Proposal for Candidate Radio Interface Technologies for IMT-Advanced Based on LTE Release 10 and Beyond (LTE-Advanced)

Takehiro Nakamura

3GPP TSG-RAN Chairman

Introduction

- In response to the ITU-R Circular Letter 5/LCCE/2 which invites proposals for candidate radio interface technologies for the terrestrial component of IMT-Advanced, the Third Generation Partnership Project (3GPP) is providing *a complete submission* of ***LTE Release 10 & beyond (LTE-Advanced)*** under Step 3 of the IMT-Advanced process in Document IMT−ADV/2(Rev.1)
- This submission of the 3GPP candidate SRIT (which includes an FDD RIT component and a TDD RIT component) is based on the currently approved work within 3GPP and follows the ITU-R IMT-Advanced submission format and guidelines.
- The *3GPP Proponent* [1] has provided all required information within each of required major components either directly or by endorsement of this contribution made by 3GPP individual members on behalf of 3GPP:
- Following slides show overview of this submission together with relevant information

[1] The *3GPP Proponent* of the 3GPP submission is collectively the 3GPP Organizational Partners (OPs). The Organizational Partners of 3GPP are ARIB, ATIS, CCSA, ETSI, TTA and TTC (http://www.3gpp.org/partners)

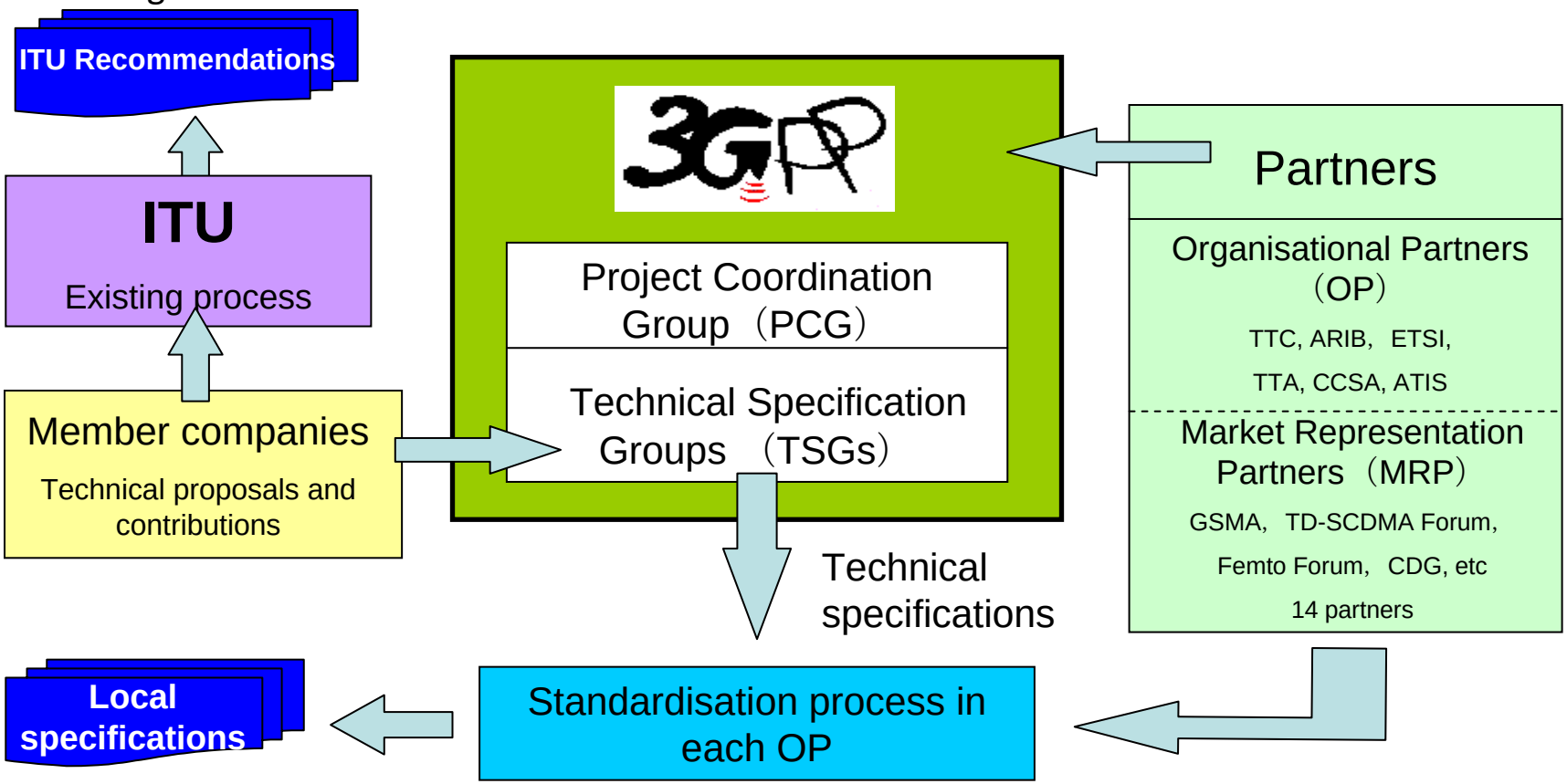
Contents

- 3GPP standardisation activities
- LTE Release 8
- LTE-Release 10 and beyond (LTE-Advanced)
- Self-evaluation
- ITU-R submission documents

3GPP Standardisation Activities

3GPP Standardisation Process

- 3GPP develops technical specifications on 3G **and beyond** mobile communication systems
- 3GPP Organisational Partners standardize local specifications based on the specifications developed by 3GPP
- The standardisation process in each OP is only a form of transposition and that no technical changes are introduced



Membership of 3GPP

- The membership in 3GPP includes:
  - the 6 Organizational Partner SDOs,
  - 372 Individual Member companies,
  - 14 Market Representation Partners,
  - and 3 Observer entities.
- The detailed listing may be found at the following link: http://webapp.etsi.org/3gppmembership/Results.asp?Member=ALL_PARTNERS&SortMember=Name&DirMember=ASC&Partner=on&SortPartner=Name&DirPartner=ASC&Market=on&SortMarket=Name&DirMarket=ASC&Observer=on&SortObserver=Name&DirObserver=ASC&SortGuest=Name&DirGuest=ASC&Name=&search=Search

Standardisation Organisations Communicating with 3GPP

Developing Recommendations

ITU-R/T

Input specs

Referring to 3GPP specs (contributed by individual members)

Developing Wireless LAN/MAN specs

IEEE Celebrating 125 Years of Engineering the Future

Wi Fi ALLIANCE

WiMAX FORUM

Cross reference of specs

3GPP A GLOBAL INITIATIVE

Referring to specs

Developing internet protocol specs

IETF

Developing Mobile application specs

oma Open Mobile Alliance

Cross reference of specs

Requirements

MRP

GSM ASSOCIATION

CDG

ngmn the engine of broadband wireless innovation

femtoforum driving convergence worldwide

Terminal certification based on 3GPP specs

Terminal Certification

GCF

Partners of 3GPP Referring to 3GPP specs for the local specs

Organisational Partners

EU: ETSI

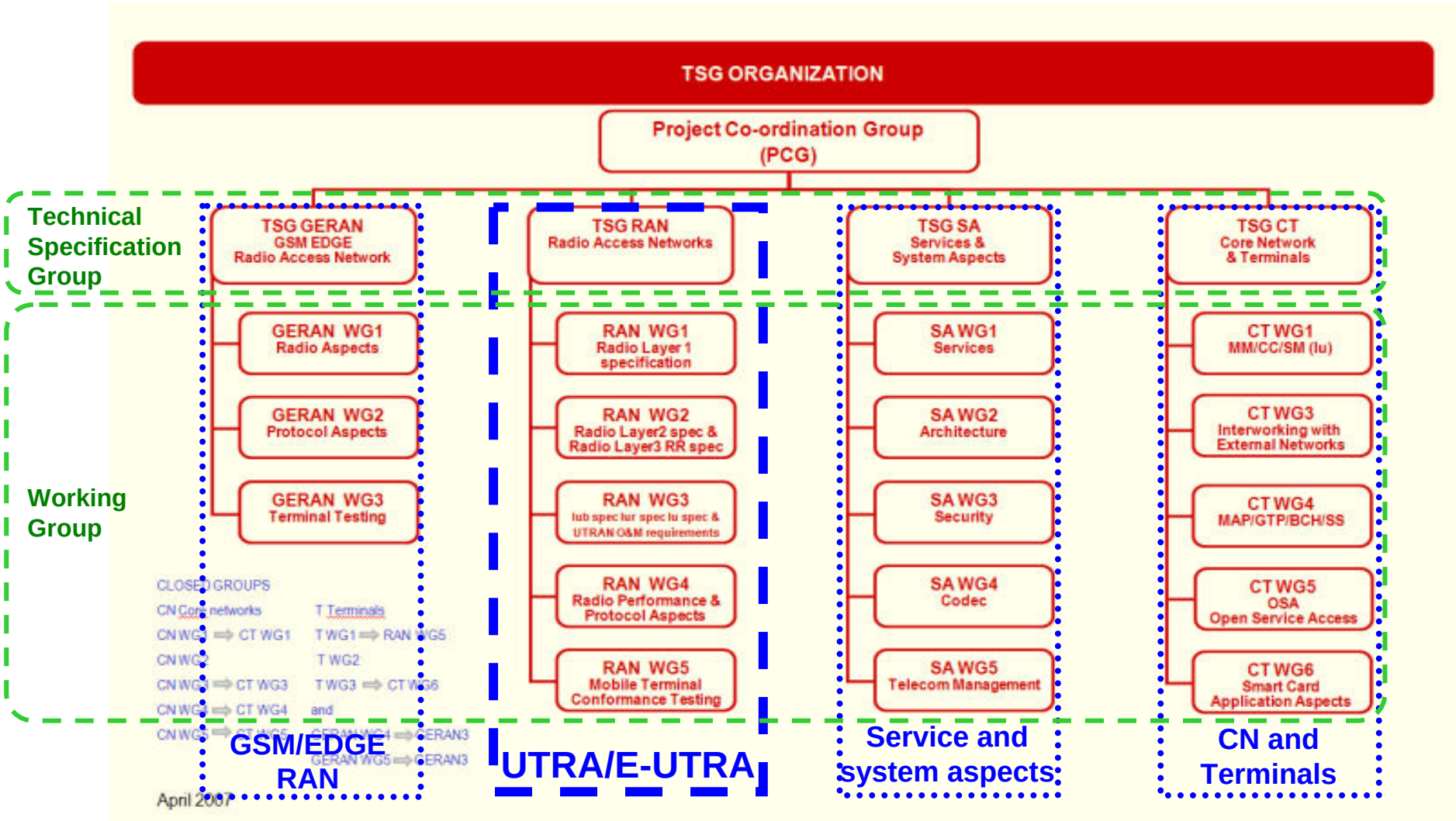
Japan: ARIB TTC Telecommunication Technology Committee

