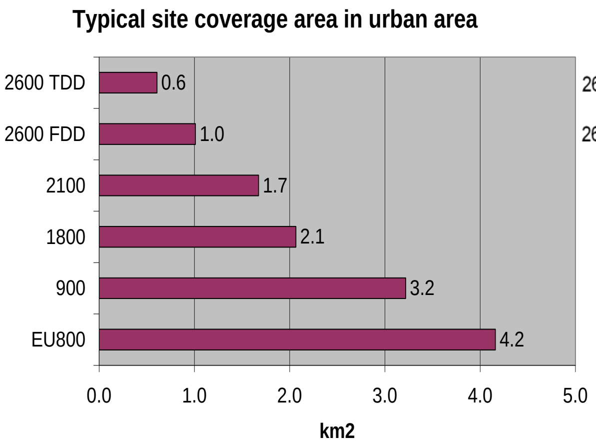
Band	MHz	Uplink MHz	Downlink MHz	
1	**2x60**	**1920-1980**	**2110-2170**	**UMTS core**
2	**2x60**	**1850-1910**	**1930-1990**	**US PCS**
3	**2x75**	**1710-1785**	**1805-1880**	**GSM 1800**
4	**2x45**	**1710-1755**	**2110-2155**	**NAM AWS**
5	**2x25**	**824-849**	**869-894**	**850**
7	**2x70**	**2500-2570**	**2620-2690**	**2600 FDD**
8	2x35	880-915	925-960	GSM 900
9	2x35	1749-1784	1844-1879	Japan, Korea 1700
10	2x60	1710-1770	2110-2170	US AWS extension.
11	2x20	1427.9-1447.9	1475.9-1495.9	Japan 1500
12	2x18	698-716	728-746	US
13	**2x10**	**777-787**	**746-756**	**Verizon**
14	2x10	788-798	758-768	US – Public Safety
17	**2x12**	**704-716**	**734-746**	**AT&T**
18	2x15	815-830	860-875	Japan – 800 (KDDI)
19	2x15	830-845	875-890	Japan – 800 (DoCoMo)
20	**2x30**	**832-862**	**791-821**	**EU 800 DD, MEA**
21	2x15	1448-1463	1496-1511	Japan 1500
22	2x80	3410-3490	3510-3590	3.5 GHz FDD
23	2x20	2000-2020	2180-2200	US S-band
24	2x34	1626.5-1660.5	1525-1559	US (LightSquared)
25	2x65	1850-1915	1930-1995	US PCS extension (Sprint)
26	2x35	814-849	859-894	850 extension (Korea-KT, Sprint)

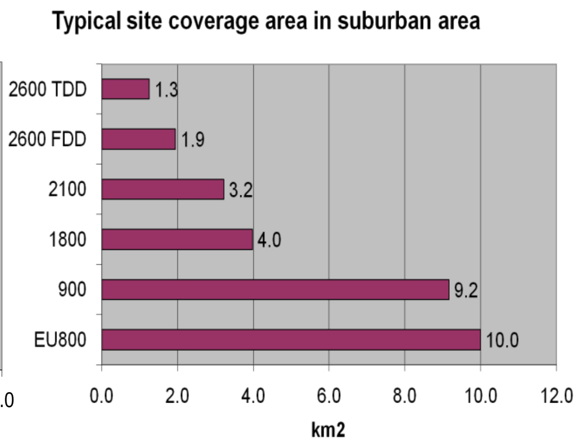
TD-LTE

Band	MHz	Uplink MHz	Downlink MHz	
33	1x20	1900-1920	1900-1920	UMTS core – TDD
34	1x15	2010-2025	2010-2025	UMTS core – TDD, China TD/SCDMA
35	1x60	1850-1910	1850-1910	US (band 2 – TDD variant)
36	1x60	1930-1990	1930-1990	US (band 2 – TDD variant)
37	1x20	1910-1930	1910-1930	US PCS centre-gap
38	**1x50**	**2570-2620**	**2570-2620**	**China, LatAM, Europe**
39	1x40	1880-1920	1880-1920	China PHS
40	**1x100**	**2300-2400**	**2300-2400**	**MEA, India, China, Russia**
41	1x194	2496-2690	2496-2690	US (Clearwire)
42	1x200	3400-3600	3400-3600	3.4/5 GHz – TDD
43	1x200	3600-3800	3600-3800	3.7/8 GHz – TDD

Source: TS 36.101; ***commercialized bands***

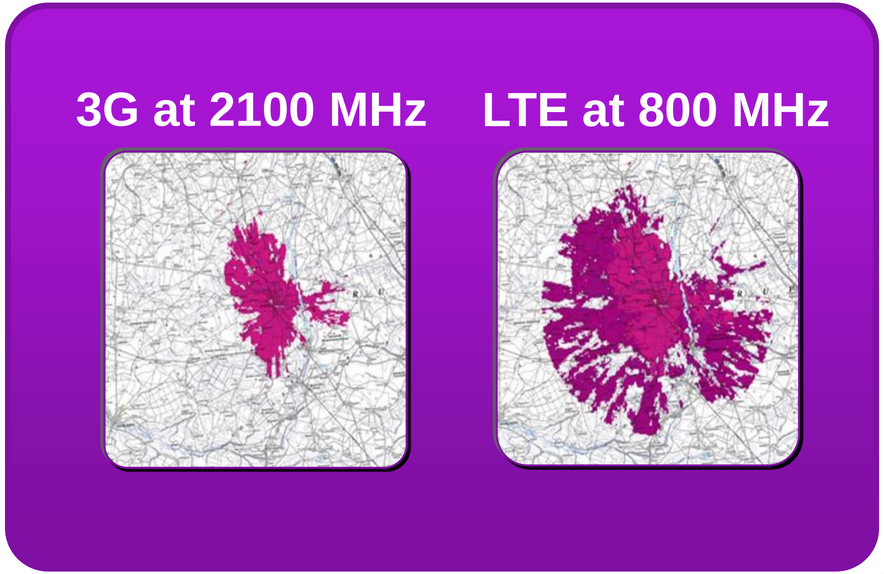
Coverage – Low Band and FDD best for wide area
LTE - FDD 800 MHz





BS antenna height [m]	30
MS antenna height [m]	1.5
Standard Deviation [dB]	8.0
Location Probability	95 %
Slow Fading Margin [dB]	8.8
Correction factor [dB]	-5
Indoor loss [dB]	15

Example: LTE 800 Coverage (Germany)



> 3 – times more coverage on 800 MHz

Source: Deutsche Telekom

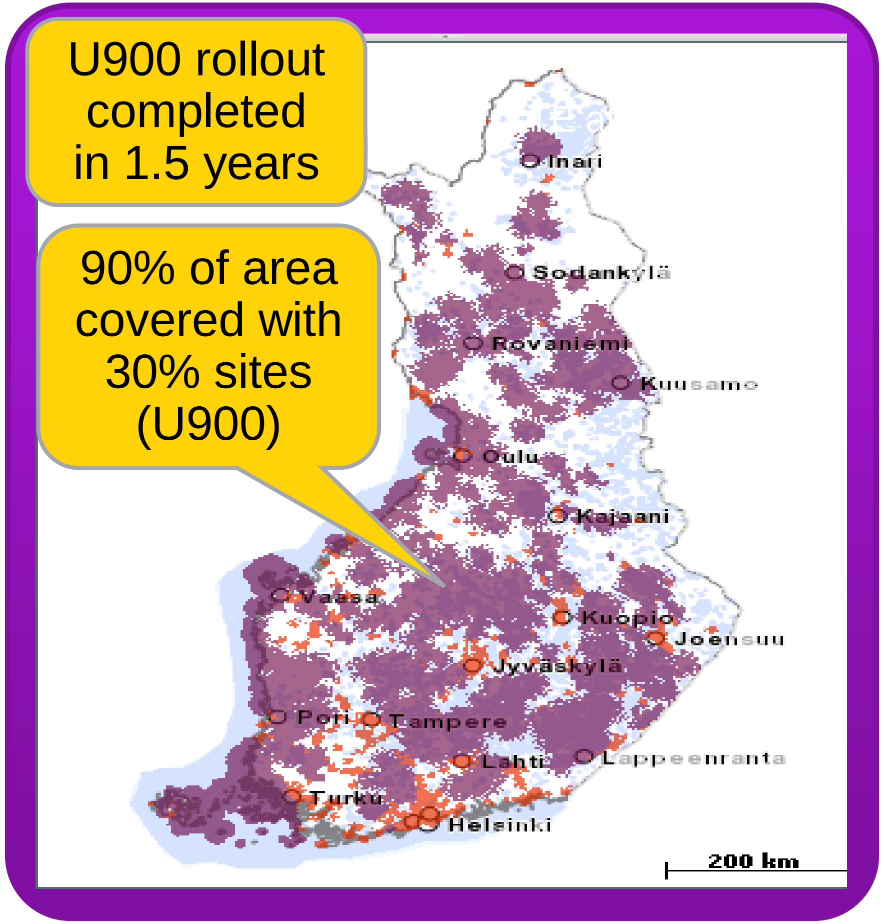
- **Government regulation (USO):** -> specific rollout requirements within 800 MHz spectrum license
- Service provided outside wireline-DSL areas

