LTE Radio Physical Layer

Sadayuki Abeta
NTT DOCOMO

Contents

- Introduction
- Downlink Aspects for LTE Release 8
- Uplink Aspects for LTE Release 8
- Enhancements for LTE-Advanced (Release 10 and beyond)

Physical Layer Specifications

- TS 36.201 E-UTRA Physical layer: General description .
- TS 36.211 E-UTRA Physical channels and modulation .
- TS 36.212 E-UTRA Multiplexing and channel coding .
- TS 36.213 E-UTRA Physical layer procedures .
- TS 36.214 E-UTRA Physical layer - Measurements
- The latest version of the specifications can be downloaded from:
  - http://www.3gpp.org/ftp/Specs/

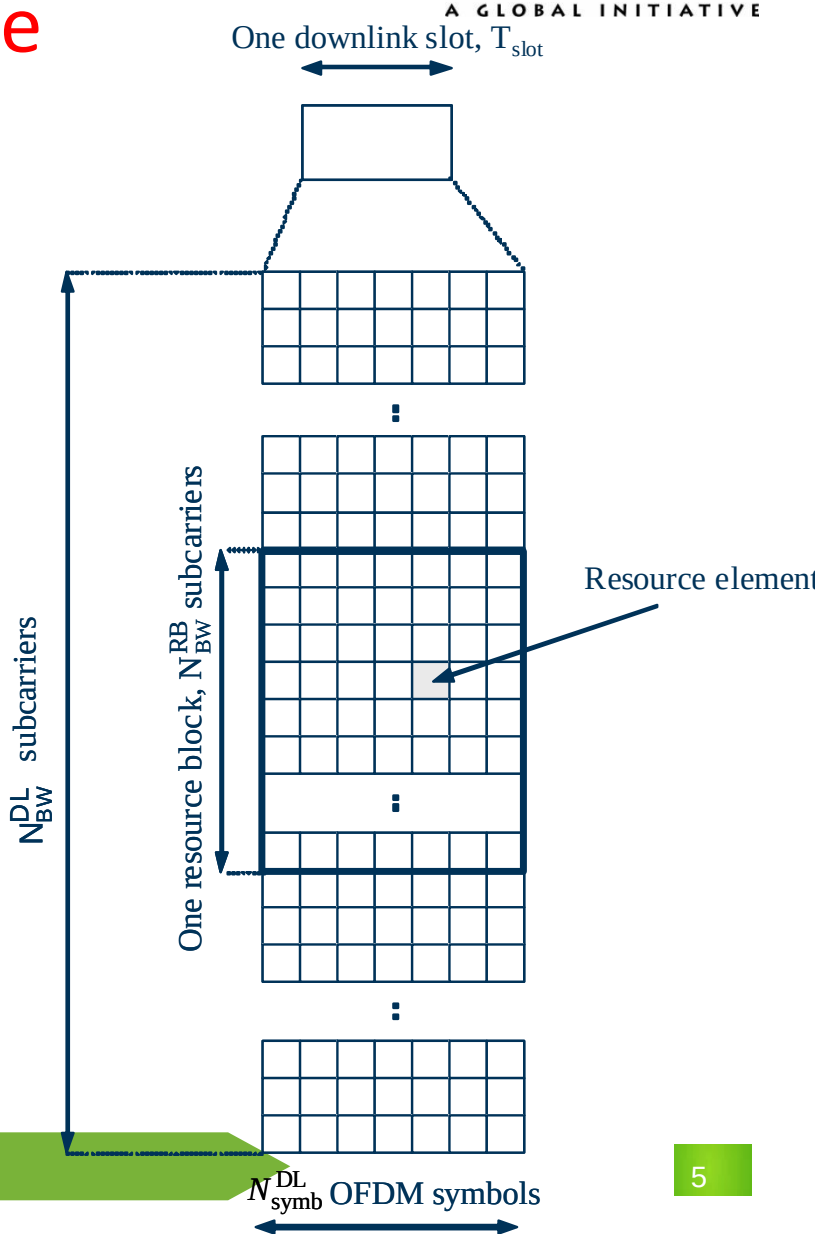
LTE Release 8 Major Parameters

A GLOBAL INITIATIVE

Access Scheme	**DL**	**OFDMA**
	UL	**SC-FDMA**
Bandwidth		**1.4, 3, 5, 10, 15, 20 MHz**
Minimum TTI		**1 ms**
Sub-carrier spacing		**15 kHz**
Cyclic prefix length	**Short**	**4.7 μs**
	Long	**16.7 μs**
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**

Transmission Resource structure

- Basic unit of resource is the Physical Resource Block (PRB)
- 12 sub-carriers x 0.5 ms
- Allocated in pairs (in time domain)
- 1 sub-carrier x 1 symbol = 1 resource element (RE)
- Spatial domain measured in "layers"