Korea: TTA

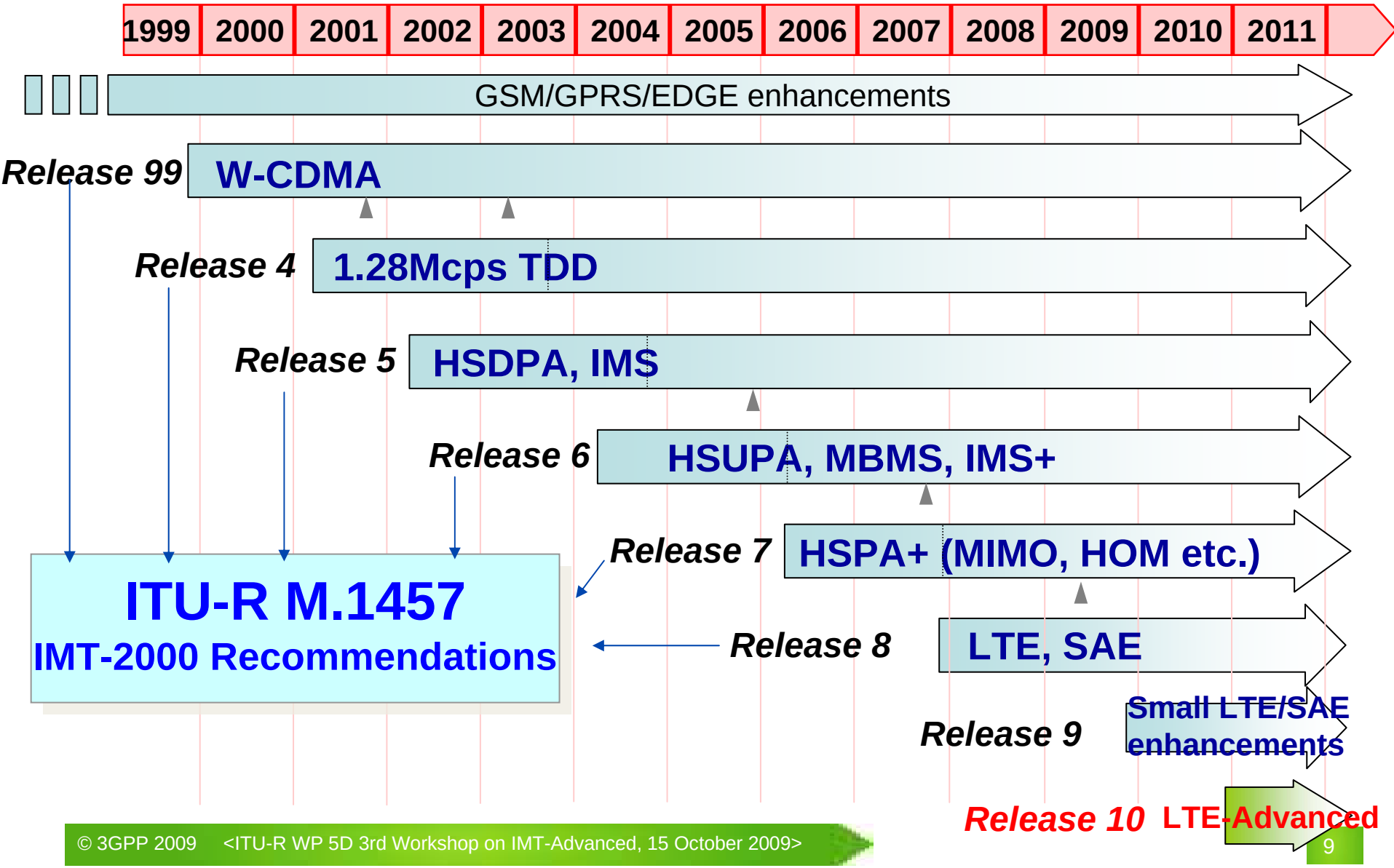
China: CCSA

North America: atis

3GPP Structure



Release of 3GPP specifications

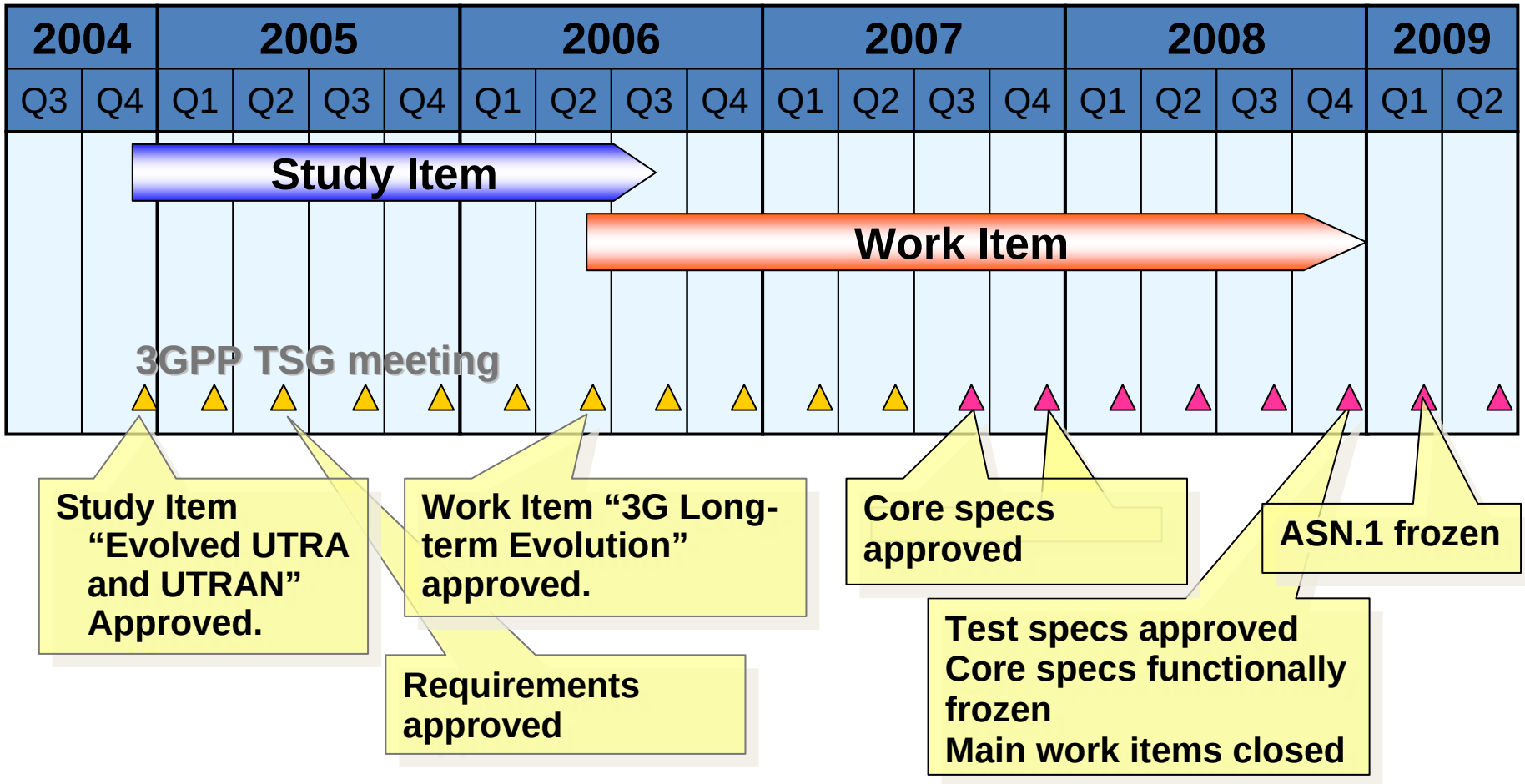


LTE Release 8

Motivation of LTE Release 8

- Need to ensure the continuity of competitiveness of the 3G system for the future
- User demand for higher data rates and quality of services
- PS optimised system
- Continued demand for cost reduction (CAPEX and OPEX)
- Low complexity
- Avoid unnecessary fragmentation of technologies for paired and unpaired band operation

LTE Release 8 Standardisation History



LTE Release 8 Key Features

- High spectral efficiency
  - OFDM in Downlink
    - Robust against multipath interference
    - High affinity to advanced techniques
      - Frequency domain channel-dependent scheduling
      - MIMO
  - DFTS-OFDM("Single-Carrier FDMA") in Uplink
    - Low PAPR
    - User orthogonality in frequency domain
  - Multi-antenna application
- Very low latency
  - Short setup time & Short transfer delay
  - Short HO latency and interruption time
    - Short TTI
    - RRC procedure
    - Simple RRC states
- Support of variable bandwidth
  - 1.4, 3, 5, 10, 15 and 20 MHz

LTE Release 8 Key Features (Cont'd)

- Simple protocol architecture
  - Shared channel based
  - PS mode only with VoIP capability
- Simple Architecture
  - eNodeB as the only E-UTRAN node
  - Smaller number of RAN interfaces
    - eNodeB ↔ MME/SAE-Gateway (S1)
    - eNodeB ↔ eNodeB (X2)
- Compatibility and inter-working with earlier 3GPP Releases
- Inter-working with other systems, e.g. cdma2000
- FDD and TDD within a single radio access technology
- Efficient Multicast/Broadcast
  - Single frequency network by OFDM
- Support of Self-Organising Network (SON) operation

LTE Release 8 Major Parameters

Access Scheme	**UL**	**DFTS-OFDM**
	DL	**OFDMA**
Bandwidth		**1.4, 3, 5, 10, 15, 20MHz**
Minimum TTI		**1msec**
Sub-carrier spacing		**15kHz**
Cyclic prefix length	**Short**	**4.7μsec**
	Long	**16.7μsec**
Modulation		**QPSK, 16QAM, 64QAM**
Spatial multiplexing		**Single layer for UL per UE** **Up to 4 layers for DL per UE** **MU-MIMO supported for UL and DL**

LTE-Release 8 User Equipment Categories

Category		1	2	3	4	5
Peak rate Mbps	DL	10	50	100	150	300
	UL	5	25	50	50	75
Capability for physical functionalities						
RF bandwidth		20MHz				
Modulation	DL	QPSK, 16QAM, 64QAM				
	UL	QPSK, 16QAM				QPSK, 16QAM, 64QAM
Multi-antenna						
2 Rx diversity		Assumed in performance requirements.				
2x2 MIMO		Not supported	Mandatory			
4x4 MIMO		Not supported				Mandatory

