LTE Introduction

Helsinki University of Technology

December 8th, 2009

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NSN Fellow – Radio System Performance

Explosion of Mobile Data Usage

Ficora Mid-2009 Report
(Finnish Communications Regulatory Authority)

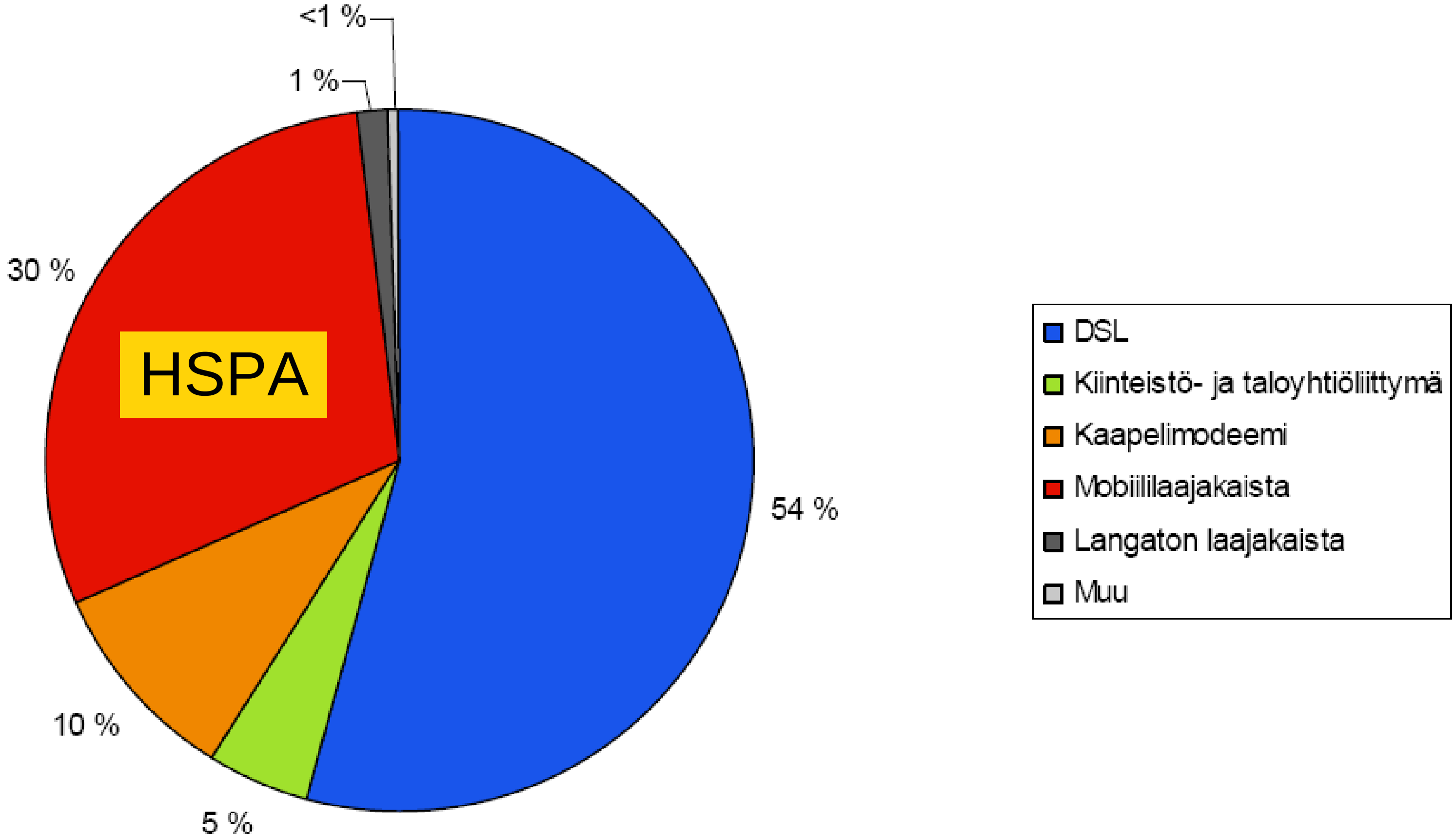
- 664.000 HSPA subscribers, which is 12.5% penetration of the whole population (5.3 M population)
- Other wireless solutions close to non-existent: Digita 450 Flarion 32 ksubs and WiMAX 11 ksubs
- HSPA penetration has increased 115% during the last 12 months and 40% during the last 6 months
- DSL penetration has decreased 4% during the last 12 months

Vuosi	**2006**	**2007**		**2008**		**2009**
Ajankohta	**31.12.**	**30.6.**	**31.12.**	**30.6.**	**31.12.**	**30.6.**
DSL	1 161 100	1 210 900	1 270 500	1 270 100	1 231 300	1 216 300
Kiinteistö- ja taloyhtiöliittymä	72 900	98 100	114 000	104 600	134 900	104 700
Kaapelimodeemi	181 100	192 900	209 600	212 900	214 800	215 500
Mobiililaajakaista			143 100	307 100	479 700	664 300
Langaton laajakaista			15 300	19 600	26 100	31 600
Muu	13 800	18 300	7 700	9 000	9 800	11 500
Yhteensä	**1 428 900**	**1 520 200**	**1 760 200**	**1 923 300**	**2 096 600**	**2 243 900**

Taulukko 1. Laajakaistaliittymien kehitys vuosina 2006 – 2009.

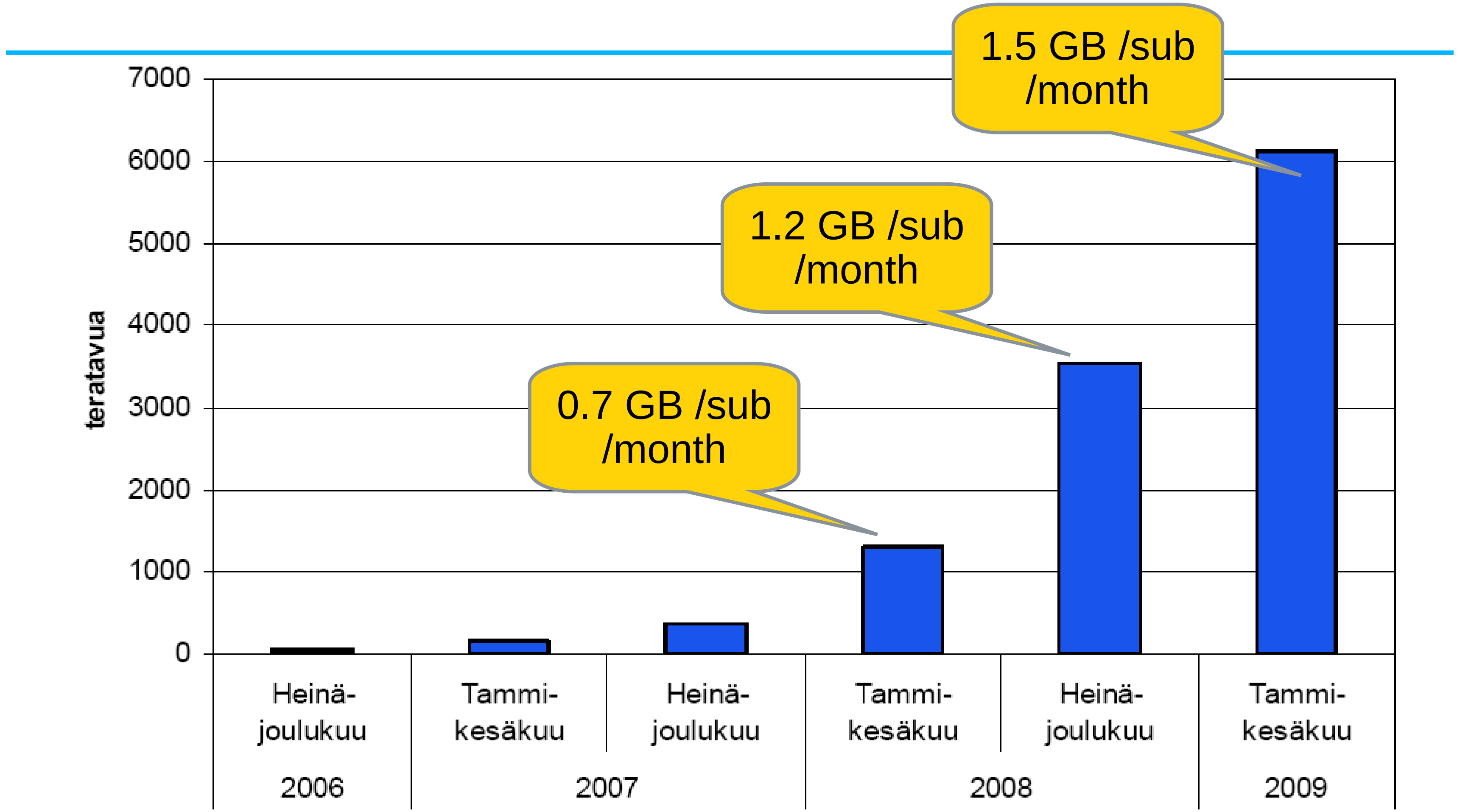
http://www.ficora.fi/attachments/suomimq/5jdCGapBJ/Markkinakatsaus_2_2009.pdf

HSPA Makes 30% of All Broadband Connections



Kuvio 2. Laajakaistaliittymät liittymätyypeittäin 30.6.2009.

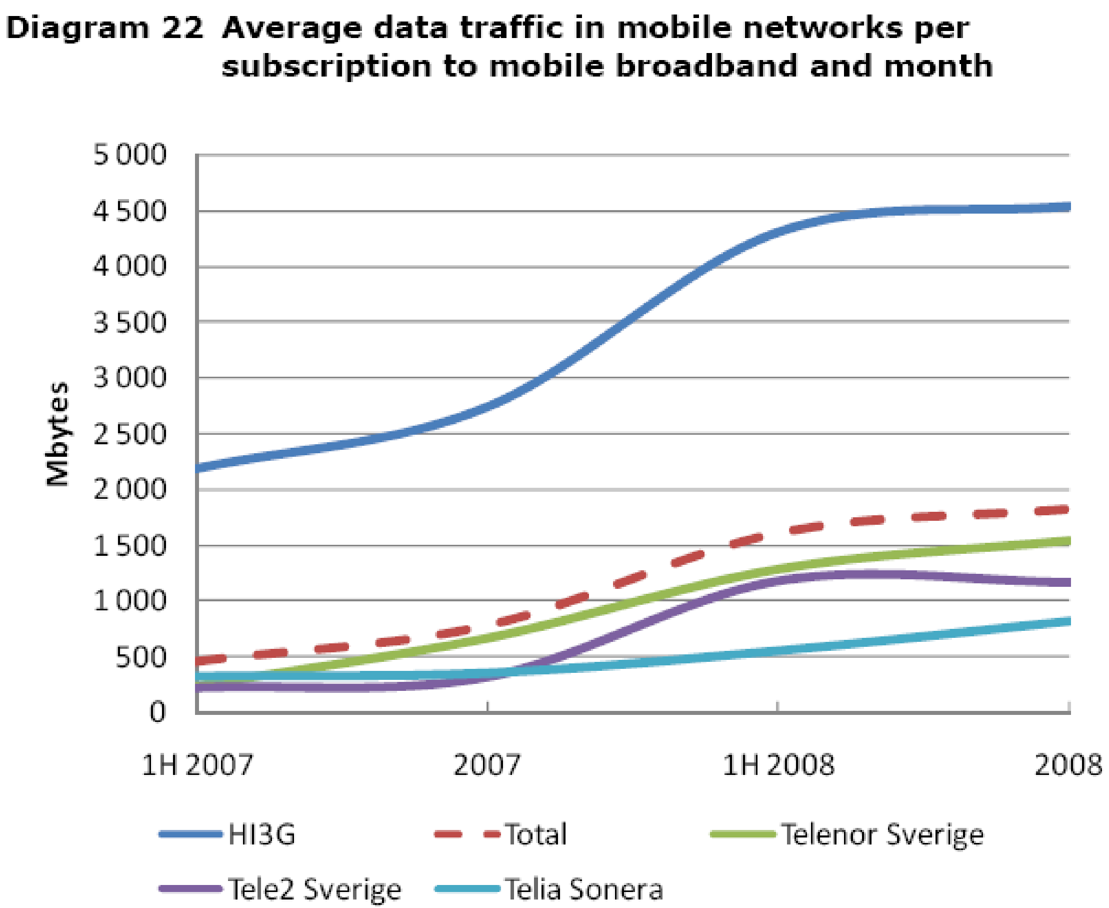
HSPA Data Volume Increased by 5x During Last 12 Months. Usage per Sub More than Doubled.



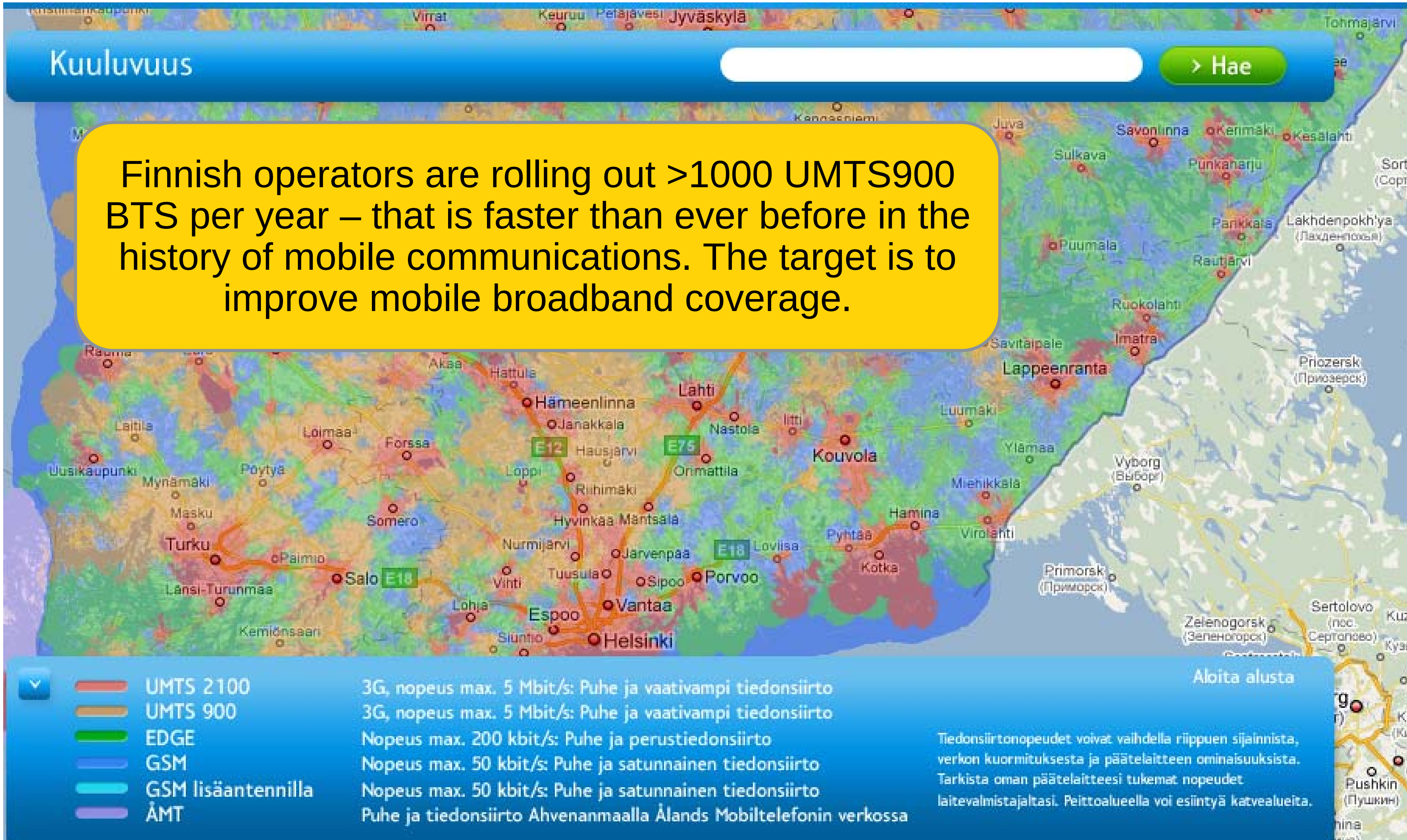
Kuvio 6. Matkaviestinverkoissa siirretyn dataliikenteen määrä vuosina 2006 - 2009 (Vuosikatsauksessa 2008 jul-kaistu datasiirtomäärä koskien vuoden 2008 toista puoliskoa on korjattu).