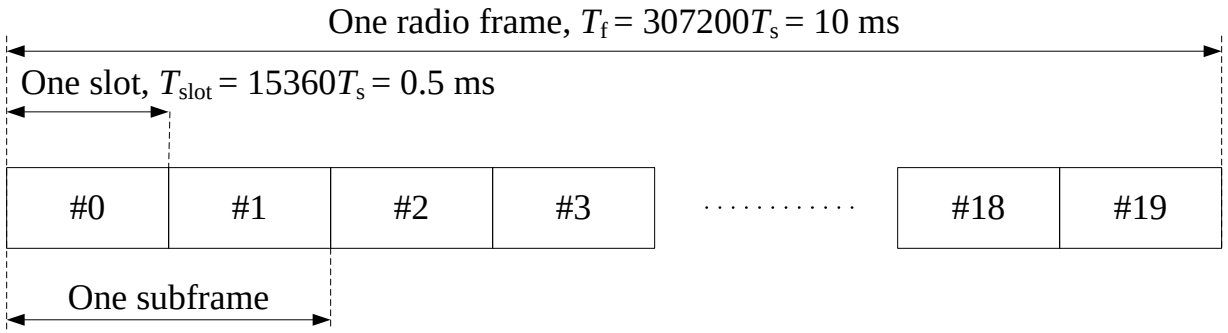


One radio interface for FDD and TDD

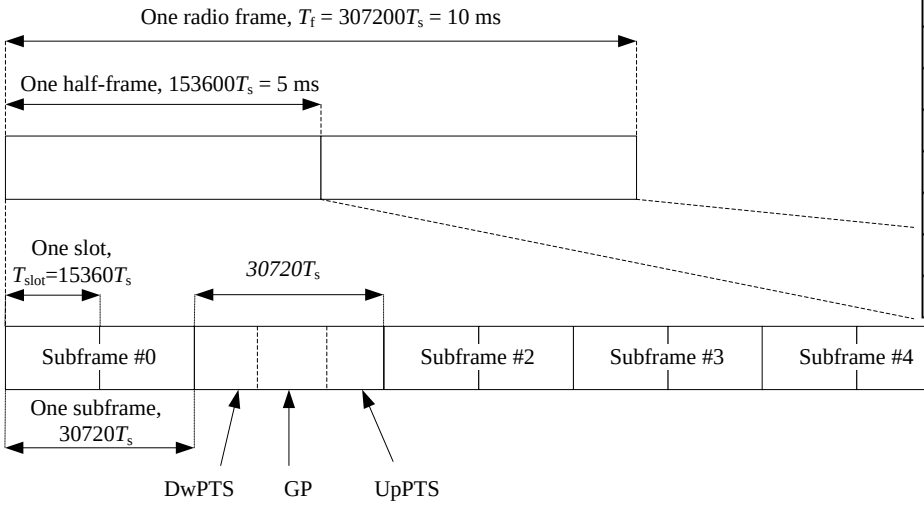
A GLOBAL INITIATIVE

Supports both FDD and TDD

- FDD



- TDD



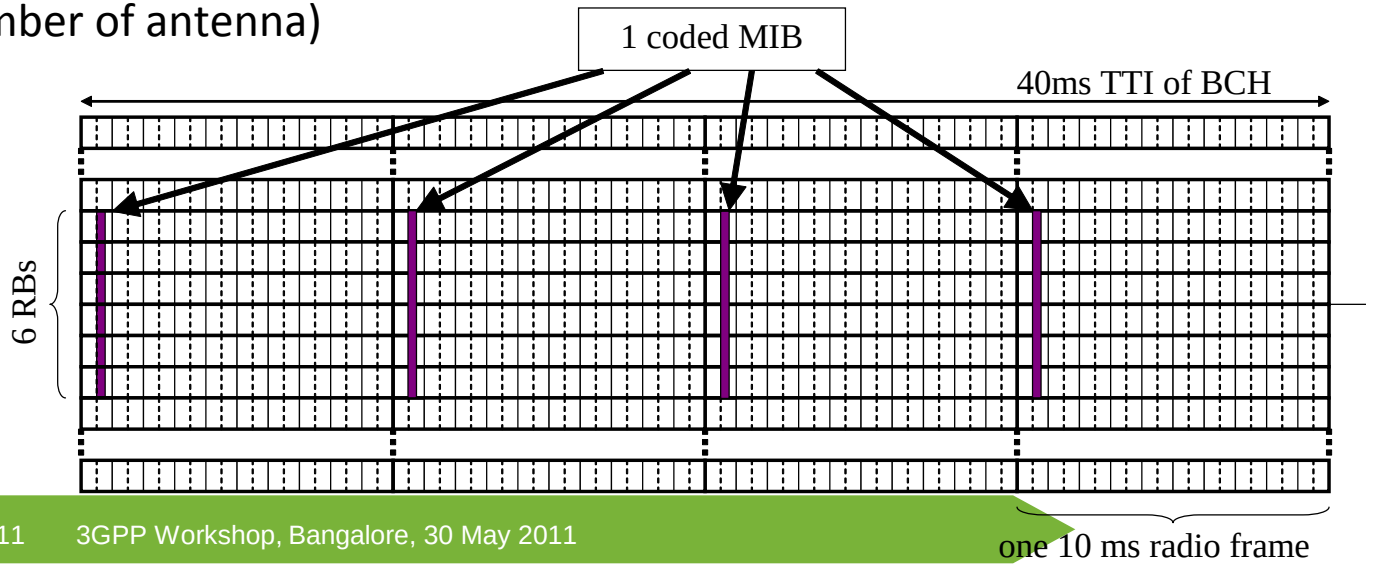
Uplink-downlink configuration	Subframe number									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

Contents

- Introduction
- Downlink Aspects for LTE Release 8
- Uplink Aspects for LTE Release 8
- Enhancements for LTE-Advanced (Release 10 and beyond)

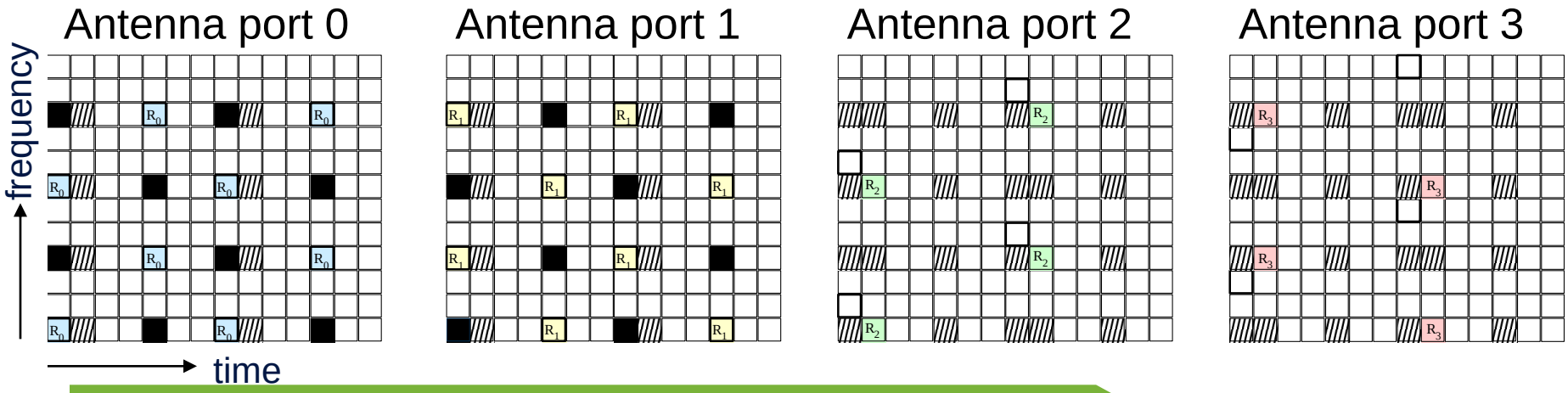
Cell acquisition signalling

- Synchronisation signals (SS) in subframes 0 and 5 of each 10 ms radio frame
  - Used in initial cell search
  - Common scheme irrespective to bandwidth simplify the procedure
- Physical broadcast channel (PBCH) in subframe 0 of each radio frame
  - Carries the Master Information Block (MIB)
    - Includes indication of system bandwidth
  - Robust design for cell-wide coverage:
    - Low rate, QPSK, robust channel coding (1/3-rate tail-biting convolutional code with repetition), 40 ms TTI
  - CRC indicates number of transmit antennas (SS and PBCH are transparent to number of antenna)



