REV-090003r1

LTE-Advanced Physical Layer

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Chairman 3GPP TSG RAN WG1

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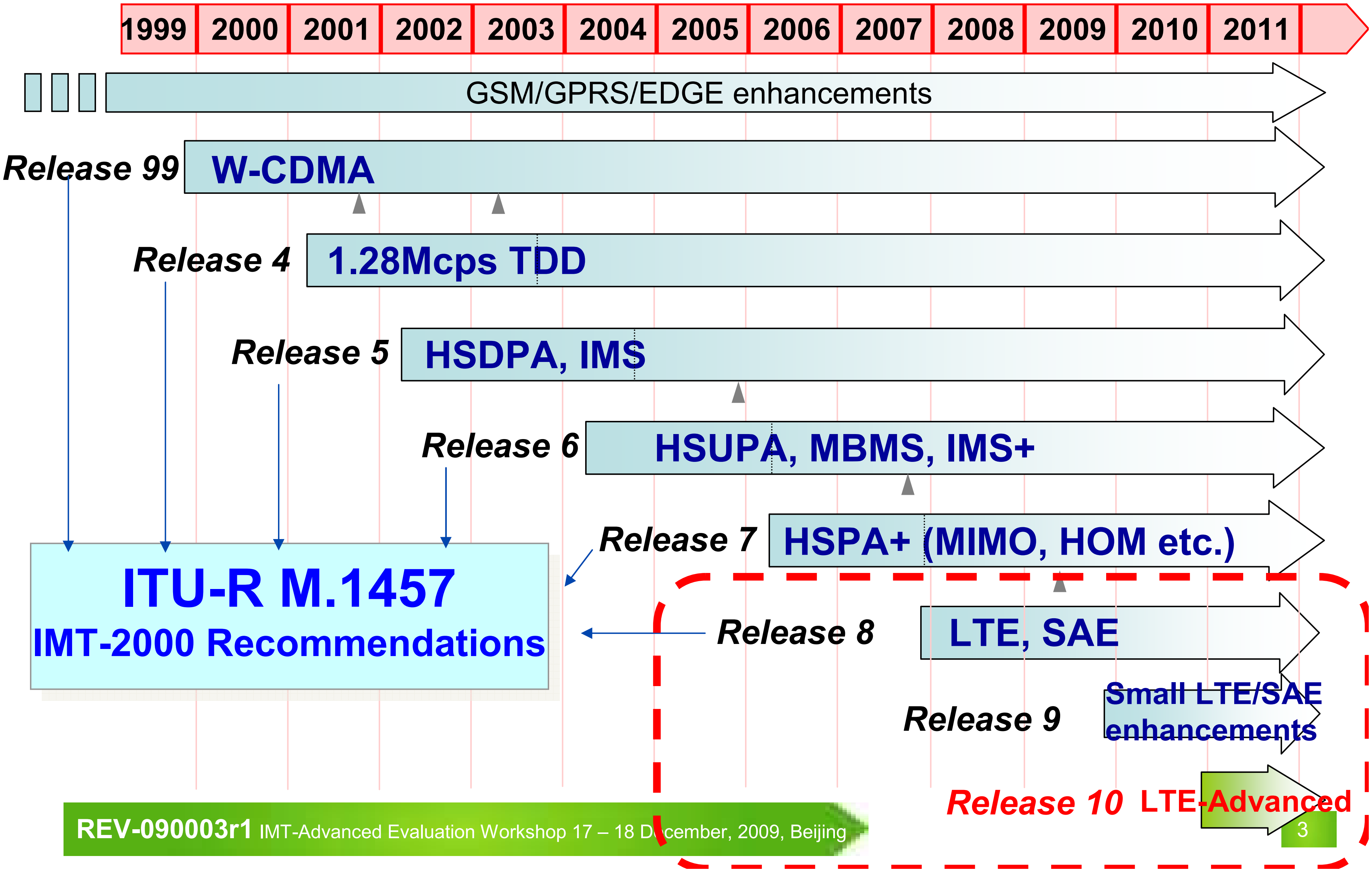
Releases of 3GPP specifications



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/

Orthogonal Multiple Access Schemes

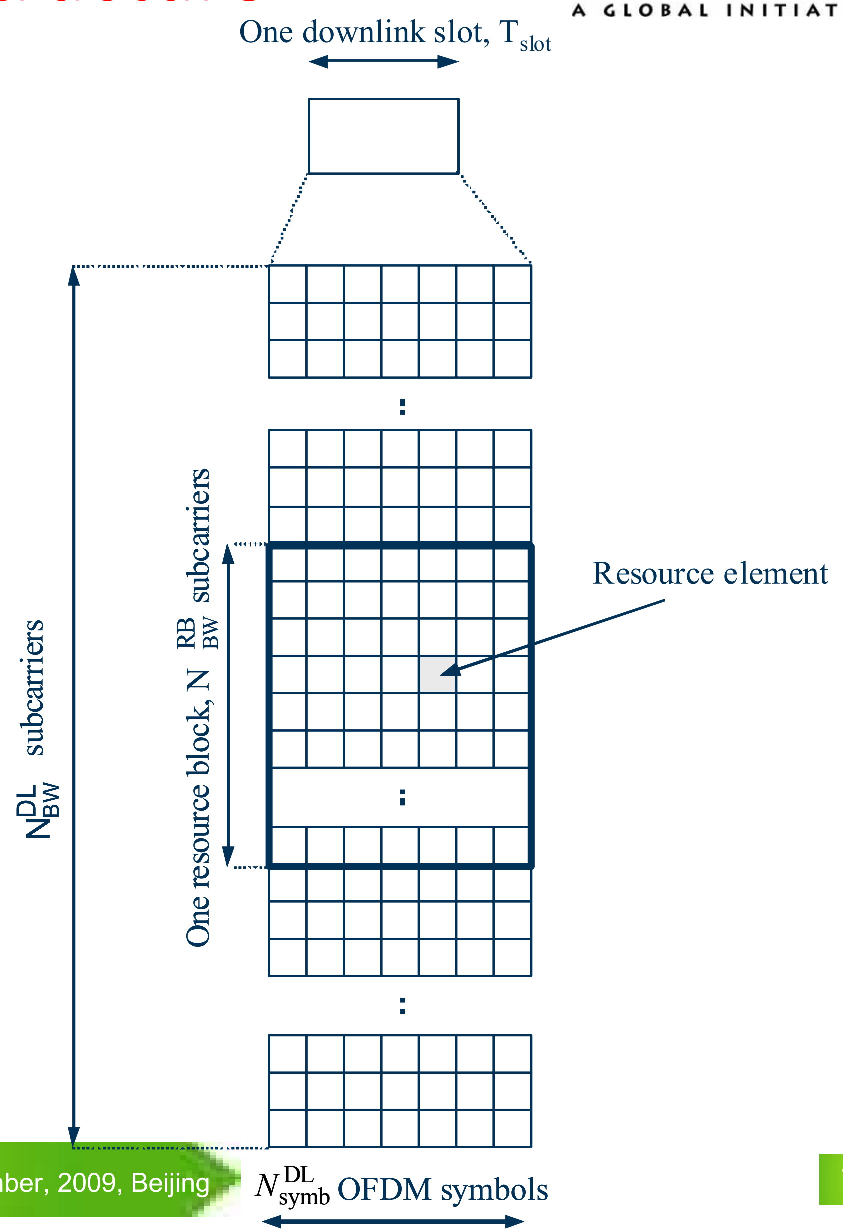
- Downlink: OFDMA
  - High spectral efficiency
  - Robust against frequency-selectivity / multi-path interference
    - Inter-symbol interference contained within cyclic prefix
  - Supports flexible bandwidth deployment
  - Facilitates frequency-domain scheduling
  - Well suited to advanced MIMO techniques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