Coverage – Low Band and FDD best for wide area WCDMA/HSPA – FDD 900MHz

- **Government regulation (USO):**

  -> provide access to 1 Mbps broadband for every household – either wireline or wireless
- Target date: July 1, 2010
- HSPA900 chosen in view of time-line and 800 MHz spectrum availability
- > 500 devices in all form-factors & price-points

Example: UMTS 900 Coverage (Finland)



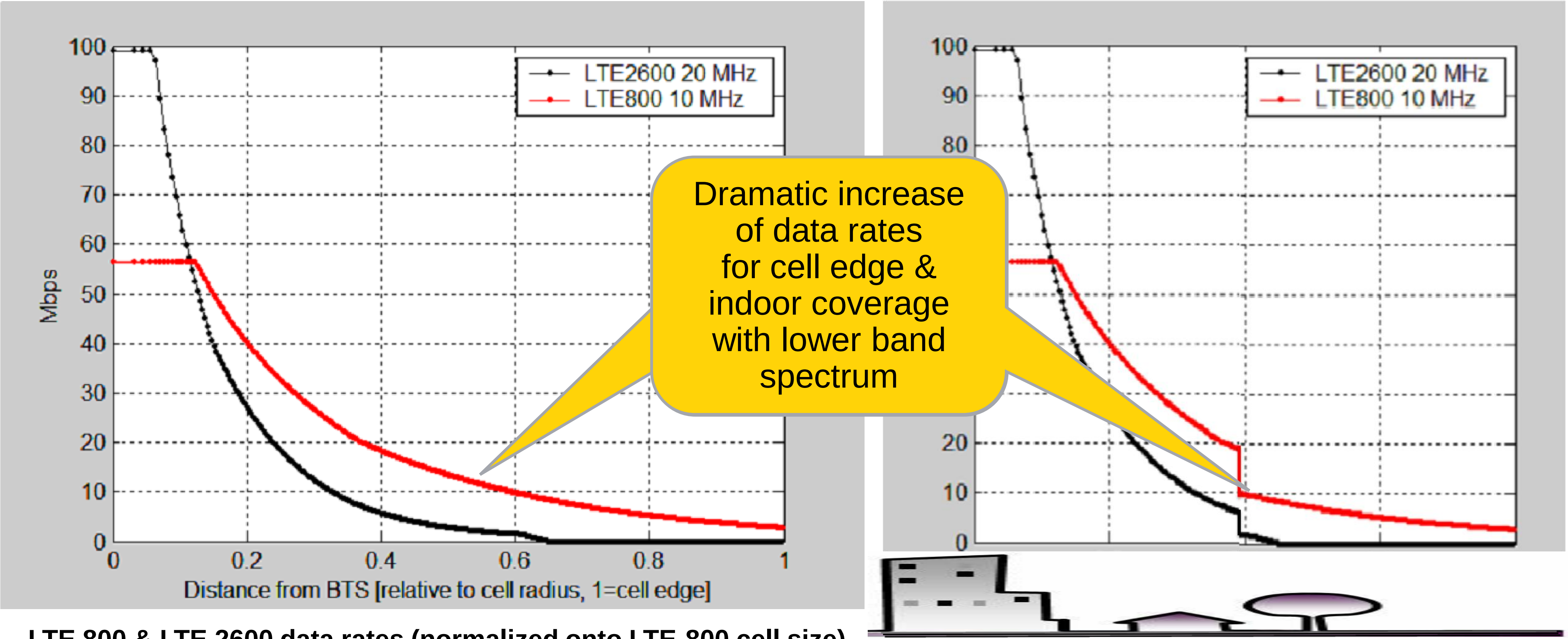
= UMTS900

= UMTS2100

Source: TeliaSonera

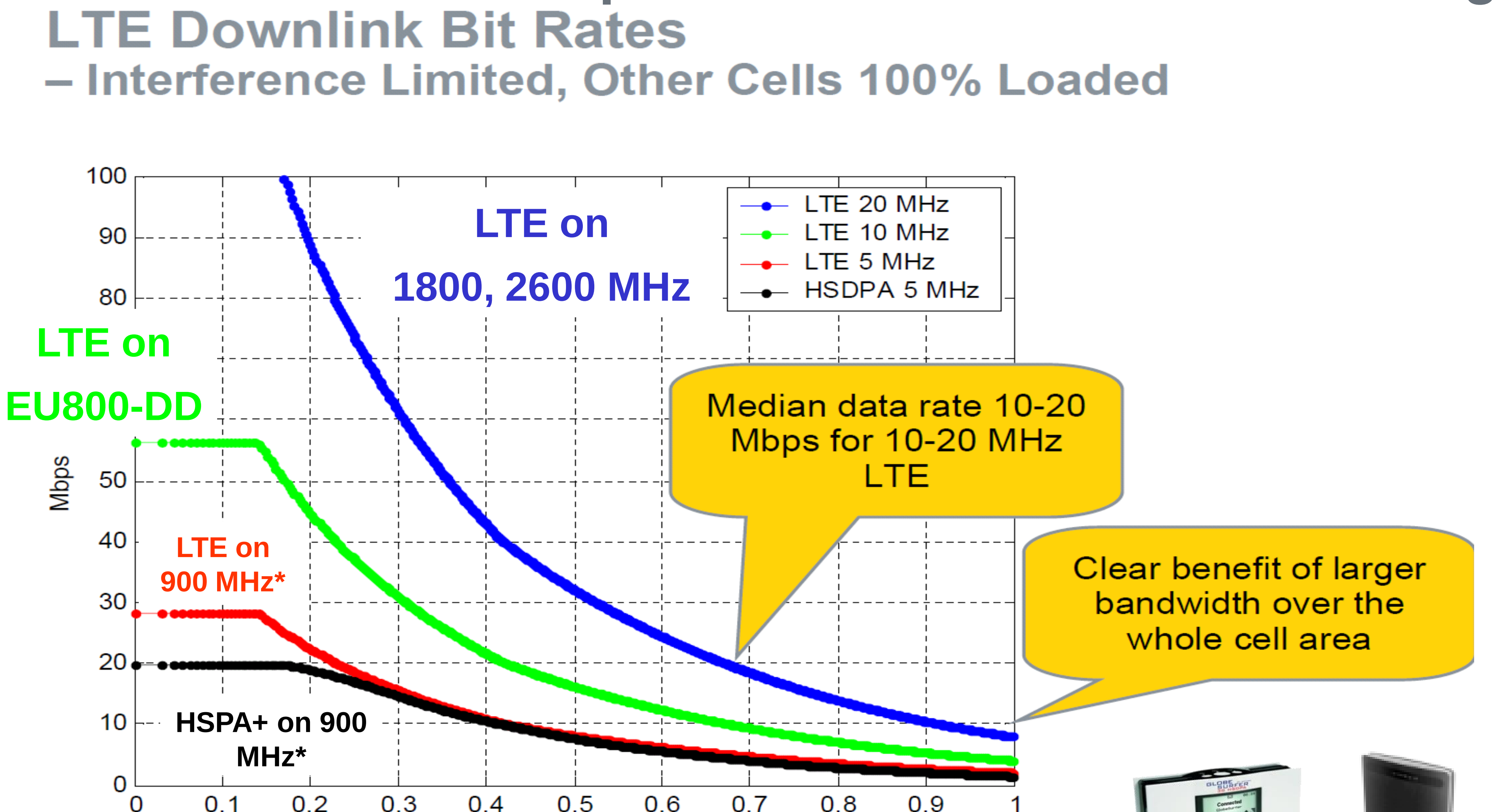
3 – times more coverage on 900 MHz

Coverage – Low Band and FDD
The power of 700/800/900 MHz for urban indoor coverage



LTE 800 & LTE 2600 data rates (normalized onto LTE-800 cell size)

More bandwidth = Superior data rates across cell range

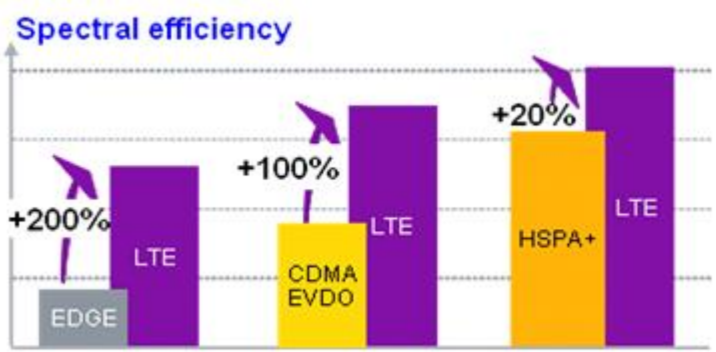


* GSM operation in parallel

10 km

(indicative range for 30m antennas)