Traffic per Sub for Different Operators in Sweden

- H3G subscribers consume 5x more data than Telia subscribers



UMTS900 Provides Nationwide Broadband



Finnish operators are rolling out >1000 UMTS900 BTS per year – that is faster than ever before in the history of mobile communications. The target is to improve mobile broadband coverage.

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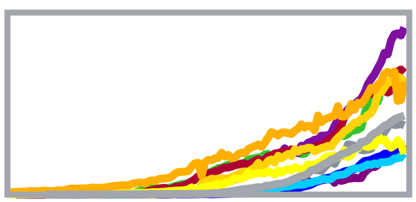
Drivers for LTE

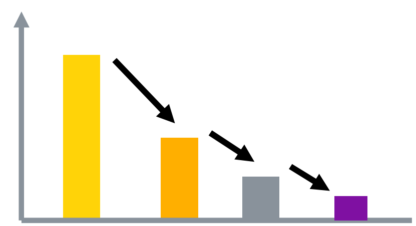
User experience

- Speed
- Coverage
- Flat rate

Traffic volume

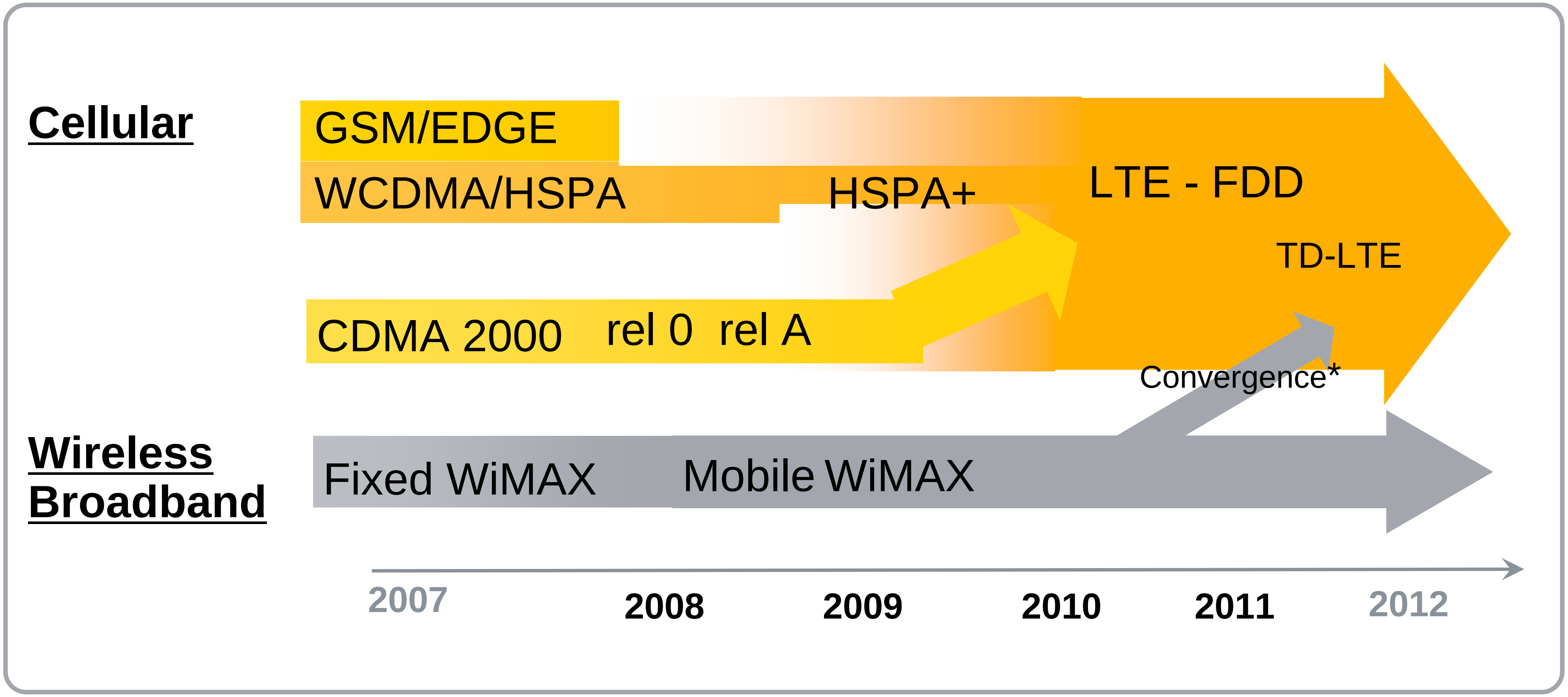


Cost per bit



LTE in 3GPP

Mobile evolution driven by radio, LTE the mainstream path



* operators with sufficient spectrum and mobile offering

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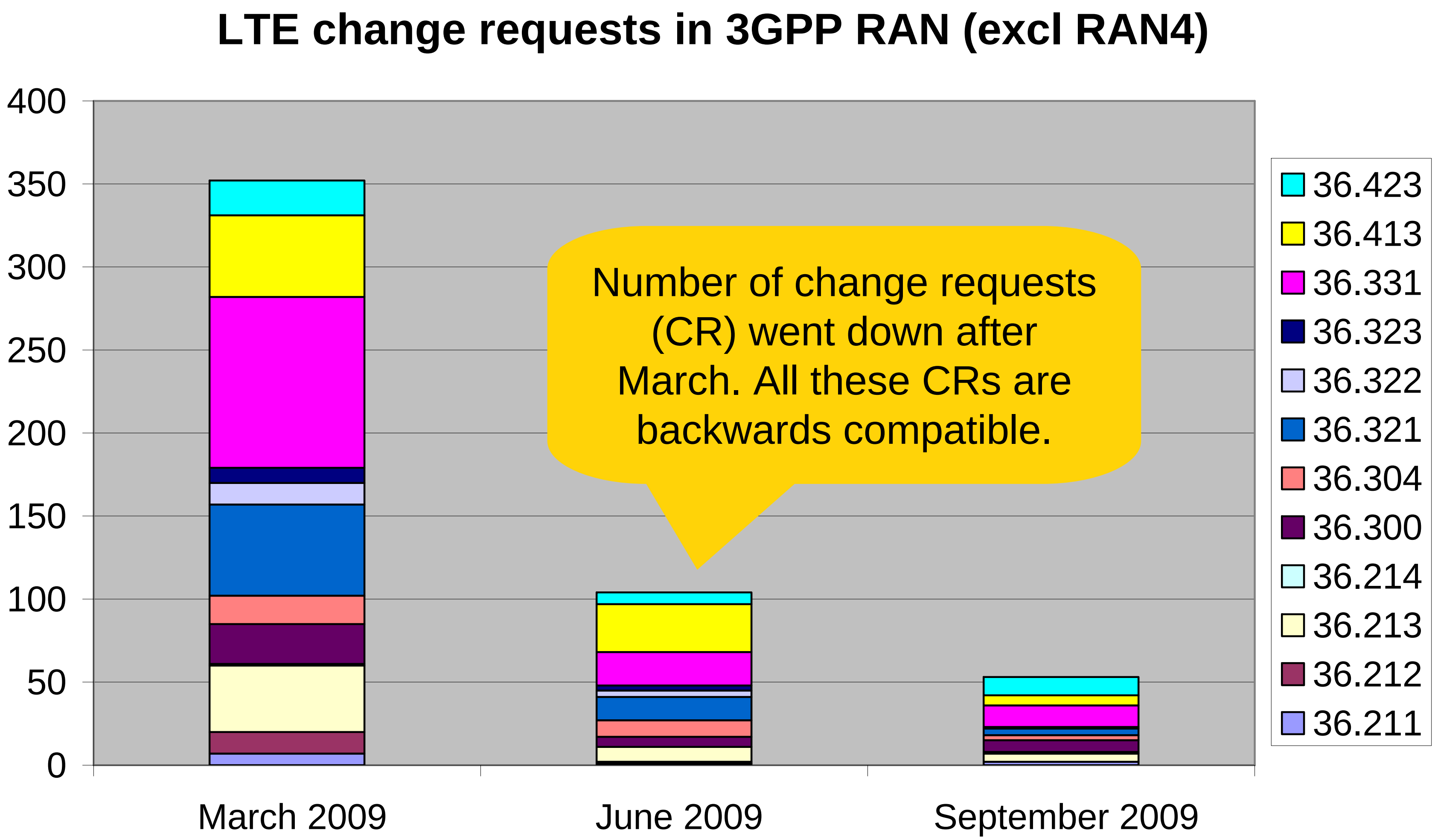
LTE Status in 3GPP

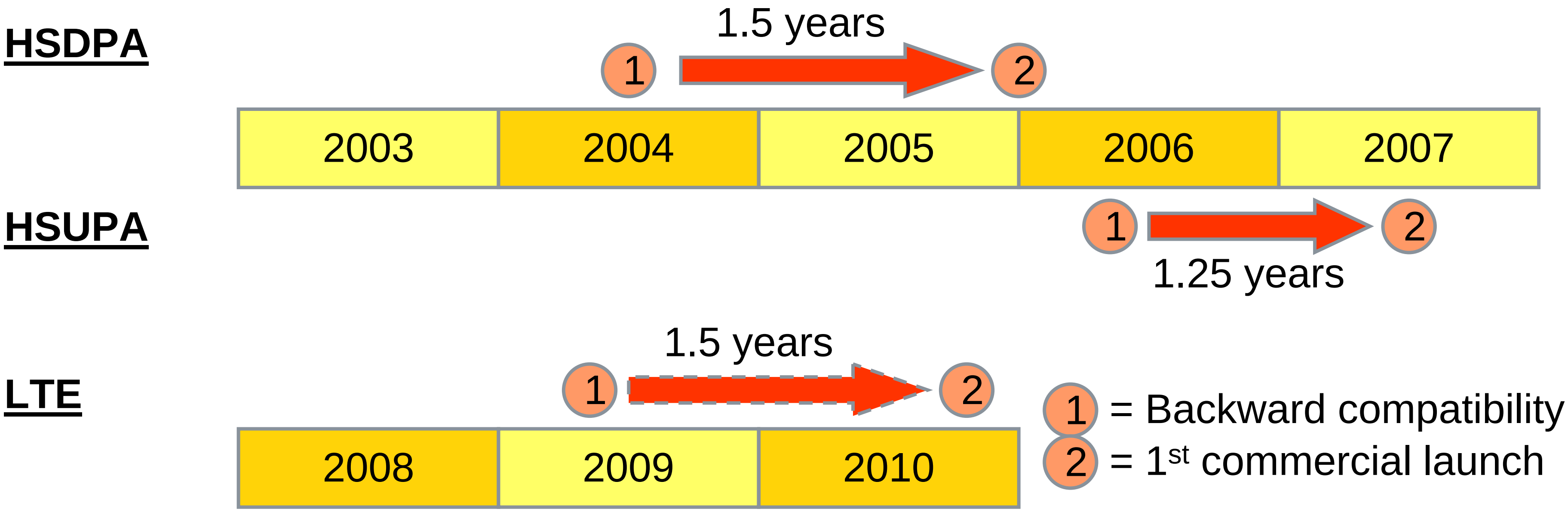
- LTE functional freeze has been reached, so no new functionality to be introduced anymore in Release 8
- RRC (Radio Resource Control) specification was the biggest open issue in LTE specifications
- The ASN.1 was frozen in March 2009
- Any commercial devices need to be build on top of the March 2009 RRC specification
- For network interfaces 05/2009 ASN.1 is needed due to the non-backwards compatible changes for 05/2009 version

LTE Release 8 Uses Stabile March 2009 Baseline (Backwards Compatibility)



LTE Timing in 3GPP

- LTE Release 8 started backwards compatibility March 2009
- Historically, it has taken 1.25-1.5 years from the backwards compatibility until commercial launch with HSDPA and HSUPA
- LTE commercial launch expected 2H/2010 based on HSDPA/HSUPA track record



LTE Chip Set Timing

LTE chip samples from Qualcomm November 2009

LTE USB modems available 2H/10

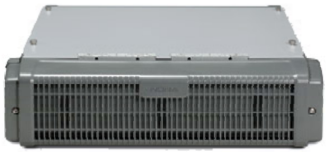
Qualcomm Now Sampling Industry's First Dual-carrier HSPA+ and Multi-Mode 3G/LTE Chipsets for Global Markets

- Trend Shows Industry Coming Together for Widespread Deployment of Two Advanced Network Technologies in 2010 -

November 12, 2009: 07:30 AM ET

SAN DIEGO, Nov. 12 /PRNewswire-FirstCall/ -- Qualcomm Incorporated (Nasdaq: QCOM), a leading developer and innovator of advanced wireless technologies, products and services, today announced that it is sampling the industry's first chipsets for dual-carrier HSPA+ and multi-mode 3G/LTE. The Mobile Data Modem (TM) (MDM(TM)) MDM8220(TM) solution is the first chipset to support Dual-carrier High-Speed Packet Access Plus (DC-HSPA+); and the MDM9200(TM) and the MDM9600(TM) chipsets are the industry's first multi-mode 3G/Long Term Evolution (LTE) solutions. These chipsets demonstrate significant progress toward enabling the mass-market commercial deployment of two next-generation network technologies that bring more advanced data capabilities to mobile devices for new global markets in addition to North America.

LTE Connection Using March 2009 Baseline



Press Release
Espoo, Finland - September 17, 2009

World's first LTE call on commercial software
Nokia Siemens Networks successfully demonstrates LTE calls using standards-compliant release

Nokia Siemens Networks recently made the world's first LTE call using commercial base station and fully standard compliant software. The successful demonstration clearly proves the readiness of Nokia Siemens Networks' products for early commercial deployments worldwide.

Standard compliant LTE network products and terminals are a precondition for commercial network rollouts and for end users to benefit from a large terminal variety from different vendors. The Nokia Siemens Networks' call was made via base stations with fully compliant software to the 3GPP Rel.8 (March 2009 baseline) LTE standard, bringing LTE trials closer to the behavior of future commercial deployments.

Testing with Four LTE Devices

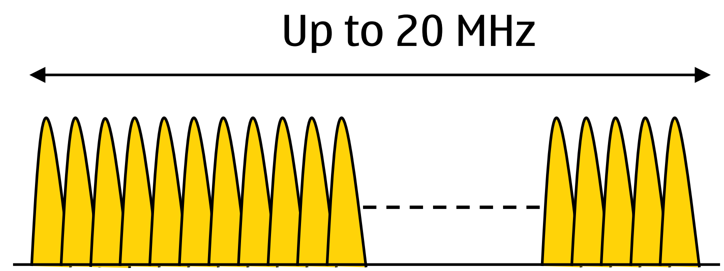
Press Release
Dallas, Texas, USA - October 29, 2009

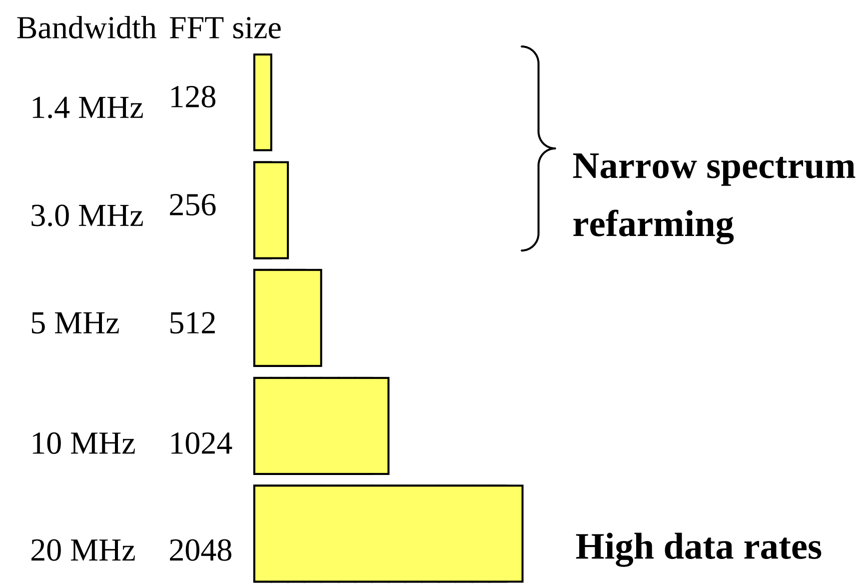
Nokia Siemens Networks conducts LTE interoperability testing with four leading device vendors
Further progress on the road towards commercial LTE deployment

