

Radio Access Techniques for LTE-Advanced

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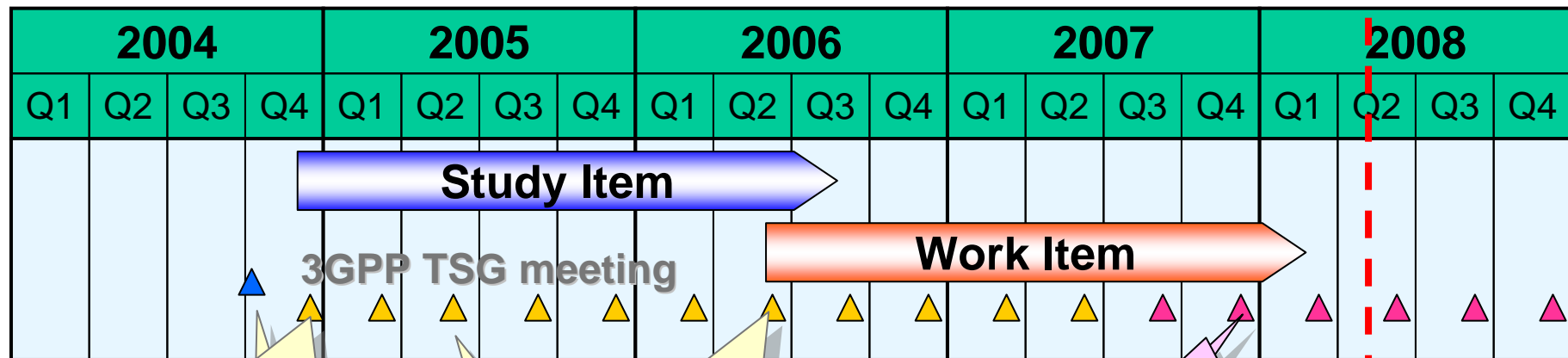
August 20, 2008

- **Outline of Rel-8 LTE (Long-Term Evolution)**
- **Targets for IMT-Advanced**
- **Requirements for LTE-Advanced**
- **Radio access techniques for LTE-Advanced**

**Outline of Rel-8 LTE (Long-Term Evolution)
– Evolved UTRA and UTRAN –**

History of Standardization Activities on Rel-8 LTE

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Dec. 2004
Start SI discussion

June 2006
Start WI discussion

Sep. – Dec. 2007
Completion of major specifications

Nov. 2004
LTE Workshop

June 2005
Requirements specified

Sep. – Dec. 2008
Completion of test specifications

Requirements for Evolved UTRA and UTRAN

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■ Spectrum

- Support of scalable bandwidths, i.e., **1.4, 3, 5, 10, 15, and 20 MHz**

■ Packet-switching (PS) mode only

- VoIP capability in PS domain

■ Latency

- Short C-plane latency (transition time)
 - Idle to active: **Less than 100 msec**
 - Dormant to active: **Less than 50 msec**
- U-plane latency
 - Latency in RAN is less than **5 msec one way**

■ Peak data rate

- DL: **100 Mbps**, UL: **50 Mbps**

■ User throughput (relative to Rel-6 HSDPA, HSUPA)

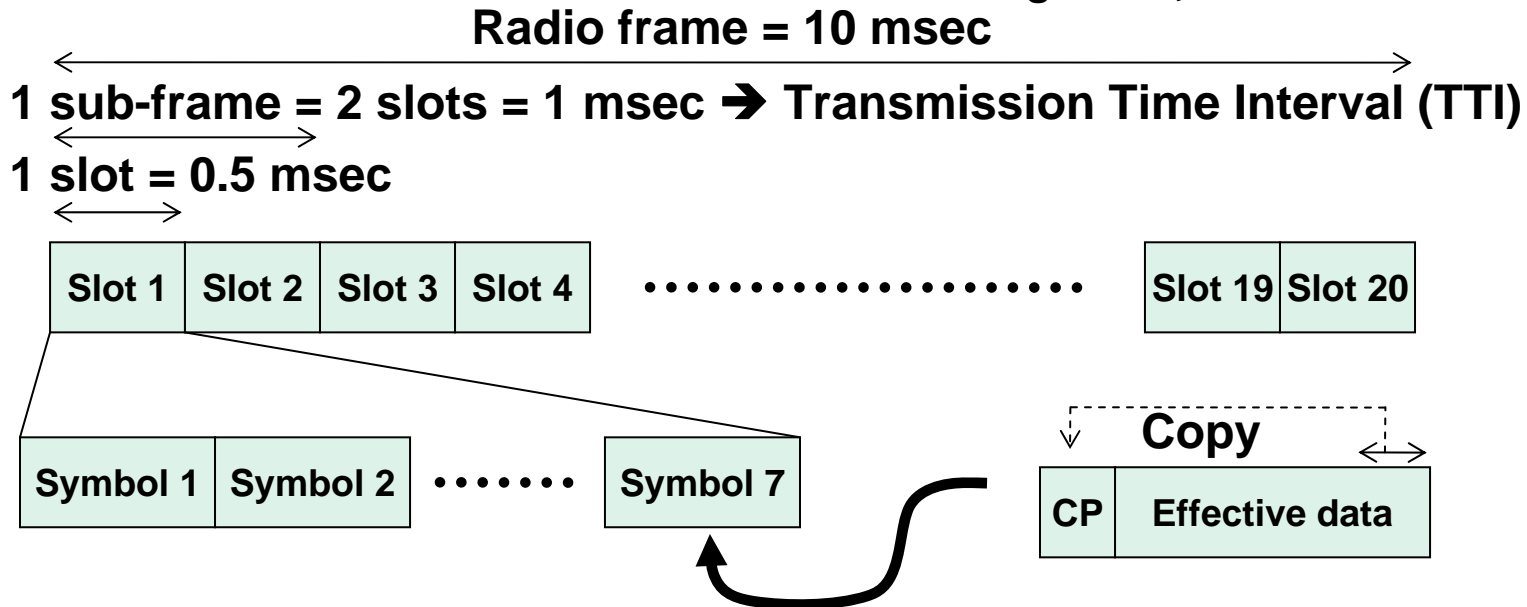
- Cell edge user throughput: **2 – 3 times** (DL), **2 – 3 times** (UL)
- Average user throughput: **3 – 4 times** (DL), **2 – 3 times** (UL)

