LTE Radio Physical Layer

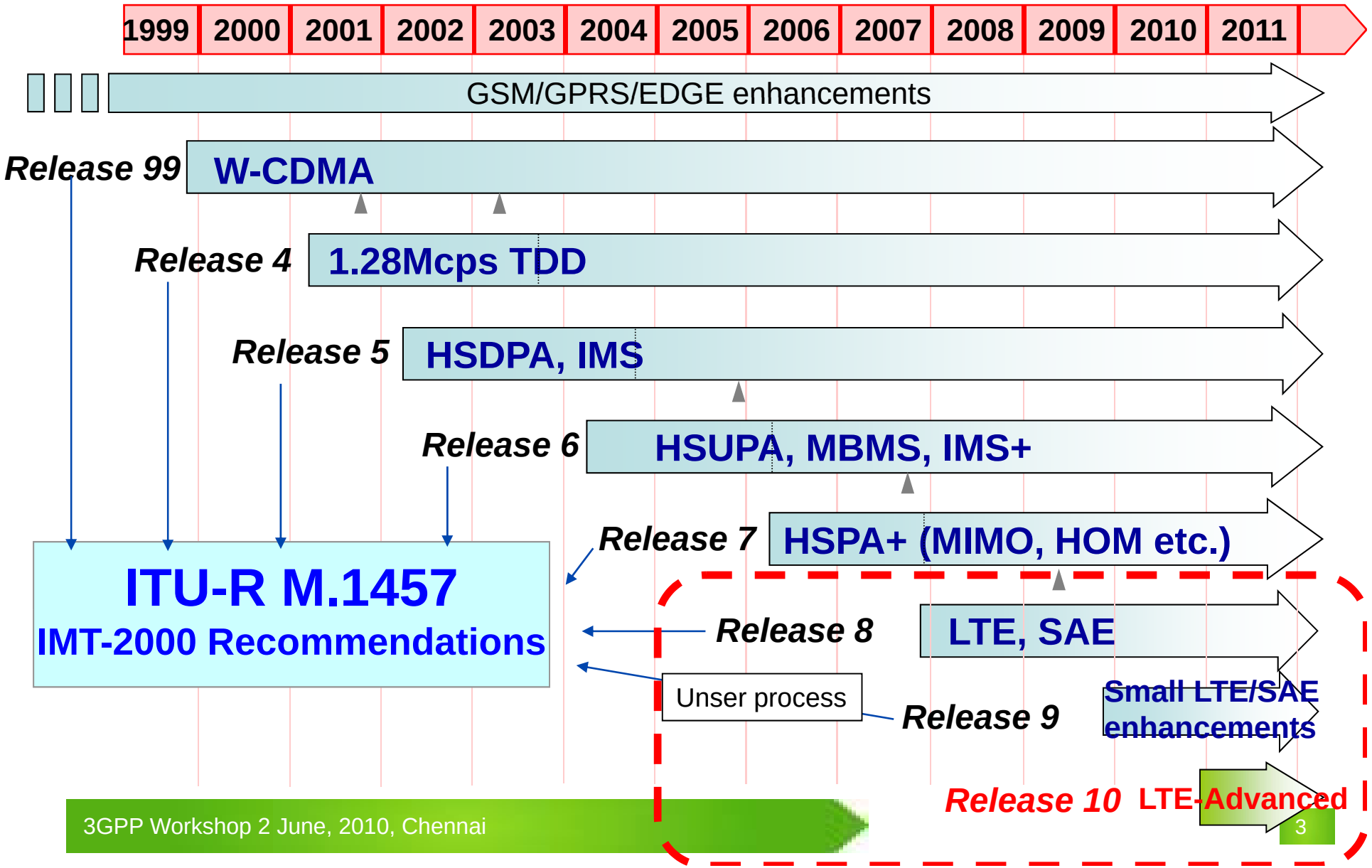
Tetsushi Abe, NTT DOCOMO

Vice-Chairman 3GPP TSG RAN WG1

Contents

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

Releases of 3GPP specifications



Physical Layer Specifications

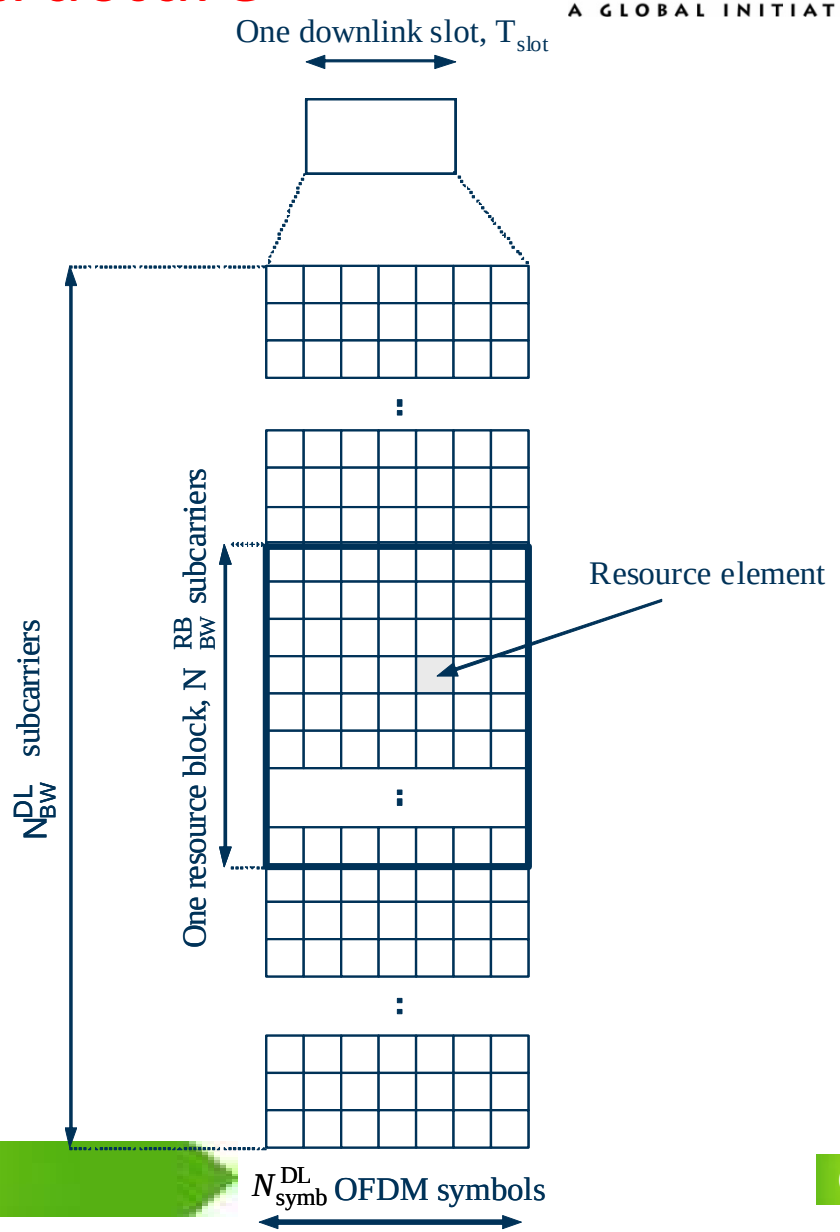
- TS 36.201 E-UTRA Physical layer: General description .
- TS 36.211 E-UTRA Physical channels and modulation .
- TS 36.212 E-UTRA Multiplexing and channel coding .
- TS 36.213 E-UTRA Physical layer procedures .
- TS 36.214 E-UTRA Physical layer - Measurements
- The latest version of the specifications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

LTE Release 8 Major Parameters

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**

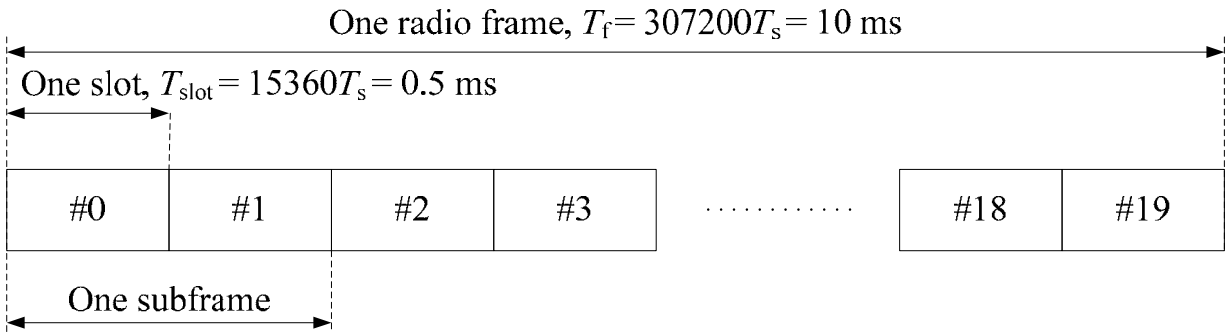
Transmission Resource structure

- 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"