Practical Data Rate Evolution – End-user experience



LTE improves data rates compared to HSPA

- **with *wider bandwidth*, and**
- **with *higher spectral efficiency* (20-40%)**

	Peak rates	**Typical drive test rates**	
HSPA+ 5 MHz	21 Mbps (42 Mbps)	7 Mbps	
DC-HSPA 10 MHz	42 Mbps (84 Mbps)	14 Mbps	DC-HSPA doubles data rates
LTE **10 MHz**	74 Mbps	**20 Mbps**	= 2 x more spectrum + 40% vs HSPA
LTE **20 MHz**	100 (150) Mbps	**40 Mbps**	= 4 x more spectrum + 40% vs HSPA

Spectrum Resources – Europe

- Main LTE bands in **Europe: *800, 1800 and 2600 MHz***

Overall spectrum available		Typical future CSP deployment scenario	
2600 (2x70 MHz + 50 MHz)	*new spectrum*	LTE 20 MHz TD-LTE 20 MHz	**LTE capacity & highest data rates**
2100 (2 x 60 MHz)	*WCDMA/HSPA*	Multicarrier HSPA	*HSPA capacity*
1800 (2 x 75 MHz)	*GSM*	LTE 10+MHz & GSM (defragmentation)	**LTE capacity +** *GSM capacity*
900 (2 x 35 MHz)	*GSM*	HSPA 5+MHz & GSM (defragmentation)	*HSPA coverage + GSM maintenance*
EU800 (2 x 30 MHz)	*new spectrum, Digital Dividend / TV-transition*	LTE 10 MHz	**LTE coverage**

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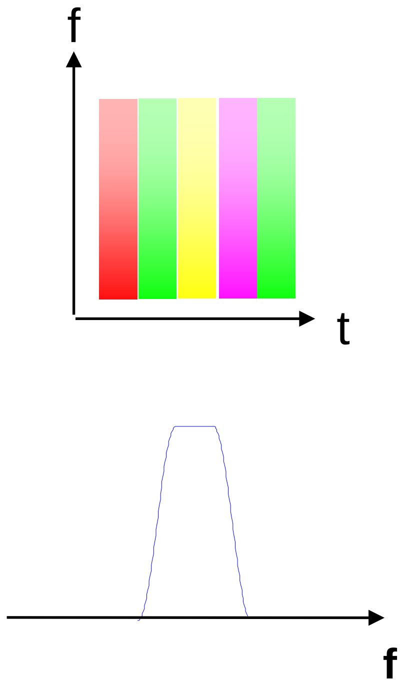
Multiple Access Methods