LTE Release 8 Specifications

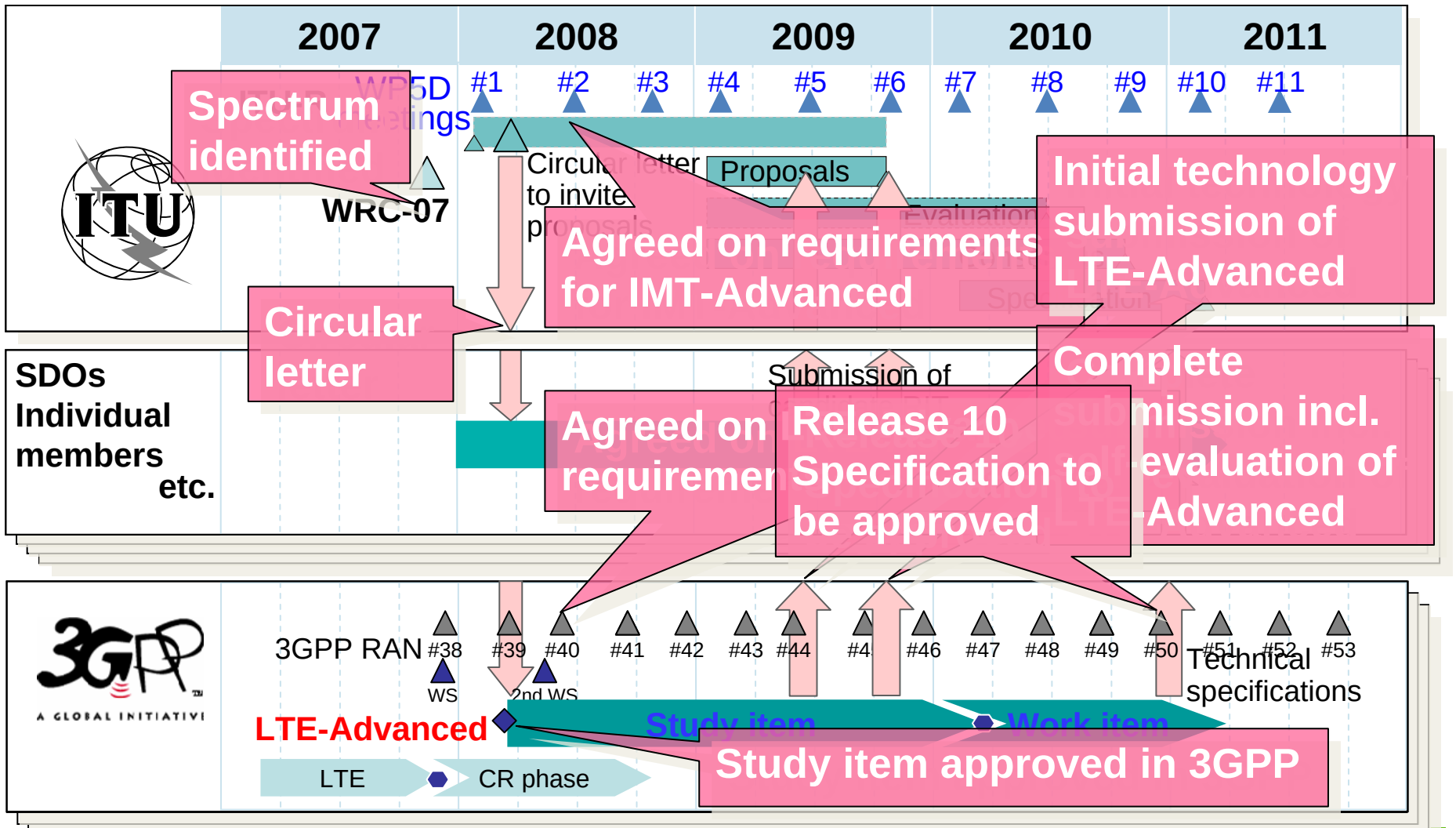
- LTE is specified in 36 series technical specifications
- The latest version of the LTE Release 8 specifications (September 2009 version) can be found in
  - http://www.3gpp.org/ftp/Specs/2009-09/Rel-8/36_series/

LTE Release 10 and Beyond (LTE-Advanced)

Overview of LTE-Advanced

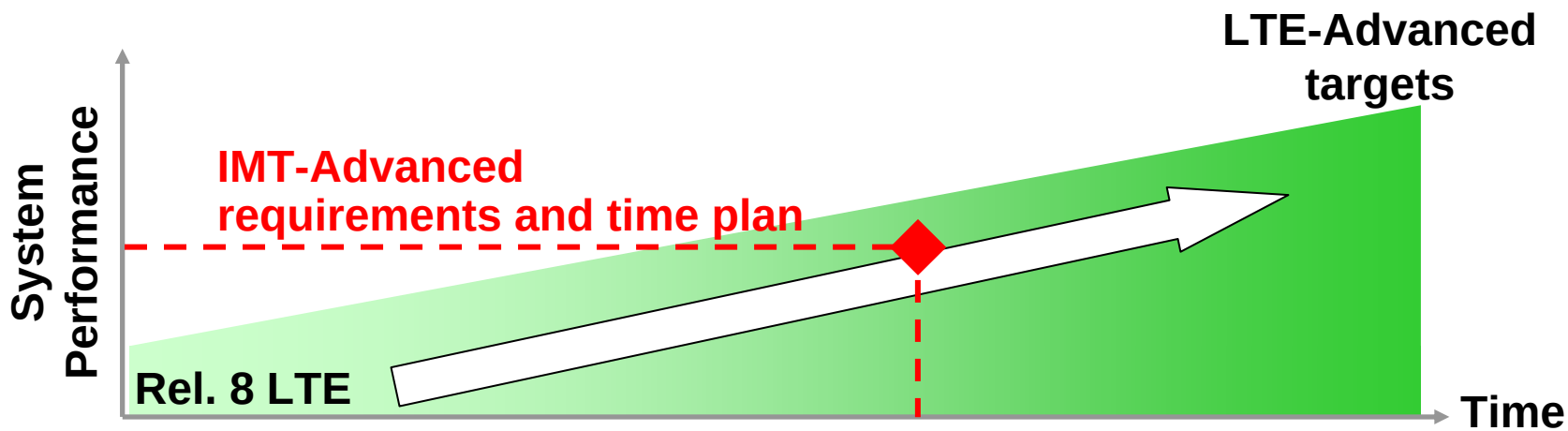
- Motivation of LTE-Advanced
  - IMT-Advanced standardisation process in ITU-R
  - Additional IMT spectrum band identified in WRC07
  - Further evolution of LTE Release 8 and 9 to meet:
    - Requirements for IMT-Advanced of ITU-R
    - Future operator and end-user requirements
- 3GPP status
  - Feasibility study is ongoing under study item, “Further advancements for E-UTRA(LTE-Advanced)”
  - Requirements and targets for LTE-Advanced were agreed and possible technologies to meet the requirements and the targets were identified
  - Self-evaluations were conducted and confirmed that LTE-Advanced meet the all requirements of IMT-Advanced
  - All necessary documents to be submitted to ITU-R WP 5D#6 as the complete submission were approved in 3GPP
- Proposal of LTE-Advanced is an SRIT including FDD RIT and TDD RIT

Standardisation Schedule For IMT/LTE-Advanced



General Requirements for LTE-Advanced

- LTE-Advanced is an evolution of LTE
- LTE-Advanced shall meet or exceed IMT-Advanced requirements within the ITU-R time plan
- Extended LTE-Advanced targets are adopted



System Performance Requirements

- Peak data rate
  - 1 Gbps data rate will be achieved by 4-by-4 MIMO and transmission bandwidth wider than approximately 70 MHz
- Peak spectrum efficiency
  - DL: Rel. 8 LTE satisfies IMT-Advanced requirement
  - UL: Need to double from Release 8 to satisfy IMT-Advanced requirement

		Rel. 8 LTE	LTE-Advanced	IMT-Advanced
Peak data rate	DL	300 Mbps	1 Gbps	1 Gbps(*)
	UL	75 Mbps	500 Mbps	
Peak spectrum efficiency [bps/Hz]	DL	15	30	15
	UL	3.75	15	6.75

*"100 Mbps for high mobility and 1 Gbps for low mobility" is one of the key features as written in Circular Letter (CL)

System Performance Requirements (Cont'd)

- Capacity and cell-edge user throughput
  - Target for LTE-Advanced was set considering gain of 1.4 to 1.6 from Release 8 LTE performance

		Ant. Config.	Rel. 8 LTE*1	LTE-Advanced*2	IMT-Advanced*3
Capacity [bps/Hz/cell]	DL	2-by-2	1.69	2.4	–
		4-by-2	1.87	2.6	2.2
		4-by-4	2.67	3.7	–
	UL	1-by-2	0.74	1.2	–
		2-by-4	–	2.0	1.4
Cell-edge user throughput [bps/Hz/cell/user]	DL	2-by-2	0.05	0.07	–
		4-by-2	0.06	0.09	0.06
		4-by-4	0.08	0.12	–
	UL	1-by-2	0.024	0.04	–
		2-by-4	–	0.07	0.03

x1.4-1.6

*1 See TR25.912(Case 1 scenario) *2 See TR36.913(Case 1 scenario)
*3 See ITU-R M.2135(Base Coverage Urban scenario)

Other Important Requirements

- Spectrum flexibility
  - Actual available spectra are different according to each region or country
  - In 3GPP, various deployment scenarios for spectrum allocation are being taken into consideration in feasibility study

Total 12 scenarios are identified with highest priority

	Tx BWs	No. of Component Carriers (CCs)	Bands	Duplex
1	UL: 40 MHz DL: 80 MHz	UL: Contiguous 2x20 MHz CCs DL: Contiguous 4x20 MHz CCs	3.5 GHz band	FDD
2	100 MHz	Contiguous 5x20 MHz CCs	Band 40 (2.3 GHz)	TDD
3	100 MHz	Contiguous 5x20 MHz CCs	3.5 GHz band	TDD
4	UL: 40 MHz DL: 80 MHz	UL: Non-contiguous 20 + 20 MHz CCs DL: Non-contiguous 2x20 + 2x20 MHz CCs	3.5 GHz band	FDD
5	UL: 10 MHz DL: 10 MHz	UL/DL: Non-contiguous 5 MHz + 5 MHz CCs	Band 8 (900 MHz)	FDD
6	80 MHz	Non-contiguous 2x20 + 2x20 MHz CCs	Band 38 (2.6 GHz)	TDD
⋮	⋮	⋮	⋮	⋮

- Support for flexible deployment scenarios including downlink/uplink asymmetric bandwidth allocation for FDD and non-contiguous spectrum allocation

Other Important Requirements (Cont'd)

- LTE-Advanced will be deployed as an evolution of LTE Release 8 and on new bands.
- LTE-Advanced shall be backwards compatible with LTE Release 8 in the sense that
  - a LTE Release 8 terminal can work in an LTE-Advanced NW,
  - an LTE-Advanced terminal can work in an LTE Release 8 NW
- Increased deployment of indoor eNB and HNB in LTE-Advanced.