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

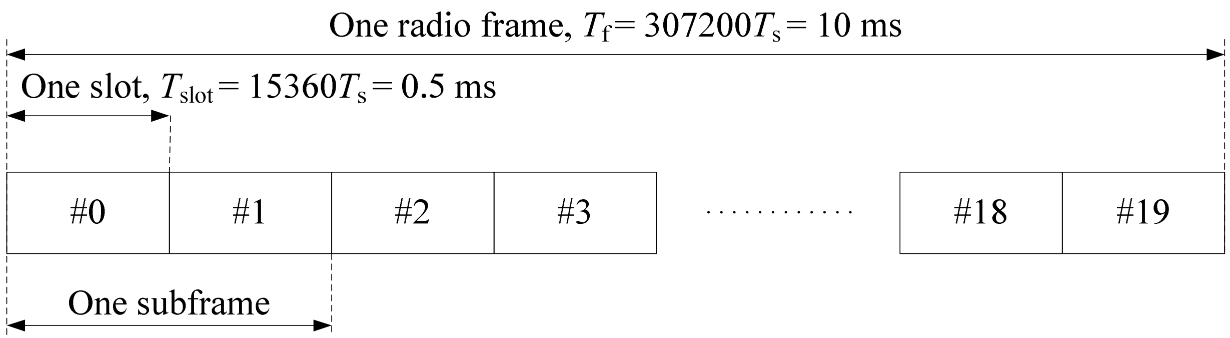
- Basic unit of resource is the Physical Resource Block (PRB)
- 12 sub-carriers x 0.5 ms
- Allocated in pairs (in time domain)
- 1 sub-carrier x 1 symbol = 1 resource element (RE)
- Spatial domain measured in "layers"



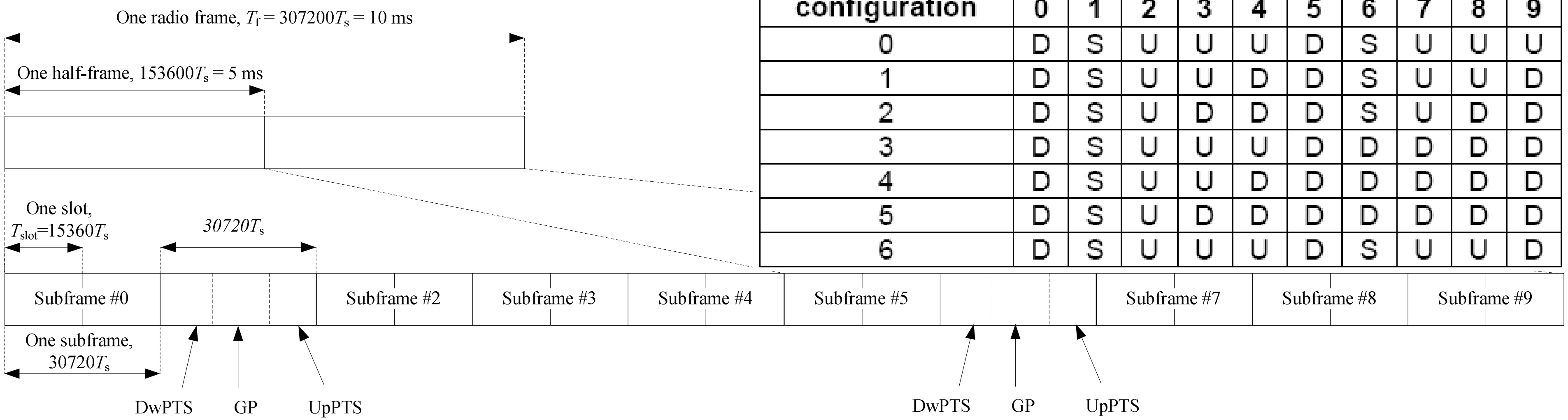
One radio interface, 2 frame structures

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

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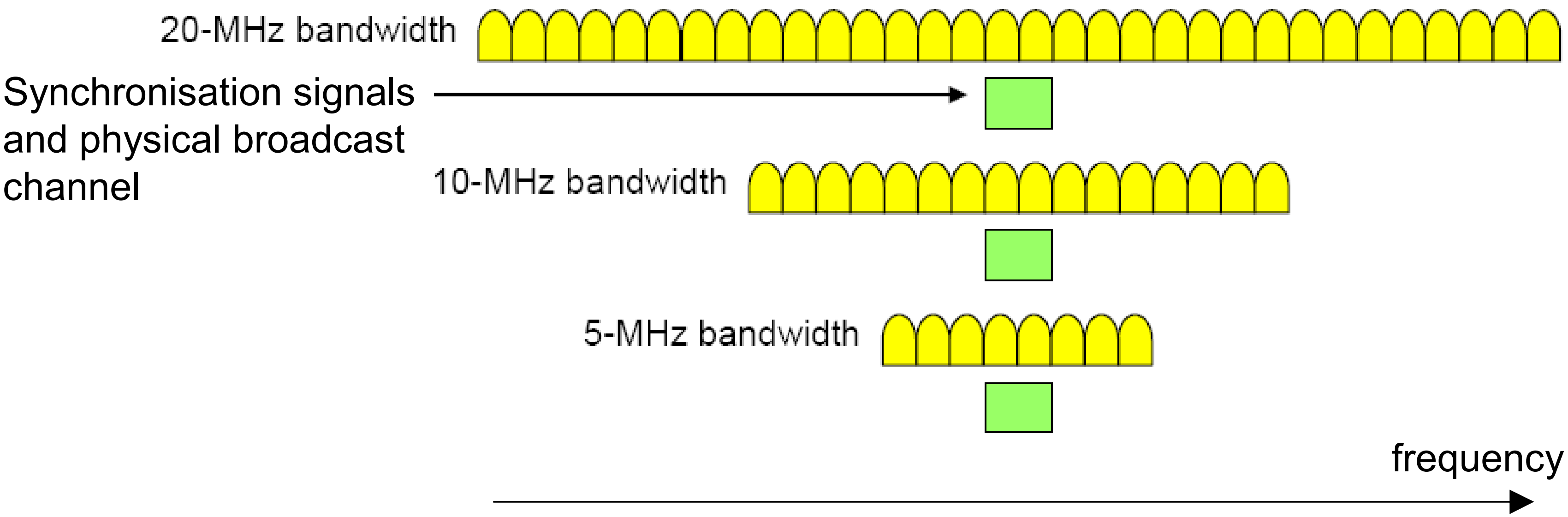
- Introduction
- Downlink Aspects
- Uplink Aspects
- Specific support for TDD
- Specific support for half-duplex FDD
- UE categories in Rel-8
- Enhancements for LTE-Advanced