LTE Technology

Downlink Air Interface Technology

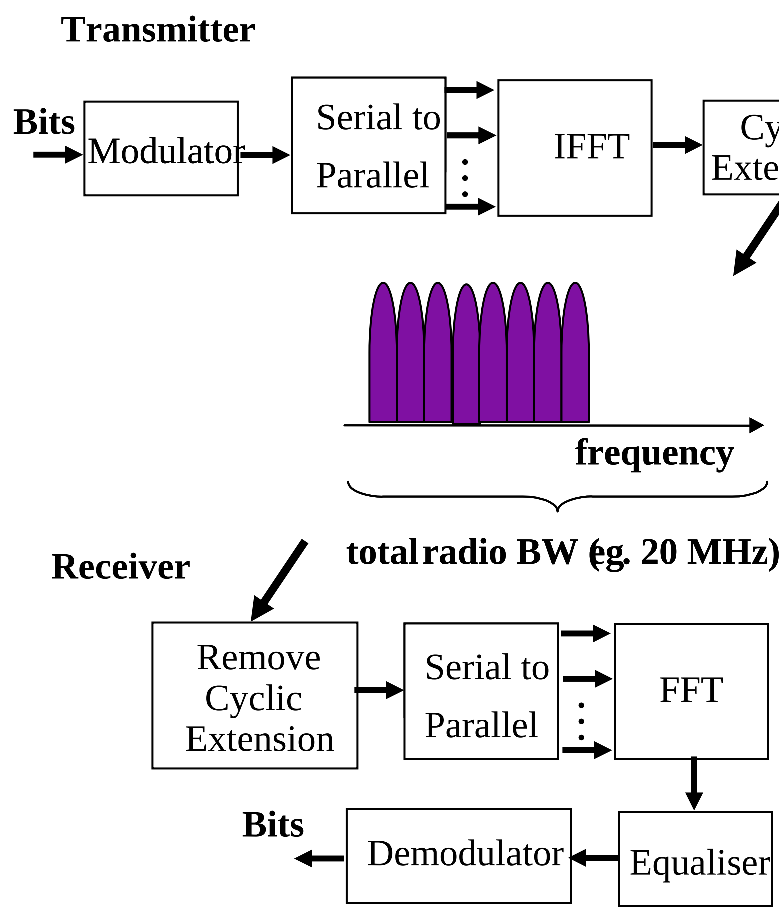
- OFDM-based DL air interface
- Frequency bandwidth options are 1.4 MHz, 3.0 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz
- Each BW has fundamentally similar features
  - Symbols are parameterized equally
  - 15 kHz subcarrier spacing
  - Clock is 2^N (8x) multiple of 3.84 MHz
  - FFT scales as a power of two
- 3GPP is discussion also alternative parameters for the broadcast use (Mobile TV case)





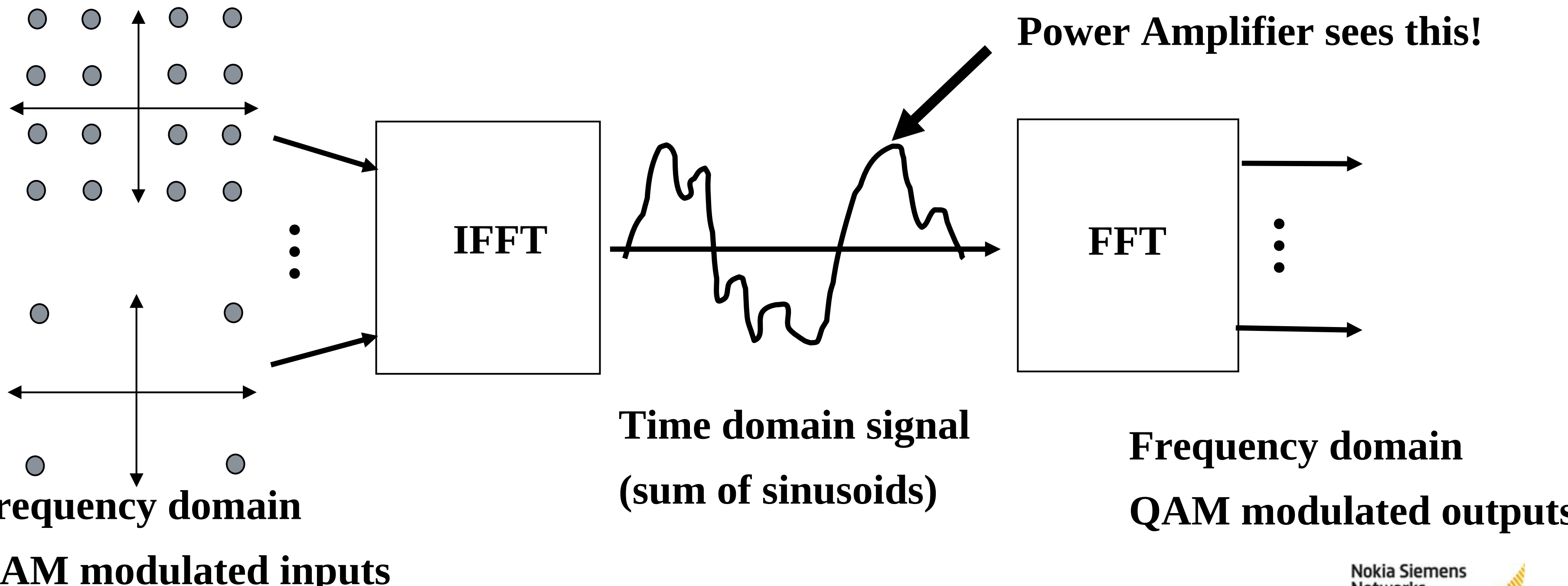
OFDM Transmitter/Receiver Chain

- OFDM is used in various systems, like:
  - DVB-T
  - DVB-H
  - WLAN (IEEE family)
  - WiMAX
- Key component is the inverse discrete Fourier transform
- Moving between time and frequency domain representation



Why not to use OFDM in the uplink?

- The transmitted OFDM signal should be seen as a sum of sinusoid
- This is not suited for a highly linear, power efficient terminal amplifier
- The envelope needs to be with as low Peak-to-Average Ratio (PAR) as possible.

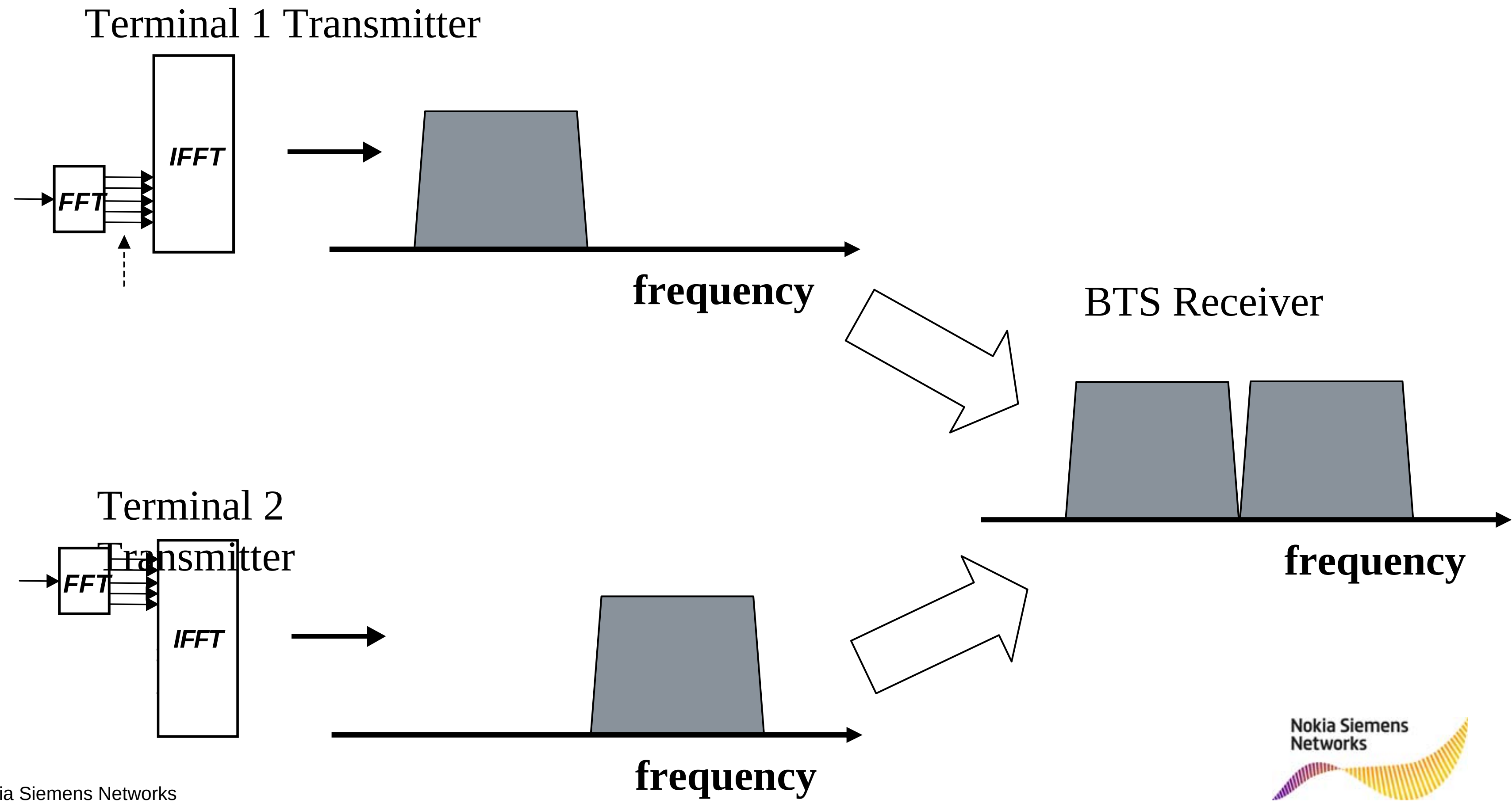


Uplink Multiple Access – SC-FDMA

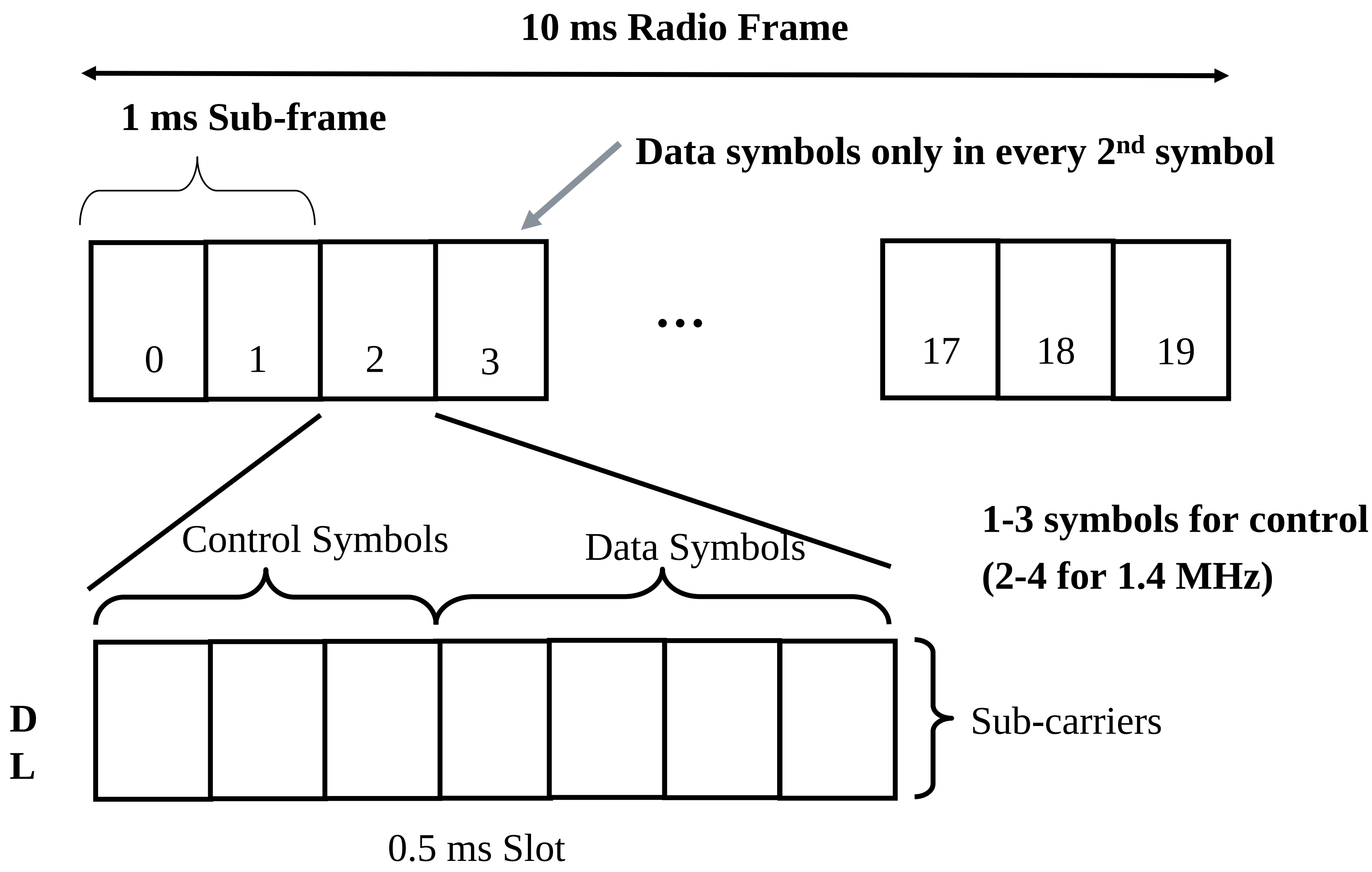
User multiplexing in frequency domain

Smallest uplink bandwidth 180 kHz.

- Largest 20 MHz (terminal are required to able to receive & transmit up to 20 MHz, depending on the frequency band though.)