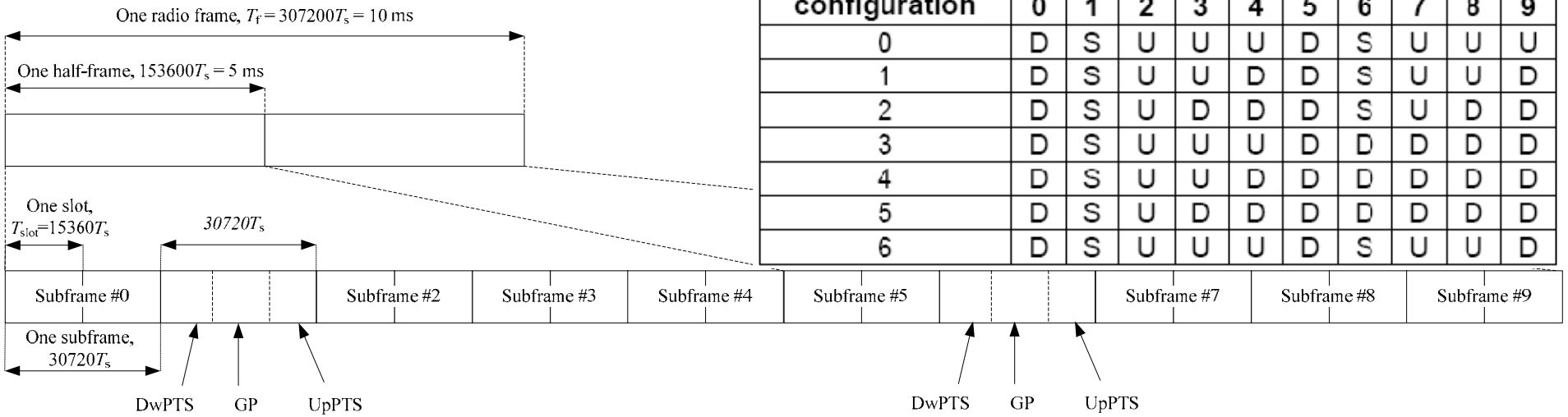


One radio interface, 2 frame structures

- Supports both FDD and TDD (two RITs within one SRIT)
  - FDD



  - TDD



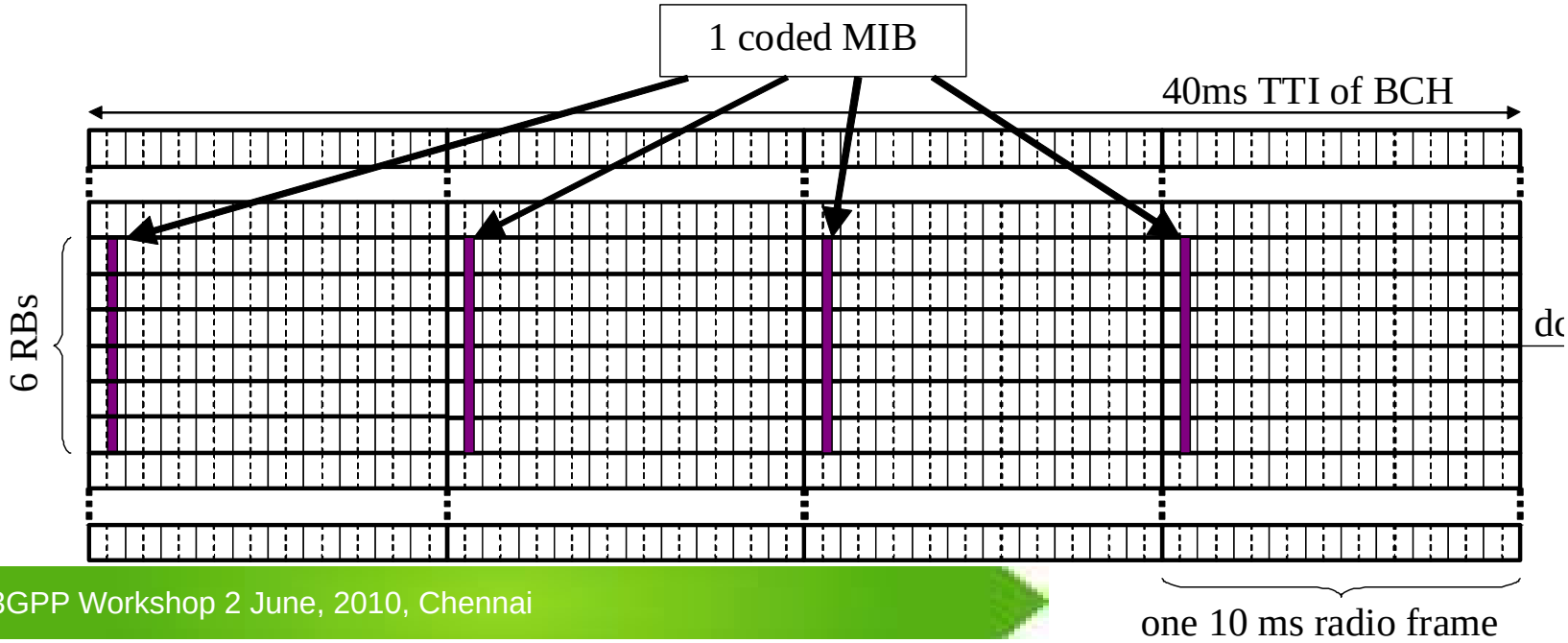
Uplink-downlink configuration	Subframe number									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

Contents

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

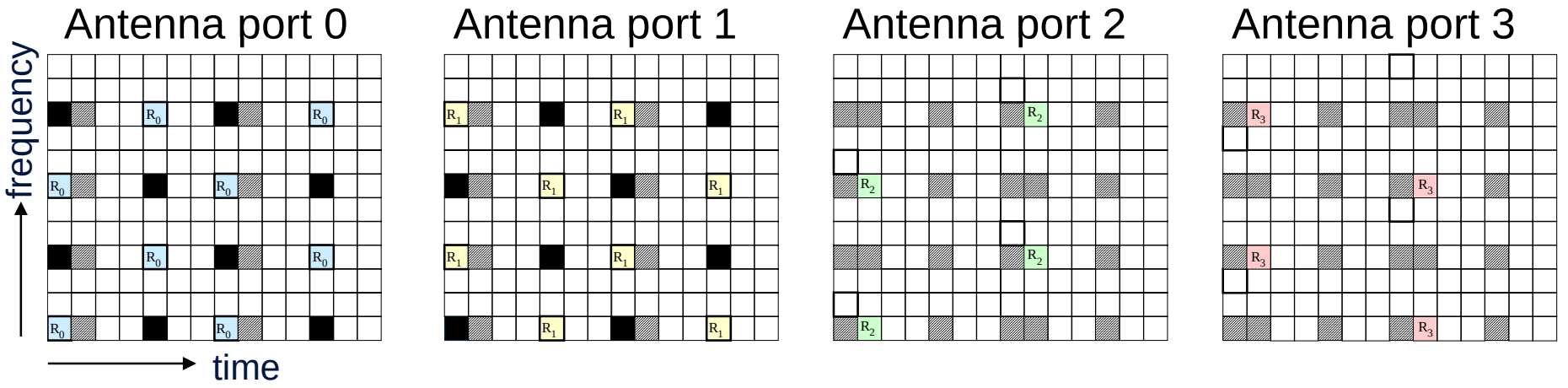
Cell acquisition signalling

- Synchronisation signals in subframes 0 and 5 of each 10 ms radio frame
  - Used in initial cell search
- 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



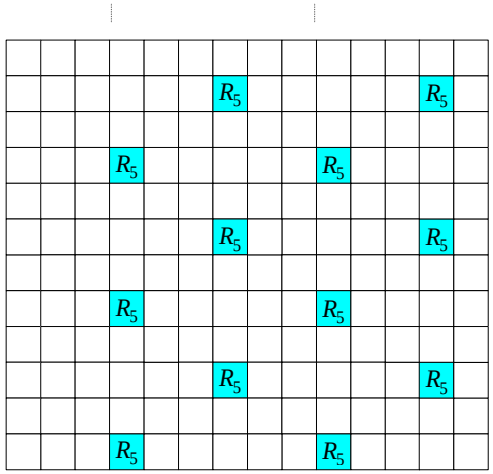
Reference Signals (RS)

- 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 may be applied on the REs used for RS
  - QPSK sequence with low PAPR