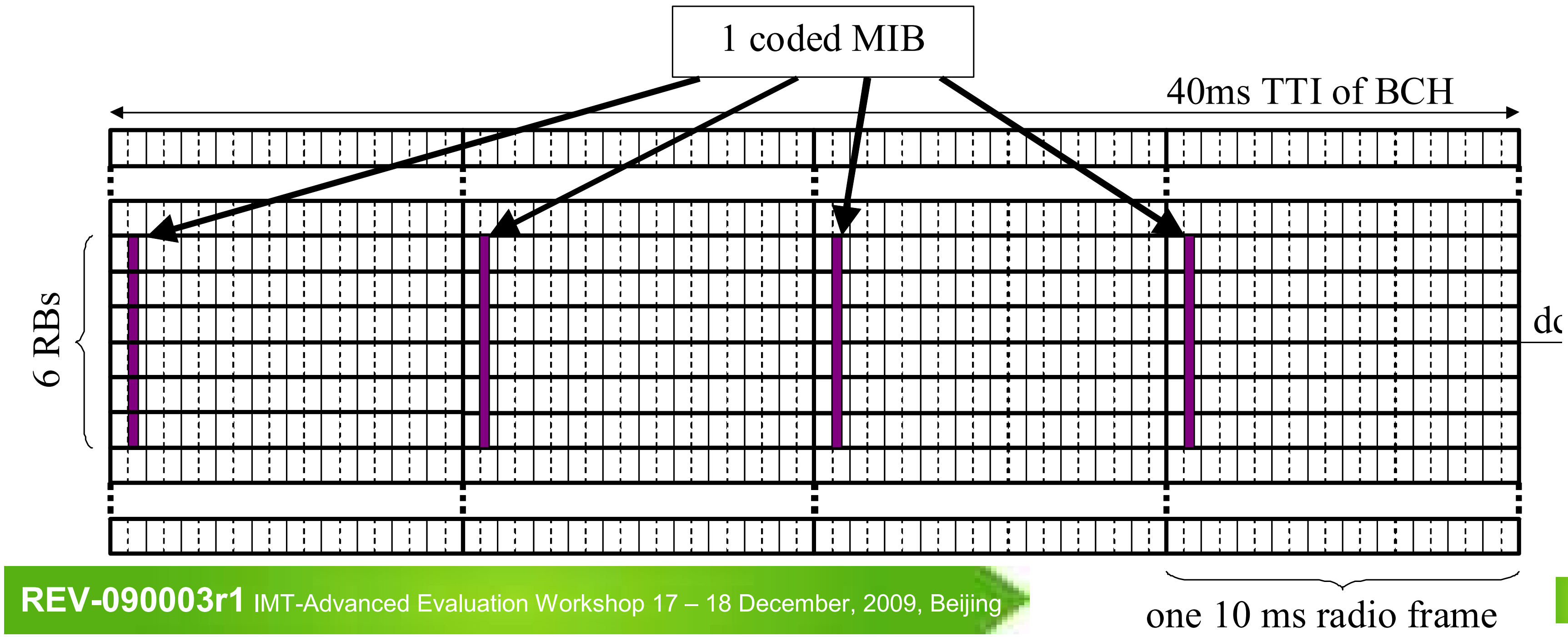
Low complexity cell acquisition

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



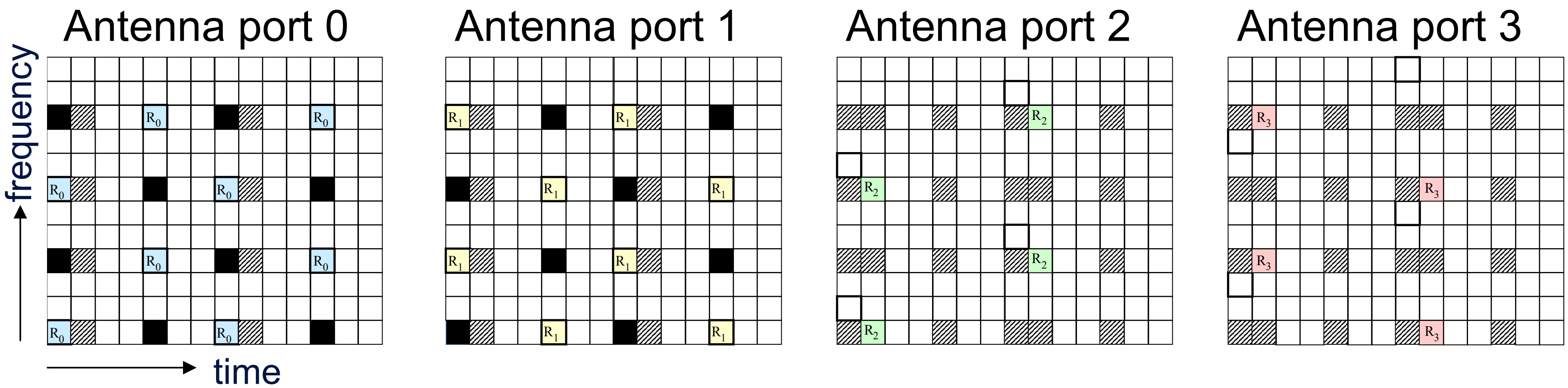
Cell acquisition signalling

- Synchronisation signals in subframes 0 and 5 of each 10 ms radio frame
- 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

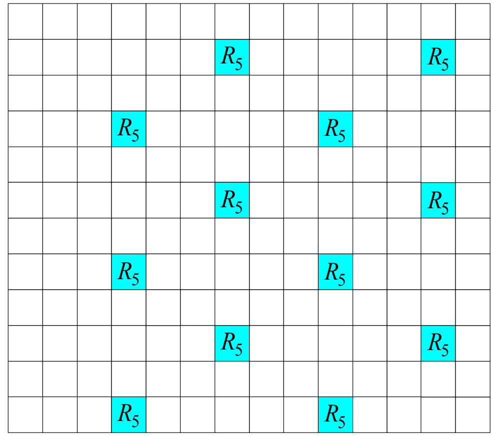


Reference Signals (RS)

- 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

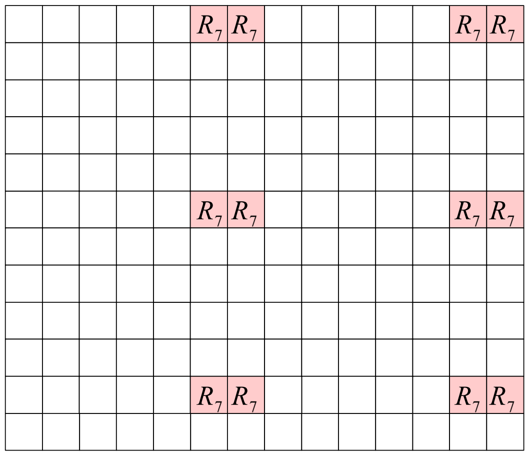


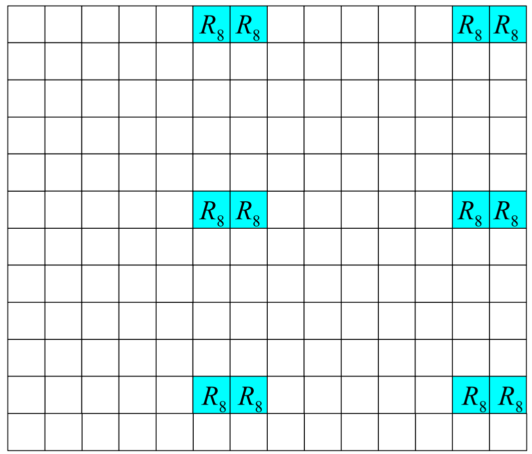
In Rel-8:

- UE-specific (precoded) RS may be provided in data transmissions to specific UEs

In Rel-9:

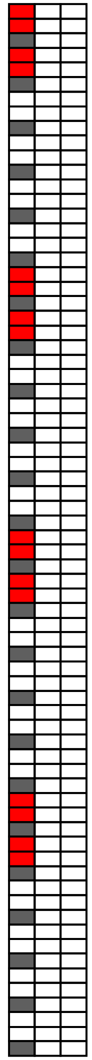
- UE-specific RS extended to dual-layer transmission
- CDM between RS of the two layers