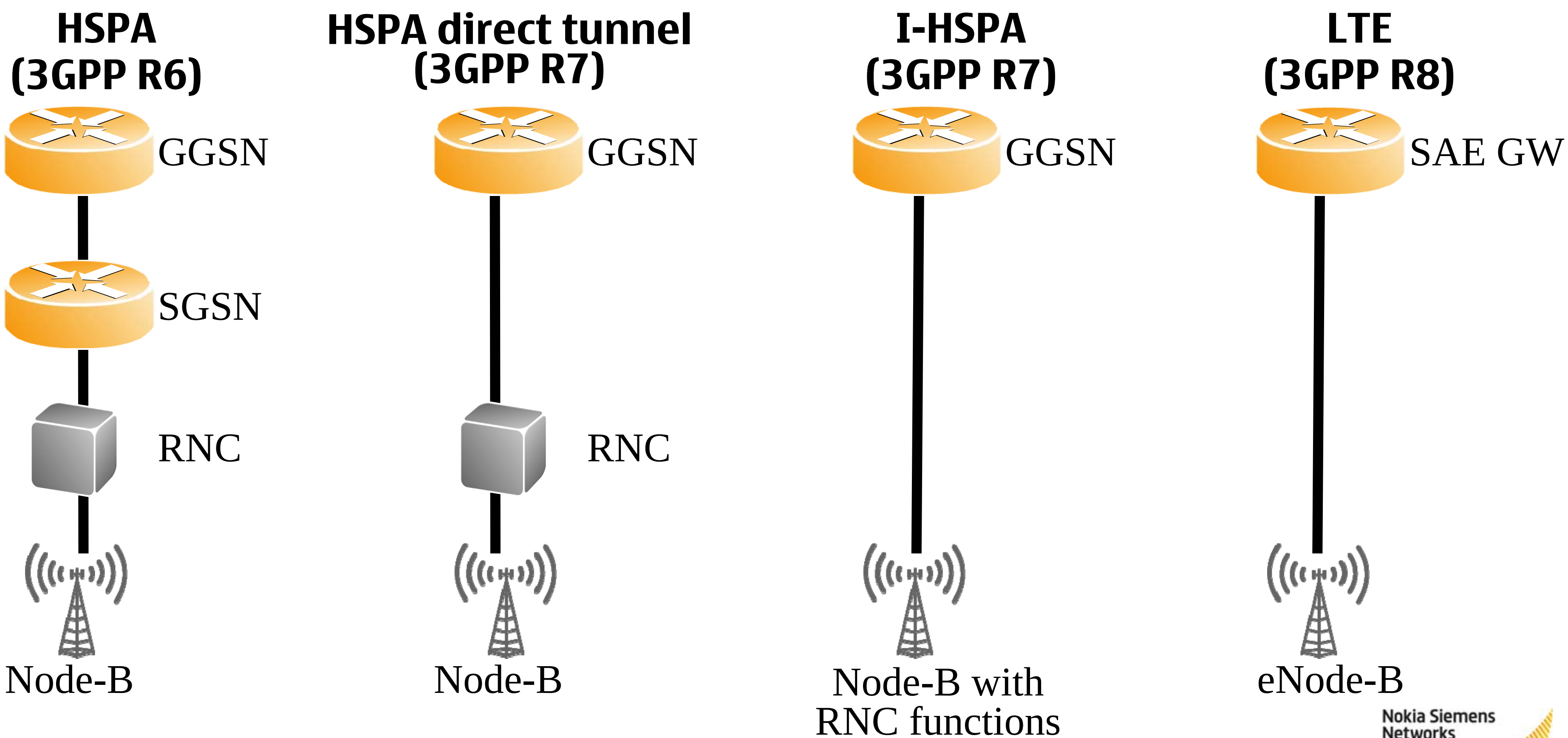


LTE Physical Layer Structure – Frame Structure



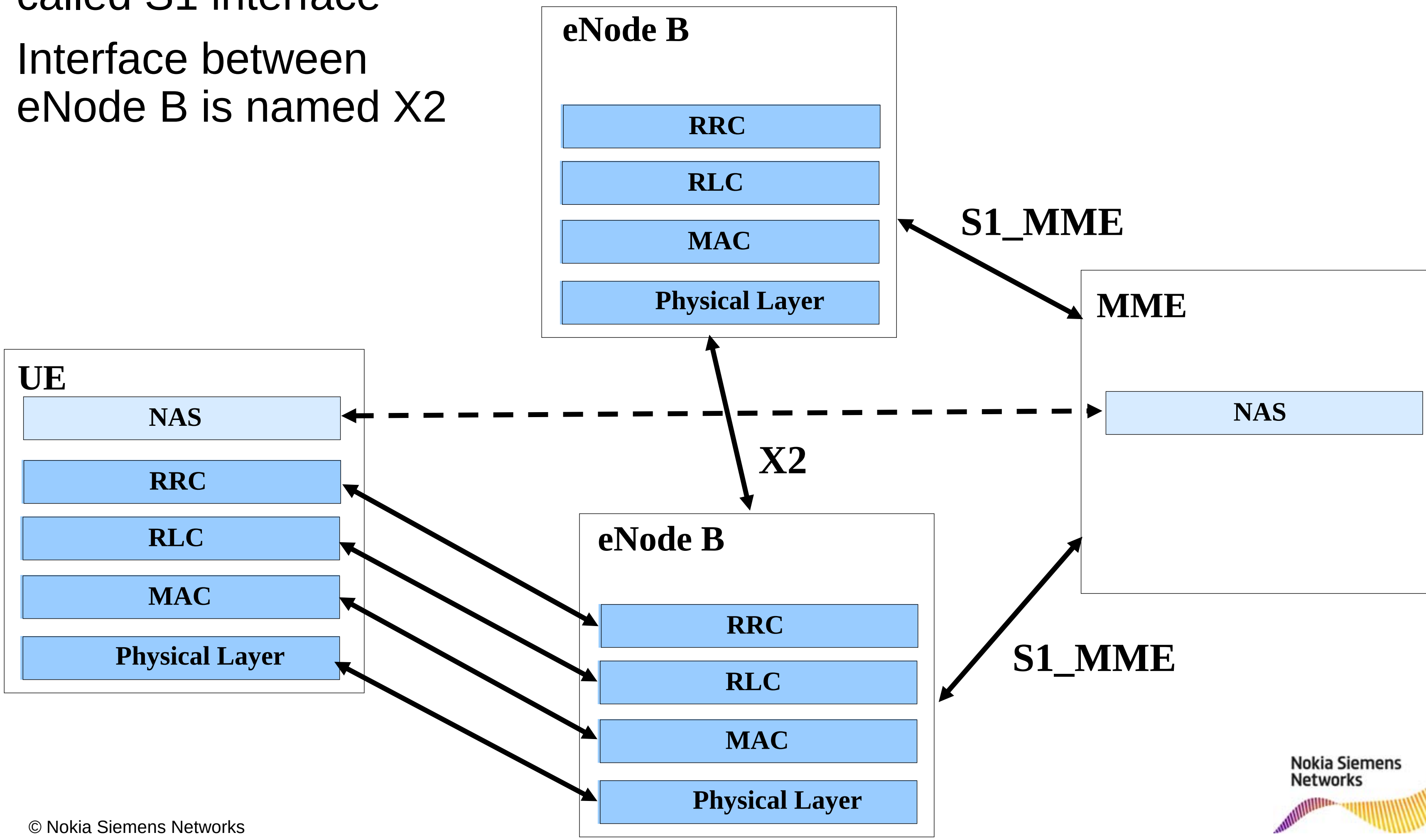
Architecture Evolution – User Plane

- Flat architecture = single network element in user plane in radio network and in core network



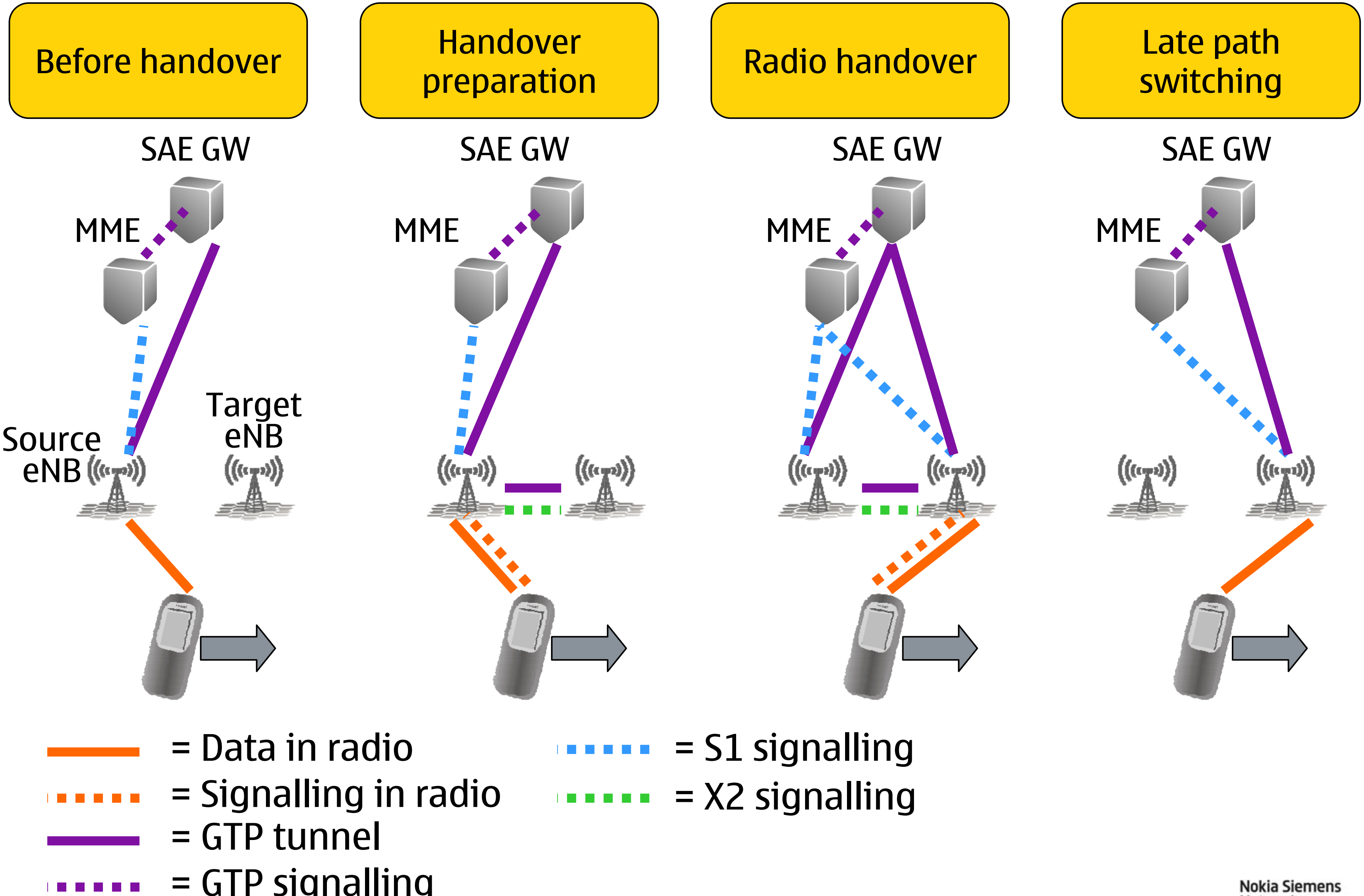
LTE Architecture – Control Plane

- The interface between RAN & Core network is called S1 interface
- Interface between eNode B is named X2



LTE Handovers

Handover Procedure



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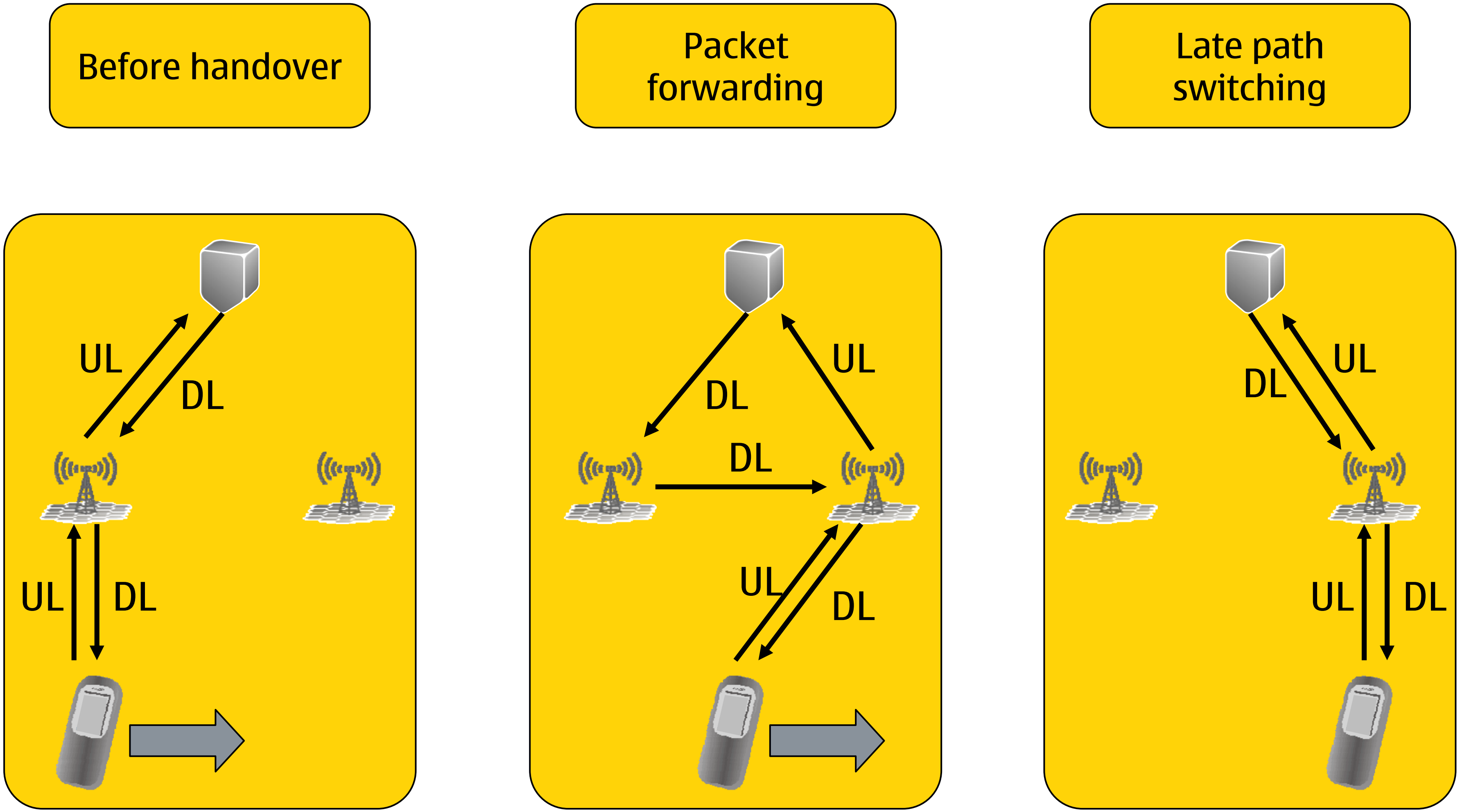
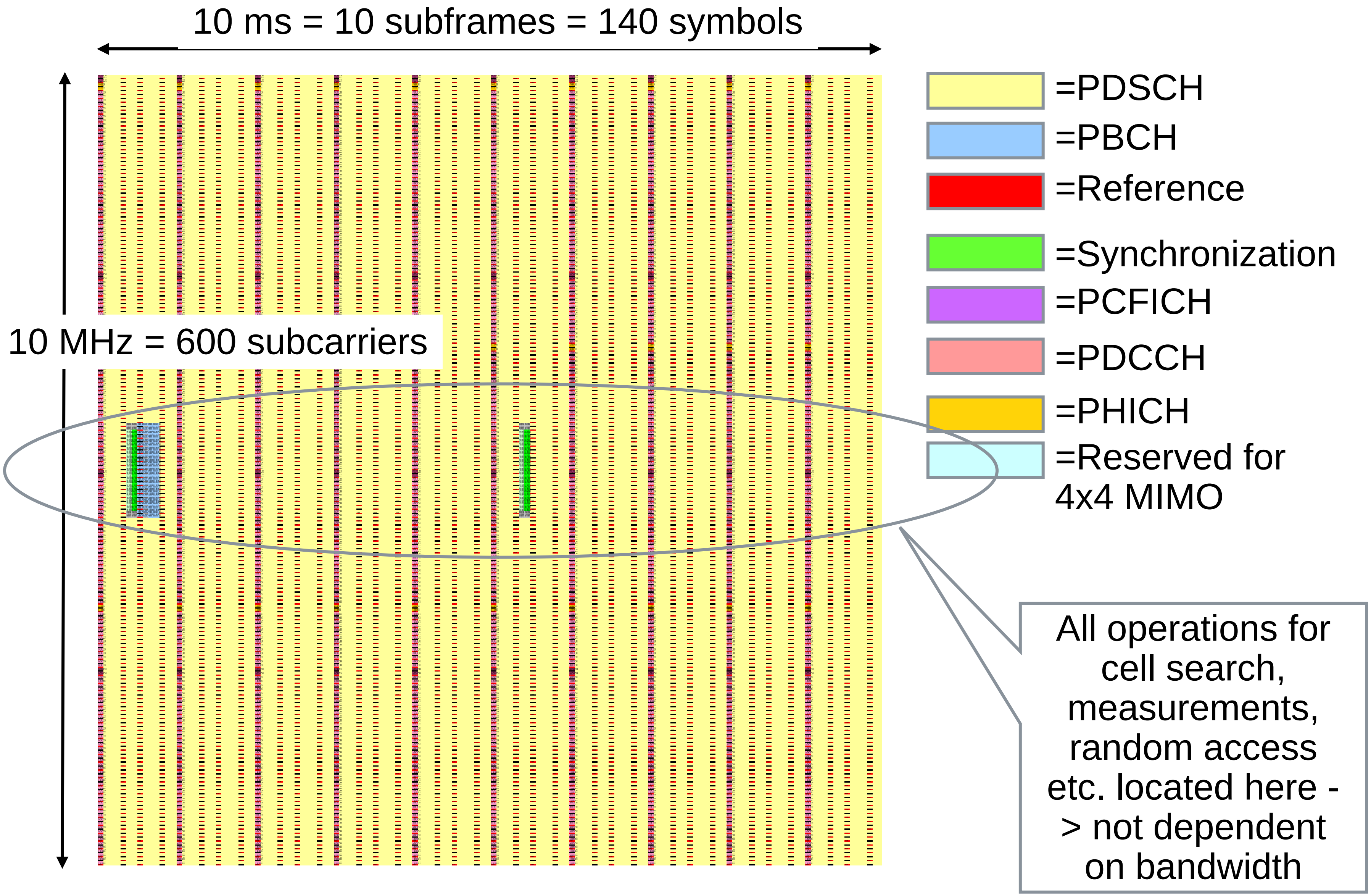
User Plane Switching in Handover