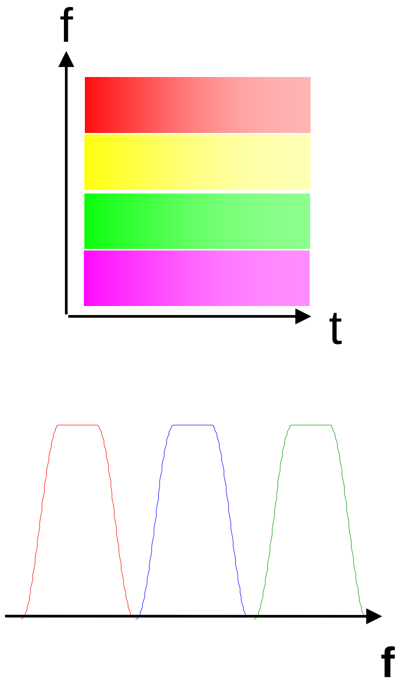
TDMA

- Time Division



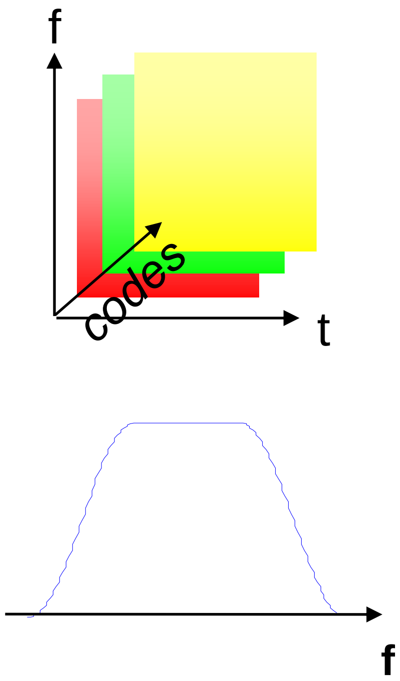
FDMA

- Frequency Division



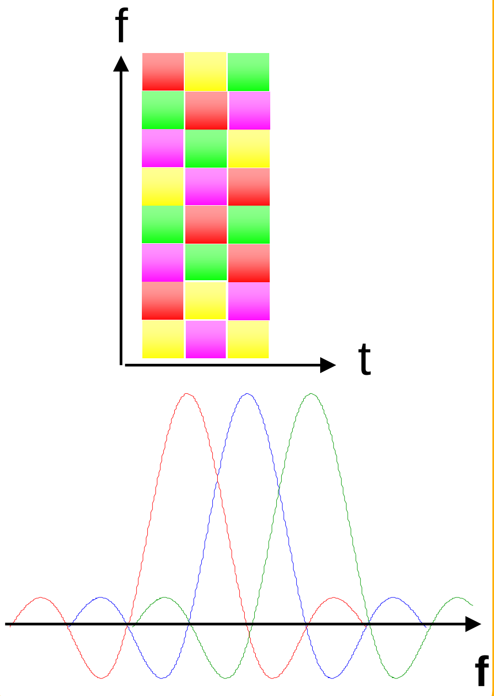
CDMA

- Code Division



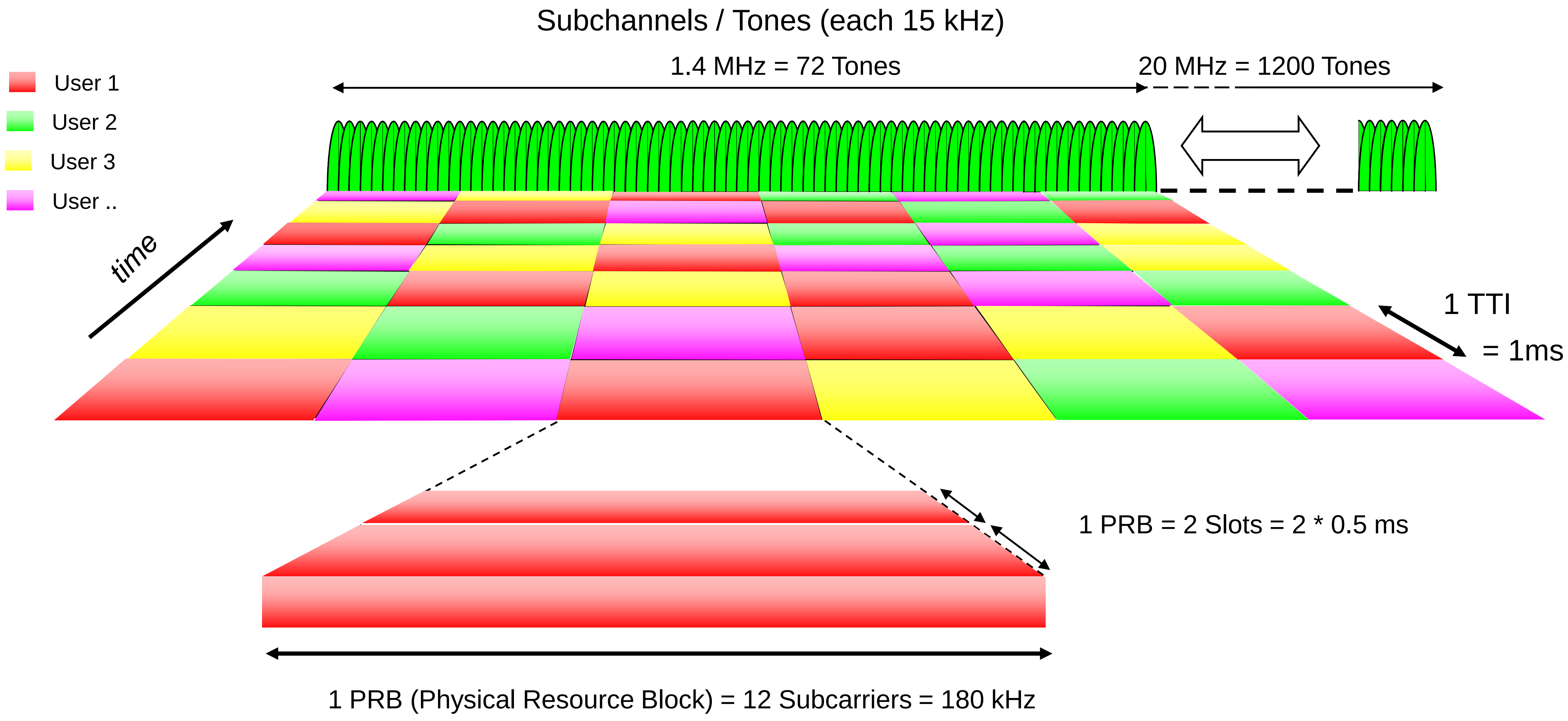
OFDMA

- Frequency Division
- Orthogonal subcarriers

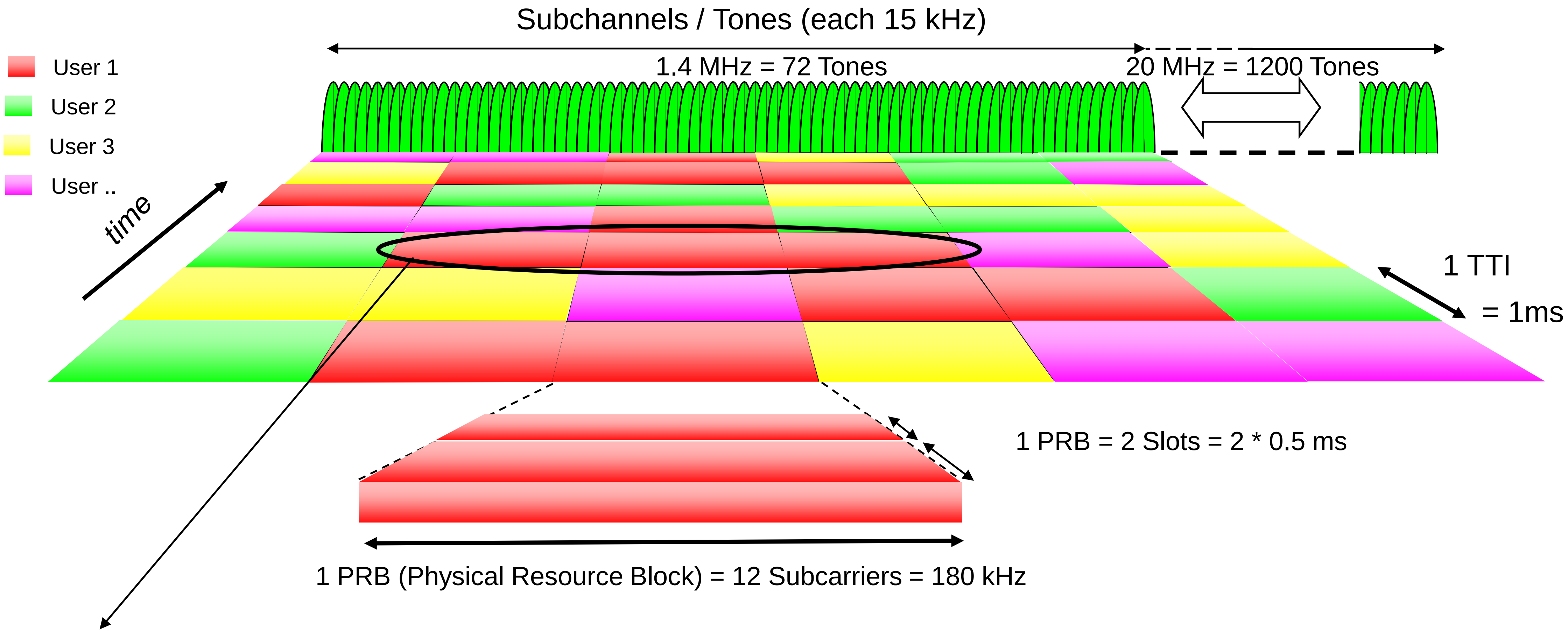


User 1 User 2 User 3 User ..

Downlink - OFDM

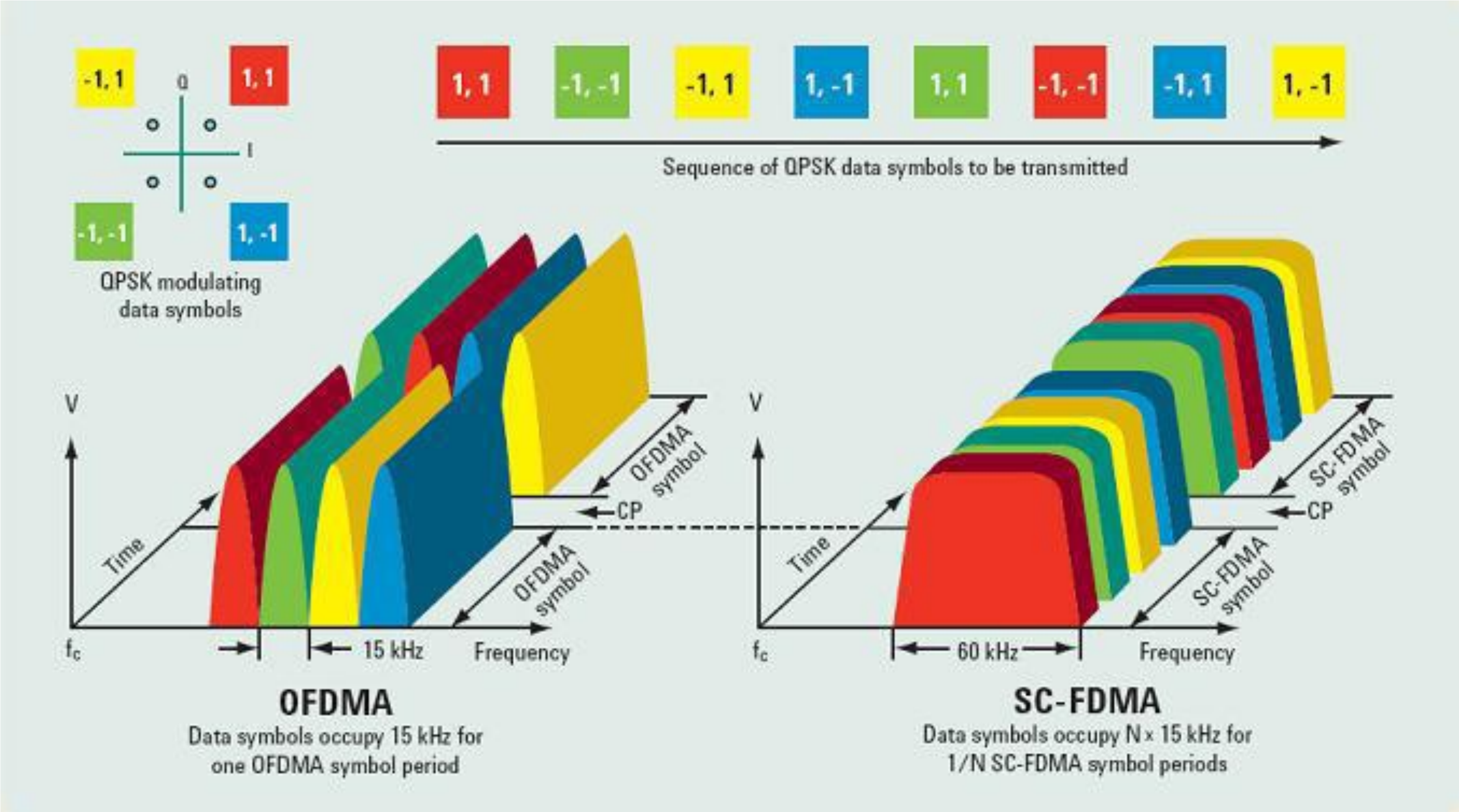


Uplink – Single Carrier FDMA

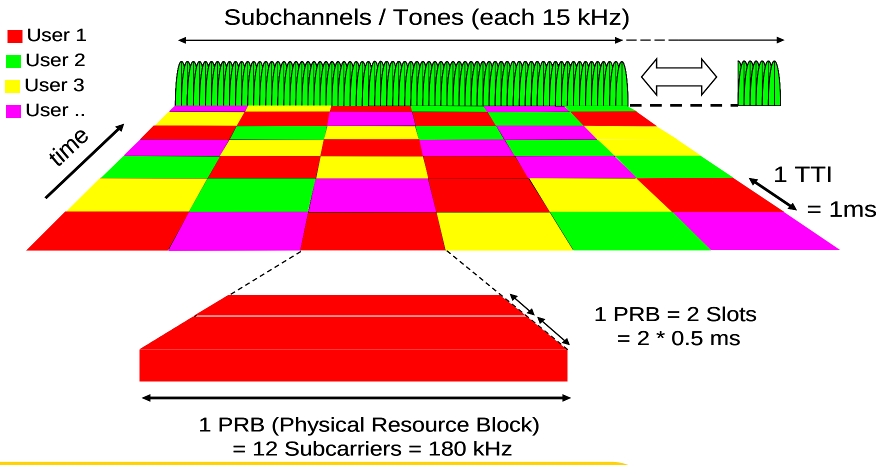


SC-FDMA: PRB's are grouped to bring down Peak to Average Power Ratio (PAPR)
→ better power efficiency at the terminal