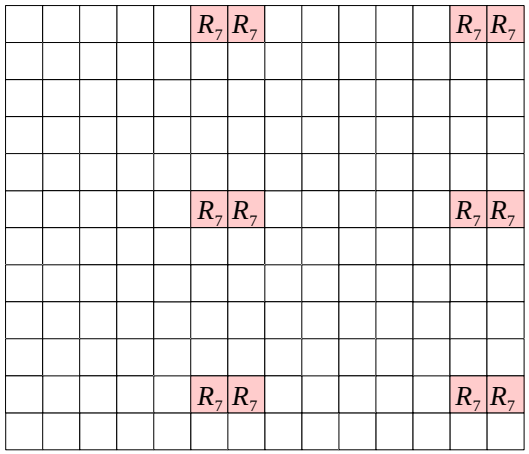


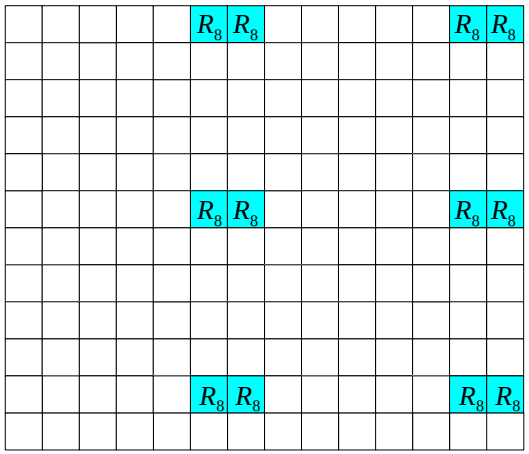
UE-specific Reference Signals

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



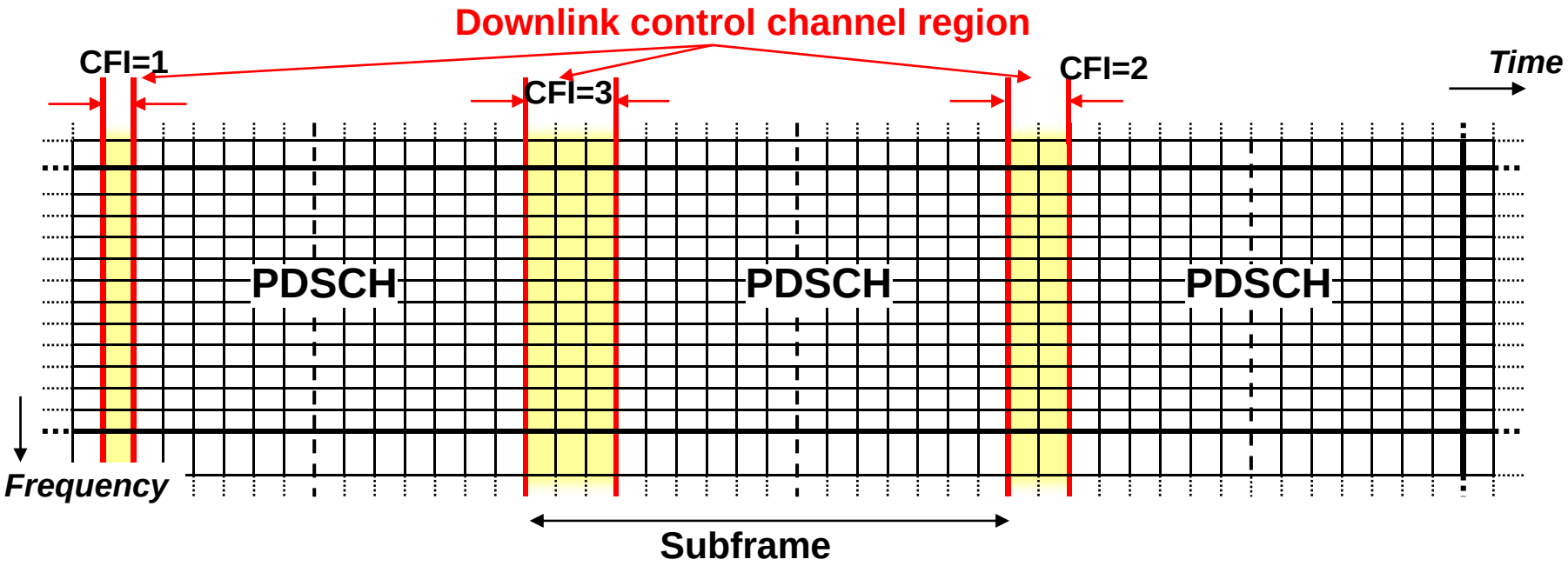
- In Rel-9:
  - UE-specific RS extended to dual-layer transmission
  - CDM between RS of the two layers





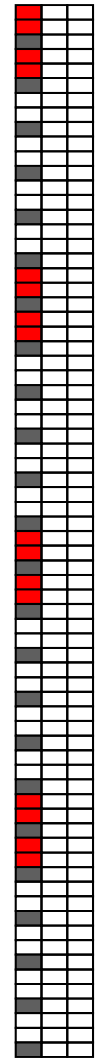
Downlink Channel Structure

- 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)



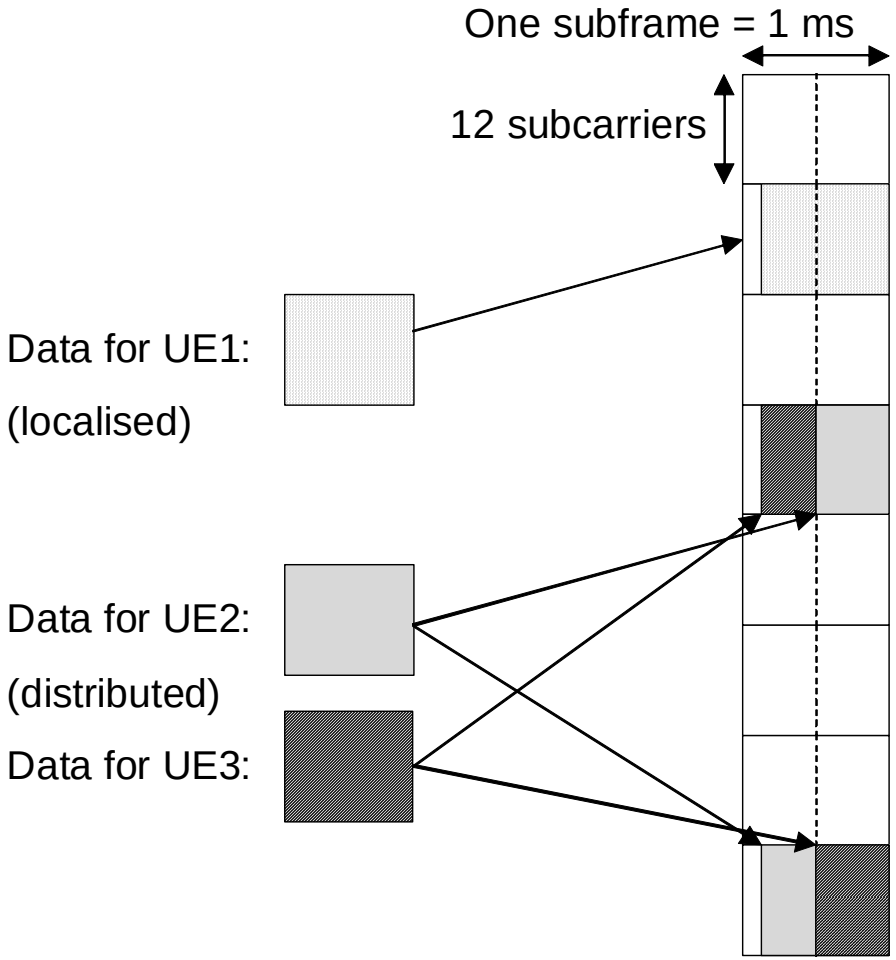
Downlink control signaling

- 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

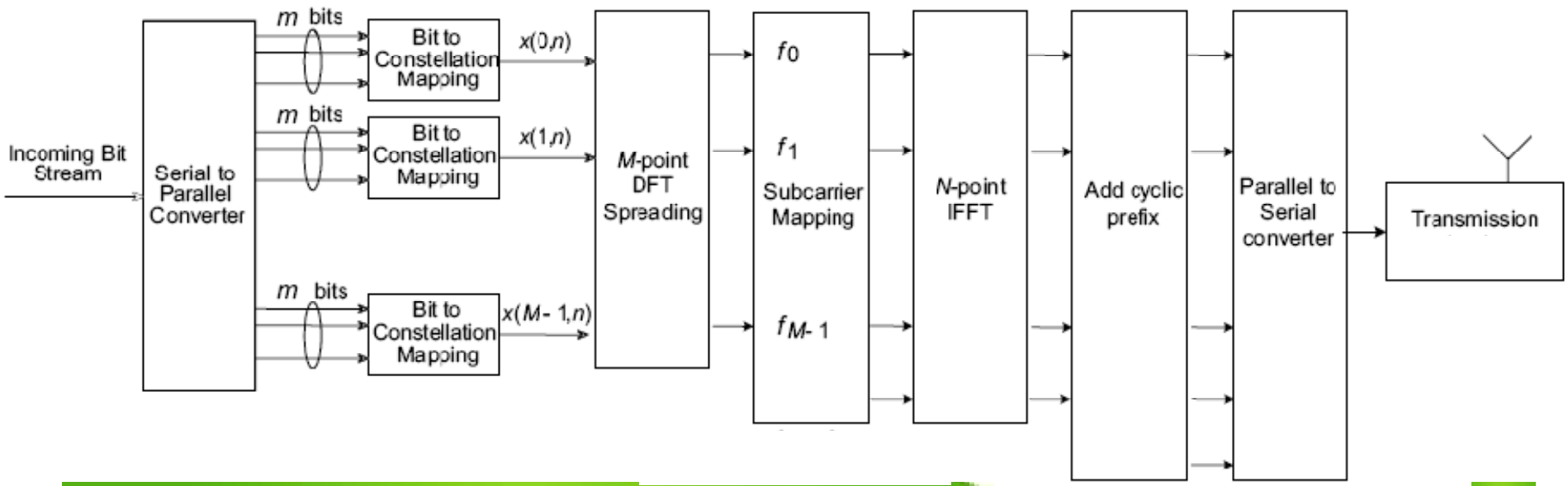
- In Rel-9, each UE is configured in one of 8 “transmission modes” for PDSCH reception:
  - Mode 1: Single antenna port, port 0
  - Mode 2: Transmit diversity
  - Mode 3: Large-delay CDD
  - Mode 4: Closed-loop spatial multiplexing
  - Mode 5: MU-MIMO
  - Mode 6: Closed-loop spatial multiplexing, single 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)