LTE Data Rates

LTE Structure for 10 MHz with 2x2 MIMO



Peak Data Rates – Downlink

- Following overheads reduced
  - Synchronization, reference, PBCH, PCFICH, PHICH and 1 PDCCH symbol
- Relative overheads
  - Reference symbol overhead 9.5% with 2x2 MIMO
  - PDCCH overhead 7.1% with single symbol (two symbols with 1.4 MHz)
  - Other overheads <1% with 10 MHz bandwidth
- Peak rate 172 Mbps with 2x2 MIMO and 20 MHz
- Following overheads not reduced: CRC, L2/L3 headers, IP headers

Modulation coding		1.4 MHz	3.0 MHz	5.0 MHz	10 MHz	15 MHz	20 MHz
QPSK 1/2	Single stream	0.7	2.1	3.5	7.0	10.6	14.1
16QAM 1/2	Single stream	1.4	4.1	7.0	14.1	21.2	28.3
16QAM 3/4	Single stream	2.2	6.2	10.5	21.1	31.8	42.4
64QAM 3/4	Single stream	3.3	9.3	15.7	31.7	47.7	63.6
64QAM 4/4	Single stream	4.3	12.4	21.0	42.3	63.6	84.9
64QAM 3/4	2x2 MIMO	6.6	18.9	31.9	64.3	96.7	129.1
64QAM 1/1	2x2 MIMO	8.8	25.3	42.5	85.7	128.9	172.1
64QAM 1/1	4x4 MIMO	16.6	47.7	80.3	161.9	243.5	325.1

Peak Data Rates – Uplink

- Following overheads reduced
  - 1 symbol for reference symbol
  - 1 resource block for PUCCH
- Relative overheads
  - Reference symbol overhead 14.3%
  - PUCCH overhead 2.5%
- Peak rate 57 Mbps with 20 MHz and 16QAM
- Following overheads not reduced: CRC, L2/L3 headers, IP headers

Modulation coding		**1.4 MHz**	**3.0 MHz**	**5.0 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
QPSK 1/2	Single stream	0.7	2.0	3.5	7.1	10.8	14.3
16QAM 1/2	Single stream	1.4	4.0	6.9	14.1	21.6	28.5
16QAM 3/4	Single stream	2.2	6.0	10.4	21.2	32.4	42.8
16QAM 1/1	Single stream	2.9	8.1	13.8	28.2	43.2	57.0
64QAM 3/4	Single stream	3.2	9.1	15.6	31.8	48.6	64.2
64QAM 1/1	Single stream	4.3	12.1	20.7	42.3	64.8	85.5
64QAM 1/1	V-MIMO (cell)	8.6	24.2	41.5	84.7	129.6	171.1

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Maximum Data Rates with LTE

- Transport block sizes defined in 3GPP 36.213

Downlink

		1.4 MHz	3.0 MHz	5.0 MHz	10 MHz	15 MHz	20 MHz
	Resource blocks	6	15	25	50	75	100
Modulation	MIMO usage						
QPSK	Single stream	0.9	2.3	4.0	8.0	11.8	15.8
16QAM	Single stream	1.8	4.6	7.7	15.3	22.9	30.6
64QAM	Single stream	4.4	11.1	18.3	36.7	55.1	75.4
64QAM	2x2 MIMO	8.8	22.2	36.7	73.7	110.1	149.8

Uplink

		1.4 MHz	3.0 MHz	5.0 MHz	10 MHz	15 MHz	20 MHz
	Resource blocks	6	15	25	50	75	100
Modulation	MIMO usage						
QPSK	Single stream	1.0	2.7	4.4	8.8	13.0	17.6
16QAM	Single stream	3.0	7.5	12.6	25.5	37.9	51.0
64QAM	Single stream	*4.4*	*11.1*	*18.3*	*36.7*	*55.1*	*75.4*

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LTE UE Categories

- All categories support 20 MHz
- 64QAM mandatory in downlink, but not in uplink (except Class 5)
- 2x2 MIMO mandatory in other classes except Class 1
- Class 3 expected initially

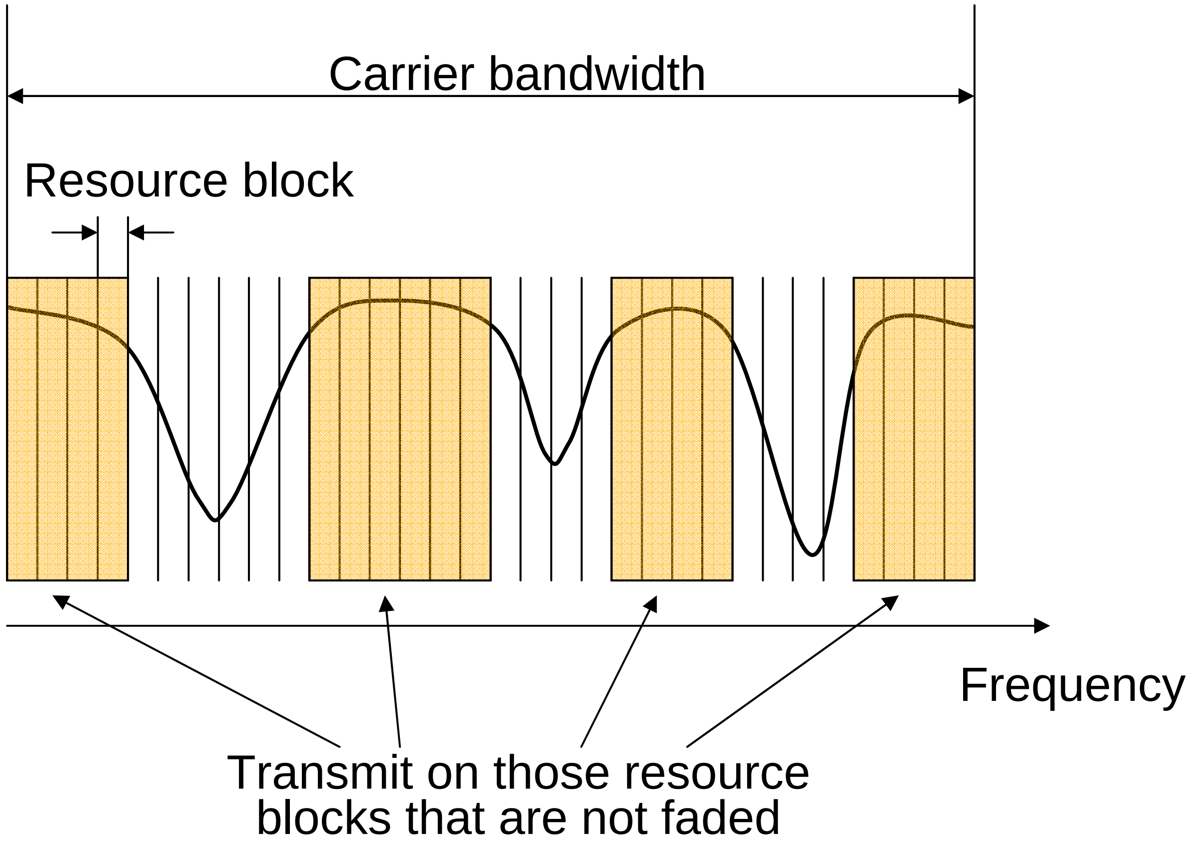
	Class 1	Class 2	Class 3	Class 4	Class 5
Peak rate DL/UL	10/5 Mbps	50/25 Mbps	100/50 Mbps	150/50 Mbps	300/75 Mbps
RF bandwidth	20 MHz	20 MHz	20 MHz	20 MHz	20 MHz
Modulation DL	64QAM	64QAM	64QAM	64QAM	64QAM
Modulation UL	16QAM	16QAM	16QAM	16QAM	64QAM
Rx diversity	Yes	Yes	Yes	Yes	Yes
BTS tx diversity	1-4 tx	1-4 tx	1-4 tx	1-4 tx	1-4 tx
MIMO DL	Optional	2x2	2x2	2x2	4x4

Samsung LTE Modem (Teliasonera)

http://www.teliasonera.com/press/pressreleases/item.page?prs.itemId=453980

Frequency Domain Scheduling

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



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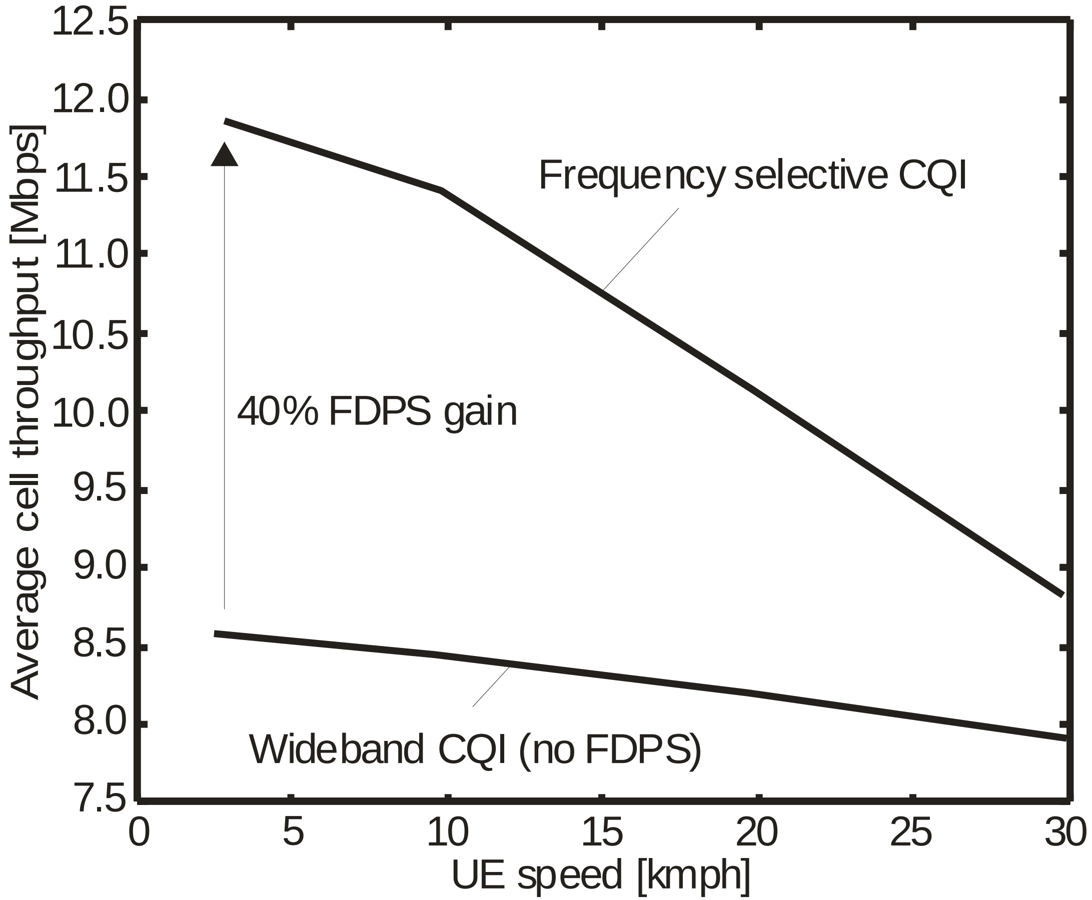
Gain of Frequency Domain Scheduling

- Up to 40% gain from frequency domain scheduling with
  - low km/h
  - large number of users
  - no MIMO



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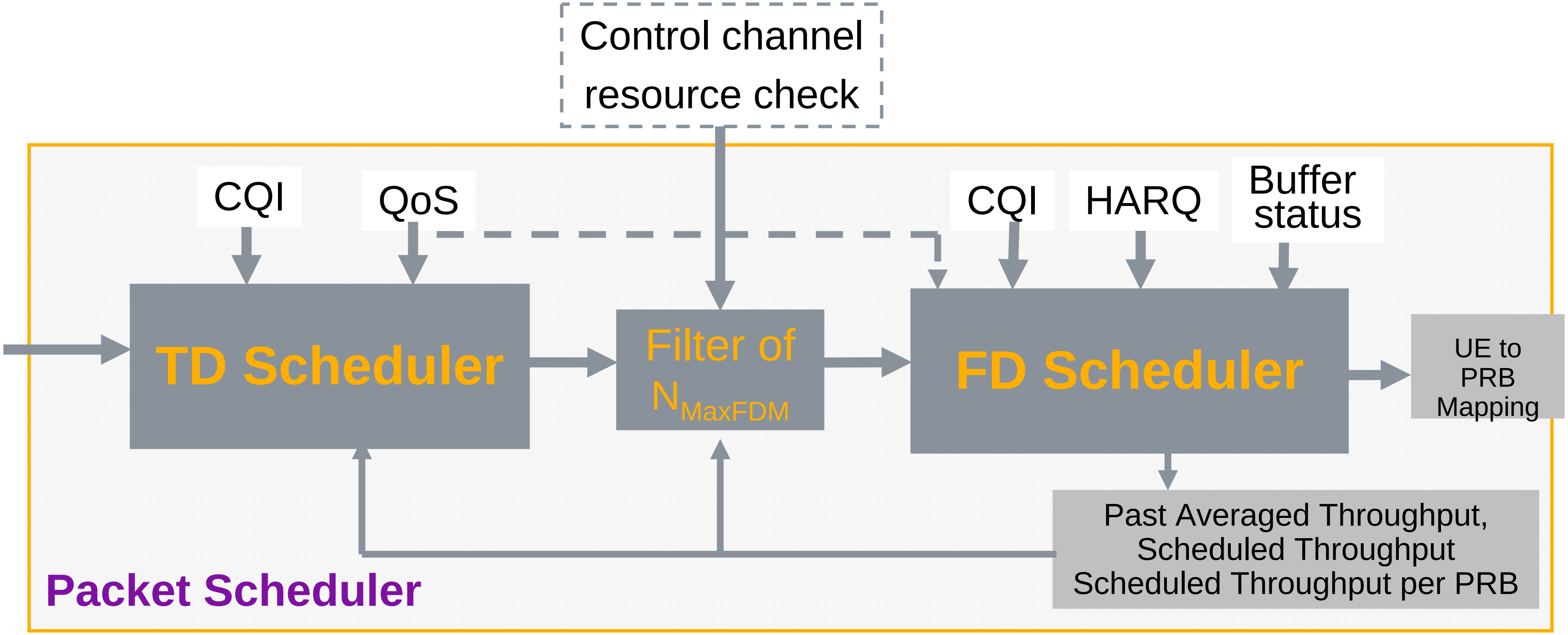
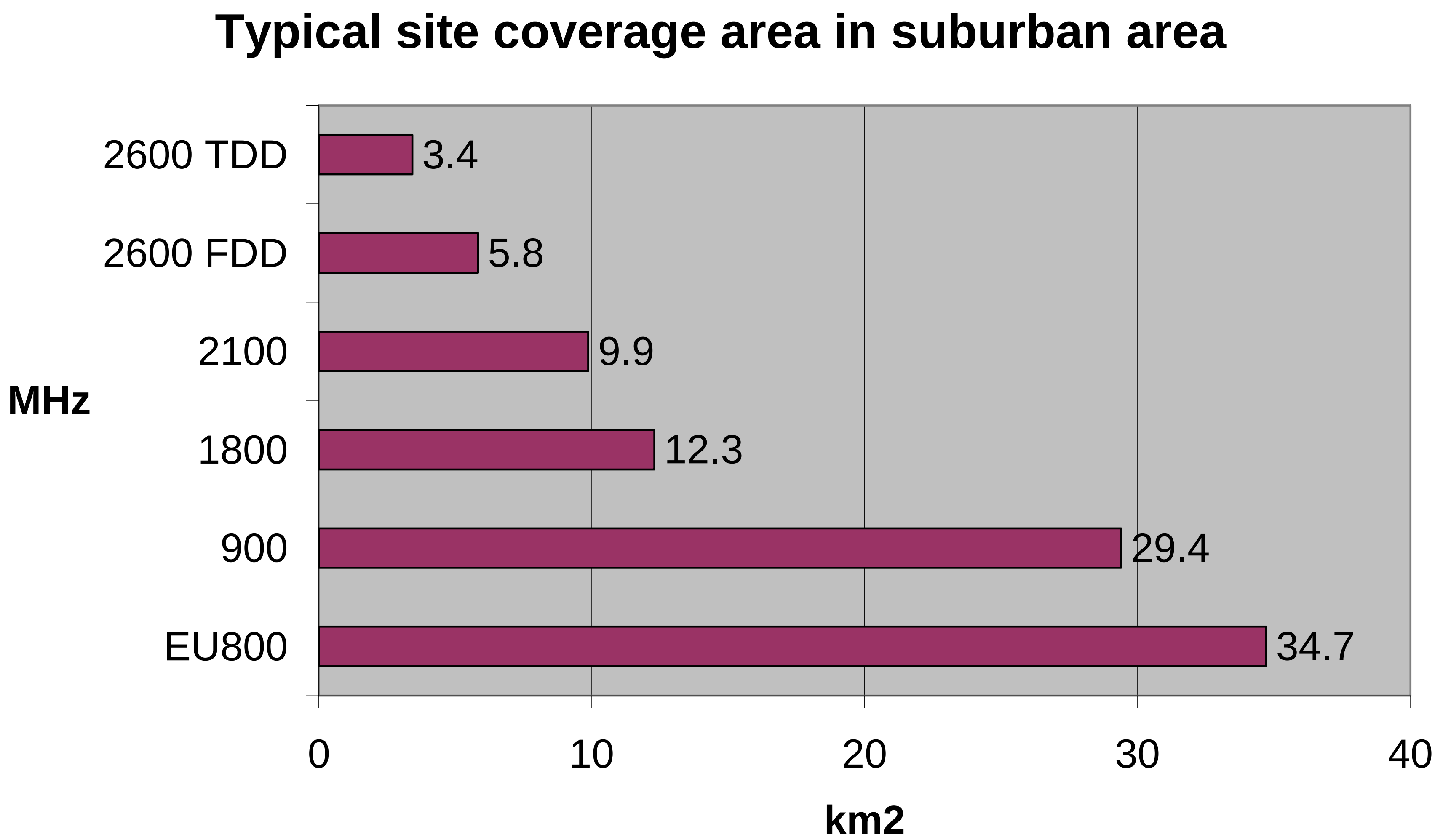
Time and Frequency Domain Schedulers

- Time domain scheduling provides QoS differentiation
- Frequency domain scheduling provide efficiency gains



LTE Coverage

Coverage Impact of the Spectrum



Okumura-Hata with 6 dB lower antenna gain with 800 and 900.
TDD link budget loss 3 dB.