OFDMA vs SC-FDMA



LTE Radio principles



Downlink:

OFDMA

- Improved spectral efficiency
- Reduced interference
- Very well suited for MIMO

Uplink:

SC-FDMA

- Power efficient uplink increasing battery lifetime
- Improved cell edge performance by low peak to average ratio
- Reduced Terminal complexity

- Enabling peak cell data rates of 173 Mbps DL and 58 Mbps in UL *
- Scalable bandwidth: 1.4 / 3 / 5 / 10 /15 / 20 MHz also allows deployment in lower frequency bands (rural coverage, refarming)
- Short latency: 10 – 20 ms **

* At 20 MHz bandwidth, FDD, 2 Tx, 2 Rx, DL MIMO, PHY layer gross bit rate

** roundtrip ping delay (server near RAN)

E-UTRAN Node B (eNodeB)

- eNodeB is the only node that controls all radio related functions:

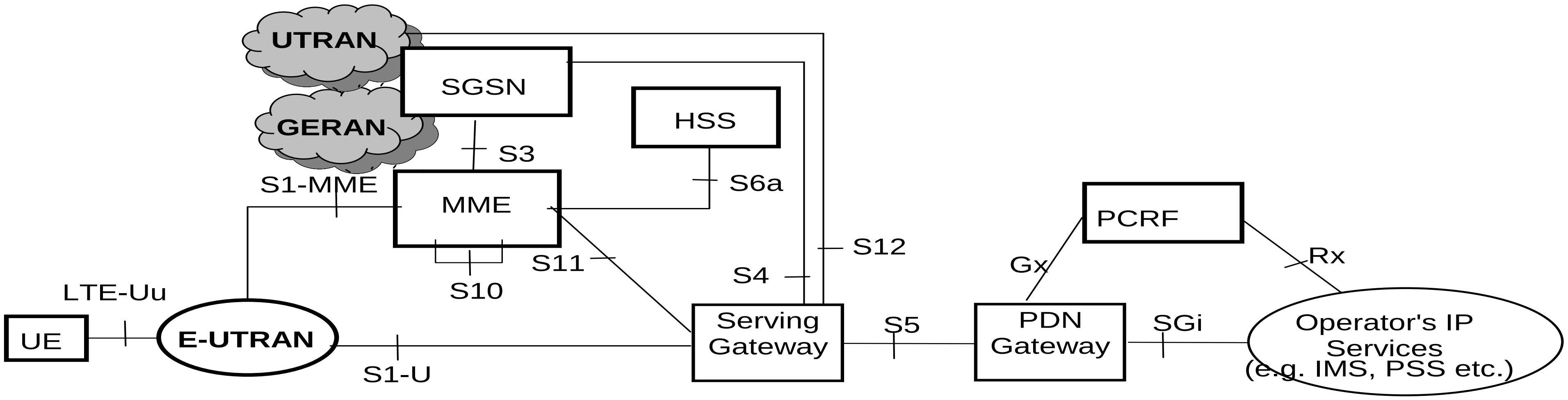
  - Acts as layer 2 bridge between UE and EPC
    - Termination point of all radio protocols towards UE
    - Relaying data between radio connection and corresponding IP connectivity towards EPC
  - Performs ciphering/deciphering of the UP data and IP header compression/decompression
  - Responsible for **Radio Resource Management** (RRM)-
    - allocating resources based on requests
    - prioritizing and scheduling traffic according to required Quality of Service (QoS).
  - **Mobility Management-**
    - controls and analyses radio signal level measurements by UE, makes similar measurement itself and based on those makes HO decision.

Agenda

- Introduction
- WCDMA/HSPA/HSPA+
- LTE
  - Introduction
  - LTE Spectrum
  - Radio Access Overview
  - Core Network Overview
  - Voice over LTE (VoLTE)
- LTE-Advanced
- Summary

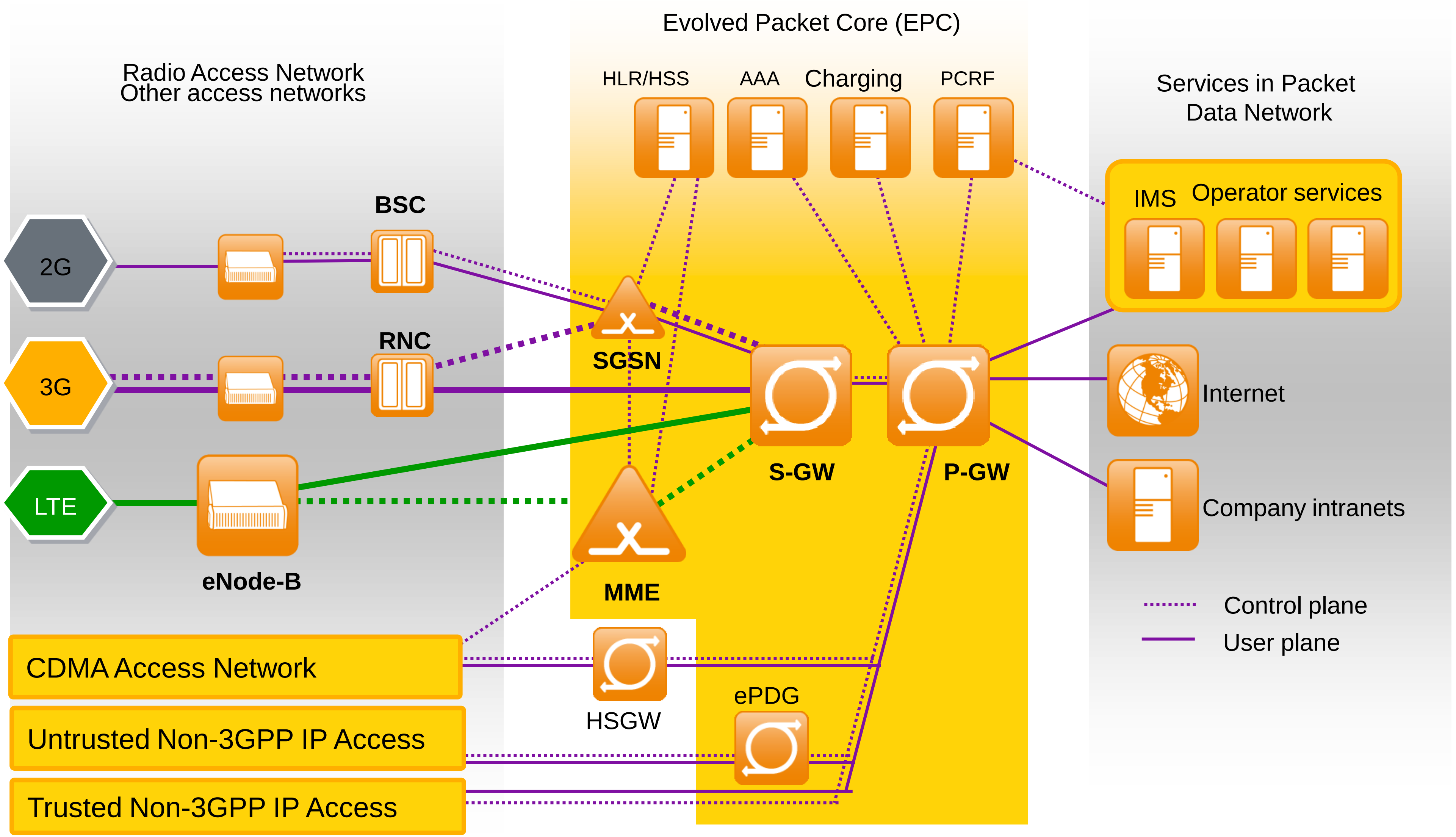
Main EPS Standards: 23.401

- Defines EPS architectures for 3GPP accesses using GTP protocol (GTP on S5/S8)
  - One example is given below
- Defines role of MME, SGW and PGW
- Two GW configurations: standalone SGW and PGW, co-located SGW/PGW
- Defines high level procedures (mobility management, session management, interworking with existing accesses, etc.)