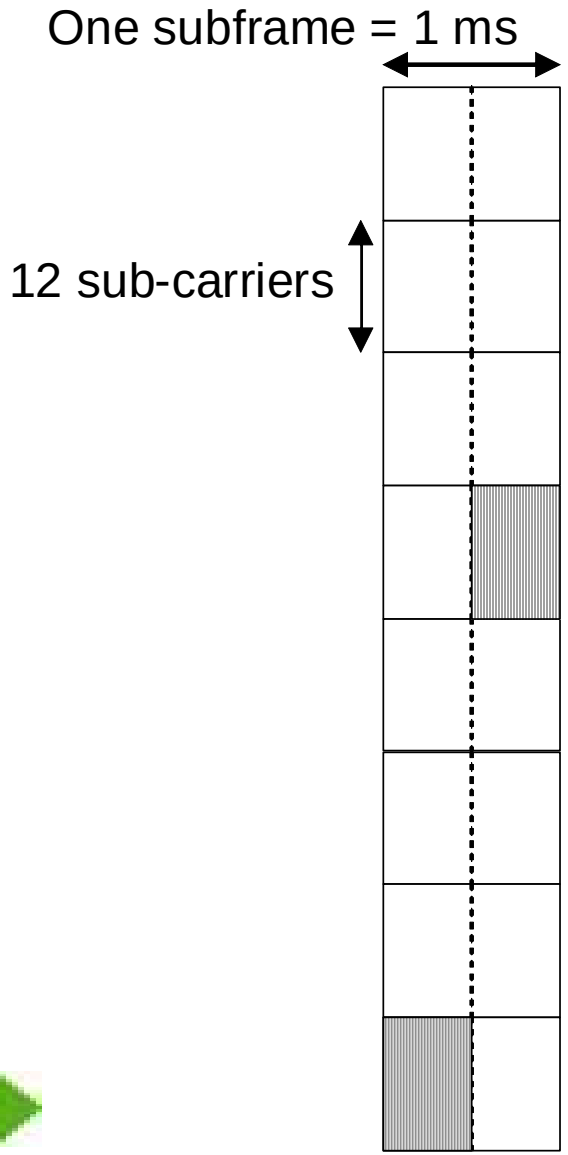
Uplink multiple access: SC-FDMA

- 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

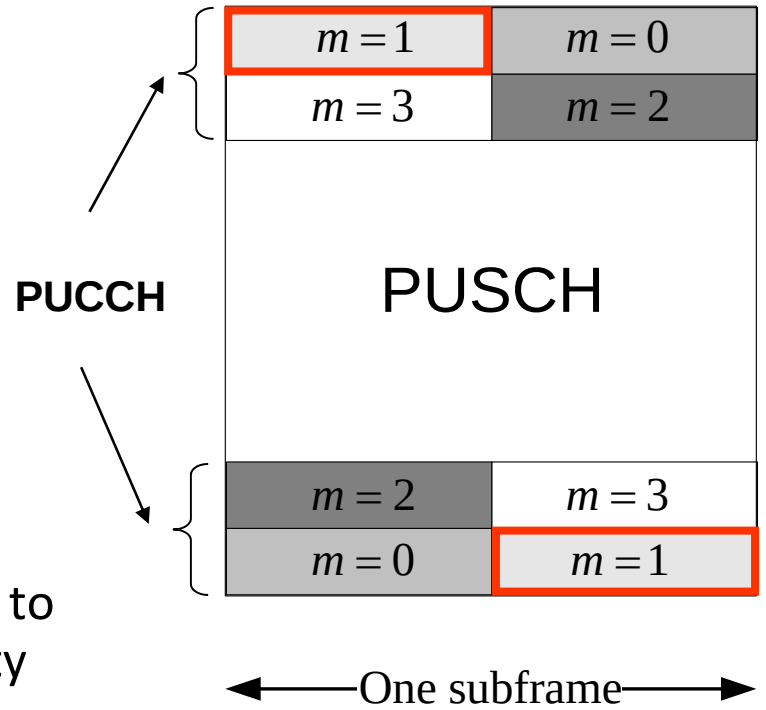


UL Reference Signals

- Zadoff Chu sequences
- 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

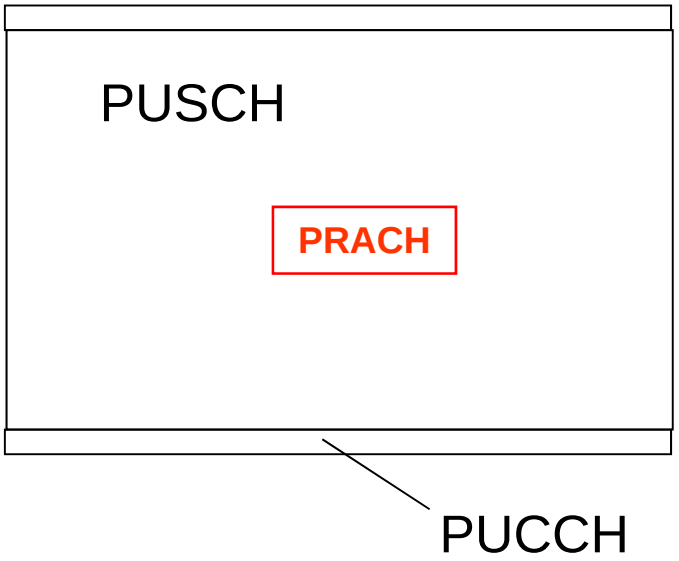


Uplink Control Signalling

- 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)

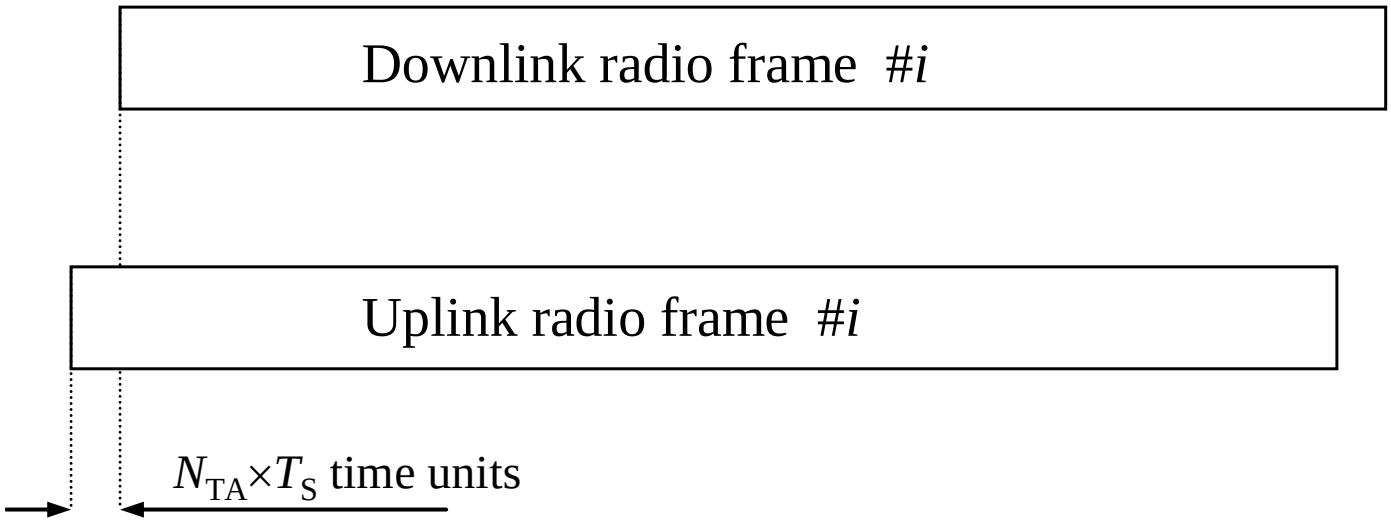
- RACH procedure begins with a preamble (PRACH)
- PRACH resources assigned by eNB within PUSCH region
- PRACH preamble fits into 6 PRBs
  - Sufficient for timing estimation
  - Invariant with bandwidth for low complexity
  - Zadoff Chu sequence
    - Excellent correlation properties
      - Zero correlation 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

- 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)

Note that discussion on Rel-10 features described in the following slides are still on going at 3GPP and the specifications are not yet finalized.