Downlink control signalling

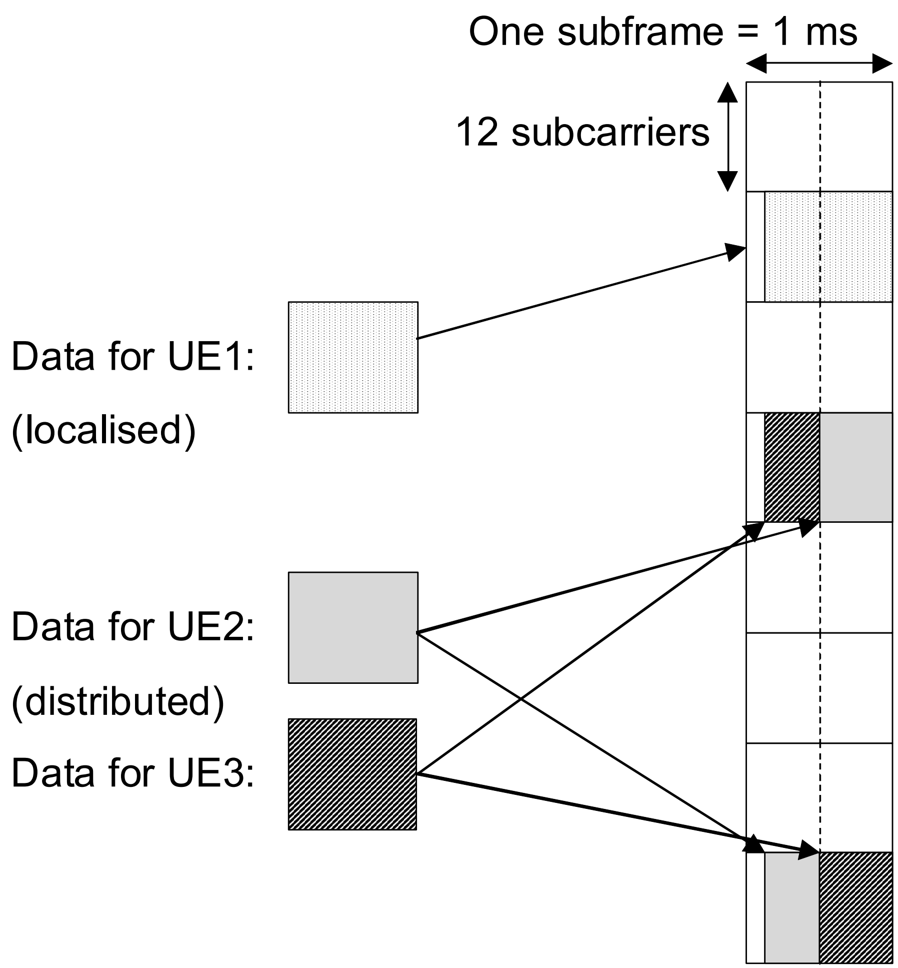
- Flexible design to avoid unnecessary overhead
  - First 1-3 OFDM symbols in each subframe (2-4 in narrow bandwidths)
  - Control region size is dynamically variable
    - Length indicated by Physical Control Format Indicator Channel (PCFICH) in first OFDM symbol of each subframe
    - PCFICH is designed to be robust
      - 16 QPSK symbols transmitted with full frequency diversity



- Within the control region:
  - 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

- Physical Downlink Shared Channel (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 physical layer processing

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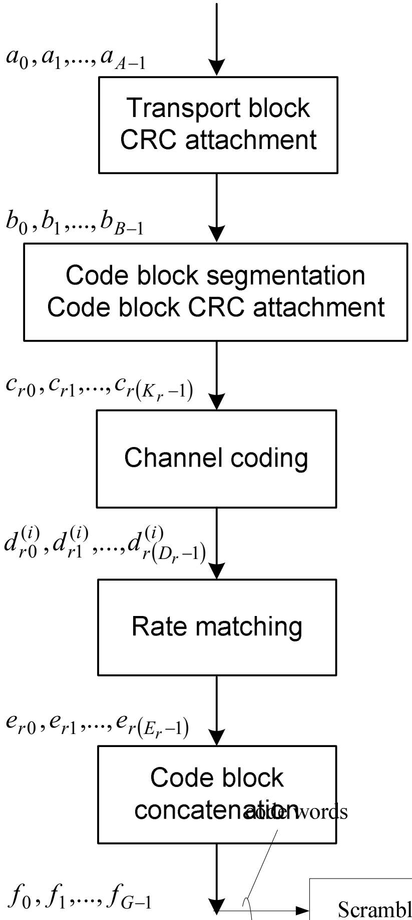
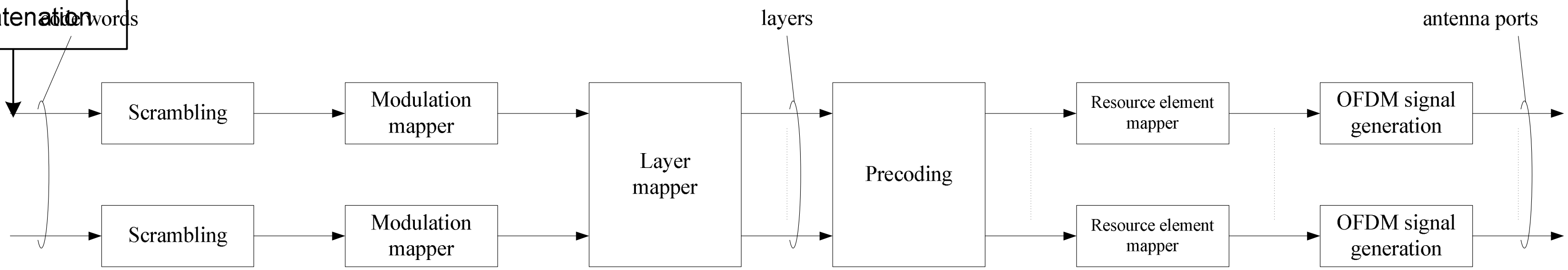


- Each TTI, 1 or 2 transport blocks are processed from MAC layer
- Channel coding is based on 1/3 rate turbo code with trellis termination to approach Shannon capacity
- Circular buffer rate matching
- Modulation QPSK, 16QAM, 64QAM
- Layer mapping and precoding for support of multi-antenna transmission



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)

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)

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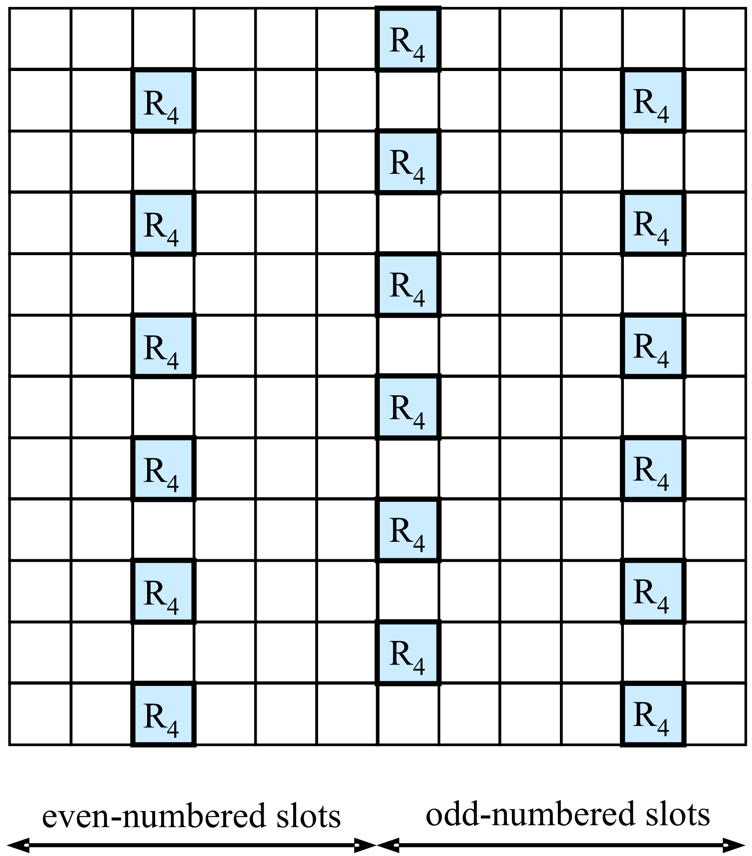
- Mode 5:
  - Rank 1 MU-MIMO
  - Based on same precoding codebooks and feedback as Mode 4
  - PDCCH indicates power offset for PDSCH
- Mode 6:
  - Based on mode 4 but for single-layer only
- Mode 7:
  - UE-specific RS
  - Suitable for UE-specific beamforming, e.g. based on angle of arrival (no closed-loop 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