Non-roaming architecture for 3GPP accesses

3GPP R8 Architecture:
Flat architecture for high efficiency



Core Technology Overview

Mobility Management Entity

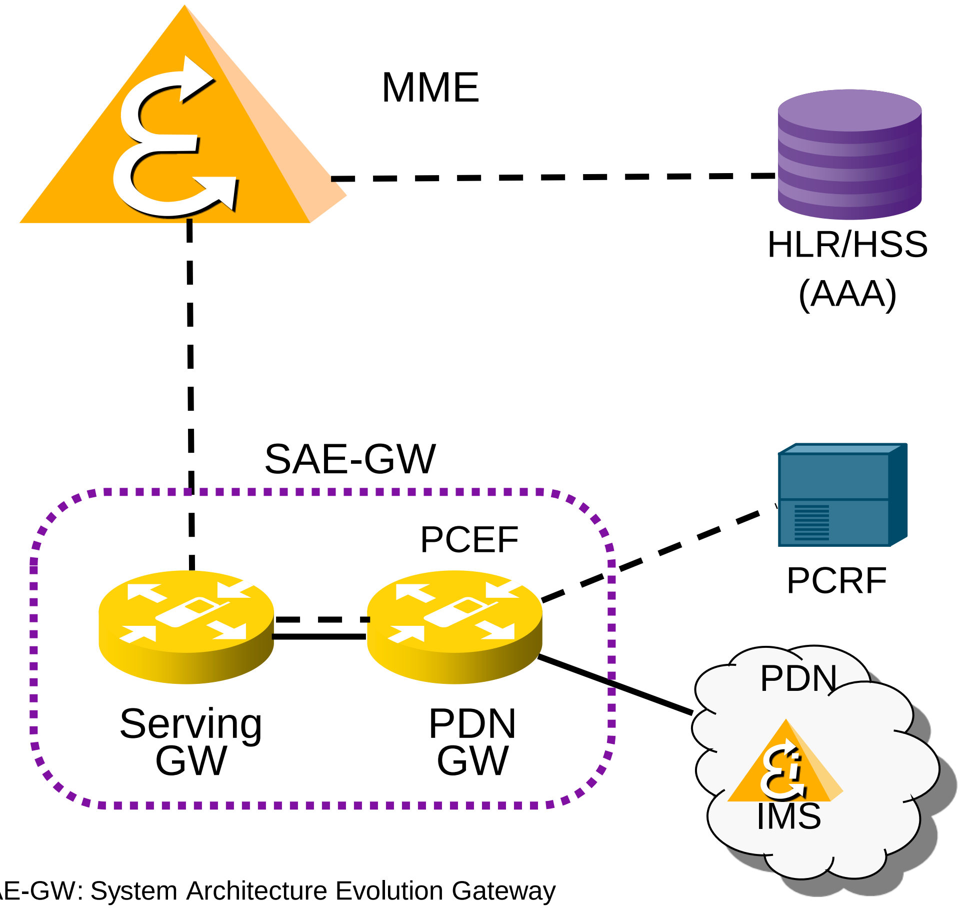
- C-Plane Part
- Session & Mobility management
- Idle mode mobility management
- Paging
- AAA Proxy

Serving Gateway

- User plane anchor for mobility between the 2G/3G access system and the LTE access system.
- Resides in visited network in roaming cases
- Lawful Interception

Packet Data Network Gateway

- Gateway towards Internet/Intranets
- User plane anchor for mobility between 3GPP and non-3GPP access systems (HA).
- Charging Support
- Policy and Charging Enforcement (PCEF) *)
- Packet Filtering
- Lawful Interception



SAE-GW: System Architecture Evolution Gateway
= S-GW + PDN-GW

*) PCRF: Policy and Charging Rules Function communicates with PCEF (Policy and Charging Enforcement Function within PDN SAE GW)

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Reasons for VoLTE - simultaneous voice and data

Spectral efficiency

”More bang for the MHz and buck”, 2x more voice calls at reduced cost

Voice quality

HD voice, GBR QoS, short call setup time

Simplification

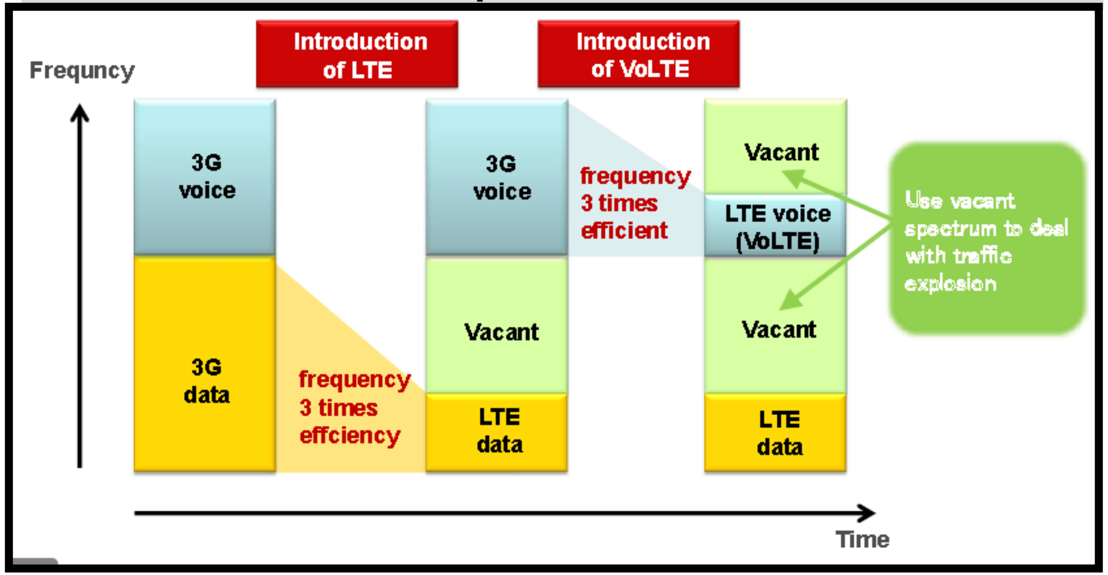
Voice becomes data and runs in the same all IP environment

Richer voice

A multimedia environment enriches voice and equips for OTT fight

Why VoLTE – Operator view (DoCoMo)

Benefit for the operator



- Benefits for customers
  - Faster call set-up
  - Mobile broadband still available during voice call
  - Service quality better than OTT VoIP apps
    - Priority handling, SRVCC
  - Existing supplementary services are supported

Our philosophy behind: Maintain the same service quality as the existing 3G voice service to satisfy customer needs.

Comparison vs. OTT VoIP

Services	VoLTE	OTT VoIP Apps	
Use of E.164 Number	✓	Limited	Limited to certain numbers/operators
Emergency Call	✓	✗	
CLIP/CLIR	✓	✗	Originating number not always displayed
Priority Calls	✓	✗	
Voice mails	✓	✓	Supported by certain app e.g. Skype
Call Diversion	✓	✓	
Other supplementary services	✓	✗	

… however, DoCoMo has not launched VoLTE yet.

Potential voice evolution steps in LTE

LTE used for high speed packet data access only

- Operator voice service provided over CS network

Fallback to CS voice

- LTE network is used for data only
- Terminal is simultaneously registered to both LTE and 2G/3G CS network
- Voice calls are initiated and received over CS network

Single radio Voice Call Continuity (VCC)

- Operator provides VoIP over LTE
- IMS acts as control machinery
- Voice calls can be handed over to CS network

All-IP network

- Operator provides VoIP over LTE
- IMS acts as control machinery
- Voice calls can be handed over to other packet switched networks