Cell Size in LTE – L1 Parameter

- 3GPP specs allows 100 km cell range

3GPP 36.313

.2.3 Transmission timing adjustments

Upon reception of a timing advance command, the UE shall adjust its uplink transmission timing. The timing advance command is expressed in multiples of 16 T_s and is relative to the current uplink timing.

In case of random access response, 11-bit timing advance command [8], T_A, indicates N_{TA} values by index values of T_A = 0, 1, 2, ..., 1282, where actual amount of the time alignment is given by $N_{TA} = T_A \times 16$. N_{TA} is defined in [3].

Timing advance: 1282*0.52e-6*3e8/2 = 100 km cell range

T_A=0.52 µs

$T_s = T_A/16$

RACH preamble format 3 = (3e-3-(2*24576+21024)*0.52e-6/16)*3e8/2 = 100 km

Table 5.7.1-1: Random access preamble parameters

3GPP 36.211

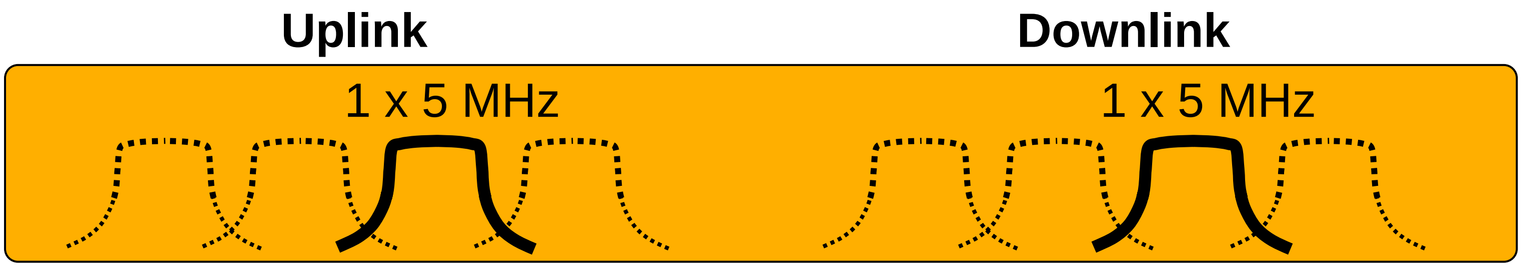
Preamble format	T_{CP}	T_{SEQ}
0	$3168 \cdot T_s$	$24576 \cdot T_s$
1	$21024 \cdot T_s$	$24576 \cdot T_s$
2	$6240 \cdot T_s$	$2 \cdot 24576 \cdot T_s$
3	$21024 \cdot T_s$	$2 \cdot 24576 \cdot T_s$

Format 3 uses 3 ms for RACH reception

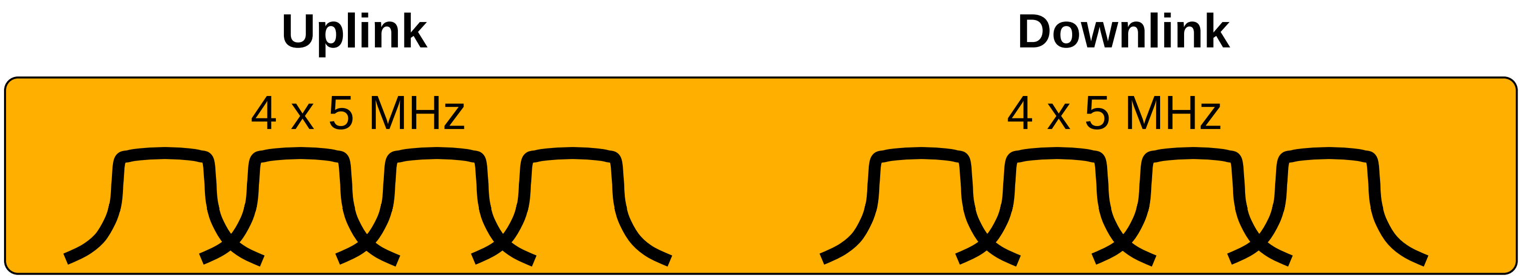
HSPA Evolution

Multicarrier HSPA Evolution in Release 9/10

- HSPA release 7 UE can receive and transmit only on 1 frequency even if the operator has total 3-4 frequencies



- HSPA release 8 brought dual cell HSDPA
- Further HSPA releases will bring multicarrier HSDPA and HSUPA which allows UE to take full benefit of operator's spectrum



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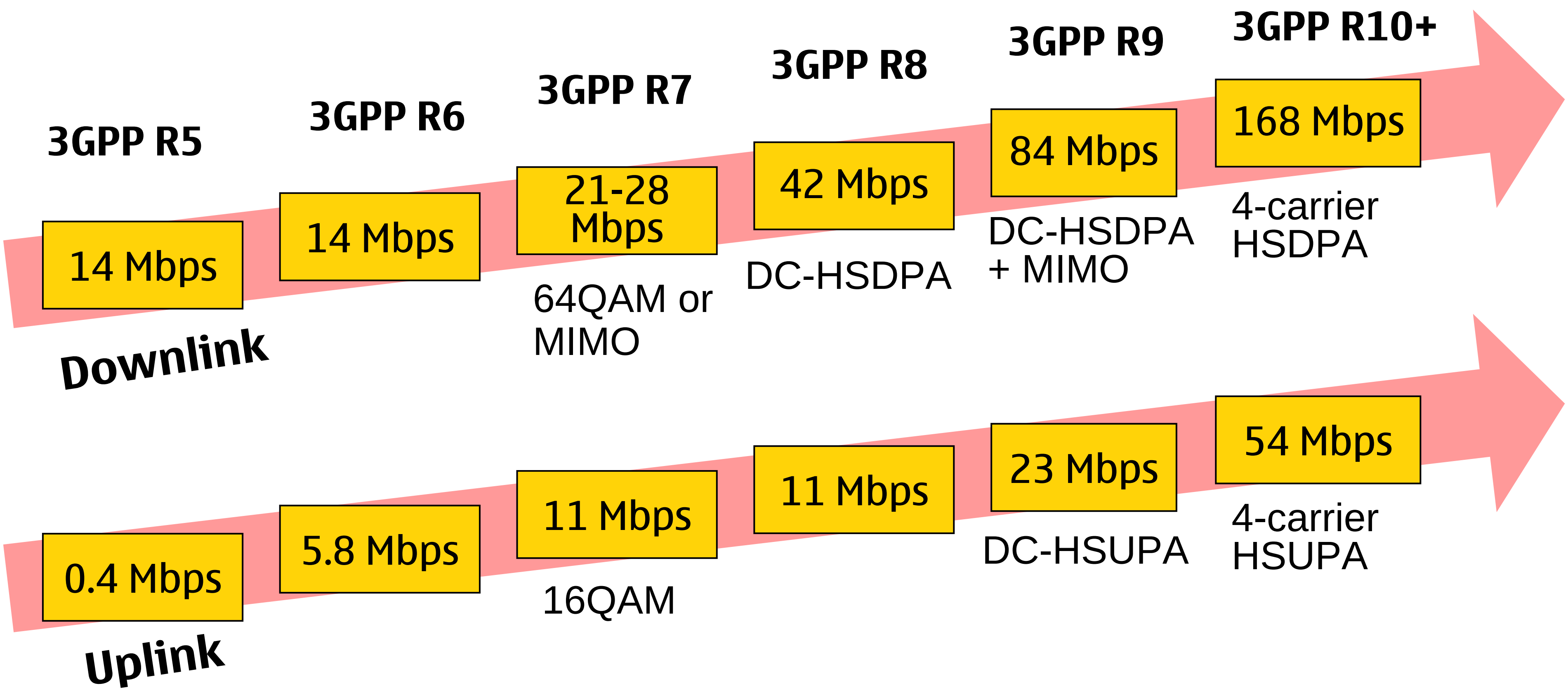
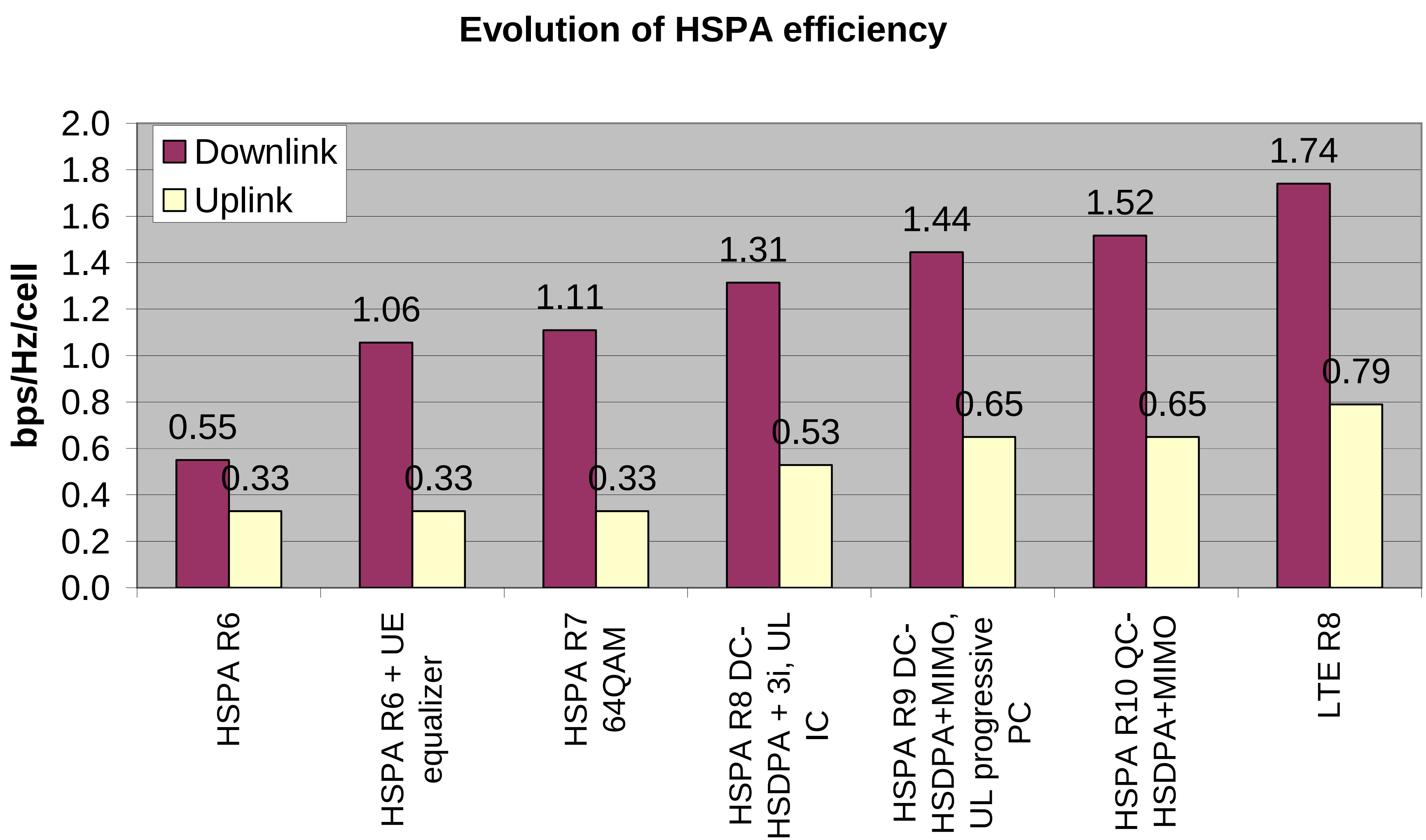
HSPA Data Rate Evolution

- HSPA has data rate evolution beyond 100 Mbps



HSPA and LTE Spectral Efficiency Evolution



Harmonization of HSPA and LTE

- HSPA and LTE have been developed by the same standardization organization. The target has been simple multimode implementation.

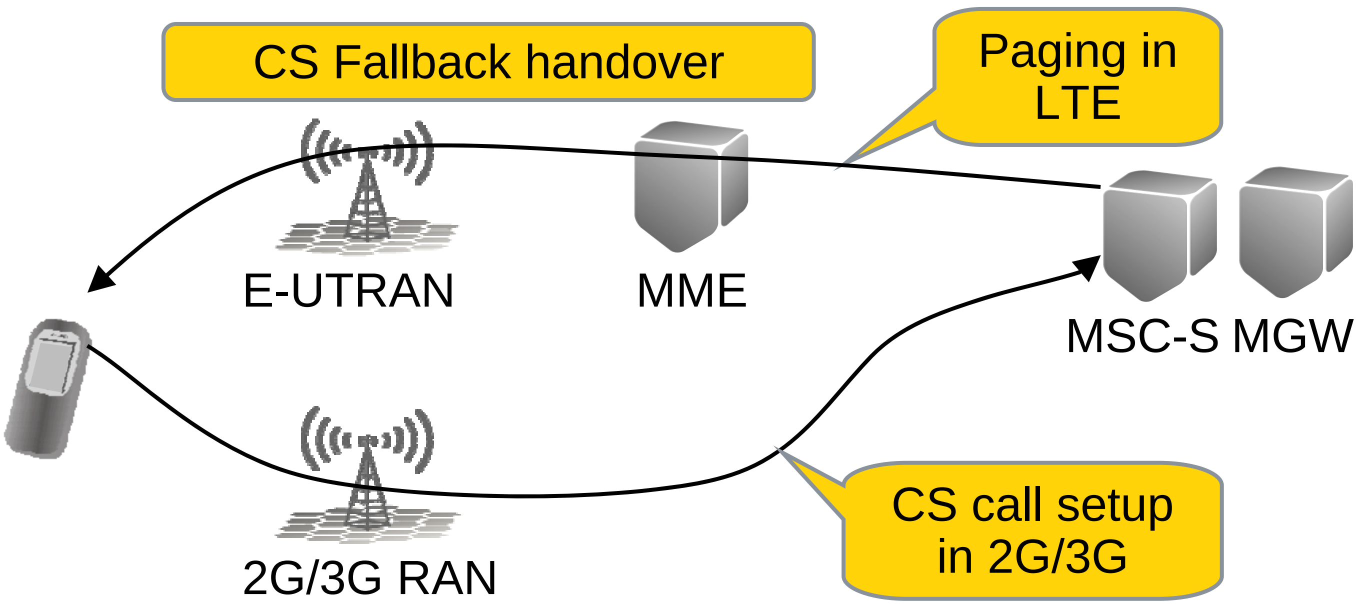
- HSPA and LTE have in common
  - Sampling rate using the same clocking frequency
  - Same kind of Turbo coding (also maximum block size close enough)