■ Spectrum efficiency (relative to Rel-6 HSDPA, HSUPA)

- **3 – 4 times** (DL), **2 – 3 times** (UL)

Frame Structure in Evolved UTRA

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- **Short sub-frame length**

- Adopted 1-msec sub-frame length to achieve short round trip delay (RTD)

- **Common frame structure between FDD and TDD**

- **Inserted cyclic prefix (CP) at each FFT block to avoid inter-block interference both in DL and UL**

- **Defined sub-frame with long CP and smaller number of symbols to provide MBMS (Multimedia Broadcast Multicast Service) with single-frequency network (SFN) in DL**

Major Radio Link Parameters

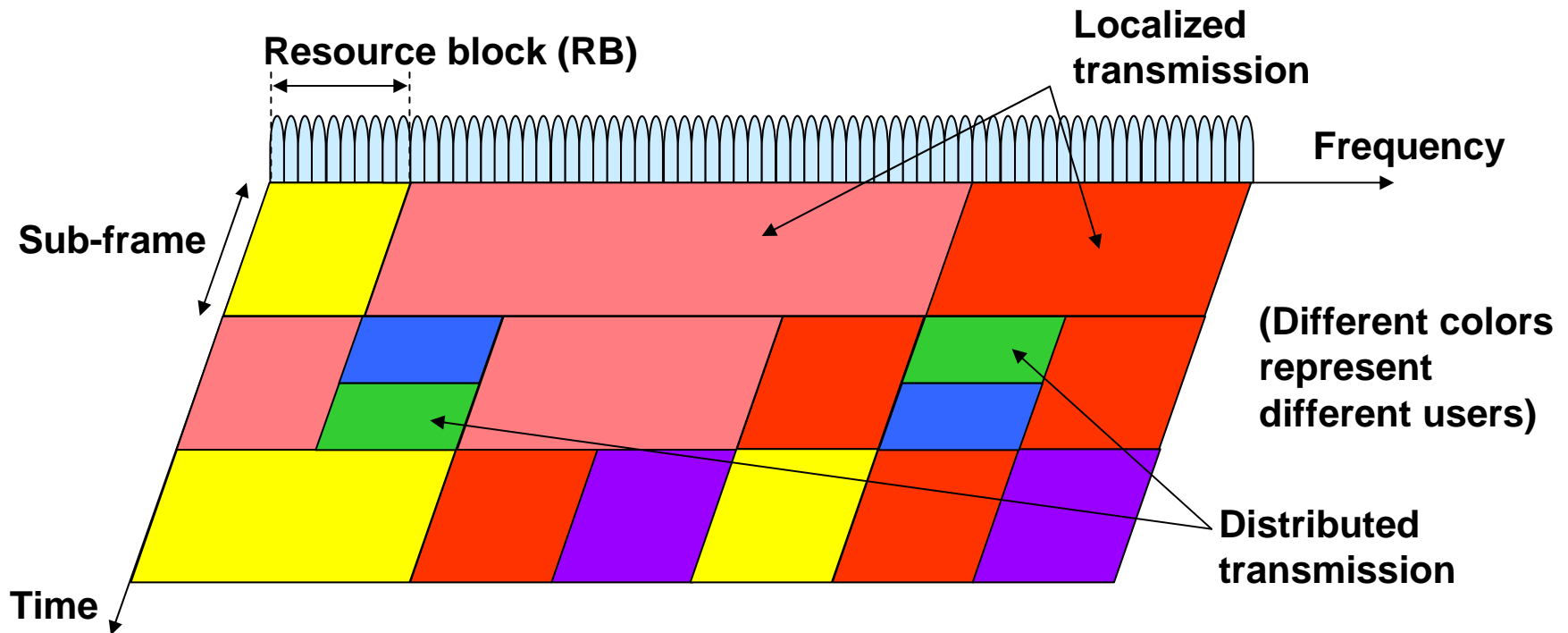
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Carrier frequency		IMT band
Multiple access scheme	UL	SC (Single-Carrier)–FDMA
	DL	OFDMA
Transmission bandwidth		1.4, 3, 5, 10, 15, 20 MHz
Sub-frame length		1 msec
Sub-carrier spacing		15 kHz
Cyclic prefix length	Short	4.7 μsec
	Long	16.7 μsec
Modulation scheme		QPSK, 16QAM, 64QAM* * Optional in UL
Channel coding		Turbo coding
Multi-antenna		1-by-2, 2-by-2 (4-by-2), 4-by-4 MIMO