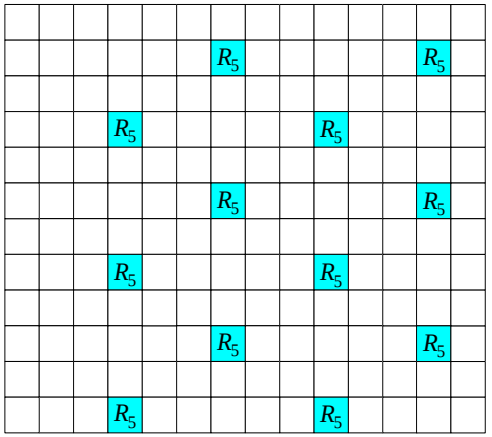
Reference Signals (RS)

- In Rel-8, cell-specific RS are provided for 1, 2 or 4 antenna ports
  - Pattern designed for effective channel estimation
    - Sparse diamond pattern supports frequency-selective channels and high-mobility with low overhead
  - Up to 6 cell-specific frequency shifts are configurable
  - Power-boosting can be applied on the REs used for RS
  - QPSK sequence with low PAPR



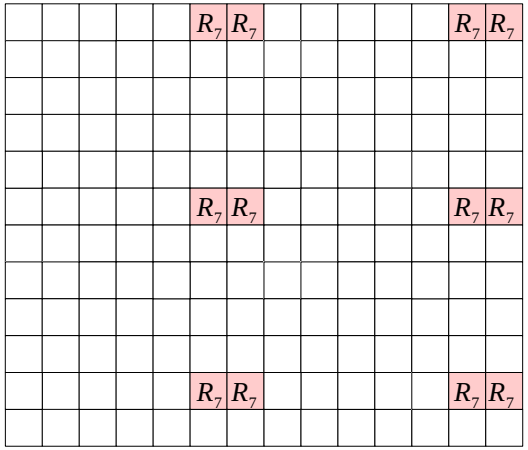
UE-specific Reference Signals

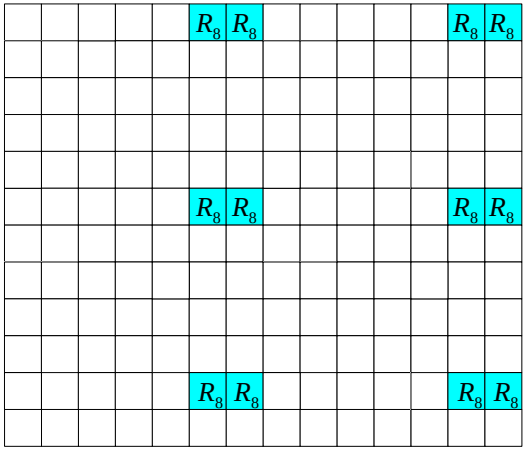
A GLOBAL INITIATIVE



- In Rel-8:
  - UE-specific (precoded) RS may be provided in data transmissions to specific UEs

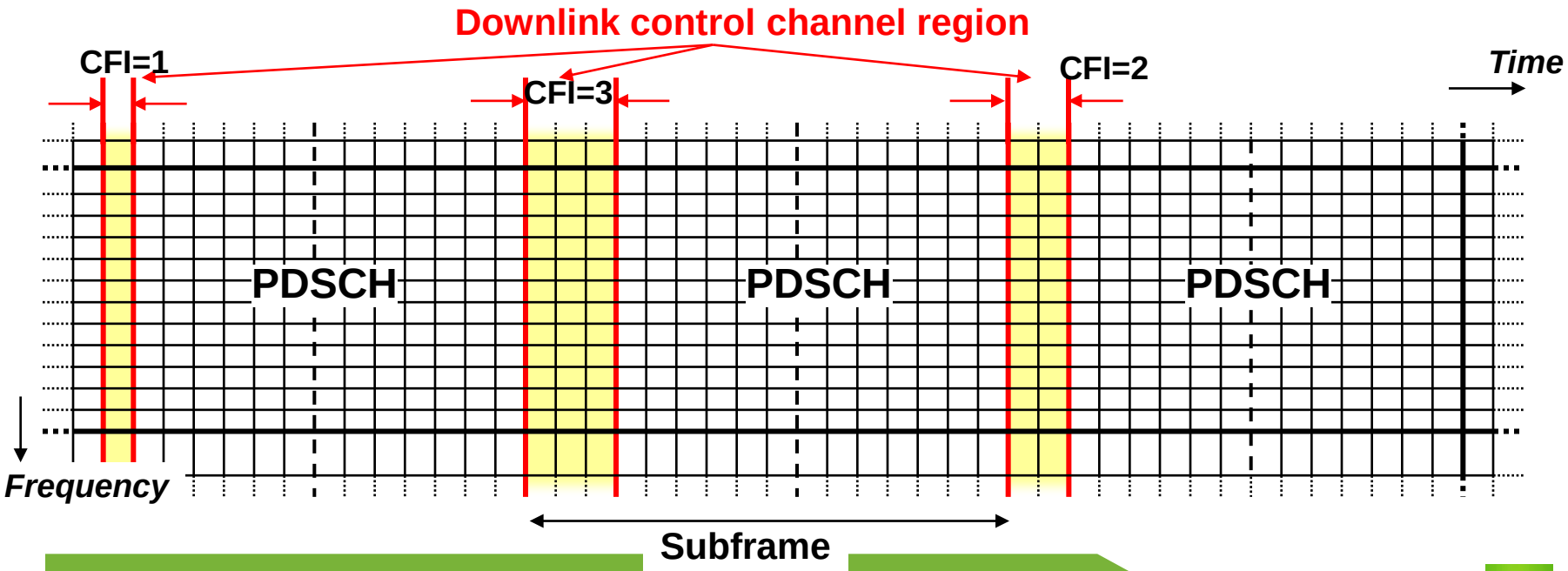
- In Rel-9:
  - UE-specific RS extended to dual-layer transmission
  - CDM between RS of the two layers



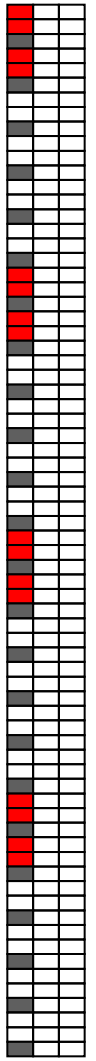


Downlink Channel Structure

- Flexible control design to avoid unnecessary overhead
  - Control region is first 1-3 OFDM symbols in each subframe (2-4 in narrow bandwidths)
  - Control region size (CFI: control channel format indicator) is dynamically variable
- Data transmission on Physical Downlink Shared Channel (PDSCH)