System Performance Requirements for LTE-Advanced

- 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)

- 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

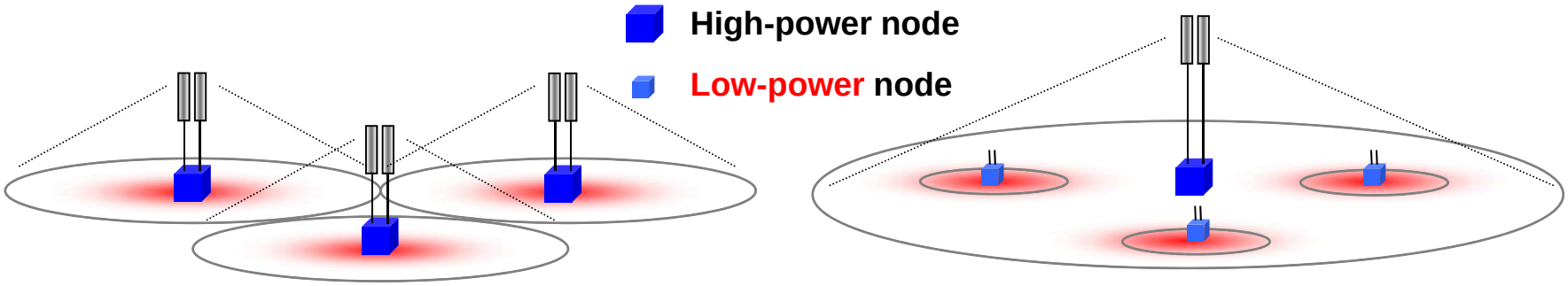
		Ant. Config.	Rel. 8 LTE*1	LTE-Advanced*2	IMT-Advanced*3
Capacity [bps/Hz/cell]	DL	2-by-2	1.69	2.4	–
		4-by-2	1.87	2.6	2.2
		4-by-4	2.67	3.7	–
	UL	1-by-2	0.74	1.2	–
		2-by-4	–	2.0	1.4
Cell-edge user throughput [bps/Hz/cell/user]	DL	2-by-2	0.05	0.07	–
		4-by-2	0.06	0.09	0.06
		4-by-4	0.08	0.12	–
	UL	1-by-2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

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



Homogeneous network deployment

Heterogeneous network network

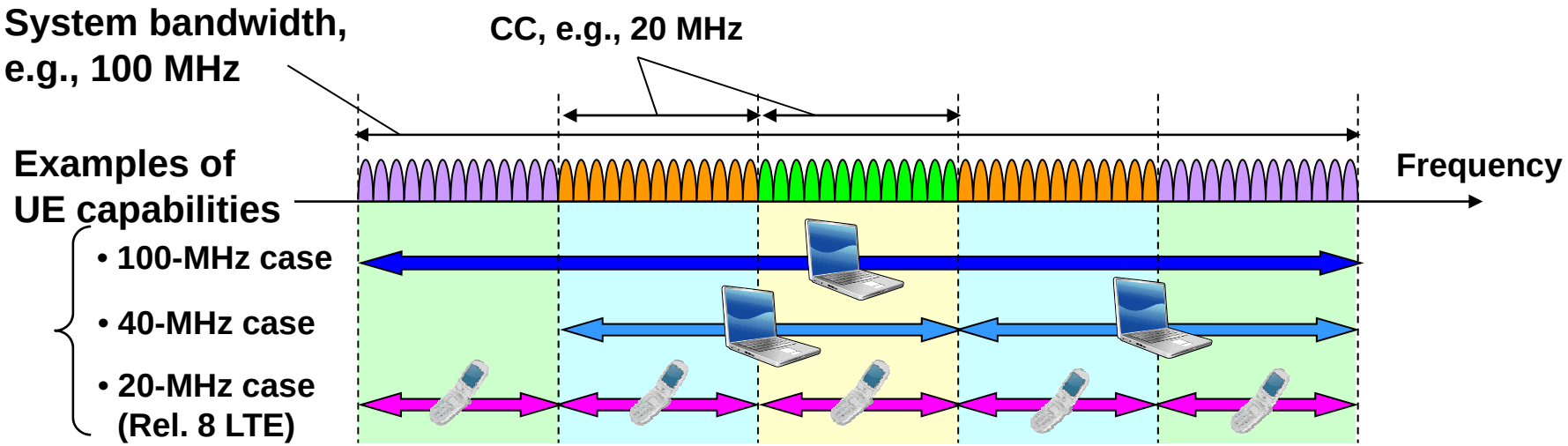
- Evaluation models for each deployment scenario in 3GPP is shown in TR36.814 ver.9.0.0 (Annex therein)

Work Items for Release 10 LTE

- 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
- Network positioning support for LTE

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



Downlink Multiple Access Scheme

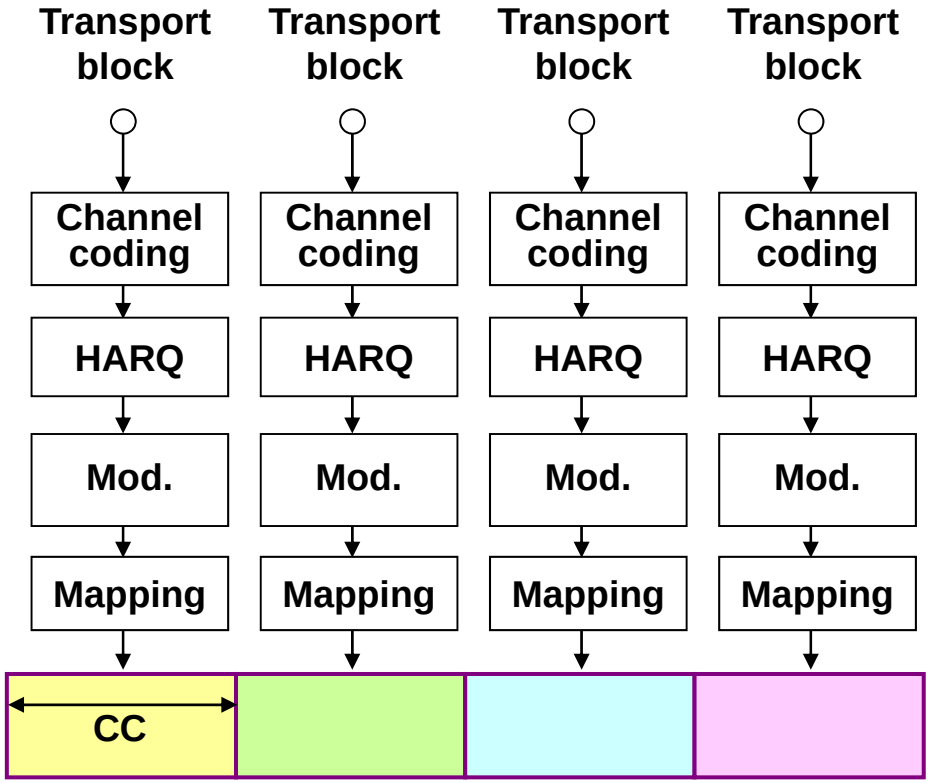
Downlink: OFDMA with component carrier (CC) based structure

➔ Priority given to reusing Rel. 8 specification for low-cost and fast development

- One transport block is mapped within one CC
- Parallel-type transmission over multiple CCs

- Good affinity to Rel. 8 LTE specifications
- Cross-carrier scheduling is possible