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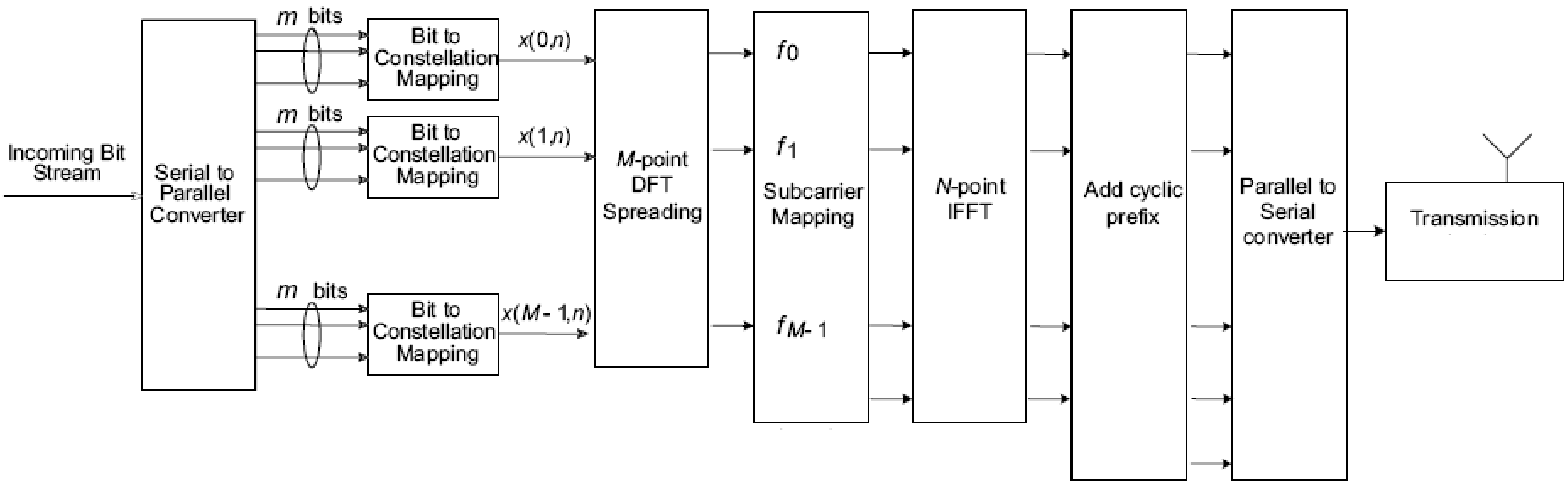
- Downlink Aspects
- **Uplink Aspects**
- Specific support for TDD
- Specific support for half-duplex FDD
- UE categories in Rel-8
- Enhancements for LTE-Advanced

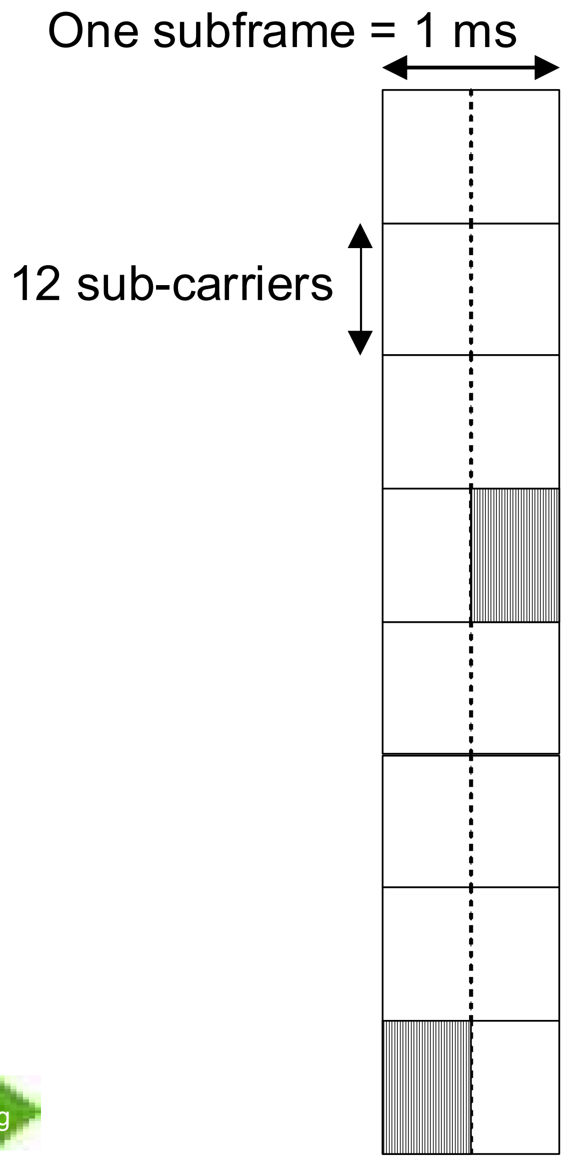
Uplink multiple access: SC-FDMA

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



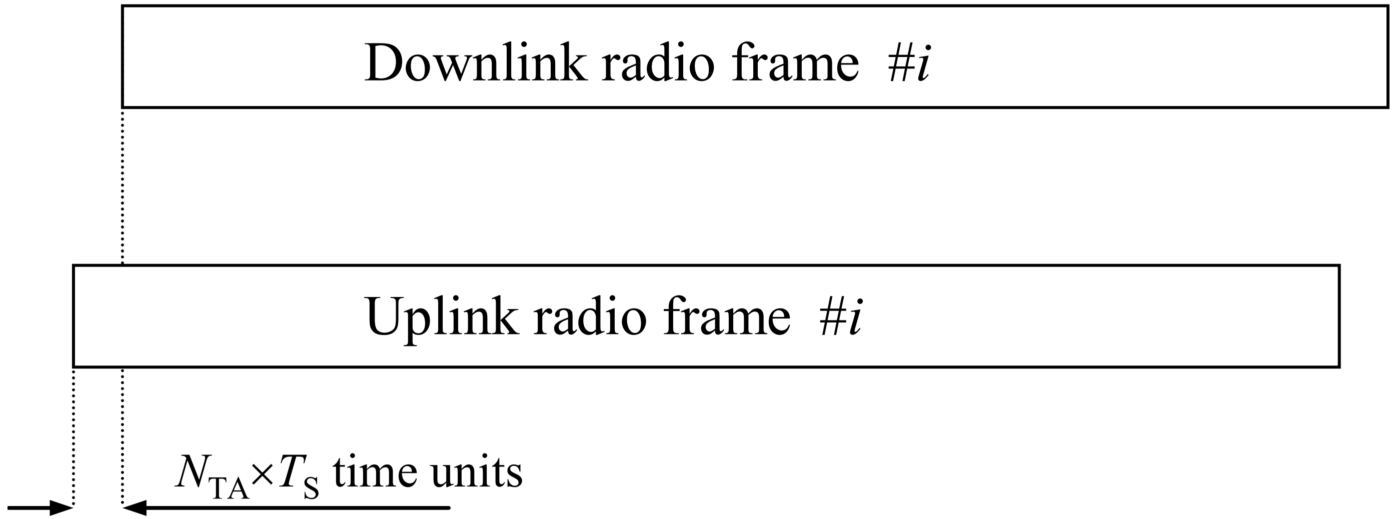
UL transmission resource allocation

- Same structure of PRBs in frequency domain as downlink
- Contiguous PRB allocation
- 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



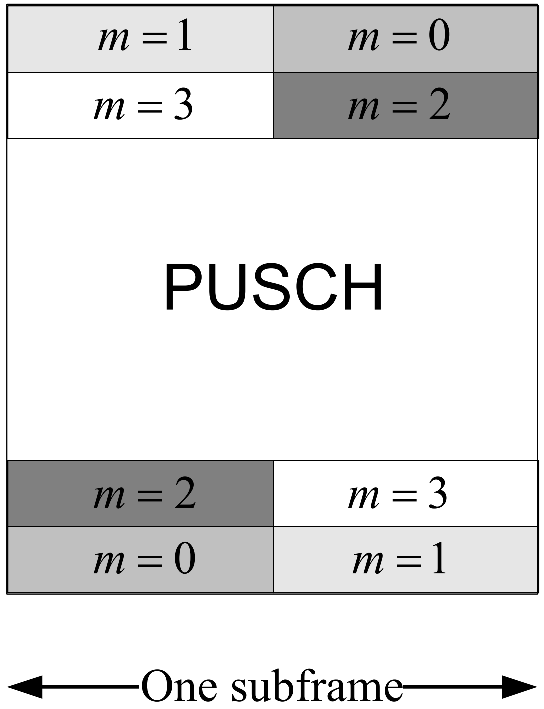
Timing Advance

- 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 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