Agenda

Introduction

WCDMA/HSPA/HSPA+

LTE

LTE-Advanced

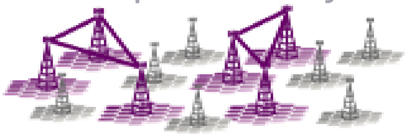
Summary

LTE-Advanced Pushes Data Rates Beyond 1 Gbps

Bandwidth Extension

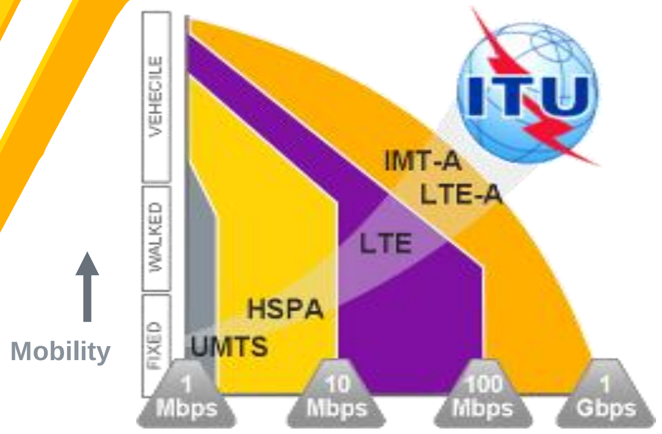
MIMO

Cooperative Systems

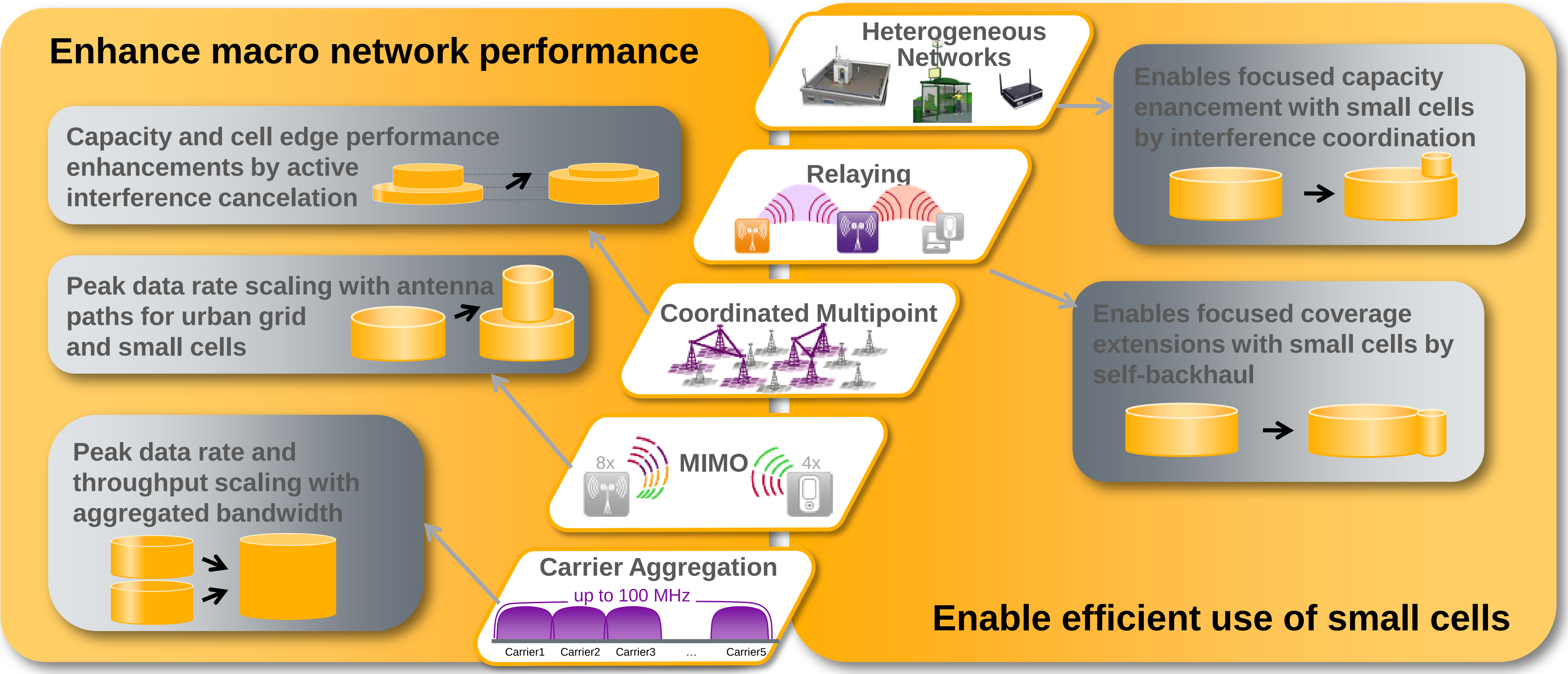


Heterogeneous Networks

Backward compatible to LTE

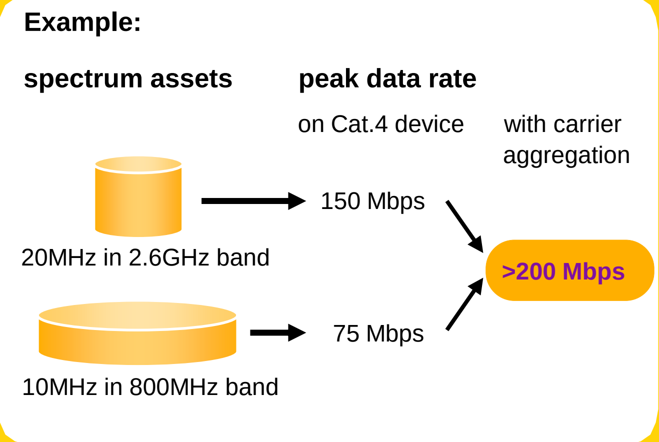


The LTE-Advanced toolbox for delivering more data efficiently to wide areas and hotspots



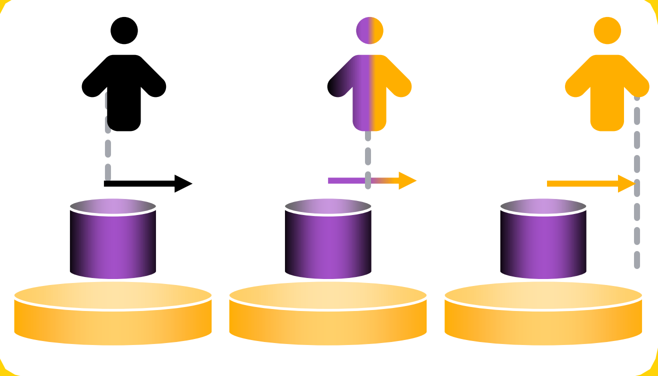
LTE-Advanced: Carrier aggregation
More dynamic spectrum usage for better user experience

Peak data rate addition



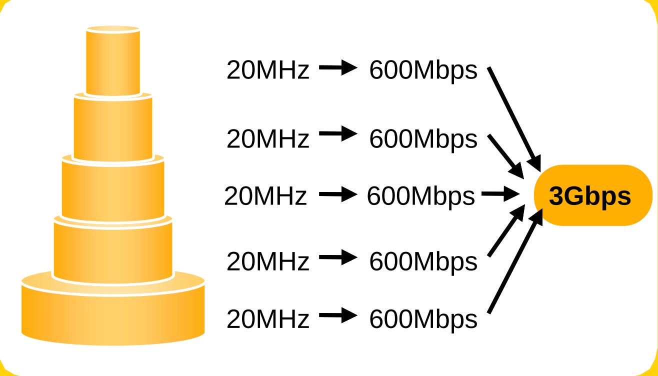
- enables **competitive peak data rates** on non-contiguous spectrum
- Mitigates the challenge of fragmented spectrum

Resource allocation gain



- Ultrafast resource allocation by scheduler instead of handover
- Users dynamically get the best resources of aggregated carrier
- **Higher average data rates**

3 Gbps



- Will be specified in **3GPP Rel.11 or later**
- Most operators have significantly less spectrum for LTE
- Even HD streaming services demand less than 20Mbps

Relevant scenarios under standardisation (3GPP Rel.10/11)

nsn

LTE Advanced: Band Combinations with initial focus

- Downlink carrier aggregation for 2 component carriers
- Up to 40 MHz combined bandwidth
- 36 combinations in total
- 13 combinations for North America
- 8 combinations for Japan
- 5 combinations for Korea
- Part of Release 11 combinations still under work
- Release 12 combinations planned for next year
- No FDD + TDD aggregation

	Release 10	Release 11	Release 12
Inter-band	1 5 Korea	3 7 Teliasonera	3 5 SK Telecom
		4 13 Verizon	2 4 TMO USA
		4 17 AT&T	23 x Dish
		7 20 Orange etal	3 26 KT
		5 12 US Cellular	3 28 eAccess
		4 12 Cox	3 19 Docomo
		2 17 AT&T	38 39 CMCC
		4 5 AT&T	1 8 Softbank
		5 17 AT&T	
		1 7 China Telecom	
		3 5 SK Telecom	
		4 7 Rogers	
		3 20 Vodafone	
		8 20 Vodafone	
		1 18 KDDI	
		1 21 Docomo	
		11 18 KDDI	
		3 8 KT	
Intra-band	1 Generic	41 Clearwire, CMCC	3 SK Telecom
	40 Generic	38 CMCC	4 TMO USA
		7 CUC, CT, Telenor	25 Sprint
			1 KDDI