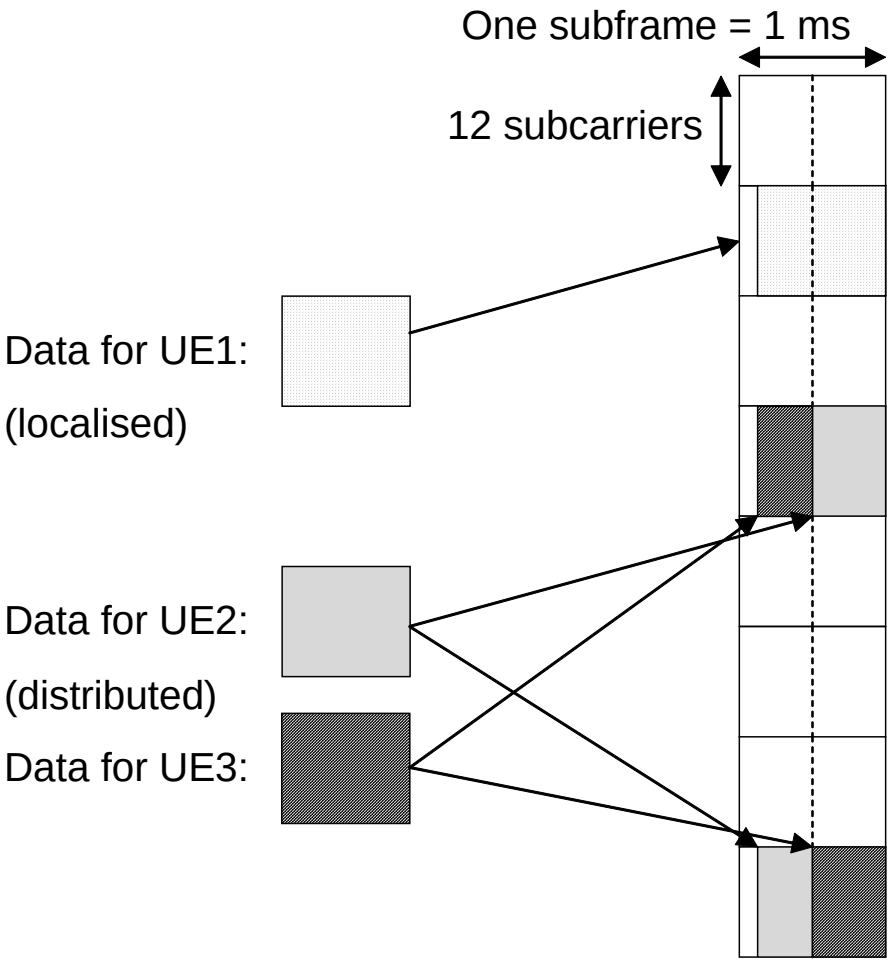
Downlink control signaling



- Physical Control Format Indicator Channel (PCFICH) indicates the control region size (CFI)
  - Located in first OFDM symbol of each subframe
  - PCFICH is designed to be robust
    - 16 QPSK symbols transmitted with full frequency diversity
- Physical Downlink Control Channel (PDCCH) carries Downlink Control Information (DCI) messages:
  - downlink resource assignments
  - uplink resource grants
  - uplink power control commands
- Physical Hybrid ARQ Indicator Channel (PHICH) carries ACK/NACK for UL data transmissions

Downlink data transmission

- PDSCH carries user data, broadcast system information, paging messages
- Transmission resources are assigned dynamically by PDCCH
  - Localised (suitable for frequency domain scheduling) or
  - distributed (suitable for maximising frequency diversity)



PDSCH transmission modes

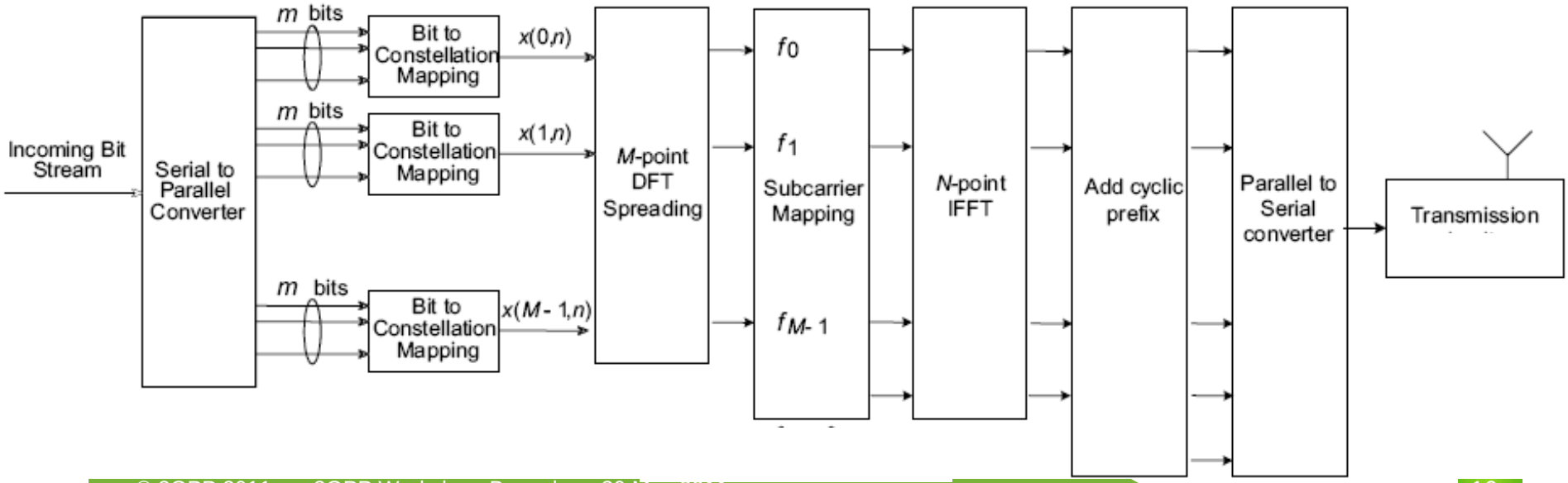
- In Rel-9, each UE is configured in one of 8 “transmission modes” for PDSCH reception:
  - Mode 1: Single antenna port, port 0
  - Mode 2: Transmit diversity
  - Mode 3: Open-loop spatial multiplexing
  - Mode 4: Closed-loop spatial multiplexing
  - Mode 5: MU-MIMO
  - Mode 6: Closed-loop spatial multiplexing, single layer
  - Mode 7: Single antenna port, UE-specific RS (port 5)
  - Mode 8 (new in Rel-9): Single or dual-layer transmission with UE-specific RS (ports 7 and/or 8)
- (in each case, transmit diversity is also available as a fallback)