Technical Outline to Achieve LTE-Advanced Requirements

- Support wider bandwidth
  - Carrier aggregation to achieve wider bandwidth
  - Support of spectrum aggregation

  ➔ Peak data rate, spectrum flexibility
- Advanced MIMO techniques
  - Extension to up to 8-layer transmission in downlink
  - Introduction of single-user MIMO up to 4-layer transmission in uplink

  ➔ Peak data rate, capacity, cell-edge user throughput
- Coordinated multipoint transmission and reception (CoMP)
  - CoMP transmission in downlink
  - CoMP reception in uplink

  ➔ Cell-edge user throughput, coverage, deployment flexibility
- Further reduction of delay
  - AS/NAS parallel processing for reduction of C-Plane delay
- Relaying
  - Type 1 relays create a separate cell and appear as Rel. 8 LTE eNB to Rel. 8 LTE UEs

  ➔ Coverage, cost effective deployment

* See appendix 1 in this slide set for further information on LTE-Advanced technologies

Self-Evaluation

3GPP Self-evaluation for LTE-Advanced

- Self-evaluation for LTE-Advanced FDD RIT and TDD RIT was conducted in 3GPP
- The capabilities addressed here span the capabilities from LTE Rel. 8 and extend through Rel-10 and beyond. As such the capabilities represent a range of possible functionalities and solutions that might be adopted by 3GPP in the work on the further specifications of LTE.
- The ITU-R report, M.2133, M.2134, M.2135 and IMT-ADV/3 were utilized in the preparation of this self-evaluation report.

Summary of Self-Evaluation Results

- The self-evaluation results shows:

  For LTE Release 10,

  FDD RIT Component meets the minimum requirements of all 4 required test environments.
  TDD RIT Component meets the minimum requirements of all 4 required test environments.
  The complete SRIT meets the minimum requirements of all 4 required test environments.

  Baseline configuration exceeding ITU-R requirements with minimum extension

  - LTE release 8 fulfills the requirements in most cases (no extensions needed)
  - Extensions to Multi-user MIMO from Release 8 fulfills the requirements in some scenarios (Urban Macro/Micro DL)

  More advanced configurations, e.g. CoMP, with further enhanced performance

- Many (18) companies participated in the simulations
  ⇨ **High reliability**

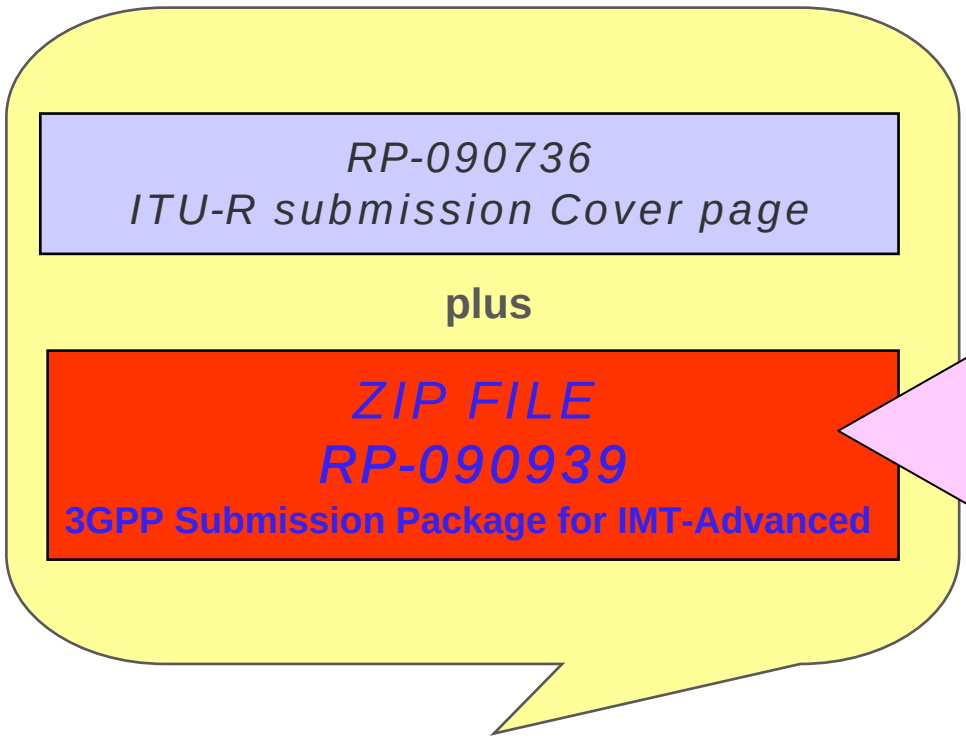
- Self evaluation reports are captured in section 16 of Technical Report TR 36.912

*See appendix 2 in this slide set for detailed information on self-evaluation results

ITU-R Submission Documents

- The 3GPP submission to the ITU-R includes the following templates organized as an FDD Radio Interface Technology component (FDD RIT) and as a TDD Radio Interface Technology component (TDD RIT). Together the FDD RIT and the TDD RIT comprise a Set of Radio Interface Technologies (SRIT).
- The 3GPP developed FDD RIT and TDD RIT templates include characteristics and link budget templates and compliance templates for services, spectrum, and technical performance.
- 3GPP provides additional supporting information in document 3GPP TR 36.912 v9.0.0; Feasibility study for Further Advancements for EUTRA(LTE-Advanced) (Release 9).
- Templates are found in Annex C of Technical Report TR 36.912.

Structure of ITU-R Submission Documents from 3GPP



Overall ITU-R Submission
ITU-R 5D/564-E
Contributed by individual members of 3GPP

RP-090743
TR36.912 v9.0.0 Main Body
Additional supporting information on LTE-Advanced
Detailed self-evaluation results in section 16
Following documents are captured in Annex A and C

RP-090744
Annex A3: Self-evaluation results
Detailed simulation results provided from 18 companies

RP-090745
Annex C1: Characteristics template
Update version of ITU-R Document 5D/496-E
Relevant 3GPP specifications listed at the end of this document
Templates for FDD RIT and TDD RIT contained separately

RP-090746
Annex C2: Link budget template
Two Link budget template files for LOS and NLOS
Each file includes link budget templates for five radio environments specified in ITU-R M.2135
Templates for FDD RIT and TDD RIT contained separately

RP-090747
Annex C3: Compliance template
This template shows LTE-Advanced fulfills all requirements of IMT-Advanced in ITU-R
Templates for FDD RIT and TDD RIT contained separately

Conclusion

- Taking into account the IMT-Advanced standardisation process in ITU-R, the project for LTE-Advanced, was started in 3GPP from March 2008 built upon the LTE Release 8 foundation
- In response to the ITU-R Circular Letter 5/LCCE/2, 3GPP provided a complete submission of LTE Release 10 and beyond (LTE-Advanced) as a candidate technology for IMT-Advanced
- 3GPP conducted a Self-Evaluation under ITU-R guidelines of LTE-Advanced with participation of many companies from across the world
- The evaluation results show that for LTE Release 10 and beyond(LTE-Advanced),
  - FDD RIT Component meets the minimum requirements of all 4 required test environments.
  - TDD RIT Component meets the minimum requirements of all 4 required test environments.
  - The complete SRIT meets the minimum requirements of all 4 required test environments.
- 3GPP is happy to answer questions from external evaluation groups and to cooperate further in each step of IMT-Advanced process in ITU-R

Contact Person for Questions Related to 3GPP ITU-R Submission

- Takehiro Nakamura

  NTT DOCOMO, Inc

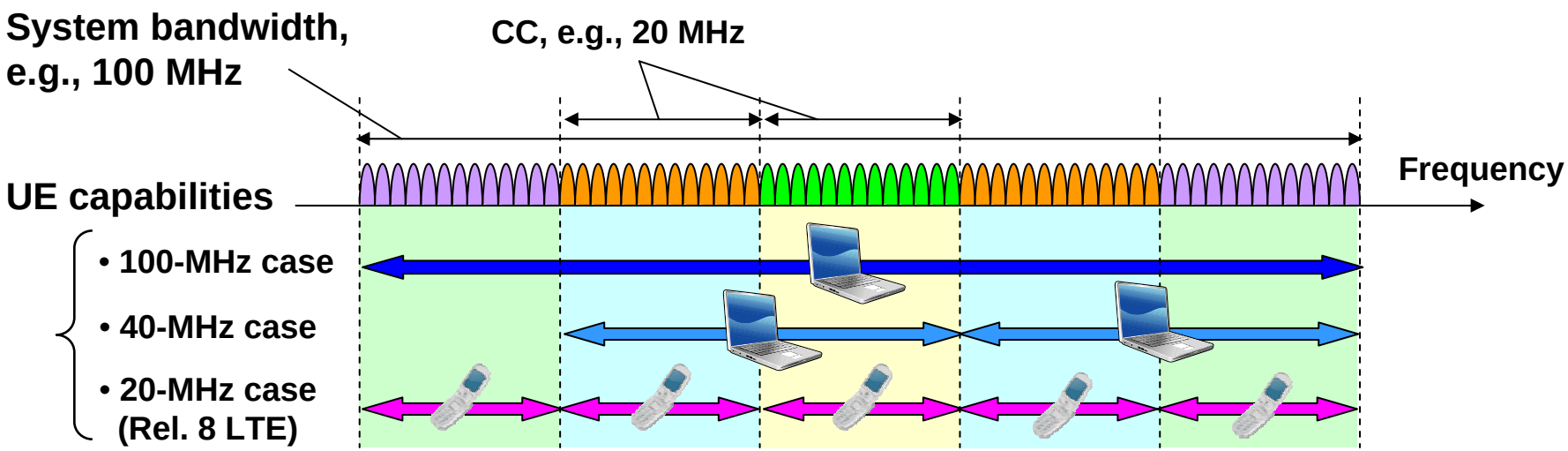
  3GPP TSG-RAN Chairman

  Email: nakamurata@nttdocomo.co.jp

Appendix 1
LTE-Advanced Technologies

Carrier Aggregation

- **Wider bandwidth transmission using carrier aggregation**
- **Entire system bandwidth up to, e.g., 100 MHz, comprises multiple basic frequency blocks called component carriers (CCs)**
  - ➔ **Satisfy requirements for peak data rate**
- **Each CC is backward compatible with Rel. 8 LTE**
  - ➔ **Maintain backward compatibility with Rel. 8 LTE**
- **Carrier aggregation supports both contiguous and non-contiguous spectrums, and asymmetric bandwidth for FDD**
  - ➔ **Achieve flexible spectrum usage**