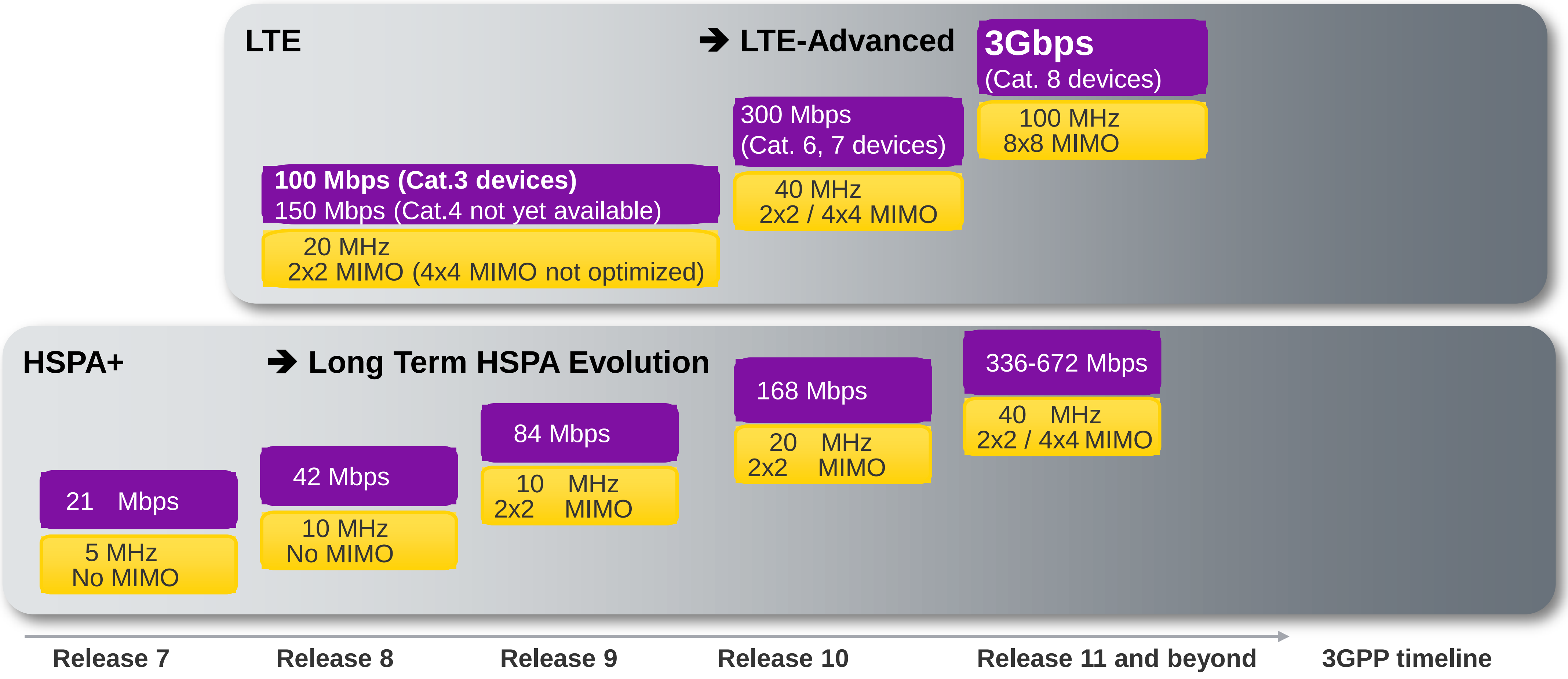
1800 + 2600

800 + 2600

800 + 1800

800 + 900

Overview - Mobile Broadband Downlink peak data rate evolution



Agenda

MOBILE BROADBAND

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Summary (1/3)

WCDMA/HSPA/HSPA+

- Strong momentum and growth in Mobile Broadband with terminals, network technology and applications
- WCDMA has both FDD (widely used) and TDD variant with FDD using 5+5 MHz and TDD 5 MHz as single carrier
- HSPA/HSPA+ is a mature technology with broad ecosystem support, which will further evolve and will remain dominant technology for many years to come
- Carrier aggregation and MIMO pushes the peak data rates and cell throughput

Summary (2/3)

LTE

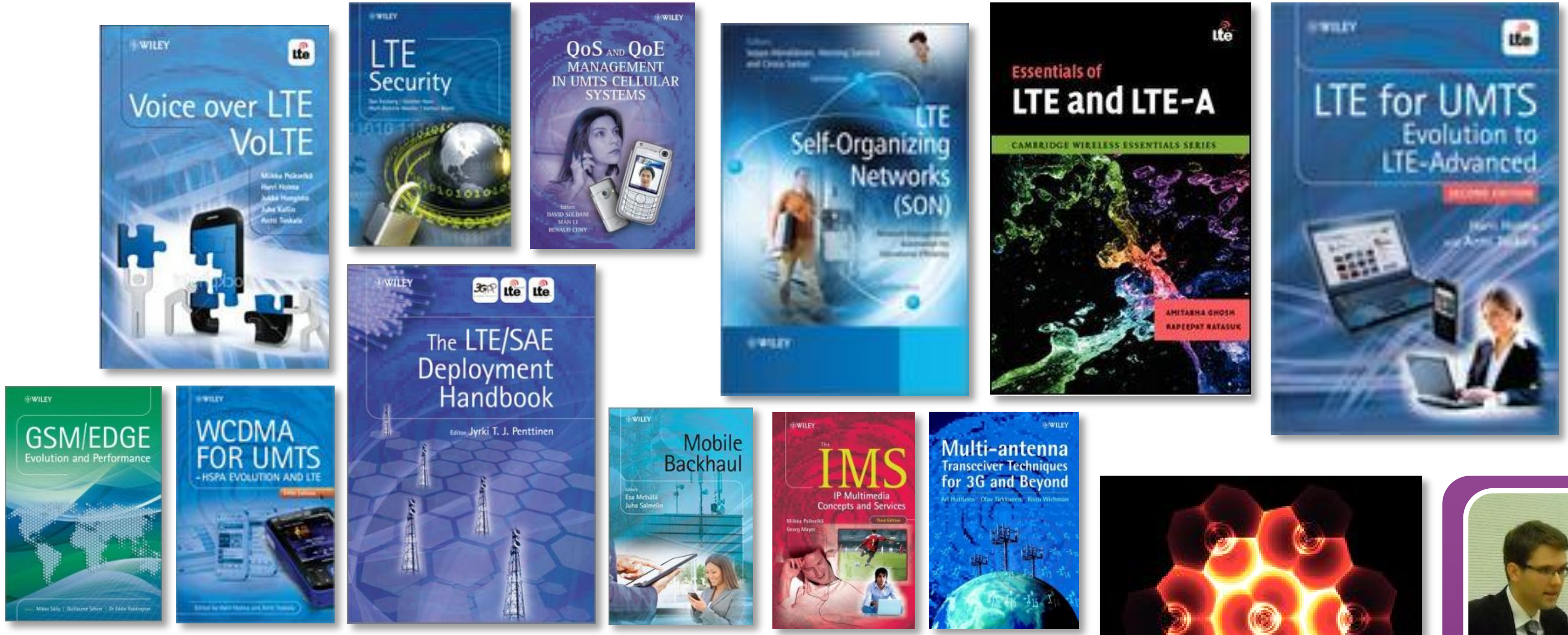
- Motivation of LTE is need for higher peak data rate, spectral efficiency, less round trip delay, packet optimized network, high degree of mobility and spectrum flexibility
- LTE has both FDD and TDD variant with frequency allocation flexibility with 1.4, 3, 5, 10, 15 and 20 MHz spectrum
- LTE frequency bands for Europe are 2600 (capacity), 1800 (capacity) and 800 (coverage) MHz
- LTE uses OFDMA in DL and SC-FDMA UL for multiple access technology. OFDMA in DL minimizes receiver complexity while SC-FDMA improves battery life time in receiver
- LTE is packet oriented flat network with minimum no. of nodes- only eNodeB in access and MME, SAE-GW (S-GW/P-GW) in core networks. (additionally, HLR/HSS, PCRF and IMS is required in core)
- Voice in LTE is accomplished by CS Fallback (initially) and SR-VCC (later).

Summary (3/3)

LTE-Advanced

- LTE-A in Rel-10 adds several enhancements in LTE
- Improvements in peak and average data rates using carrier aggregation, increased number of antennas and advanced antenna technologies
- Further improvements by use of relay and interference management
- LTE-A with Rel-10 fulfills and exceeds requirements for IMT-Advanced
- LTE-A can achieve peak data rates as high as 3 Gbps in DL and 1.5 Gbps in UL direction with 100 MHz spectrum

Nokia LTE R&D
Research and publications bringing the industry forward

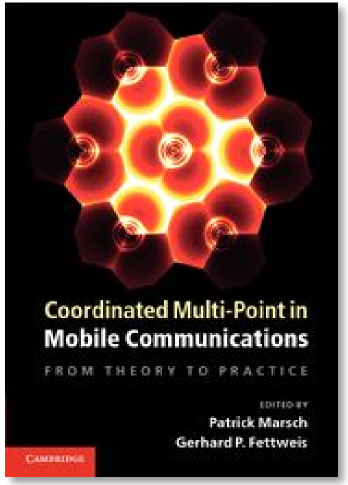


Antti Toskala

LTE Award for individual contribution to LTE development

More than 130 published LTE research papers in 2010 and 2011

- LTE-Advanced, SON, heterogeneous networks,…
- Published/accepted research conference articles and journal papers (IEEE, VTC,….)



Patrick Marsch

Johann Philipp Reis Prize 2011

for his pioneering research on Coordinated Multi-Point