Contents

- Introduction
- Downlink Aspects for LTE Release 8
- Uplink Aspects for LTE Release 8
- Enhancements for LTE-Advanced (Release 10 and beyond)

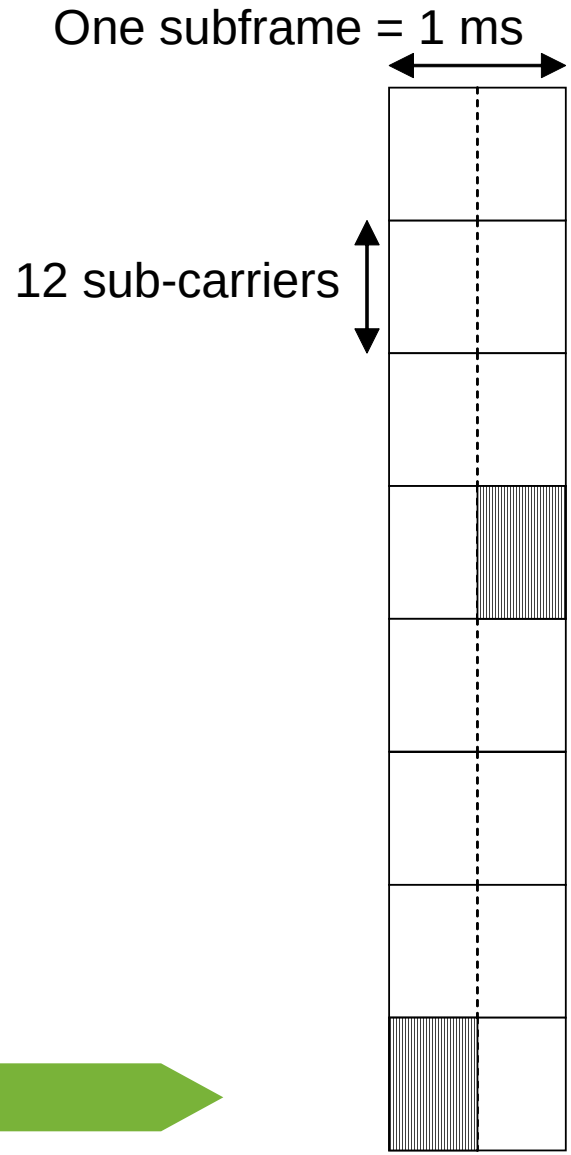
Uplink multiple access: SC-FDMA

- Same parameterisation as downlink
- DFT precoding to ensure low PAPR / cubic metric
- Cyclic prefix facilitates frequency-domain equalisation at eNodeB



UL transmission resource allocation

- Same structure of PRBs in frequency domain as downlink
- **Contiguous PRB allocation to keep single carrier property**
- Possibility to configure frequency hopping to increase frequency diversity
- Number of allocated PRBs for a given user in a given subframe is in multiples of 2, 3 and 5 for low-complexity DFT implementation

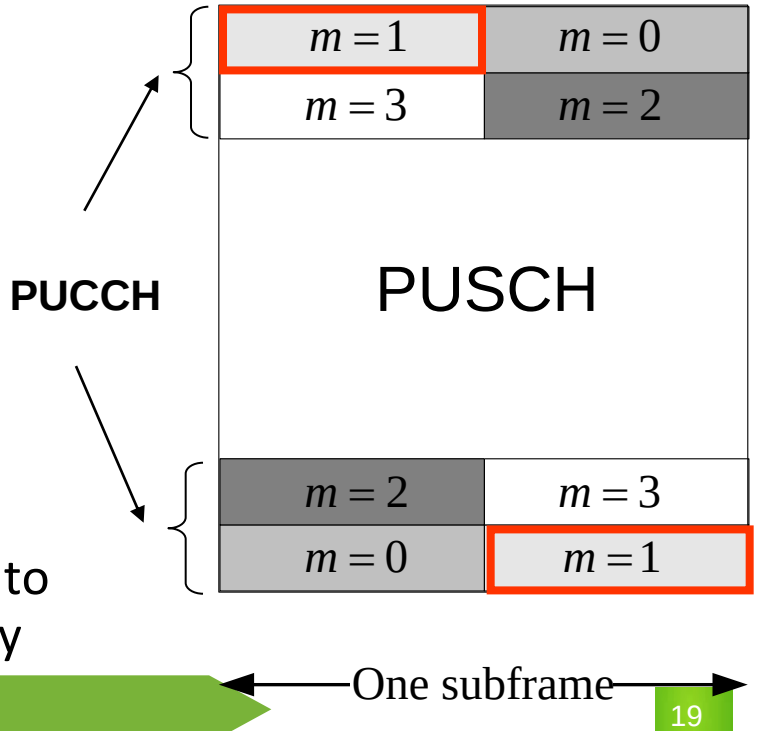


UL Reference Signals

- Zadoff Chu sequences
  - Excellent cross correlation property
- Demodulation RS (DM RS)
  - Same bandwidth as control / data transmission
- Sounding RS (SRS)
  - Supports:
    - UL frequency-domain scheduling
    - Channel sounding for downlink transmissions, especially for TDD
  - Located In last symbol of a subframe
  - Can be configured by network
  - Uses interleaving in frequency domain (alternate subcarriers) to provide additional support for multiple users transmitting SRS in the same bandwidth

Uplink channel structure

- Data transmissions on Physical Uplink Shared Channel (PUSCH)
  - In centre of uplink bandwidth
  - Minimises out-of-band emissions from wide-bandwidth data transmissions
  - 1 transport block per TTI
  - Same channel coding / rate matching as PDSCH
  - Modulation QPSK, 16QAM, 64QAM
- When PUSCH is transmitted, any control signalling is multiplexed with data to maintain single carrier structure
- When no PUSCH, control signalling is on Physical Uplink Control Channel (PUCCH)
  - Usually at edges of system bandwidth
  - PUCCH hops from one side of the carrier to the other to maximise frequency diversity