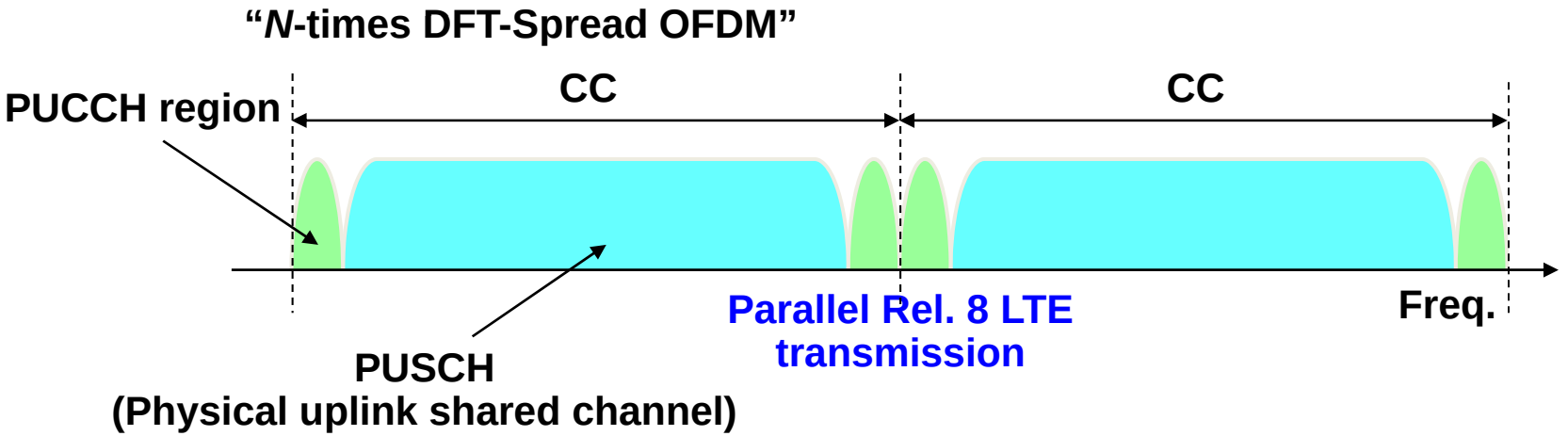
  → PDCCH in one CC can schedule PDSCH in another CC



Uplink Multiple Access Scheme

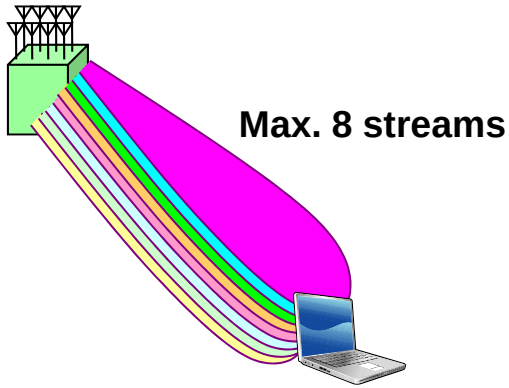
Uplink: *N*-times DFT-Spread OFDM

- 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
- Will also support non-contiguous resource allocation
  - Enhanced flexibility and efficiency of resource allocation
- Simultaneous PUCCH and PUSCH transmission will be supported.
- Independent power control will be provided per CC

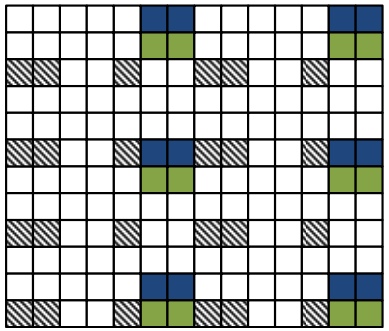


Enhanced Downlink Multi-antenna Transmission

- 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



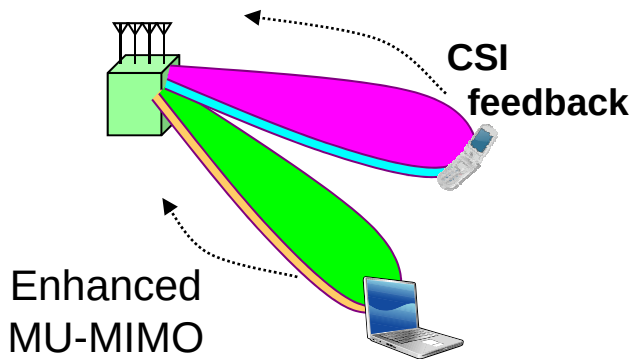
- Additional reference signals (RS) specified:
  - Channel state information RS (CSI-RS)
    - For downlink channel sounding
    - Sparse, low overhead (configurable)
      - ✓ Density: 1 resource element (RE) per antenna port per PRB
  - UE-specific demodulation RS (DM-RS)
    - UE-specific DM-RS can 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)

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

- 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

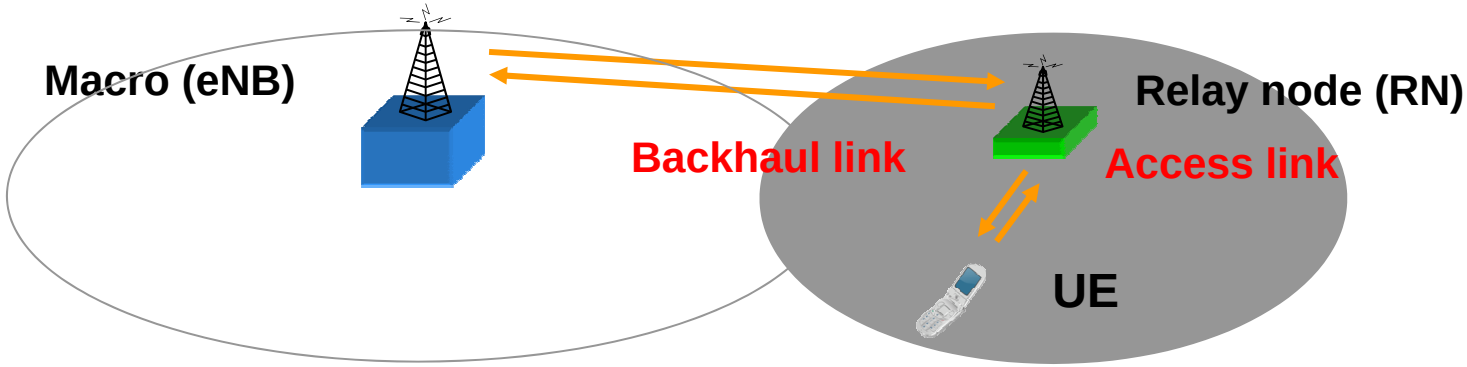
SU-MIMO up to 4 streams

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-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

Backup slides

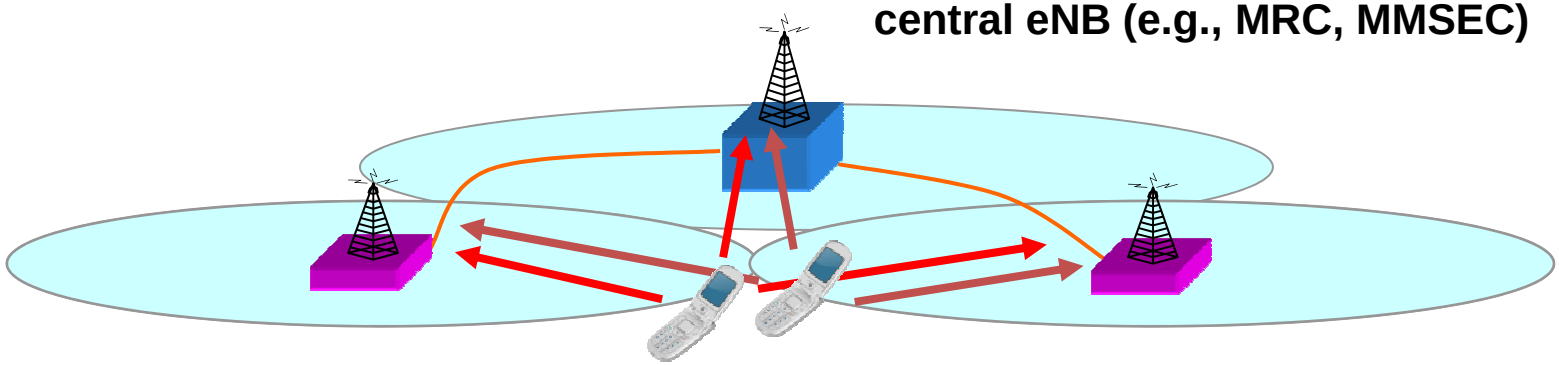
CoMP Reception in Uplink

- 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 an implementation matter and does not require any change to radio interface

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



Multipoint reception

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

Details of PDSCH transmission modes (1)