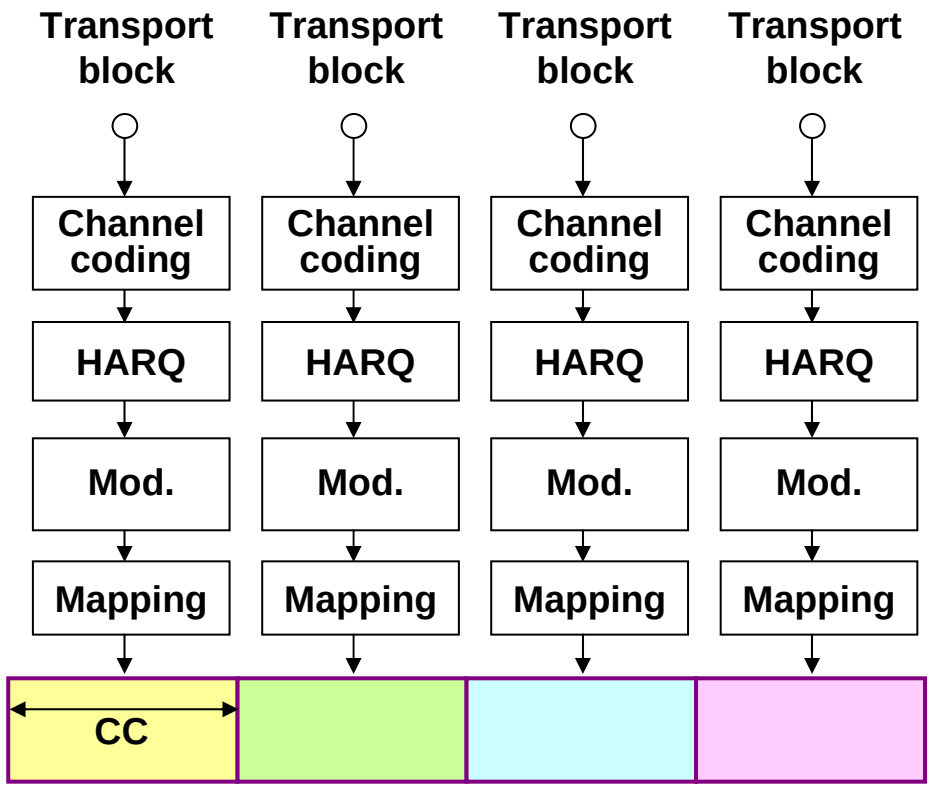


Downlink Multiple Access Scheme

- **Downlink: OFDMA with component carrier (CC) based structure**
  - ➔ **Priority given to reusing Rel. 8 specification for low-cost and fast development**

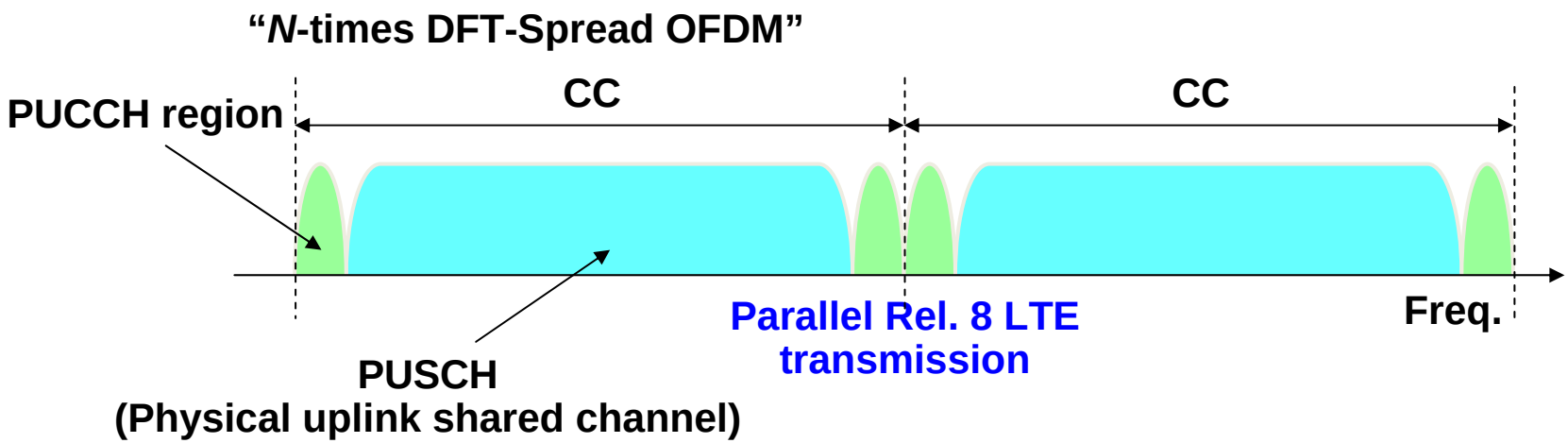
- **One transport block (TB), which corresponds to a channel coding block and a retransmission unit, is mapped within one CC**
- **Parallel-type transmission for multi-CC transmission**

- **Good affinity to Rel. 8 LTE specifications**



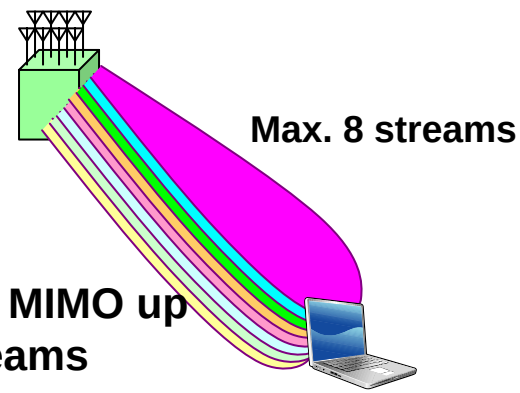
Uplink Multiple Access Scheme

- **Uplink: *N*-times DFT-Spread OFDM**
  Achieve wider bandwidth by adopting parallel multi-CC transmission
  ➔ Satisfy requirements for peak data rate while maintaining backward compatibility
  ➔ Low-cost and fast development by reusing Rel. 8 specification

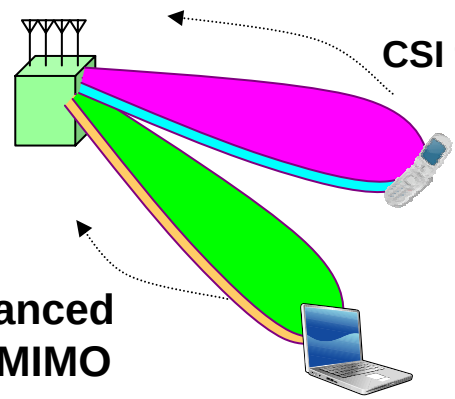


Enhanced Multi-antenna Techniques in Downlink

- **Extension up to 8-stream transmission**
- **Rel. 8 LTE supports up to 4-stream transmission, LTE-Advanced supports up to 8-stream transmission**
  - **➔ Satisfy the requirement for peak spectrum efficiency, i.e., 30 bps/Hz**
- **Specify additional reference signals (RS)**
- **Two RSs are specified in addition to Rel. 8 common RS (CRS)**
  - **Channel state information RS (CSI-RS)**
  - **UE-specific demodulation RS (DM-RS)**
    - ✓ **UE-specific DM-RS, which is precoded, makes it possible to apply non-codebook-based precoding**
    - ✓ **UE-specific DM-RS will enable application of enhanced multi-user beamforming such as zero forcing (ZF) for, e.g., 4-by-2 MIMO**



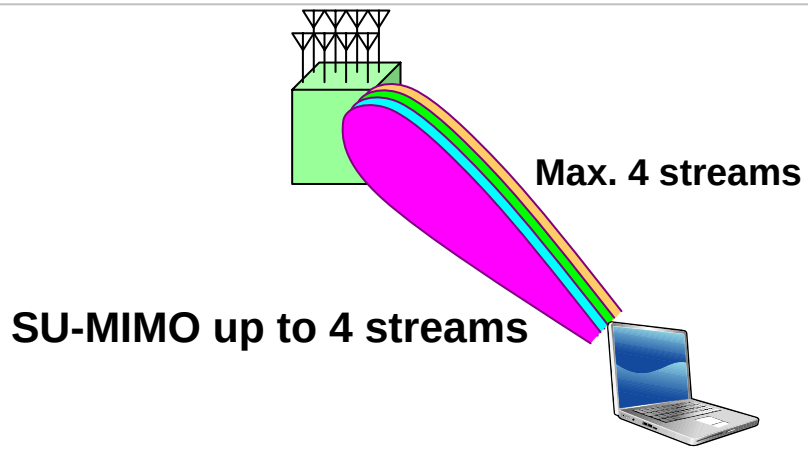
Higher-order MIMO up to 8 streams



Enhanced MU-MIMO

Enhanced Multi-antenna Techniques in Uplink

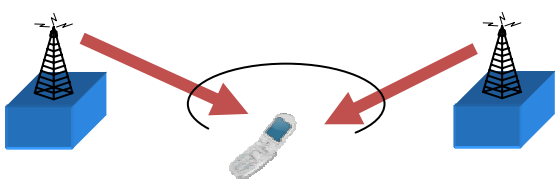
- **Introduction of single user (SU)-MIMO up to 4-stream transmission**
- **Whereas Rel. 8 LTE does not support SU-MIMO, LTE-Advanced supports up to 4-stream transmission**
  ➔ Satisfy the requirement for peak spectrum efficiency, i.e., 15 bps/Hz
- **Signal detection scheme with affinity to DFT-Spread OFDM for SU-MIMO**
- **Turbo serial interference canceller (SIC) is assumed to be used for eNB receivers to achieve higher throughput performance for DFT-Spread OFDM**
  ➔ Improve user throughput, while maintaining single-carrier based signal transmission



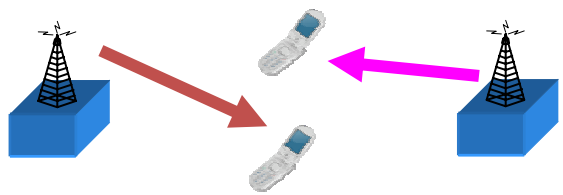
CoMP Transmission in Downlink

- **CoMP transmission schemes in downlink**
- **Joint processing (JP)**
  - ✓ **Joint transmission (JT): Downlink physical shared channel (PDSCH) is transmitted from multiple cells with precoding using DM-RS among coordinated cells**
  - ✓ **Dynamic cell selection: PDSCH is transmitted from one cell, which is dynamically selected**
- **Coordinated scheduling/beamforming (CS/CB)**
  PDSCH is transmitted only from one cell site, and scheduling/beamforming is coordinated among cells
- **CSI feedback (FB)**
- **Explicit CSI FB (direct channel FB) is investigated to conduct precise precoding, as well as implicit CSI FB (precoding matrix index FB) based on Rel. 8 LTE ➔ Tradeoff between gain and FB signaling overhead**