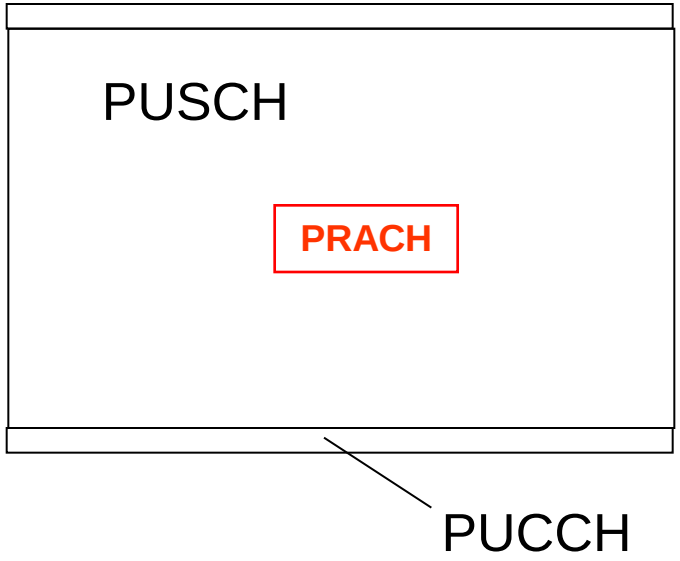
Uplink Control Signalling

- ACK/NACK for PDSCH transmissions
- Scheduling Request (SR)
- Channel Quality Information feedback can be periodic on PUCCH or aperiodic on PUSCH
  - CQI – indicates an index of a Modulation / Coding Scheme (MCS) that could be received on PDSCH with BLER ≤ 0.1
  - PMI – indicates preferred precoding matrix for PDSCH
  - RI – indicates number of useful transmission layers for PDSCH

Random Access Channel (RACH)

A GLOBAL INITIATIVE

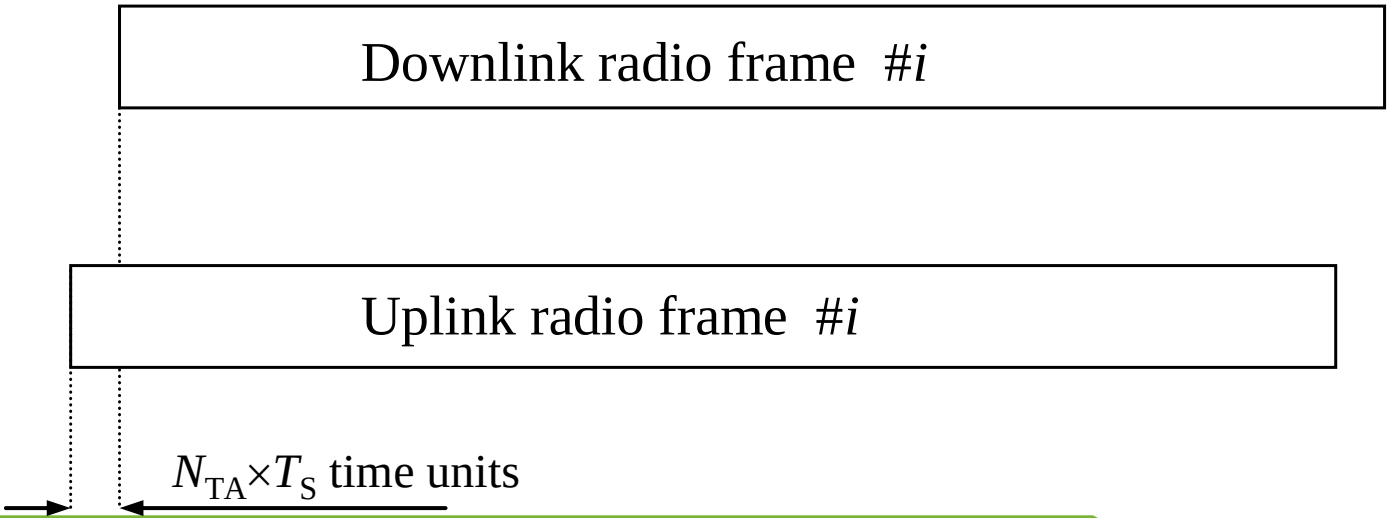
- RACH procedure begins with a preamble (PRACH)
- PRACH resources assigned by eNB within PUSCH region
- PRACH preamble fits into 6 PRBs
  - Sufficient for timing estimation
  - Invariant with bandwidth for low complexity
  - Zadoff Chu sequence
    - Excellent correlation properties
      - Zero correlation zone for different cyclic shifts
    - Flat frequency spectrum
    - Different sequences provided first by different cyclic shifts, then by different root sequences



- Multiple PRACH formats suitable for different cell sizes

Timing Advance

- Uplink transmission orthogonality between users is maintained by timing advance
- Set initially during Random Access Procedure
- Updated as necessary subsequently
- Supports at least 100 km cell range
  - Greater ranges are up to the implementation



Uplink Power Control

- Controls uplink power spectral density
  - Total uplink transmit power scales linearly with transmitted bandwidth
- Fractional power control can compensate for all or part of path loss
  - Allows trade-off between intra-cell fairness and inter-cell interference
- MCS-specific offsets may be applied
- Closed-loop power control commands can fine-tune the power setting
  - Carried on PDCCH
    - Individual commands in UL resource grants
    - Group commands for groups of UEs
- Separate power control for PUCCH and PUSCH

UL Multi-Antenna transmission

A GLOBAL INITIATIVE

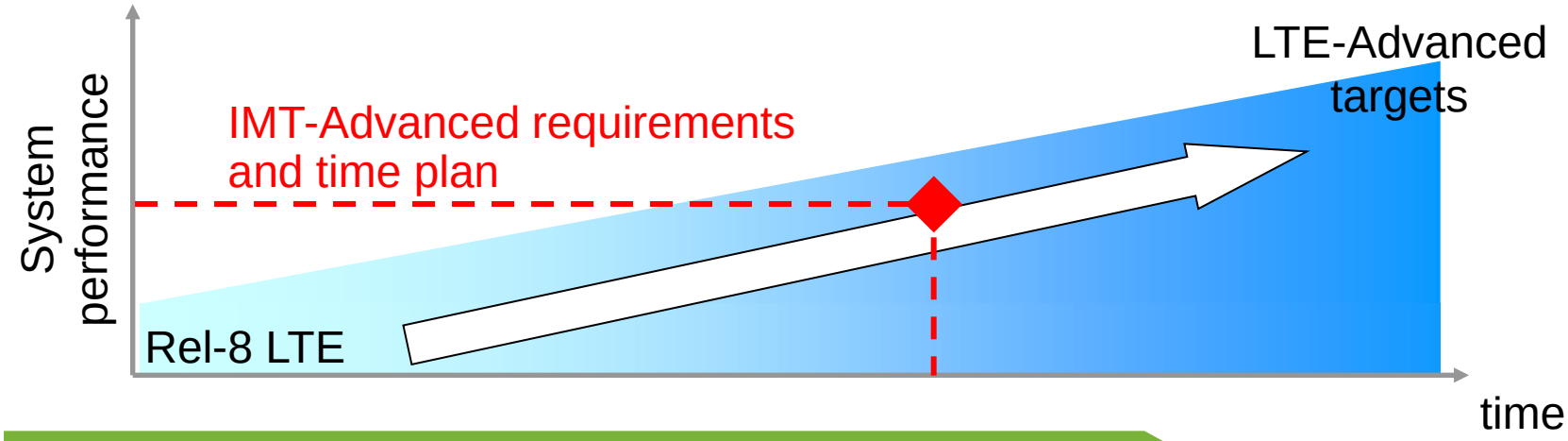
- Rel-8/9 supports:
  - Switched antenna diversity
    - Closed-loop antenna switching supported by CRC masking on PBCH
  - MU-MIMO
    - Different cyclic shifts of DM RS can be allocated to different UEs