- The harmonization of these parameters is important as sampling and Turbo decoding are typically done on HW due to high processing requirements

Voice Evolution

Voice is Still Important in LTE

- Voice with LTE terminals has a few different solutions
- The first voice solution in LTE can rely on CS fallback handover where LTE terminal will be moved to 2G/3G to make CS call
- The ultimate LTE voice solution will be VoIP + IMS
- CS voice call will not be possible in LTE since there is no CS core interface



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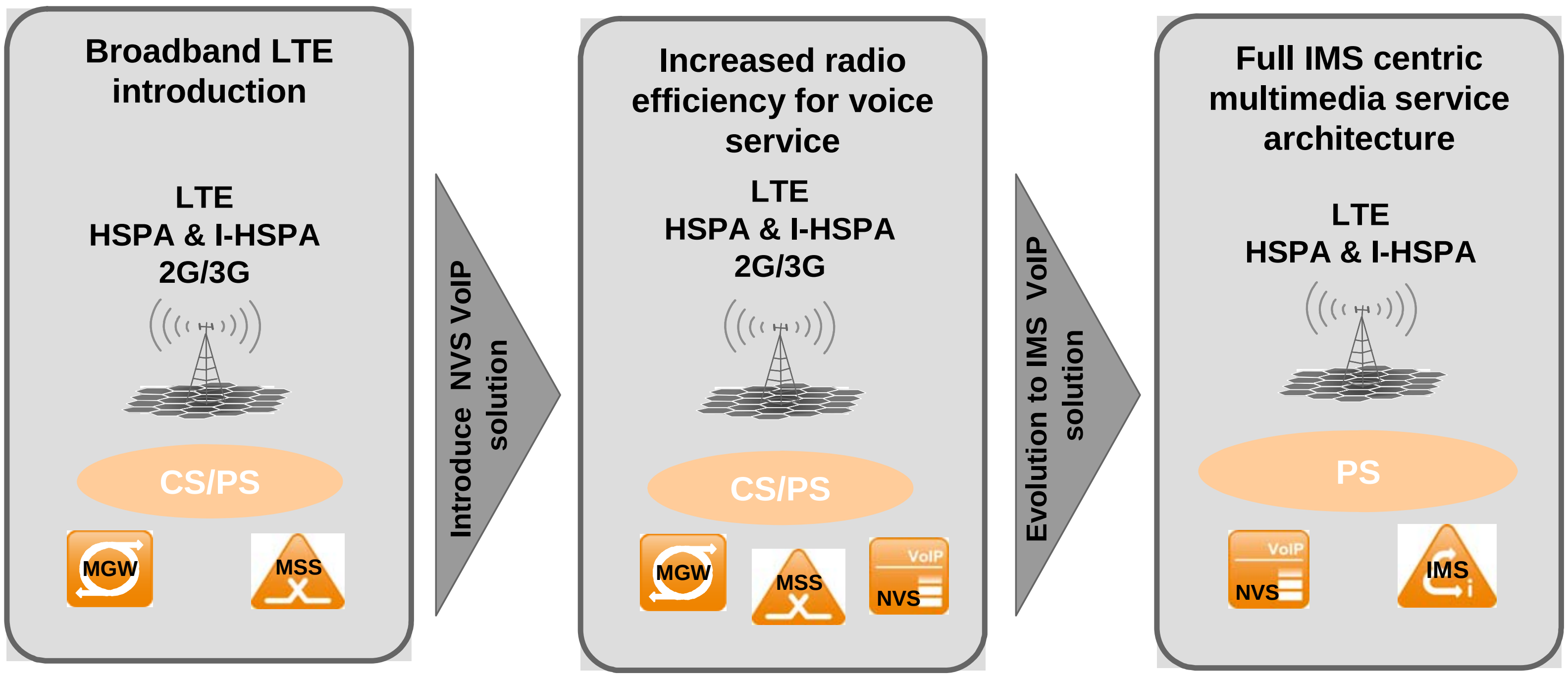
LTE Voice Evolution

Data only LTE | **Fast track LTE VoIP** | **IMS multimedia**



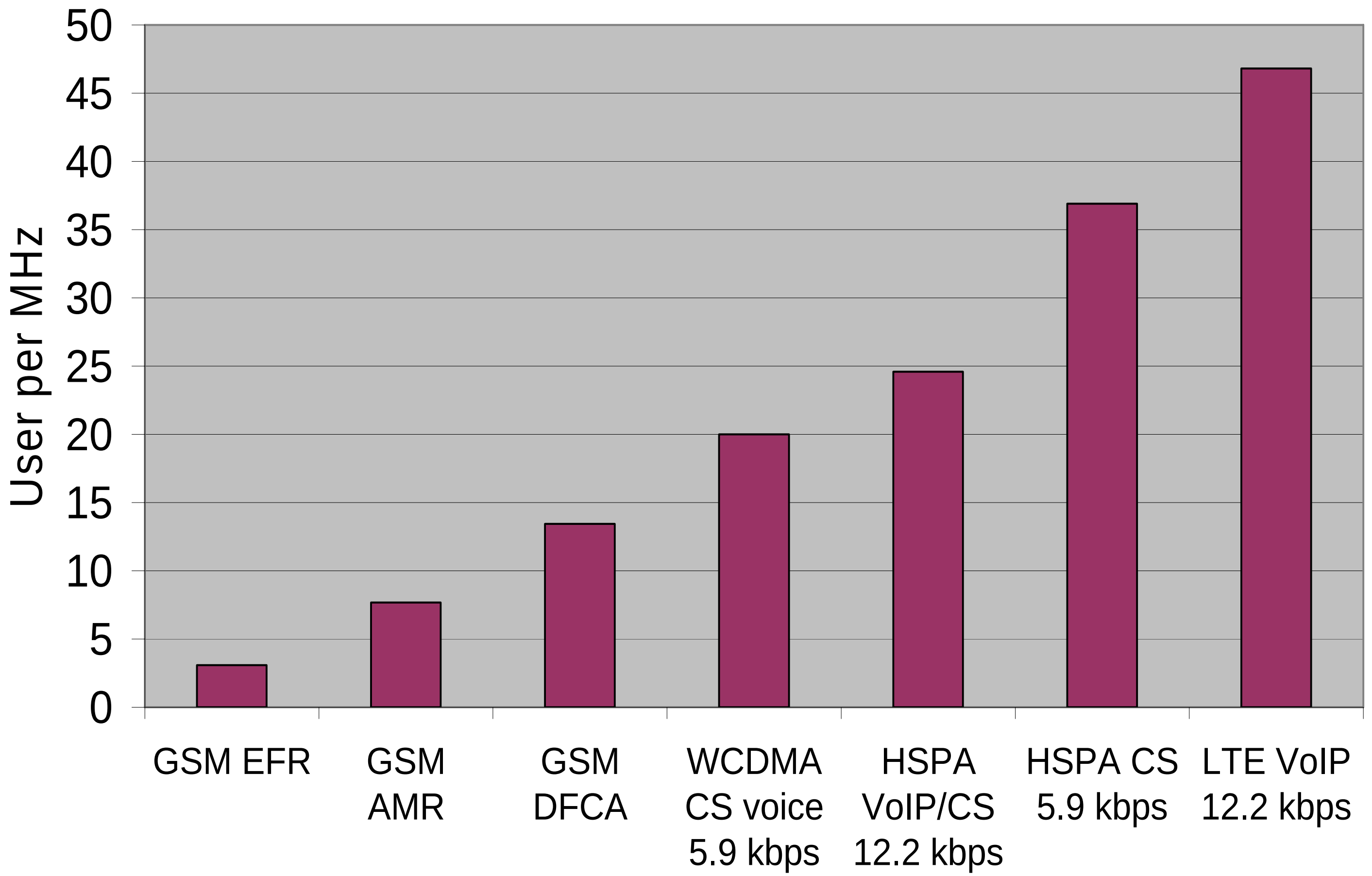
- CS fallback handover

- VoIP
- SR-VCC

- VoIP
- SR-VCC

Voice Spectral Efficiency Evolution from GSM to LTE

- 15 x more users per MHz with 3GPP LTE than with GSM EFR!



Frequency Variants

3GPP Supported FDD Frequency Bands

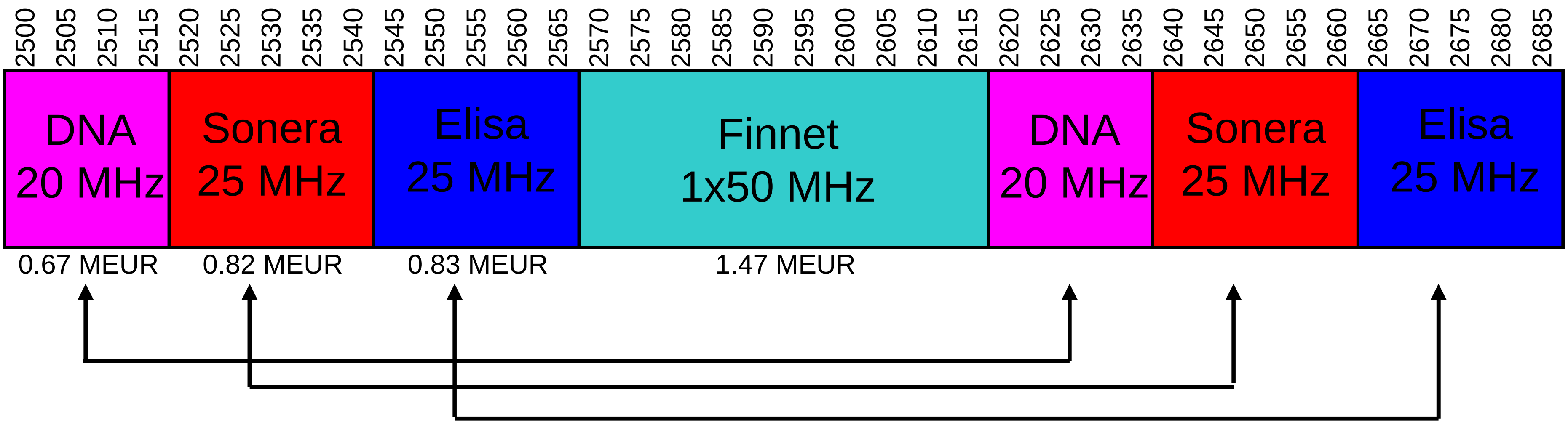
	Total [MHz]	Uplink [MHz]	Downlink [MHz]	Europe /Asia	Japan	Americas	
1	2x60	1920-1980	2110-2170	●	●		UMTS core
2	2x60	1850-1910	1930-1990			●	US PCS
3	2x75	1710-1785	1805-1880	●			1800
4	2x45	1710-1755	2110-2155			●	US AWS
5	2x25	824-849	869-894			●	US 850
6	2x10	830-840	875-885		●		Japan 800
7	2x70	2500-2570	2620-2690	●			2600
8	2x35	880-915	925-960	●			900
9	2x35	1749.9-1784.9	1844.9-1879.9		●		Japan 1700
10	2x60	1710-1770	2110-2170			●	Extended AWS
11	2x20	1427.9-1447.9	1475.9-1495.9		●		Japan 1500
12	2x18	698-716	728-746			●	US700
13	2x10	777-787	746-756			●	US700
14	2x10	788-798	758-768			●	US700
17	2x12	704-716	734-746			●	US700
18	2x15	815-830	860-875		●		Japan new 800
19	2x15	830-845	875-890		●		Japan new 800
20	2x30	832-862	791-821	●			EU800
21	2x15	1447.9-1462.9	1495.9-1510.9		●		Japan 1500 ext
22	2x90	3410-3500	3510-3600	●			3500

Typical European Spectrum Allocations

	Current	Future	
2600 (FDD 20 MHz)		LTE 20 MHz	LTE capacity and high data rates
2100 (15 MHz)	3xHSPA	Multicarrier HSPA	HSPA capacity
1800 (15 MHz)	GSM	LTE 15 MHz	LTE capacity
900 (10 MHz)	GSM	1xHSPA+ GSM	HSPA coverage + GSM maintenance
800 (10 MHz)		LTE 10 MHz	LTE coverage

First 2.6 GHz Auctions – Norway, Sweden and Finland

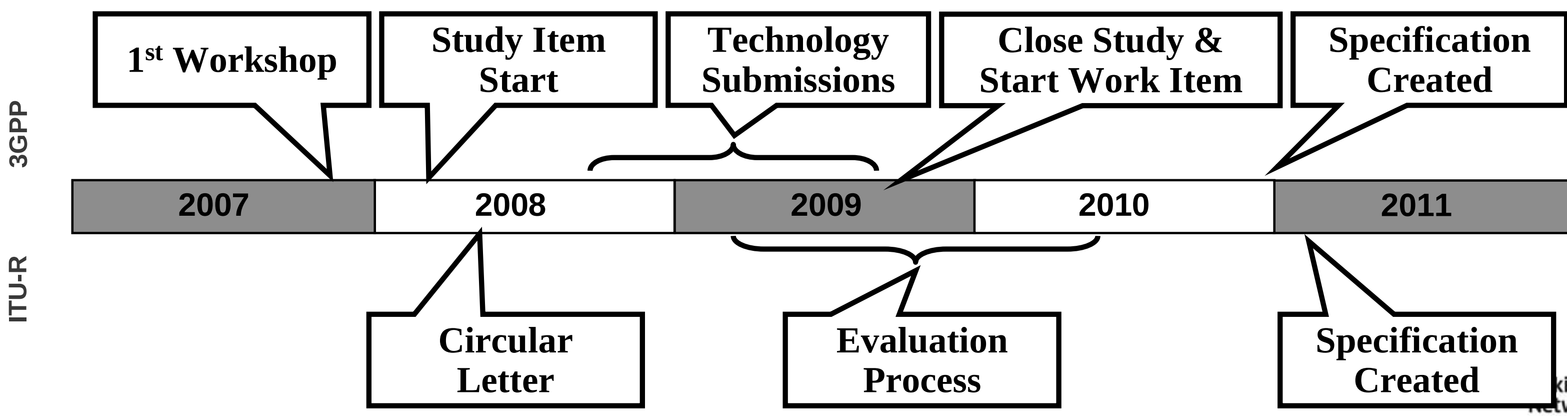
- **Norway (29 M€)**
  - Telenor 2x40 MHz
  - Teliasonera 2x20 MHz
  - Hafslund 2x10 MHz
  - Craig Wireless 1x50 MHz
- **Sweden (225 M€)**
  - Telenor 2x20 MHz
  - Telia 2x20 MHz
  - Tele2 2x20 MHz
  - HI3G 2x10 MHz
  - Intel 1x50 MHz
- **Finland (4 M€)**
  - DNA 2x20 MHz
  - Teliasonera 2x25 MHz
  - Elisa 2x25 MHz
  - Finnet 1x50 MHz