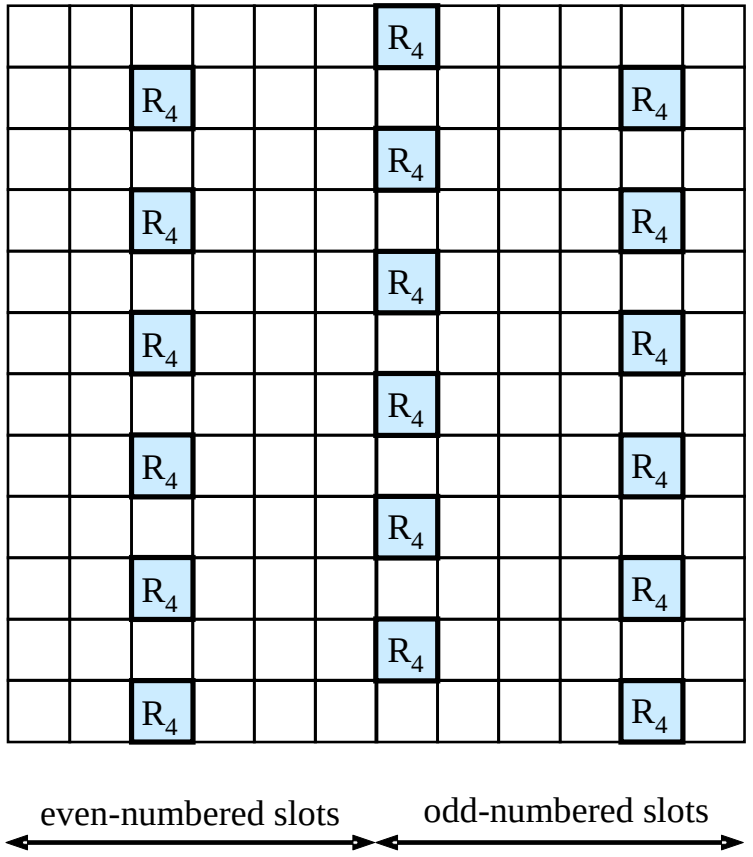
- Mode 2:
  - SFBC for 2 antenna ports
  - SFBC / FSTD for 4 antenna ports
- Mode 3:
  - Large delay CDD – increases frequency selectivity
  - Allows open-loop spatial multiplexing
  - Up to rank 2 without closed loop precoding feedback from UE
- Mode 4:
  - Precoding using specified codebook for the relevant number of antenna ports
  - Supports up to 4 layers
    - Max 2 codewords to limit signalling overhead
  - Closed-loop precoding feedback from UE
  - Used precoding matrix is indicated to UE on PDCCH

Details of PDSCH transmission modes (2)

- Mode 5:
  - Rank 1 MU-MIMO
  - Based on same precoding codebooks and feedback as Mode 4
  - PDCCH indicates power offset for PDSCH
- Mode 6:
  - Based on mode 4 but for single-layer only
- Mode 7:
  - UE-specific RS
  - Suitable for UE-specific beamforming, e.g. based on angle of arrival (no closed-loop precoding feedback from UE)
- Mode 8:
  - Dual-layer UE-specific RS
  - Closed-loop precoding feedback may or may not be used
  - Supports dual-layer SU-MIMO and single-layer MU-MIMO

MBMS

- Supports Single-Frequency Network operation for high performance: “MBSFN” subframes
  - Physical Multicast Channel (PMCH) is used instead of PDSCH
  - Special RS pattern with higher density in frequency domain supports longer “delay spread” from multi-cell transmission



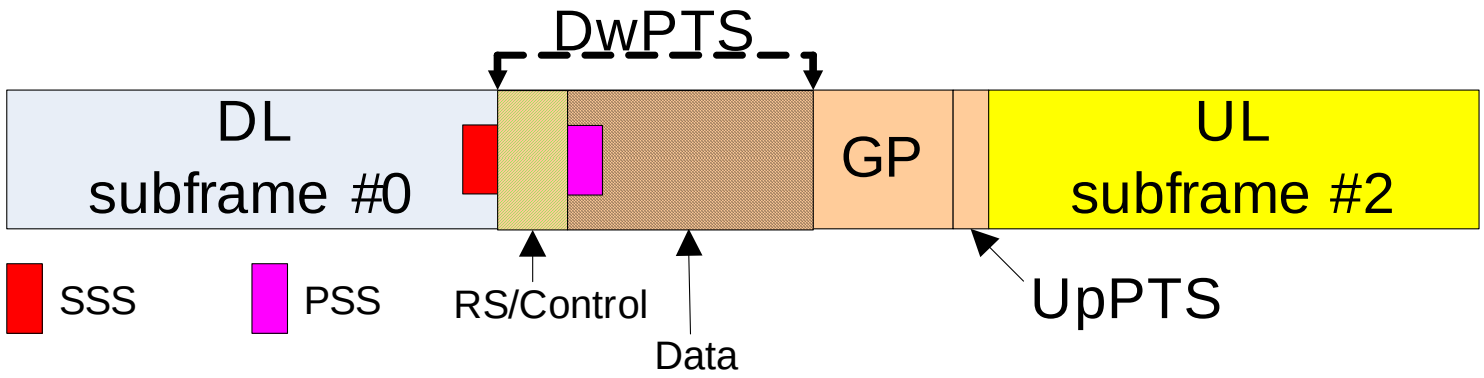
Antenna port 4

Contents

- Introduction
- Downlink Aspects
- Uplink Aspects
- Specific support for TDD
- Specific support for half-duplex FDD
- UE categories in Rel-8
- Enhancements for LTE-Advanced

TDD operation

- Special timeslot for downlink-uplink switching:



- UpPTS can transmit special short PRACH format or SRS

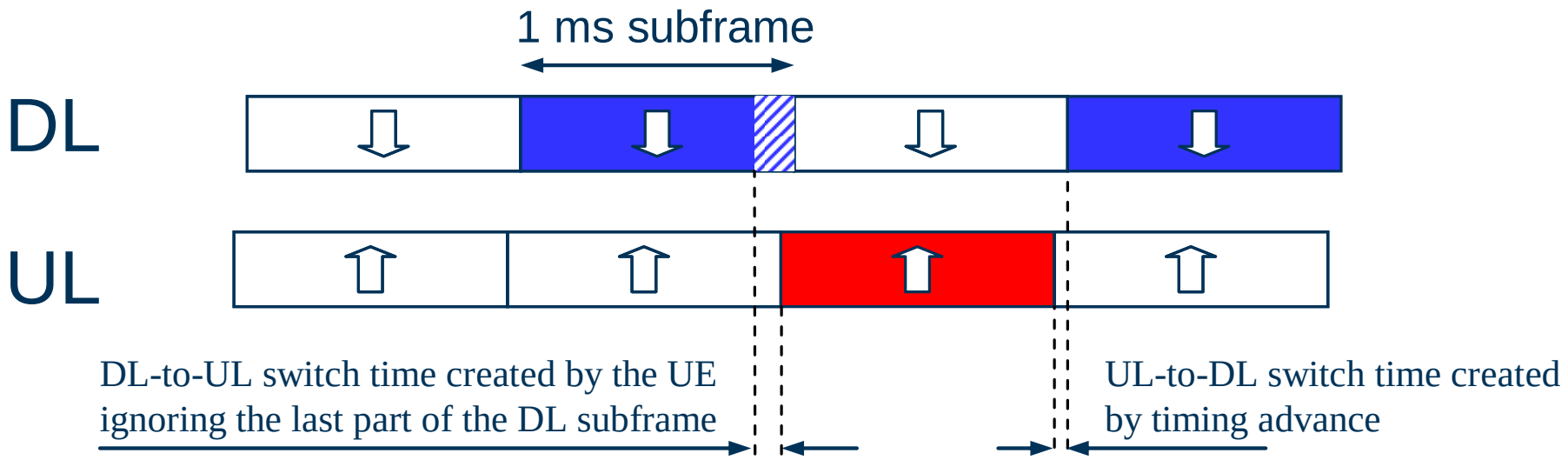
- TDD operation is also supported by:
  - An increased number of HARQ processes
  - ACK/NACK bundling / multiplexing configurations to enable control signalling to be transmitted

Contents

- Introduction
- Downlink Aspects
- Uplink Aspects
- Specific support for TDD
- Specific support for half-duplex FDD
- UE categories in Rel-8
- Enhancements for LTE-Advanced

Half-duplex FDD operation

- From UE perspective, UL and DL do not overlap in time
- For DL-UL switching time, UE ignores end of DL subframe
- For UL-DL switching time, additional timing advance offset can be applied to the UL transmissions