Contents

- Introduction
- Downlink Aspects for LTE Release 8
- Uplink Aspects for LTE Release 8
- Enhancements for LTE-Advanced (Release 10 and beyond)

General Requirements

- LTE-Advanced is an evolution of LTE
- All relevant requirements of LTE are valid also for LTE-Advanced
- LTE-Advanced shall meet or exceed IMT-Advanced requirements within the ITU-R time plan
  - LTE-Advanced was approved as one of the IMT-Advanced RIT by ITU-R
- Targets of LTE-Advanced are adopted as long term targets



System Performance Requirements for LTE-Advanced

A GLOBAL INITIATIVE

- 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 for LTE-Advanced (cont'd)

A GLOBAL INITIATIVE

- 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

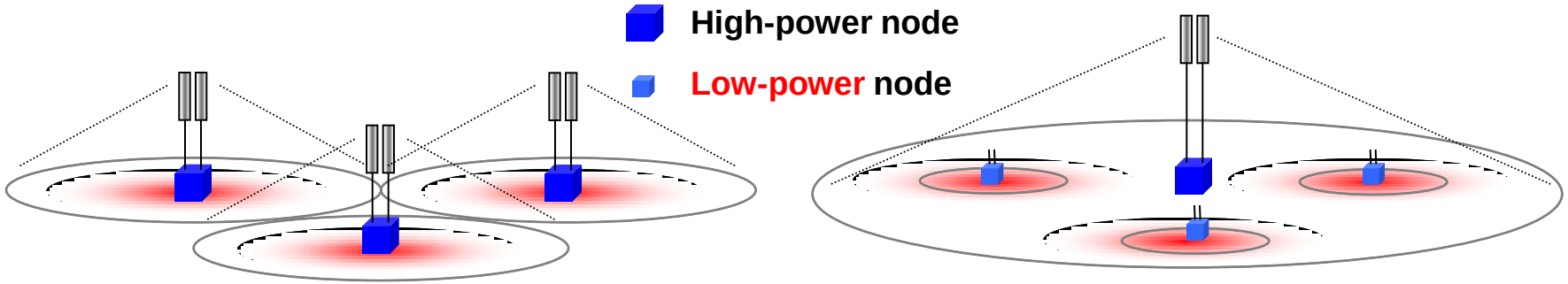
x1.4-1.6

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

Deployment scenarios for LTE-Advanced

A GLOBAL INITIATIVE

- Target deployment scenarios for LTE-Advanced cover both homogeneous and heterogeneous networks.



Homogeneous network deployment

Heterogeneous network network

- Evaluation models for each deployment scenario in 3GPP is shown in TR36.814 ver.9.0.0 (Annex therein)

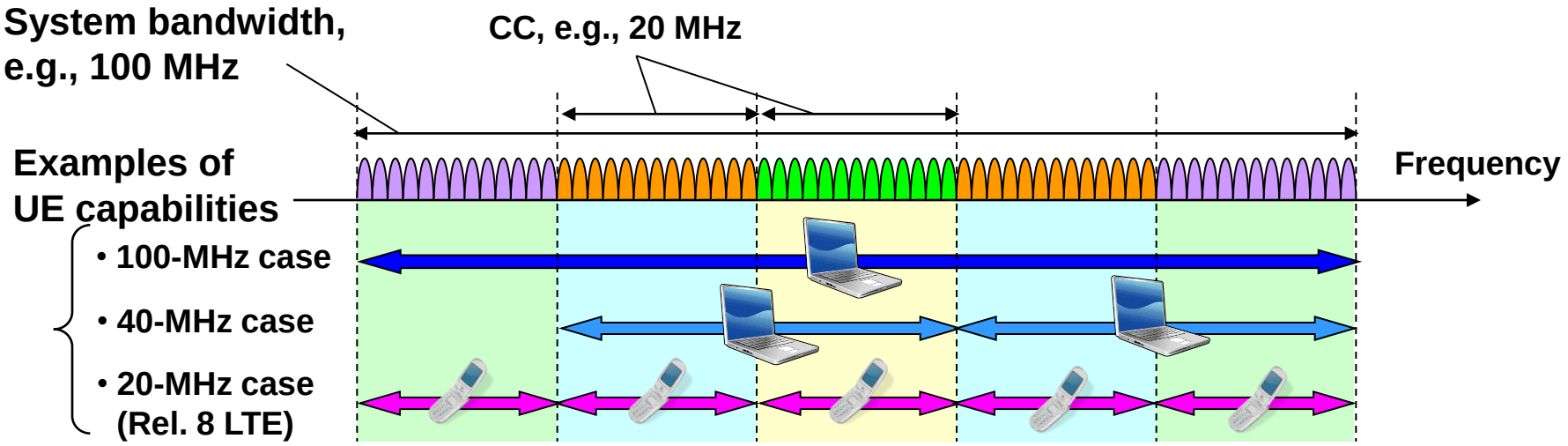
Major Work Items for Release 10 LTE in RAN1

A GLOBAL INITIATIVE

- Carrier aggregation for LTE
- Enhanced multi-antenna downlink transmission for LTE
- Uplink multiple antenna transmission for LTE
- Relays for LTE
- Enhanced ICIC for non-CA (carrier aggregation) based deployment of heterogeneous networks