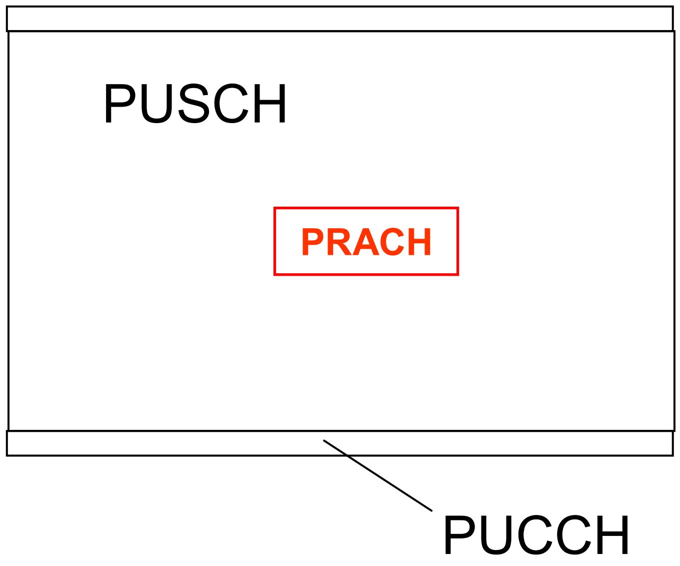
- ACK/NACK for PDSCH transmissions
- Scheduling Request (SR)
- Channel Quality Information
  - CQI – indicates an index of a Modulation / Coding Scheme (MCS) that could be received on PDSCH with BLER ≤ 0.1
  - PMI – indicates preferred precoding matrix for PDSCH
  - RI – indicates number of useful transmission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

Channel Quality reporting modes

- CQI/PMI/RI can be periodic – on PUCCH
  - Wideband or UE-selected sub-band
- CQI/PMI/RI can be aperiodic – on PUSCH
  - Triggered by 1 bit in PDCCH message
  - Wideband, UE-selected sub-band or higher-layer configured sub-band
- With or without PMI depending on the configured transmission mode

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

UL Reference Symbols

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

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

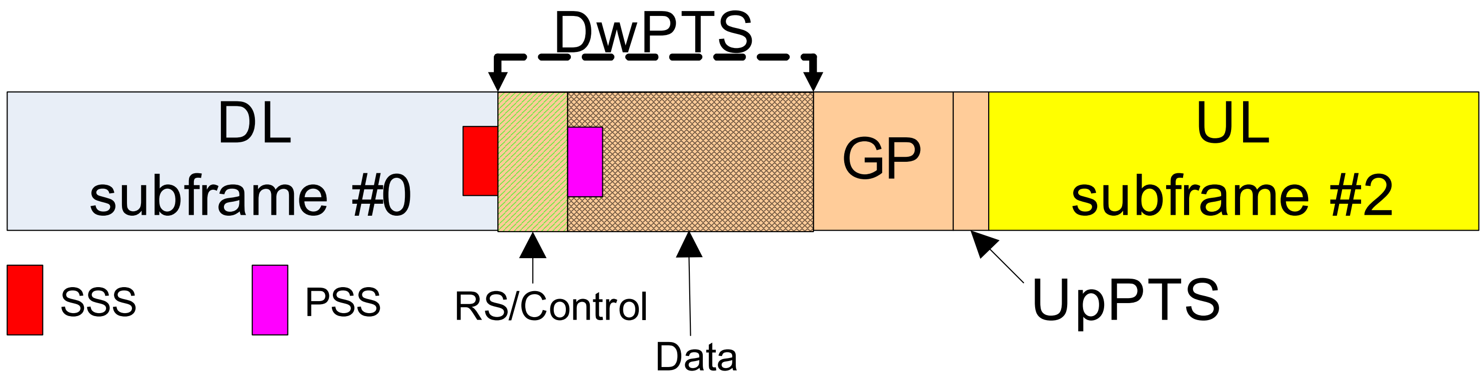
UL Multi-Antenna transmission

- 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

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

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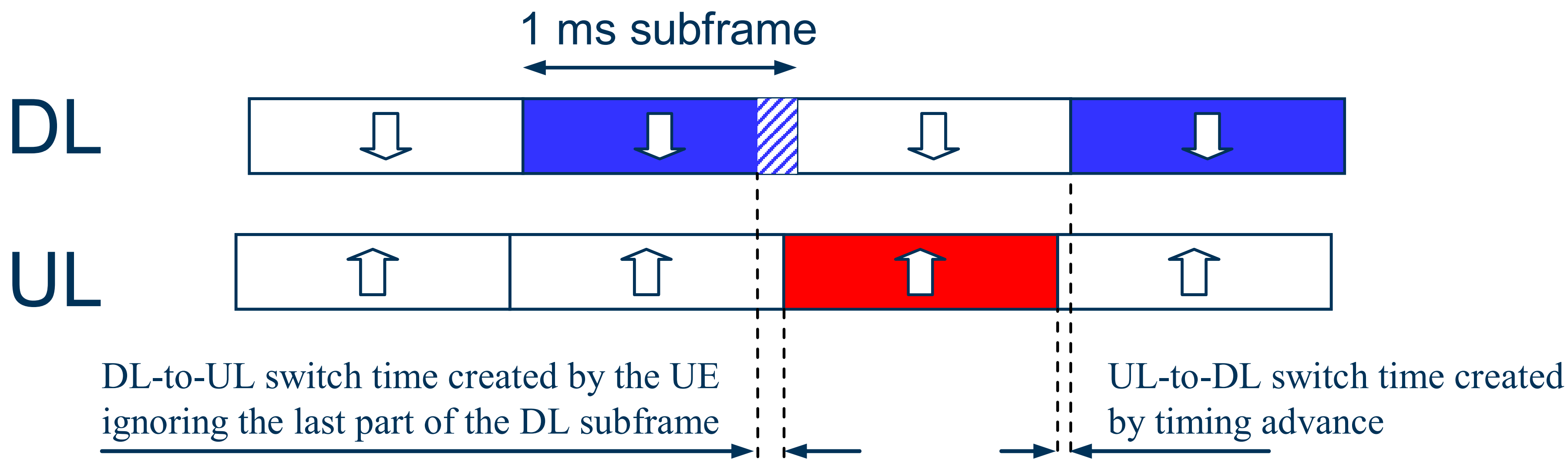
Half-duplex FDD operation

- 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



Contents

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

Contents

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

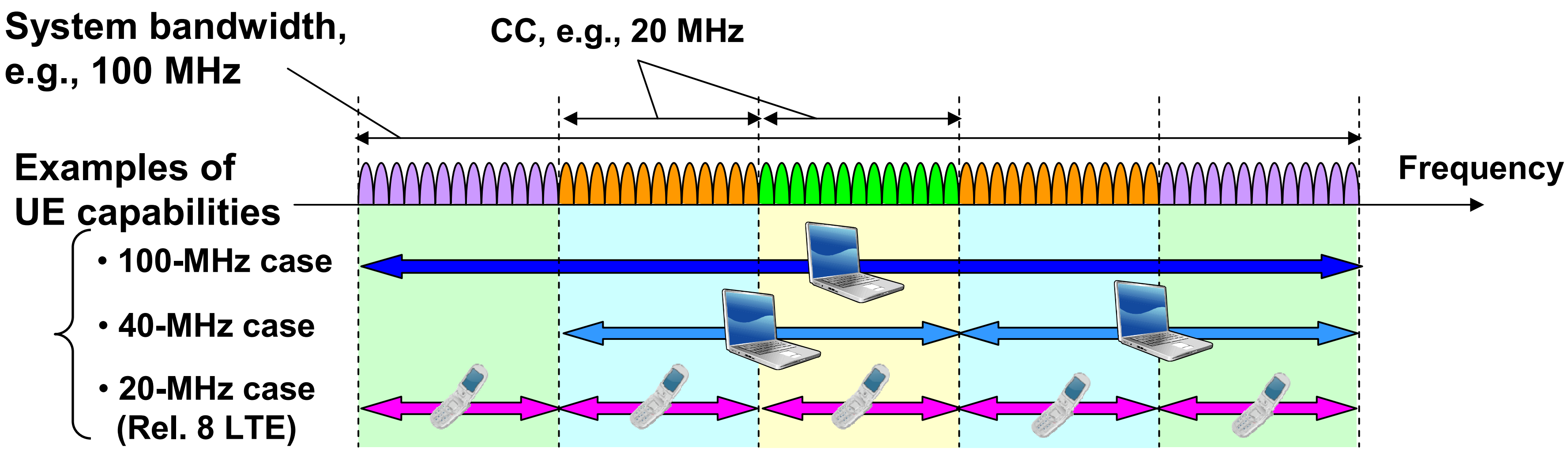
		Rel. 8 LTE	LTE-Advanced	IMT-Advanced
Peak data rate	DL	300 Mbps	1 Gbps	1 Gbps(*)
	UL	75 Mbps	500 Mbps	
Peak spectrum efficiency [bps/Hz]	DL	15	30	15
	UL	3.75	15	6.75