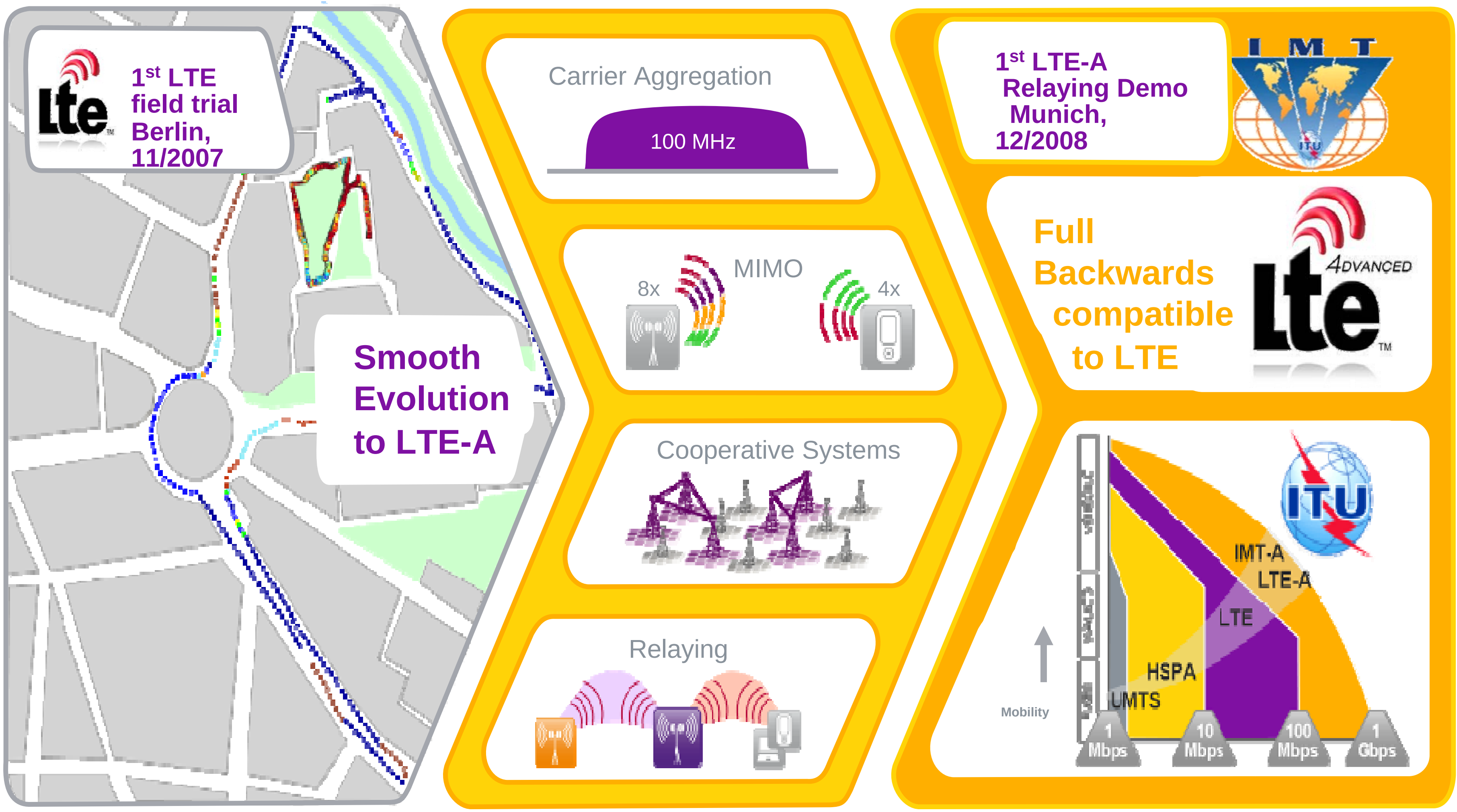
LTE-Advanced

LTE-Advanced (LTE-A) in 3GPP Release 10

- ITU has defined schedule for IMT-Advanced (IMT-A) with submission deadline October 2009
- Local area data rate up to 1 Gbps and wide area 100 Mbps
- 1st technical 3GPP workshop in April 2008
  - Until end of 2008 the clear focus was on LTE Release 8
  - The same multiple access to be used also in LTE-Advanced as in LTE
  - 3GPP during 2009 to work with the LTE-Advanced study item, no specifications available until end of 2010 (technical report in 2009), specification to be frozen approximately 06/2011



LTE-Advanced Enabling Technologies



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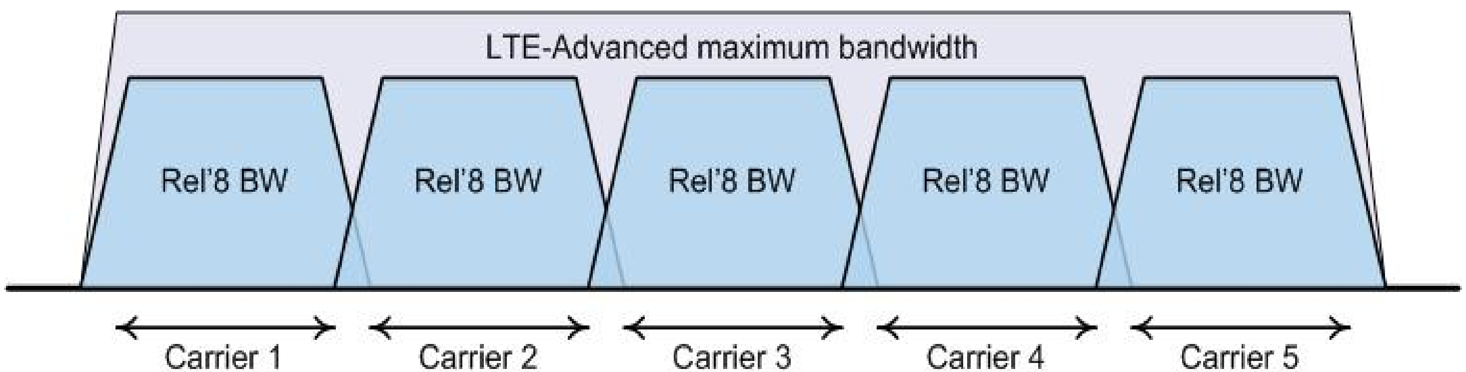
Bandwidth Extension

- High peak data rate of 1 Gbps in downlink and 500 Mbps in uplink can be achieved with bandwidth extension from 20 MHz **up to 100 MHz.**
- Backwards compatibility requirements with Release 8 LTE is achieved with ***carrier aggregation***
- We combine N Release 8 component carriers, together to form N x LTE bandwidth, for example 5 x 20 MHz = 100 MHz etc.
- LTE terminals receive/transmit on one component carrier, whereas LTE-Advanced terminals may receive/transmit on multiple component carriers simultaneously to reach the higher bandwidths.



Technology Evolution

- Peak bit rate increases by a factor of 100x
- Spectral efficiency increases by a factor of 3x (=interference limitation)
- No substantial improvements in coverage (=noise limitation)

	HSPA	HSPA+	LTE	LTE-A targets	
Peak bit rate	7-14 Mbps	42-168 Mbps	150-300 Mbps	1 Gbps	**70-150x**
Spectral efficiency	1.0 bps/Hz/cell	1.21-1.9[1] bps/Hz/cell	1.7-2.7[1] bps/Hz/cell	2.4-3.7[1] bps/Hz/cell	**2-4x**
Coverage (1 Mbps)	162 dB	162 dB	162 dB	-	**~1x**

[1] 4-rx mobile

New radio solution needed in LTE-Advanced to improve coverage and capacity

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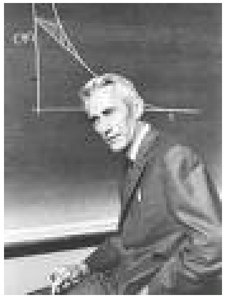
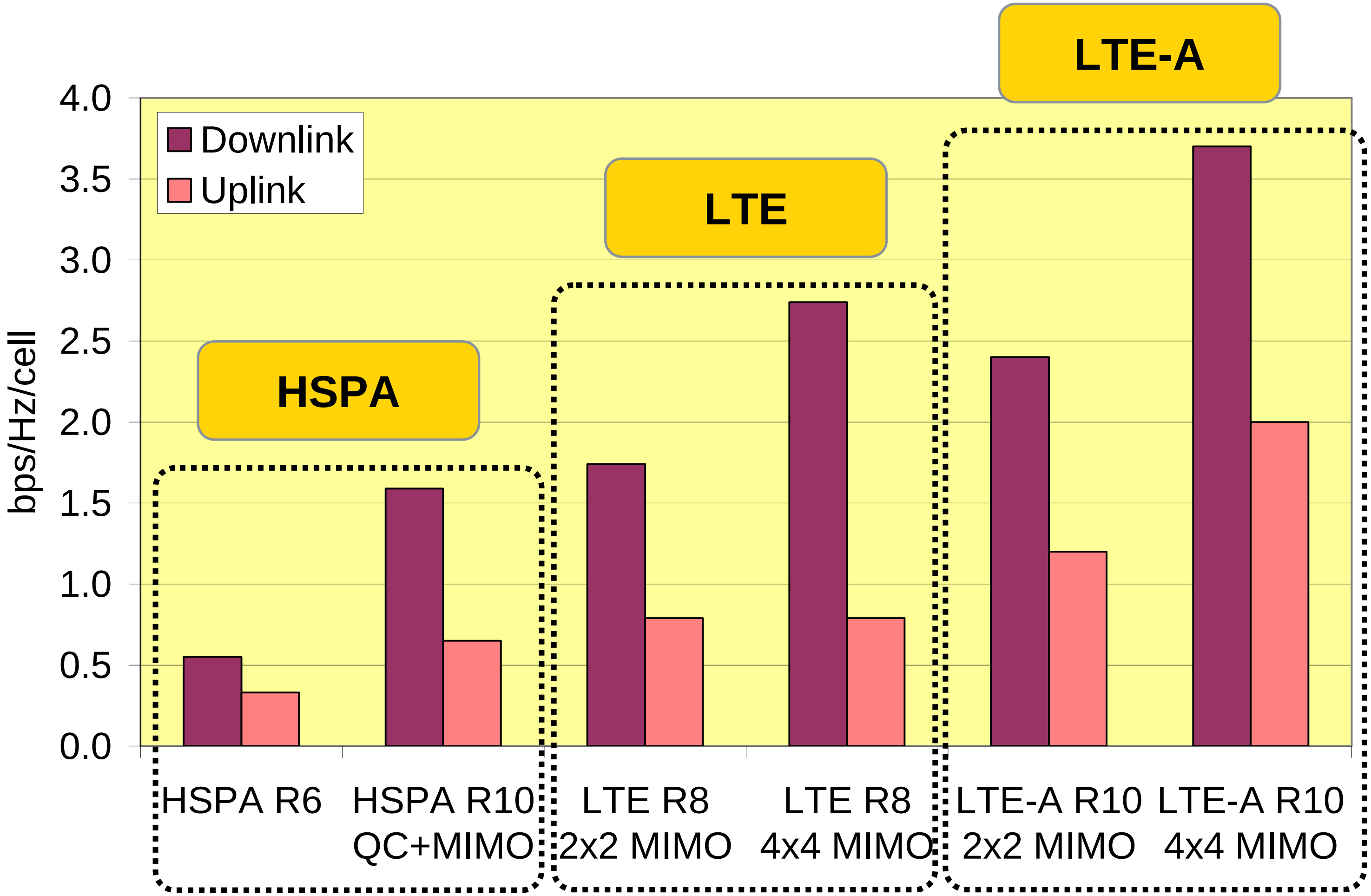
Spectral Efficiency Improves but Only Moderately

- Shannon law limits link performance improvements
- Only moderate gain in spectral efficiency





NSN Position in LTE and Radio R&D

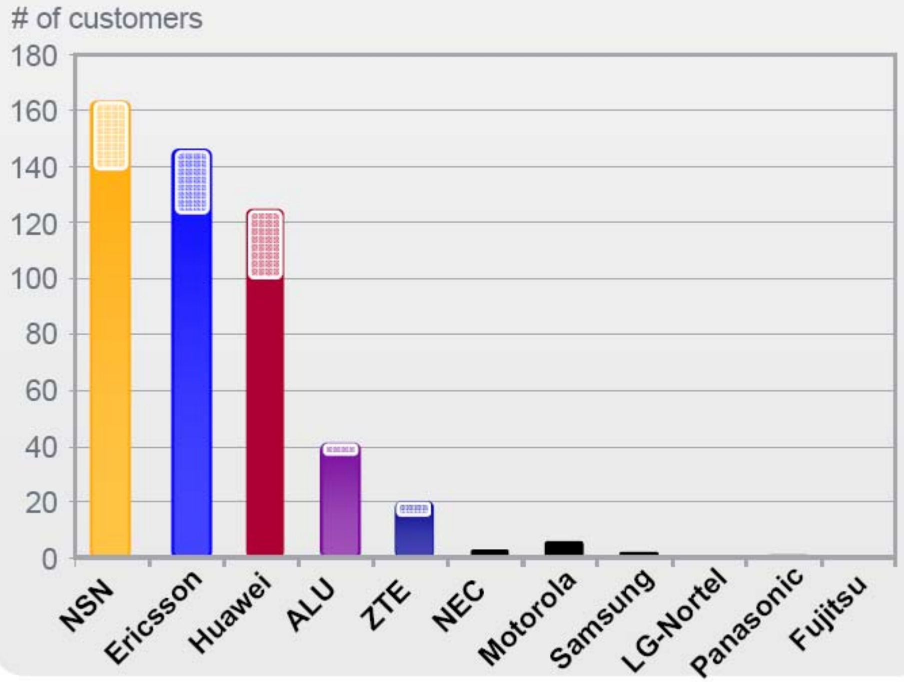
NSN Position in LTE – Nokia Capital Market Day Presentation

Driving for growth: Mobile broadband momentum

Network Systems

163 active WCDMA/HSPA radio access customers

23 new customers added YTD in 2009 – 16 in 2H09

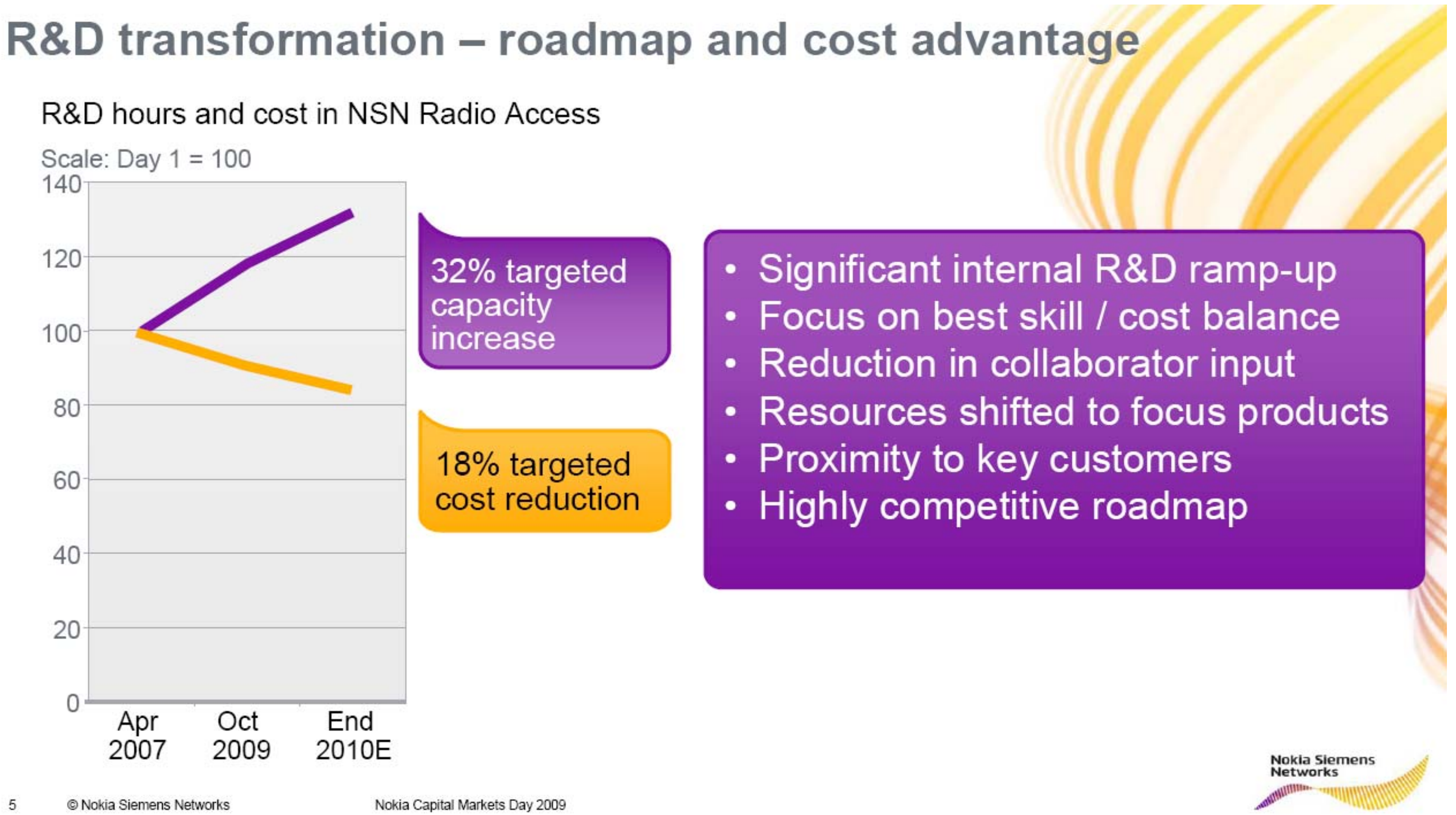


Undisputed LTE leadership

- First with LTE commercial HW: 100k LTE-ready BTS for 100+ operators
- World's first LTE call and handovers on commercial software
- Selected by 4 operators for LTE radio deployment, including NTT DoCoMo
- LTE Centers of Competence in all lead markets globally
- LTE core network pioneer: packet core for DoCoMo, Zain and IMS for Verizon

Nokia Siemens Networks

NSN Investment in R&D – Nokia Capital Market Day Presentation



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www.wiley.com