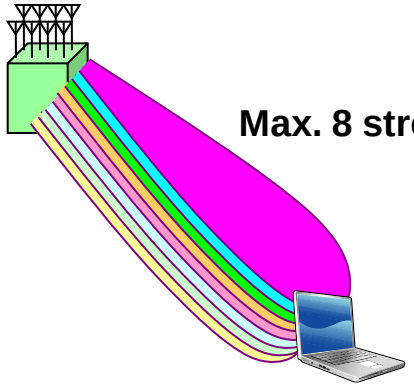
Carrier Aggregation (CA)

- Wider bandwidth transmission using carrier aggregation for both DL and UL
- 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 can be configured in a backward compatible way with Rel-8 LTE
  - ➔ Maintain backward compatibility with Rel-8 LTE
- Carrier aggregation supports both contiguous and non-contiguous spectrum, and asymmetric bandwidth for FDD
  - ➔ Achieve flexible spectrum usage

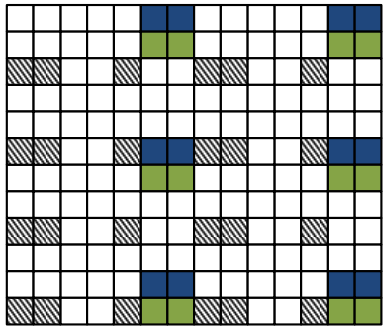


Enhanced Downlink Multi-antenna Transmission

- Extension up to 8-layer transmission
  - Increased from 4 layers in Rel-8/9
    - ➔ Satisfy the requirement for peak spectrum efficiency, i.e., 30 bps/Hz



- Additional reference signals (RS) specified:
  - Channel state information RS (CSI-RS)
    - For downlink channel sounding
    - Sparse, low overhead (configurable)
      - ✓ Density: 1 resource element (RE) per antenna port per PRB
  - UE-specific demodulation RS (DM-RS)
    - UE-specific DM-RS can be precoded, supporting non-codebook-based precoding,
      - → applied 1-8-layer transmission, and enhanced multi-user beamforming, such as zero forcing (ZF)
    - DM RS pattern for higher numbers of layers is extended from 2-layer format for transmission mode 8 in Rel-9

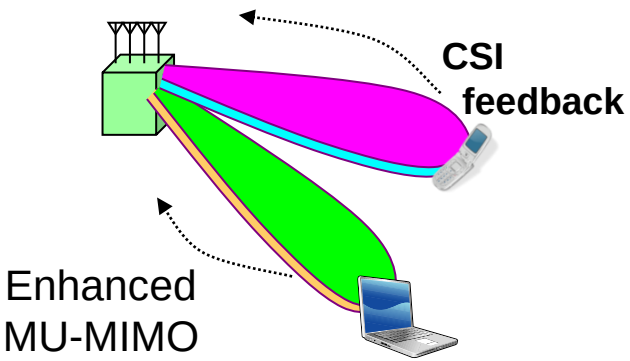


DMRS pattern

Enhanced Downlink Multi-antenna Transmission (Cont'd)

A GLOBAL INITIATIVE

Enhanced Multi-user (MU) MIMO



- MU-MIMO dimensionality
  - Maximum spatial 4 layers
  - Maximum 2 layers per user

- CSI feedback enhancement using two matrix (W1, W2) feedback frame work is now being studied
  - W1 targets wideband/long-term channel properties
  - W2 targets frequency-selective/short-term time channel properties
  - Matrix multiplication is used.

Enhanced Uplink Multi-antenna Transmission

A GLOBAL INITIATIVE

- UL transmit diversity for PUCCH to improve robustness in cell-edge
  - Orthogonal resource transmit diversity is supported for PUCCH format 1 (Scheduling request) 1a/1b (HARQ-Ack) when UE has two Tx antennas
    - ✓ the same modulation symbol from the uplink channel is transmitted from two antenna ports, on two separate orthogonal resources.

- SU-MIMO up to 4-stream transmission to satisfy the requirement for peak spectrum efficiency, i.e., 15 bps/Hz
  - Closed-loop codebook based precoding supported

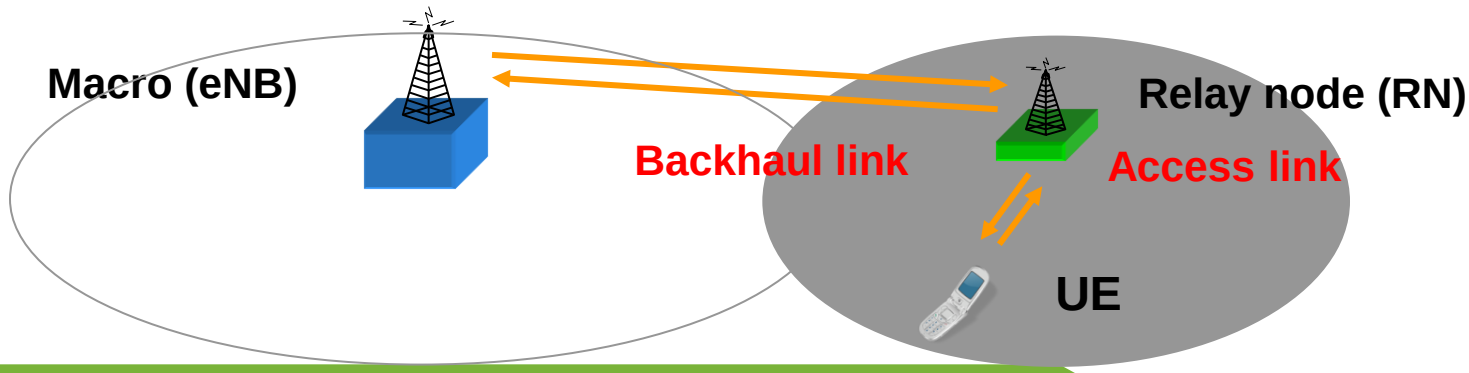
SU-MIMO up to 4 streams

Relaying for LTE

Relay design target for Rel-10 is coverage extension

➔ Supports cell deployments in areas where wired backhaul is not available or very expensive

- "Type 1" relay
  - Inband relaying: same carrier frequency for backhaul and access links
  - Time division multiplexing of backaul and access links
  - 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
- "Type 1a" relay
  - Outband relaying: different carrier frequency for backhaul from access link



Conclusions

- LTE Rel.8 is now in commercial service phase.
  - 20 commercial LTE NW launched
  - 208 operators in 80 countries investing in LTE
- LTE-Advanced is a very flexible and advanced system
  - Built on the established capabilities of the LTE Rel-8 and Rel-9 physical layer
  - Further enhancements to exploit spectrum availability and advanced multi-antenna techniques

Thank You

Sadayuki Abeta
NTT DOCOMO

More Information about 3GPP:

www.3gpp.org

contact@3gpp.org