Coherent combining or dynamic cell selection



Joint transmission/dynamic cell selection

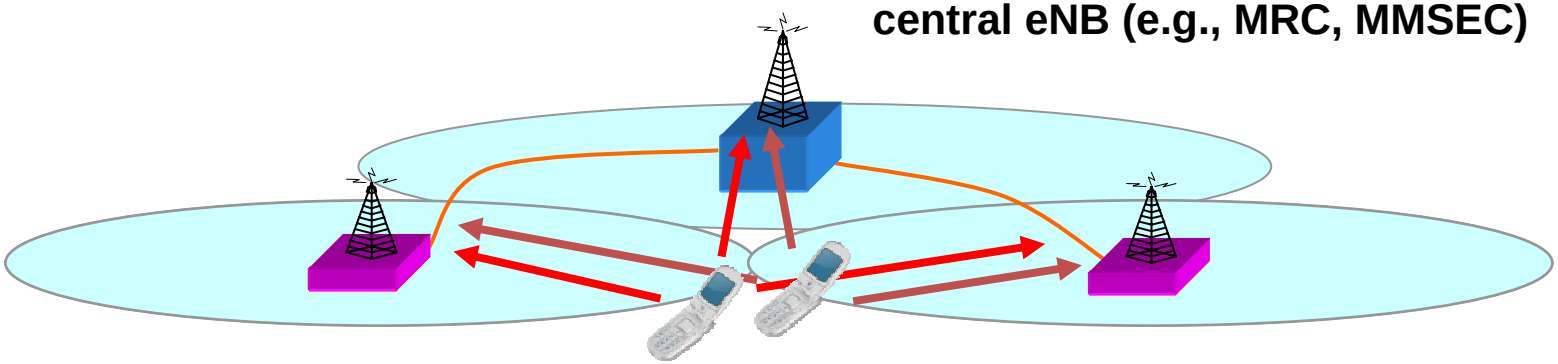


Coordinated scheduling/beamforming

CoMP Reception in Uplink

- **CoMP reception scheme in uplink**
- **Physical uplink shared channel (PUSCH) is received at multiple cells**
- **Scheduling is coordinated among the cells**
  ➔ Improve especially cell-edge user throughput
- **Note that CoMP reception in uplink is implementation matter and does not require any change to radio interface**

Receiver signal processing at central eNB (e.g., MRC, MMSEC)

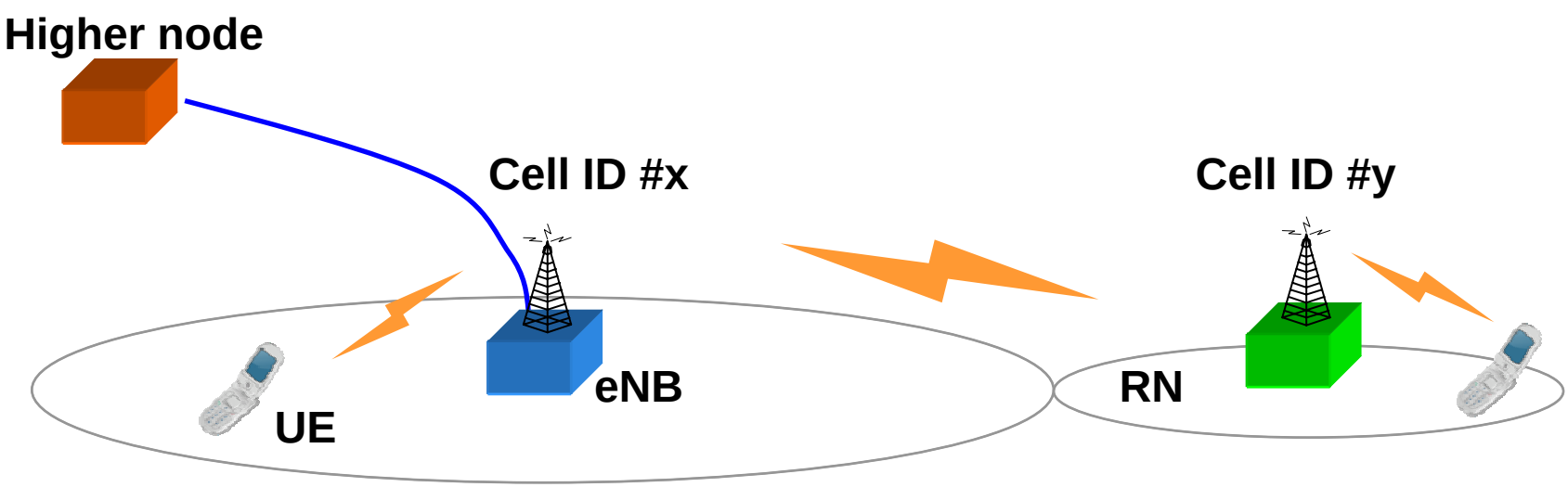


Multipoint reception

Relaying

■ **Type 1 relay**

- **Relay node (RN) creates a separate cell distinct from the donor cell**
- **UE receives/transmits control signals for scheduling and HARQ from/to RN**
- **RN appears as a Rel. 8 LTE eNB to Rel. 8 LTE UEs**
  ➔ Deploy cells in the areas where wired backhaul is not available or very expensive

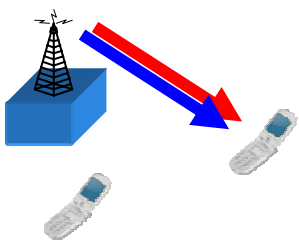


Appendix 2
Detailed Self-Evaluation Results

Full-buffer spectrum efficiency
Evaluated downlink schemes

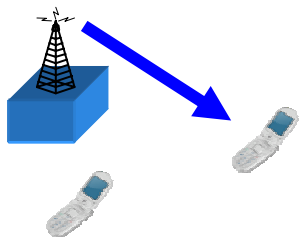
Single-user MIMO (SU-MIMO)

Ex)



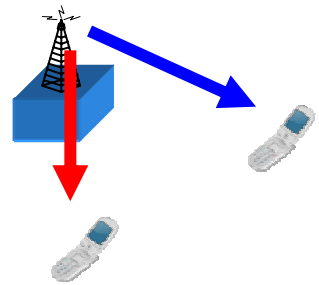
Single-layer beamforming (Single-layer BF)

Ex)



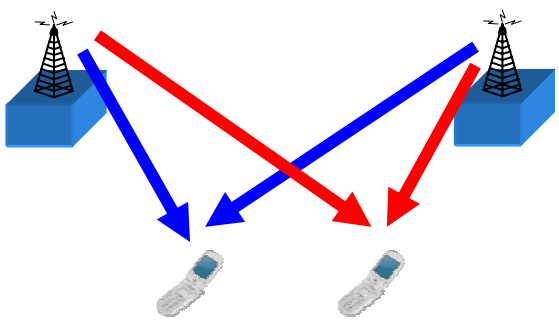
Multi-user MIMO (MU-MIMO)

Ex)



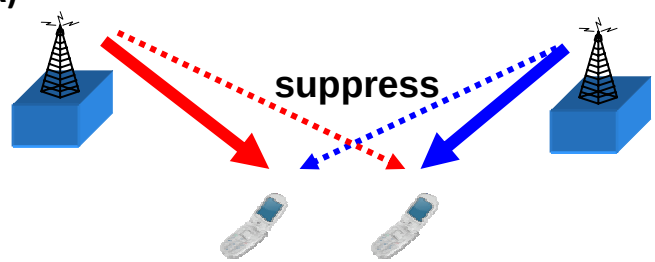
Joint processing CoMP (JP-CoMP)

Ex)



Coordinated scheduling/beamforming-CoMP (CS/CB-CoMP)

Ex)

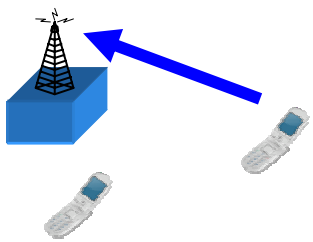


Various schemes have been evaluated

Full-buffer spectrum efficiency
Evaluated uplink schemes

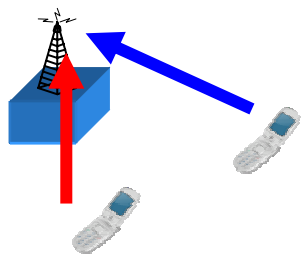
Single-input multiple-output (SIMO)

Ex)



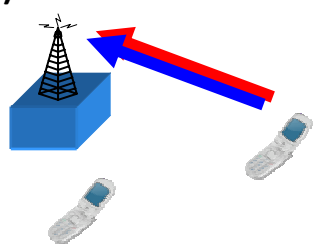
Multi-user MIMO (MU-MIMO)

Ex)



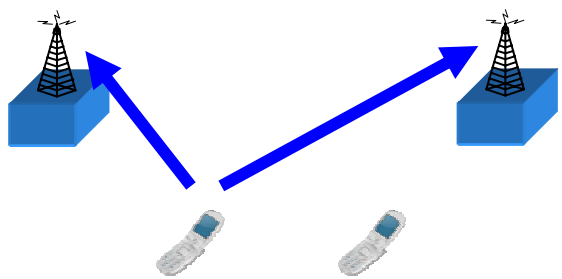
Single-user MIMO (SU-MIMO)

Ex)



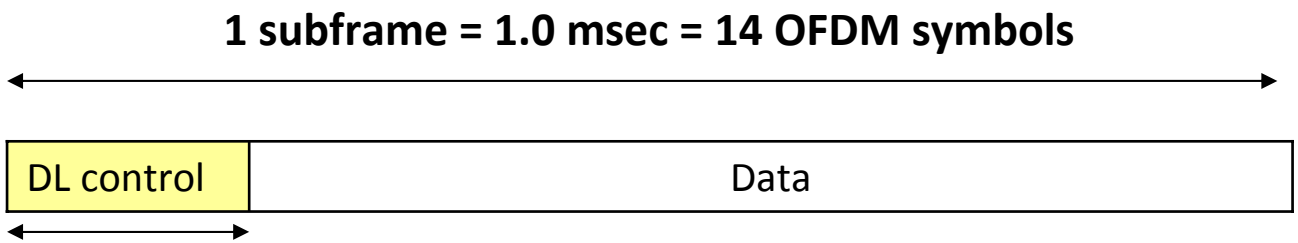
CoMP

Ex)