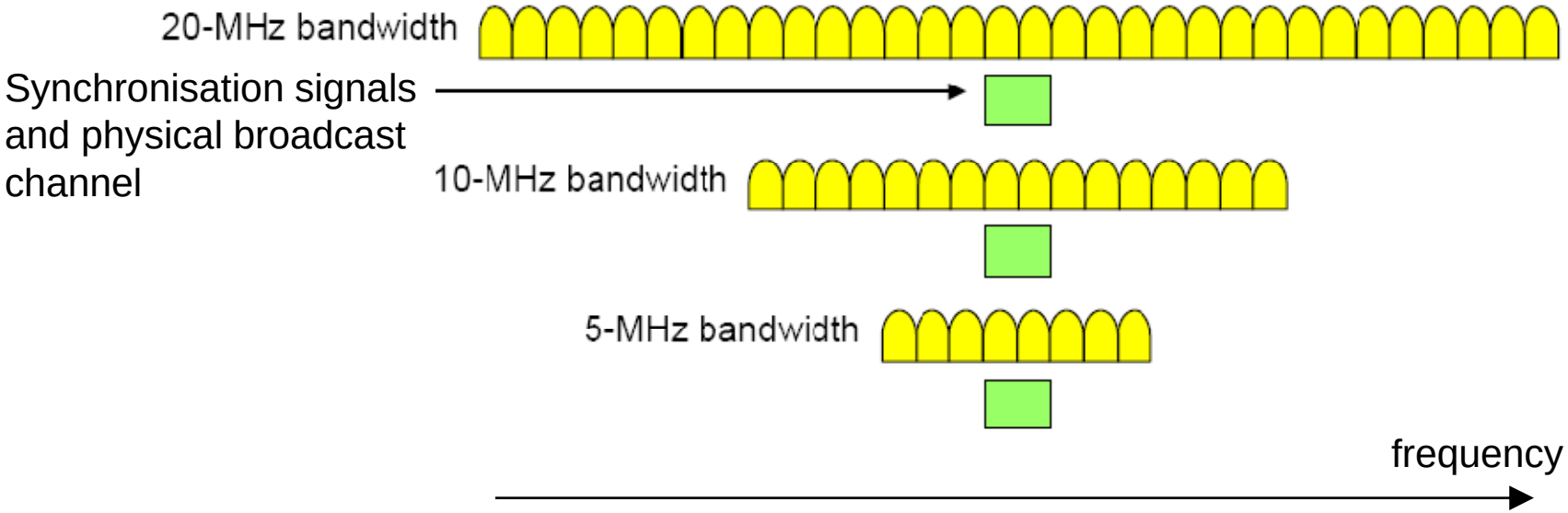


Orthogonal Multiple Access Schemes

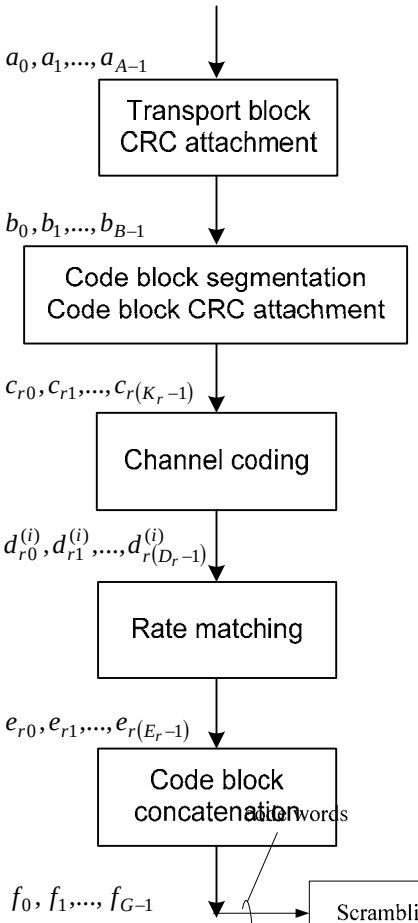
- Downlink: OFDMA
  - High spectral efficiency
  - Robust against frequency-selectivity / multi-path interference
    - Inter-symbol interference contained within cyclic prefix
  - Supports flexible bandwidth deployment
  - Facilitates frequency-domain scheduling
  - Well suited to advanced MIMO techniques
- Uplink: SC-FDMA
  - Based on OFDMA with DFT precoding
  - Common structure of transmission resources compared to downlink
  - Cyclic prefix supports frequency-domain equalization
  - Low Cubic Metric for efficient transmitter design

Low complexity cell acquisition

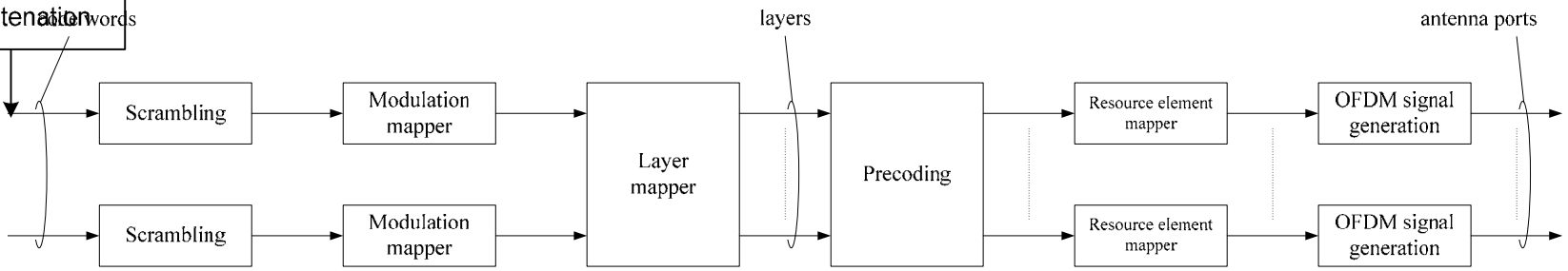
- Synchronisation signals and broadcast channel:
  - Fixed bandwidth
  - Centrally located
  - Allows straightforward bandwidth-agnostic cell-search



PDSCH physical layer processing



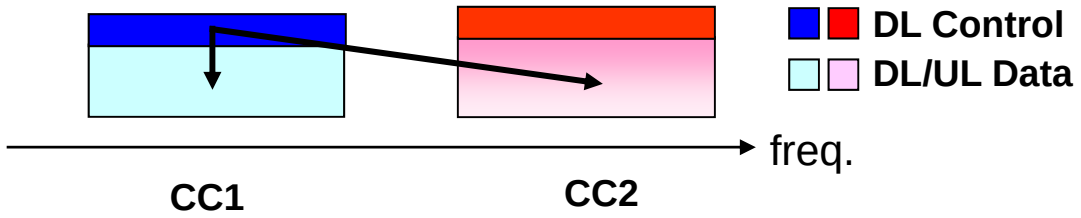
- Each TTI, 1 or 2 transport blocks are processed from MAC layer
- Channel coding is based on 1/3 rate turbo code with trellis termination to approach Shannon capacity
- Circular buffer rate matching
- Modulation QPSK, 16QAM, 64QAM
- Layer mapping and precoding for support of multi-antenna transmission



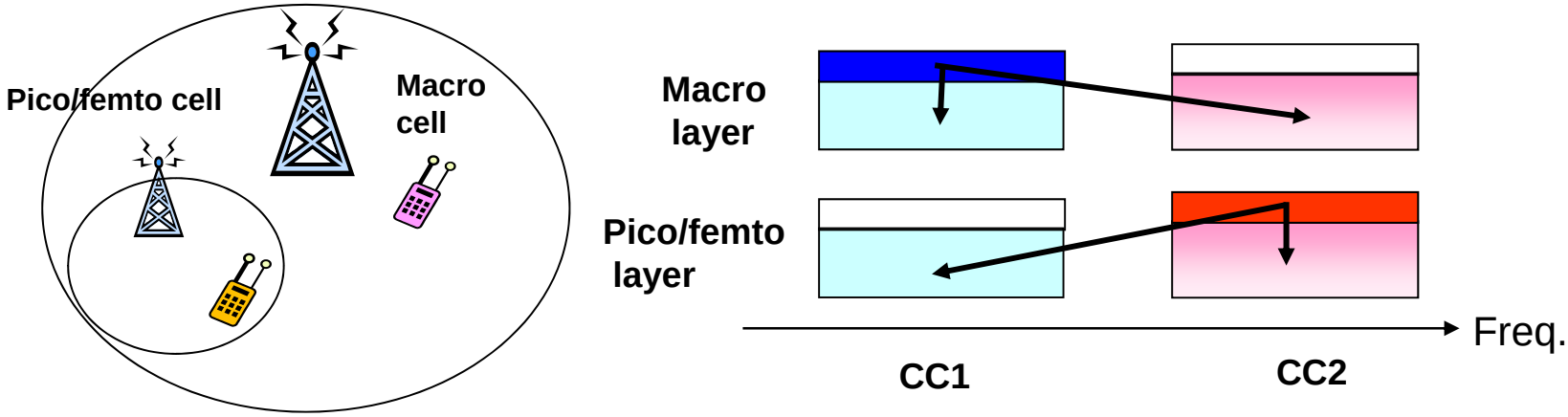
Cross-carrier scheduling for CA

- Carrier indicator field (CIF) can be semistatically configured to enable cross carrier UL and DL assignments

Example:
Use PDCCH in CC1 to schedule PDSCH in CC2



- Possible application is control channel inter-cell interference coordination (ICIC) on heterogeneous networks



Control channel design for relay

- "R-PDCCH" is designed to dynamically or semi-persistently assign resources for the downlink backhaul data (corresponding to the "R-PDSCH and R-PUSCH" physical channel).
  - DL grants are always transmitted in the first slot of a subframe
  - If a DL grant is transmitted in the first PRB of a given PRB pair, then an UL grant may be transmitted in the second PRB of the PRB pair
  - Possibility to transmit data in the 2nd slot of a R-PDCCH PRB pair
  - UL grants are only transmitted in the second slot
    - No data transmission in the first slot
  - Ongoing discussions on interleaving.
  - Only Rank 1 is supported for R-PDCCH for a given RN