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

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 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

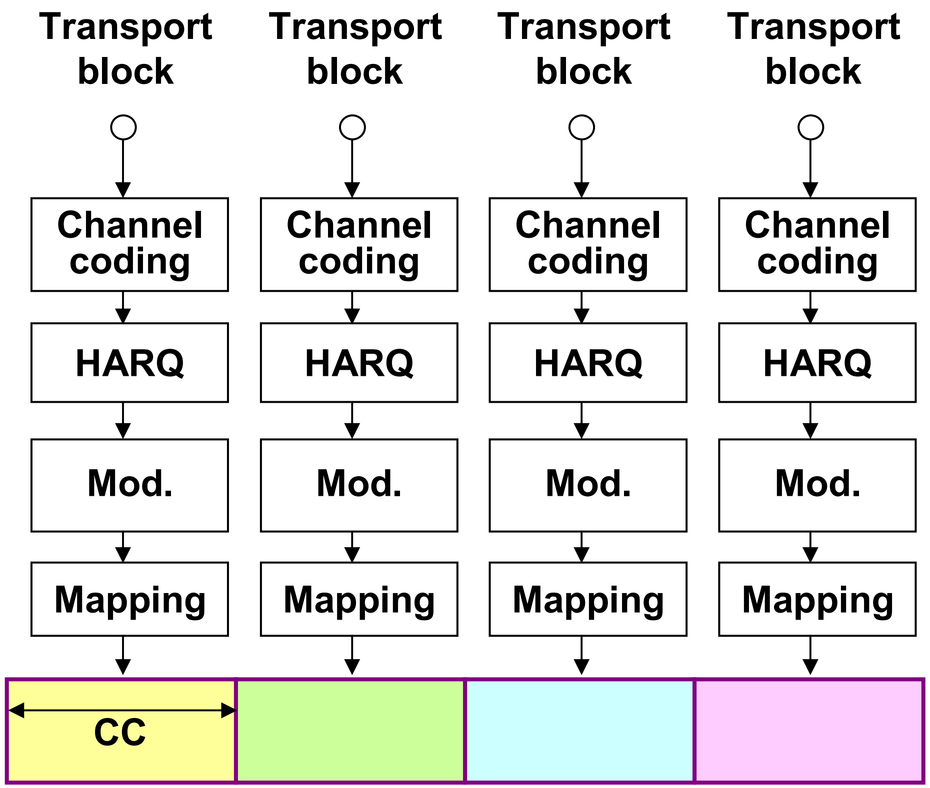
- Downlink: OFDMA with component carrier (CC) based structure

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

- One transport block is mapped within one CC
- Parallel-type transmission for multi-CC transmission

- Good affinity to Rel. 8 LTE specifications

- Cross-carrier scheduling is possible:
  - PDCCH on one carrier can relate to data on another carrier



Uplink Multiple Access Scheme

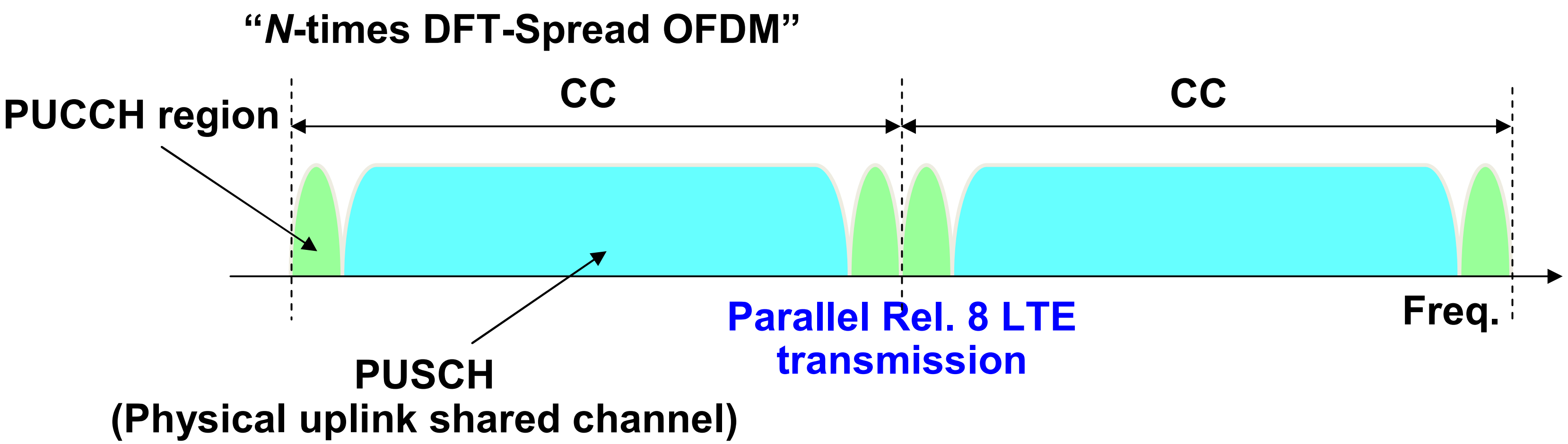
- Uplink: *N*-times DFT-Spread OFDM

  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

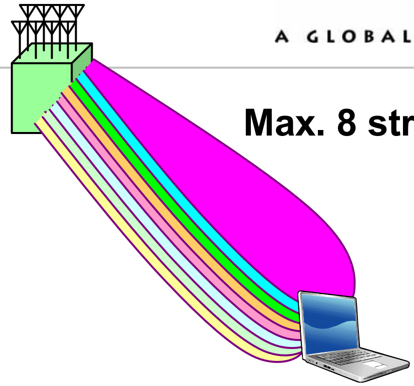
- Will also support non-contiguous resource allocation
  - Enhanced flexibility and efficiency of resource allocation
- Simultaneous PUCCH and PUSCH transmission will be supported.
- Independent power control will be provided per CC



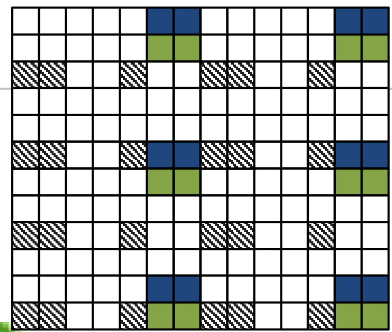
Enhanced Downlink Multi-antenna Transmission (1)

- **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)**
  - **UE-specific demodulation RS (DM-RS)**
    - **UE-specific DM-RS can be precoded, supporting 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**
    - **DM RS pattern for higher numbers of layers is extended from 2-layer format for transmission mode 8 in Rel-9**
      - **E.g. for 4 antenna ports:**



Baseline

Enhanced Downlink Multi-antenna Transmission (2)