Various schemes have been evaluated

Full-buffer spectrum efficiency
DL control channel overhead assumption



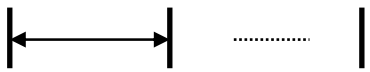
***L*: OFDM symbols (L=1, 2, 3)**

- Downlink performances have been evaluated taking into account the downlink overhead for *L* = 1, 2 and 3 cases
- Dynamic assignment of *L* is supported already in the Rel. 8 specification.
  → Average overhead depends on the environments

Detailed Self-Evaluation Results

Antenna configuration

Antenna configuration (A)



Co-polarized antennas
separated 4 wavelengths

Antenna configuration (C)

Co-polarized antennas
separated 0.5 wavelength

Antenna configuration (E)

Cross-polarized +/- 45 (deg) antennas
columns separated 0.5 wavelength

Various antenna configurations have been evaluated

Detailed Self-Evaluation Results

Downlink peak spectrum efficiency

- **LTE Rel. 8 fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g., 8-layer spatial multiplexing)**

DL peak spectrum efficiency for FDD

Scheme	Spectral efficiency [b/s/Hz]
ITU-R Requirement	15
Rel. 8 4-layer spatial multiplexing	16.3
8-layer spatial multiplexing	30.6

DL peak spectrum efficiency for TDD

Scheme	Spectral efficiency [b/s/Hz]
ITU-R Requirement	15
Rel. 8 4-layer spatial multiplexing	16.0
8-layer spatial multiplexing	30.0

Overhead assumptions
- **DL control channel (L = 1)**
- **Cell and UE specific reference signal**
- **Physical broadcast channel and synchronization signal**

Uplink peak spectrum efficiency

- **LTE Rel. 8 fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g.,4-layer spatial multiplexing)**

UL peak spectral efficiency for FDD

Scheme	Spectral efficiency [b/s/Hz]
ITU-R Requirement	6.75
2 layer spatial multiplexing	8.4
4 layer spatial multiplexing	16.8

UL peak spectral efficiency for TDD

Scheme	Spectral efficiency [b/s/Hz]
ITU-R Requirement	6.75
2 layer spatial multiplexing	8.1
4 layer spatial multiplexing	16.1

Overhead assumptions
- **UL control channel**
- **Physical random access channel**

Control plane latency

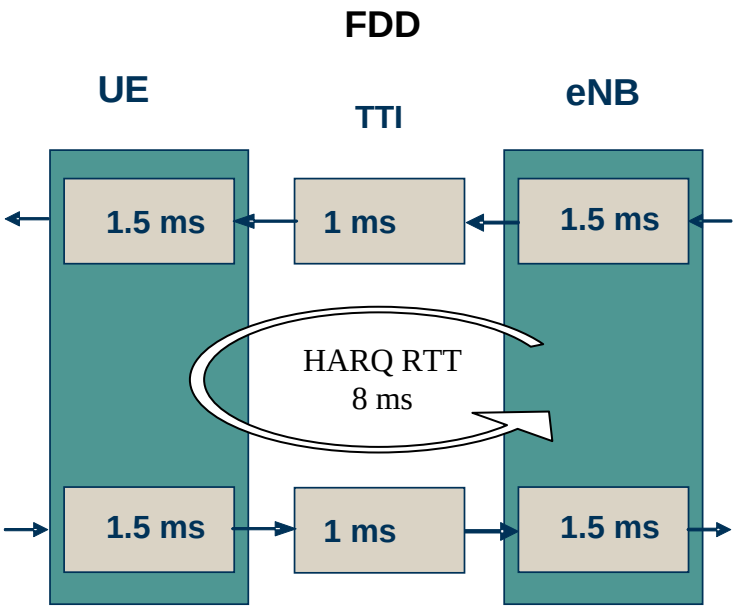
- **LTE fulfills ITU-R requirements on control plane latency for idle to connected transition**

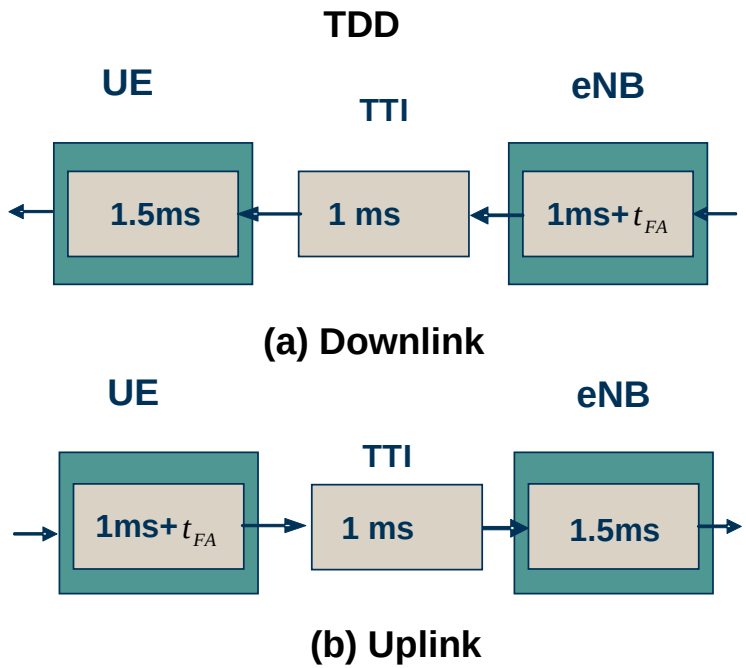
ITU-R Requirement: less than 100

Component	Description	Time (ms)
1	Average delay due to RACH scheduling period (1ms RACH cycle)	0.5
2	RACH Preamble	1
3-4	Preamble detection and transmission of RA response (Time between the end RACH transmission and UE's reception of scheduling grant and timing adjustment)	3
5	UE Processing Delay (decoding of scheduling grant, timing alignment and C-RNTI assignment + L1 encoding of RRC Connection Request)	5
6	Transmission of RRC and NAS Request	1
7	Processing delay in eNB (L2 and RRC)	4
8	Transmission of RRC Connection Set-up (and UL grant)	1
9	Processing delay in the UE (L2 and RRC)	12
10	Transmission of RRC Connection Set-up complete	1
11	*Processing delay in eNB (Uu → S1-C)*	
12	*S1-C Transfer delay*	
13	*MME Processing Delay (including UE context retrieval of 10ms)*	
14	*S1-C Transfer delay*	
15	Processing delay in eNB (S1-C → Uu)	4
16	Transmission of RRC Security Mode Command and Connection Reconfiguration (+TTI alignment)	1.5
17	Processing delay in UE (L2 and RRC)	16
	Total delay	50

User plane latency

- **LTE fulfills ITU-R requirements on user plane latency**





0 % BLER	4.0 msec
10 % BLER	4.8 msec

0 % BLER	4.9 msec
10 % BLER	6.035 msec

Cell-average and Cell-edge spectrum efficiency Indoor environment (Downlink)

- **LTE Rel. 8 with SU-MIMO 4x2 (even with maximum DL control overhead (L = 3)) fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g., MU-MIMO 4x2)**

Downlink spectral efficiency (FDD), InH

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]			Cell edge [b/s/Hz]		
			L=1	L=2	L=3	L=1	L=2	L=3
Rel. 8 SU-MIMO 4 x 2 (A)	3 / 0.1	15	4.8	4.5	4.1	0.23	0.21	0.19
MU-MIMO 4 x 2 (C)	3 / 0.1	3	6.6	6.1	5.5	0.26	0.24	0.22

Downlink spectral efficiency (TDD), InH

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]			Cell edge [b/s/Hz]		
			L=1	L=2	L=3	L=1	L=2	L=3
Rel. 8 SU-MIMO 4 x 2 (A)	3 / 0.1	10	4.7	4.4	4.1	0.22	0.20	0.19
MU-MIMO 4 x 2 (C)	3 / 0.1	4	6.7	6.1	5.6	0.24	0.22	0.20

Cell-average and Cell-edge spectrum efficiency Indoor environment (Uplink)

- **LTE Rel. 8 with SIMO 1x4 fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g., LTE Rel. 8 MU-MIMO 1x4, SU-MIMO 2x4)**

Uplink spectral efficiency (FDD), InH

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]	Cell edge [b/s/Hz]
Rel. 8 SIMO 1x4 (A)	2.25 / 0.07	13	3.3	0.23
Rel. 8 SIMO 1x4 (C)	2.25 / 0.07	10	3.3	0.24
Rel. 8 MU-MIMO 1x4 (A)	2.25 / 0.07	2	5.8	0.42
SU-MIMO 2 x 4 (A)	2.25 / 0.07	5	4.3	0.25

Uplink spectral efficiency (TDD), InH

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]	Cell edge [b/s/Hz]
Rel. 8 SIMO 1x4 (A)	2.25 / 0.07	9	3.1	0.22
Rel. 8 SIMO 1x4 (C)	2.25 / 0.07	7	3.1	0.23
Rel. 8 MU-MIMO 1x4 (A)	2.25 / 0.07	2	5.5	0.39
SU-MIMO 2 x 4 (A)	2.25 / 0.07	2	3.9	0.25

Cell-average and Cell-edge spectrum efficiency Microcellular environment (Downlink)

- **Extension of LTE Rel. 8 with MU-MIMO 4x2 (even with maximum DL control overhead (L = 3)) fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g., CS/CB-CoMP 4x2, JP-CoMP 4x2, and MU-MIMO 8x2)**

Downlink spectral efficiency (FDD), UMi

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]			Cell edge [b/s/Hz]		
			L=1	L=2	L=3	L=1	L=2	L=3
MU-MIMO 4 x 2 (C)	2.6 / 0.075	8	3.5	3.2	2.9	0.10	0.096	0.087
MU-MIMO 4 x 2 (A)	2.6 / 0.075	3	3.4	3.1	2.8	0.12	0.11	0.099
CS/CB-CoMP 4 x 2 (C)	2.6 / 0.075	5	3.6	3.3	3.0	0.11	0.099	0.089
JP-CoMP 4 x 2 (C)	2.6 / 0.075	1	4.5	4.1	3.7	0.14	0.13	0.12
MU-MIMO 8 x 2 (C/E)	2.6 / 0.075	4	4.2	3.8	3.5	0.15	0.14	0.13