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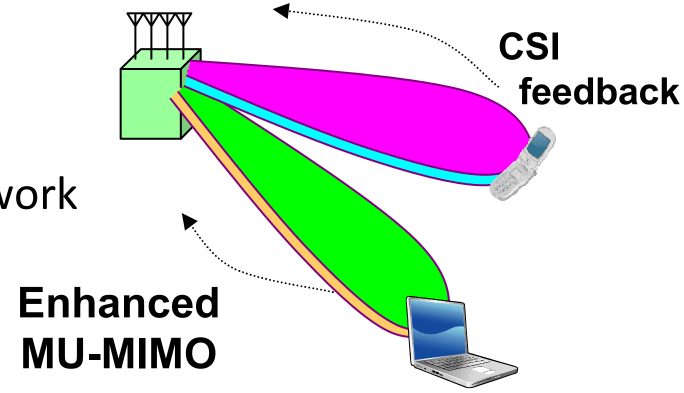
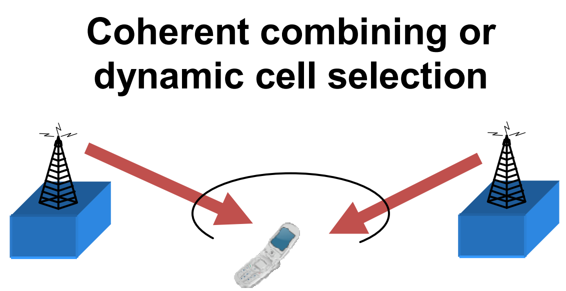
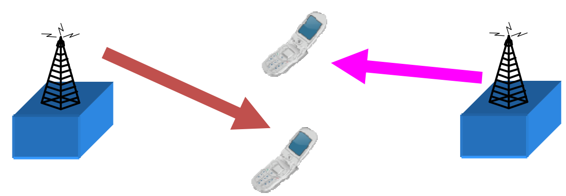


- Support for enhanced MU-MIMO is being studied
- Enhancements to CSI feedback are being studied
  - Implicit feedback based on Rel-8 CQI/PMI/RI framework
  - Explicit feedback
    - considering gain versus overhead
- CoMP schemes are being studied
  - Joint processing (JP)
    - Joint transmission (JT): 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 transmitted only from 1 cell; scheduling/beamforming is coordinated among cells



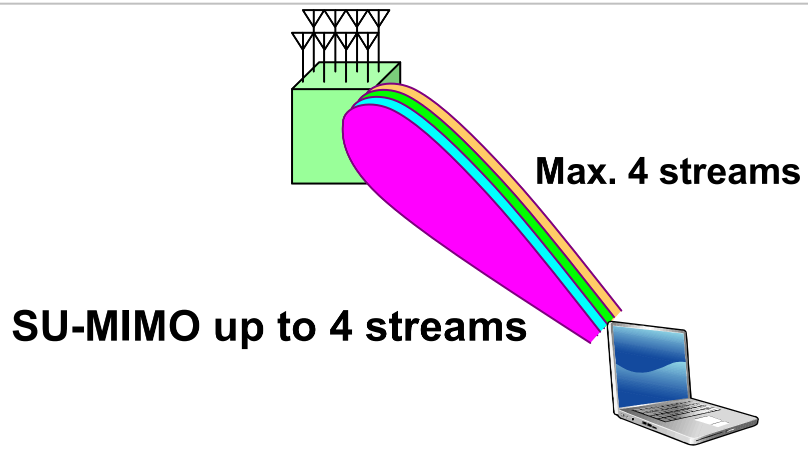
Joint transmission/dynamic cell selection



Coordinated scheduling/beamforming

Enhanced Uplink Multi-antenna Transmission

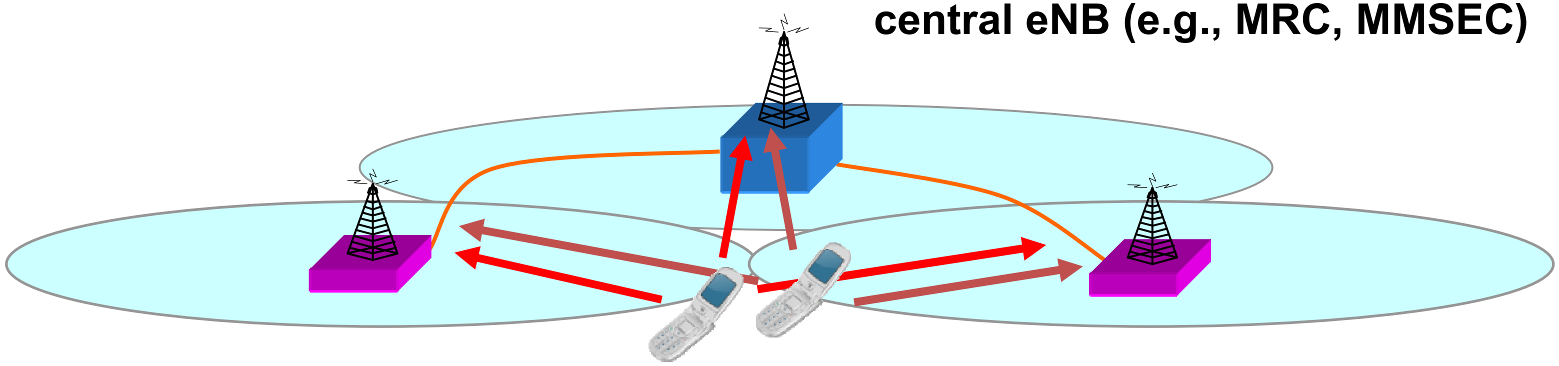
- Introduction of UL transmit diversity for PUCCH
  ➔ Improved signalling robustness and cell-edge performance
- Introduction of single user (SU)-MIMO up to 4-stream transmission
  ➔ Satisfy the requirement for peak spectrum efficiency, i.e., 15 bps/Hz
- Signal detection scheme with affinity to DFT-S-OFDM for SU-MIMO
- Turbo serial interference canceller (SIC) is assumed to be used for eNB receivers to achieve higher throughput performance for DFT-S-OFDM
  ➔ Improve user throughput, while maintaining low cubic-metric signal transmission



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

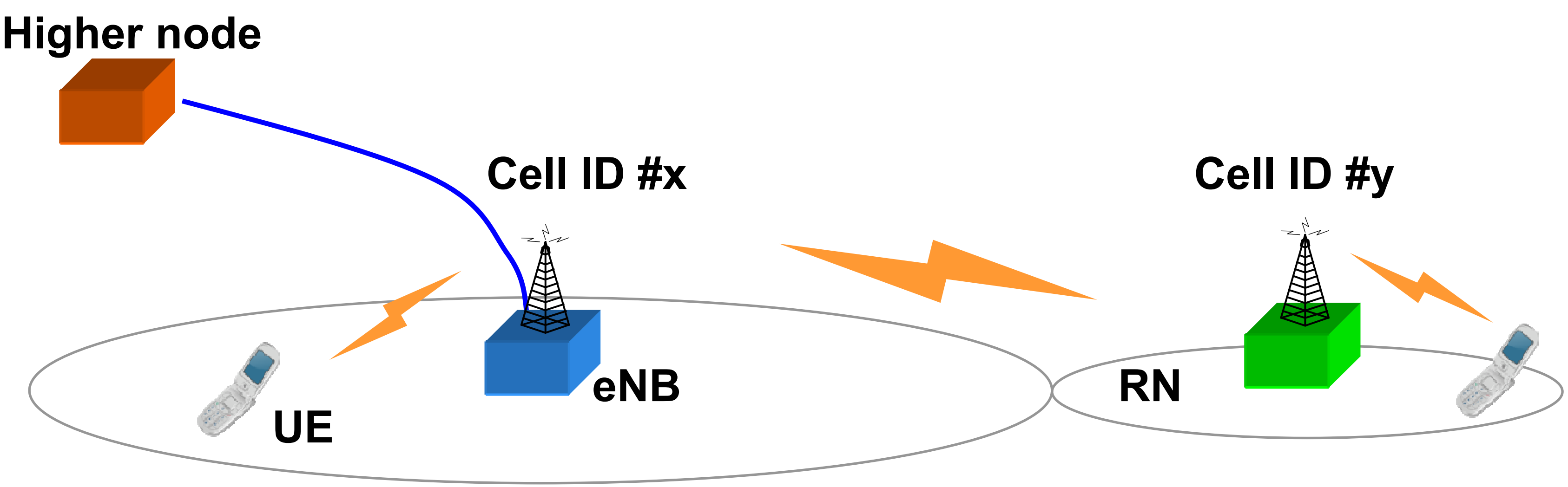


Multipoint reception

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

    ➔ Supports deployment of cells in areas where wired backhaul is not available or very expensive
- Other relay types are also being studied



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