Downlink spectral efficiency (TDD), UMi

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]			Cell edge [b/s/Hz]		
			L=1	L=2	L=3	L=1	L=2	L=3
MU-MIMO 4 x 2 (C)	2.6 / 0.075	8	3.5	3.2	3.0	0.11	0.096	0.089
MU-MIMO 4 x 2 (A)	2.6 / 0.075	1	3.2	2.9	2.7	0.11	0.10	0.095
CS/CB-CoMP 4 x 2 (C)	2.6 / 0.075	3	3.6	3.3	3.1	0.10	0.092	0.086
JP-CoMP 4 x 2 (C)	2.6 / 0.075	1	4.6	4.2	3.9	0.10	0.092	0.085
MU-MIMO 8 x 2 (C/E)	2.6 / 0.075	4	4.2	3.9	3.6	0.12	0.11	0.099

Cell-average and -edge spectrum efficiency Microcellular environment (Uplink)

- **LTE Rel. 8 with SIMO 1x4 fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g., LTE Rel. 8 MU-MIMO 1x4, MU-MIMO 2x4, and MU-MIMO 1x8)**

Uplink spectral efficiency (FDD), UMi

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]	Cell edge [b/s/Hz]
Rel. 8 SIMO 1 x 4 (C)	1.8 / 0.05	12	1.9	0.073
Rel. 8 MU-MIMO 1 x 4 (A)	1.8 / 0.05	2	2.5	0.077
MU-MIMO 2 x 4 (A)	1.8 / 0.05	1	2.5	0.086

Uplink spectral efficiency (TDD), UMi

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]	Cell edge [b/s/Hz]
Rel. 8 SIMO 1 x 4 (C)	1.8 / 0.05	9	1.9	0.070
Rel. 8 MU-MIMO 1 x 4 (A)	1.8 / 0.05	2	2.3	0.071
MU-MIMO 2 x 4 (A)	1.8 / 0.05	1	2.8	0.068
MU-MIMO 1 x 8 (E)	1.8 / 0.05	1	3.0	0.079

Cell-average and Cell-edge spectrum efficiency
Base coverage urban environment (Downlink)

- **Extension of LTE Rel. 8 with MU-MIMO 4x2 (even with maximum DL control overhead (L = 3)) fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g., CS/CB-CoMP 4x2, JP-CoMP 4x2, and CS/CB-CoMP 8x2)**

Downlink spectral efficiency (FDD), UMa

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]			Cell edge [b/s/Hz]		
			L=1	L=2	L=3	L=1	L=2	L=3
MU-MIMO 4 x 2 (C)	2.2 / 0.06	7	2.8	2.6	2.4	0.079	0.073	0.066
CS/CB-CoMP 4 x 2 (C)	2.2 / 0.06	6	2.9	2.6	2.4	0.081	0.074	0.067
JP-CoMP 4 x 2 (A)	2.2 / 0.06	1	3.0	2.7	2.5	0.080	0.073	0.066
CS/CB-CoMP 8 x 2 (C)	2.2 / 0.06	3	3.8	3.5	3.2	0.10	0.093	0.084

Downlink spectral efficiency (TDD), UMa

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]			Cell edge [b/s/Hz]		
			L=1	L=2	L=3	L=1	L=2	L=3
MU-MIMO 4 x 2 (C)	2.2 / 0.06	7	2.9	2.6	2.4	0.079	0.071	0.067
CS/CB-CoMP 4 x 2 (C)	2.2 / 0.06	4	2.9	2.6	2.4	0.083	0.075	0.070
JP-CoMP 4 x 2 (C)	2.2 / 0.06	1	3.6	3.3	3.1	0.090	0.082	0.076
CS/CB-CoMP 8 x 2 (C/E)	2.2 / 0.06	3	3.7	3.3	3.1	0.10	0.093	0.087

Cell-average and Cell-edge spectrum efficiency
Base coverage urban environment (Uplink)

- **LTE Rel. 8 with SIMO 1x4 fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g., CoMP 1x4, CoMP 2x4, and MU-MIMO 1x8)**

Uplink spectral efficiency (FDD), UMa

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]	Cell edge [b/s/Hz]
Rel. 8 SIMO 1 x 4 (C)	1.4 / 0.03	12	1.5	0.062
CoMP 1 x 4 (A)	1.4 / 0.03	2	1.7	0.086
CoMP 2 x 4 (C)	1.4 / 0.03	1	2.1	0.099

Uplink spectral efficiency (TDD), UMa

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]	Cell edge [b/s/Hz]
Rel. 8 SIMO 1x4 (C)	1.4 / 0.03	9	1.5	0.062
CoMP 1 x 4 (C)	1.4 / 0.03	1	1.9	0.090
CoMP 2 x 4 (C)	1.4 / 0.03	1	2.0	0.097
MU-MIMO 1 x 8 (E)	1.4 / 0.03	1	2.7	0.076

Cell-average and Cell-edge Spectrum Efficiency
High Speed Environment (Downlink)

- LTE Rel. 8 with SU-MIMO 4x2 (even with maximum DL control overhead (L = 3)) fulfills ITU-R requirements
- Further improved performance can be achieved by using additional technology features (e.g., MU-MIMO 4x2, MU-MIMO 8x2, and LTE Rel. 8 single-layer BF 8x2)

Downlink spectral efficiency (FDD), RMa

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]			Cell edge [b/s/Hz]		
			L=1	L=2	L=3	L=1	L=2	L=3
Rel. 8 SU-MIMO 4 x 2 (C)	1.1 / 0.04	15	2.3	2.1	1.9	0.081	0.076	0.069
Rel. 8 SU-MIMO 4 x 2 (A)	1.1 / 0.04	14	2.1	2.0	1.8	0.067	0.063	0.057
MU-MIMO 4 x 2 (C)	1.1 / 0.04	3	3.9	3.5	3.2	0.11	0.099	0.090
MU-MIMO 8 x 2 (C)	1.1 / 0.04	1	4.1	3.7	3.4	0.13	0.12	0.11

Downlink spectral efficiency (TDD), RMa

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]			Cell edge [b/s/Hz]		
			L=1	L=2	L=3	L=1	L=2	L=3
Rel. 8 SU-MIMO 4 x 2 (C)	1.1 / 0.04	8	2.0	1.9	1.8	0.072	0.067	0.063
Rel. 8 SU-MIMO 4 x 2 (A)	1.1 / 0.04	7	1.9	1.7	1.6	0.057	0.053	0.049
MU-MIMO 4 x 2 (C)	1.1 / 0.04	4	3.5	3.2	3.0	0.098	0.089	0.083
MU-MIMO 8 x 2 (C/E)	1.1 / 0.04	2	4.0	3.6	3.4	0.12	0.11	0.10
Rel. 8 single-layer BF 8 x 2 (E)	1.1 / 0.04	4	2.5	2.3	2.1	0.11	0.10	0.093

Cell-average and Cell-edge Spectrum Efficiency High Speed Environment (Uplink)

- **LTE Rel. 8 with SIMO 1x4 fulfills ITU-R requirements**
- **Further improved performance can be achieved by using additional technology features (e.g., CoMP 2x4, and MU-MIMO 1x8)**

Uplink spectral efficiency (FDD), RMa

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]	Cell edge [b/s/Hz]
Rel. 8 SIMO 1x4 (C)	0.7 / 0.015	11	1.8	0.082
Rel. 8 MU-MIMO 1x4 (A)	0.7 / 0.015	2	2.2	0.097
CoMP 2 x 4 (A)	0.7 / 0.015	2	2.3	0.13

Uplink spectral efficiency (TDD), RMa

Scheme and antenna configuration	ITU-R Requirement (Ave./Edge)	Number of samples	Cell average [b/s/Hz/cell]	Cell edge [b/s/Hz]
Rel. 8 SIMO 1 x 4 (C)	0.7 / 0.015	8	1.8	0.080
Rel. 8 MU-MIMO 1 x 4 (A)	0.7 / 0.015	2	2.1	0.093
CoMP 2 x 4 (A)	0.7 / 0.015	1	2.5	0.15
MUMIMO 1 x 8 (E)	0.7 / 0.015	1	2.6	0.10

VoIP results (FDD)

- **LTE Rel. 8 fulfills ITU-R requirements for all the environments**

VoIP capacity for FDD

Antenna configuration	Environment	ITU-R requirement	Number of samples	Capacity [User/MHz/Cell]
Antenna configuration (A)	Indoor	50	3	140
	Urban Micro	40	3	80
	Urban Macro	40	3	68
	High Speed	30	3	91
Antenna configuration (C)	Indoor	50	3	131
	Urban Micro	40	3	75
	Urban Macro	40	3	69
	High Speed	30	3	94

Evaluated schemes

DL: Rel. 8 (4x2, 1x2)

UL: Rel. 8 (1x4)

VoIP results (TDD)

- **LTE Rel. 8 fulfills ITU-R requirements for all the environments**

VoIP capacity for TDD

Antenna configuration	Environment	ITU-R requirement	Number of samples	Capacity [User/MHz/Cell]
Antenna configuration (A)	Indoor	50	2	137
	Urban Micro	40	2	74
	Urban Macro	40	2	65
	High Speed	30	2	86
Antenna configuration (C)	Indoor	50	3	130
	Urban Micro	40	3	74
	Urban Macro	40	3	67
	High Speed	30	3	92

Evaluated schemes
DL: Rel. 8 (4x2 or 1x2)
UL: Rel. 8 (1x4)

Mobility results (FDD)

- **LTE Rel. 8 fulfills ITU-R requirements for all the environments**

Mobility traffic channel link data rates for FDD

LOS/NLOS	Environment	ITU-R requirement	Median SINR [dB]	Number of samples	FDD UL Spectrum efficiency [b/s/Hz]
Antenna configuration 1 x 4, NLOS	Indoor	1.0	13.89	7	2.56
	Urban Micro	0.75	4.54	7	1.21
	Urban Macro	0.55	4.30	7	1.08
	High Speed	0.25	5.42	7	1.22
Antenna configuration 1 x 4, LOS	Indoor	1.0	13.89	4	3.15
	Urban Micro	0.75	4.54	4	1.42
	Urban Macro	0.55	4.30	4	1.36
	High Speed	0.25	5.42	4	1.45

Evaluated schemes
Rel. 8 UL (1x4)

Mobility results (TDD)

- **LTE Rel. 8 fulfills ITU-R requirements for all the environments**

Mobility traffic channel link data rates for TDD

LOS/NLOS	Environment	ITU-R requirement	Median SINR [dB]	Number of samples	TDD UL Spectrum efficiency [b/s/Hz]
Antenna configuration 1 x 4, NLOS	Indoor	1.0	13.89	4	2.63
	Urban Micro	0.75	4.54	4	1.14
	Urban Macro	0.55	4.30	4	0.95
	High Speed	0.25	5.42	4	1.03
Antenna configuration 1 x 4, LOS	Indoor	1.0	13.89	2	3.11
	Urban Micro	0.75	4.54	2	1.48
	Urban Macro	0.55	4.30	2	1.36
	High Speed	0.25	5.42	2	1.38

Evaluated schemes
Rel. 8 UL (1x4)