OFDM-Based Downlink Radio Access

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- Robust against multipath interference (MPI)
- Flexibly accommodates different spectrum arrangements
- High affinity to advanced techniques
 - Frequency domain channel-dependent scheduling
 - MIMO multiplexing/diversity
 - High quality reception using soft combining for MBMS signal



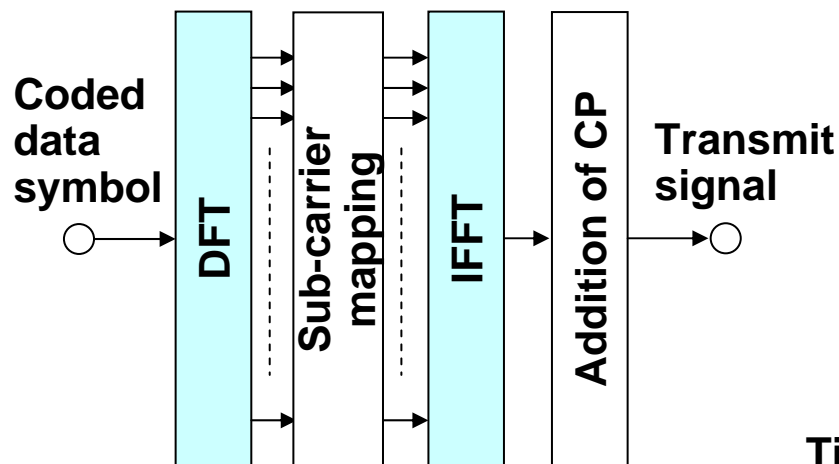
Single-Carrier-Based Uplink Radio Access

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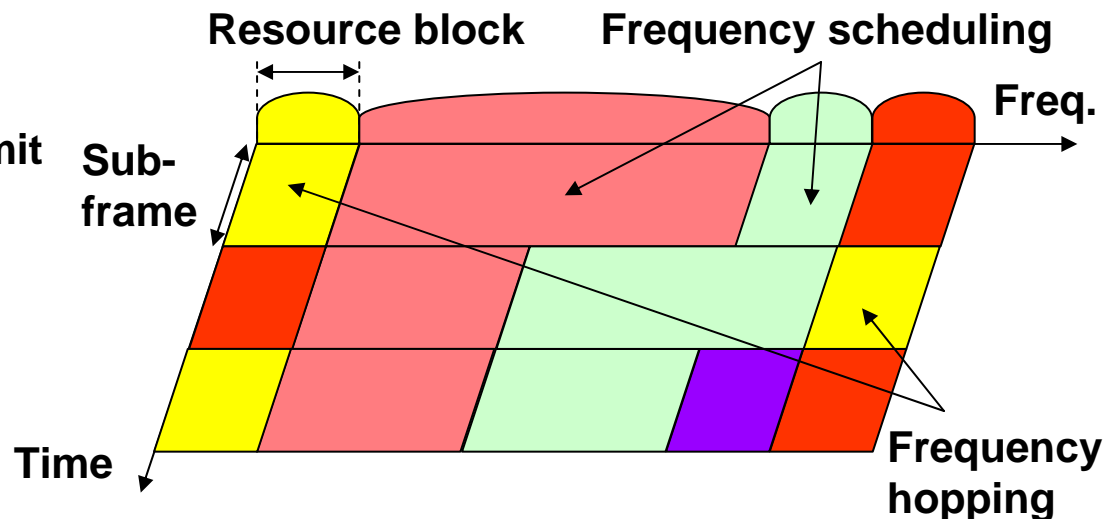
◆ Single-carrier based FDMA access in uplink

- Low PAPR (Peak-to-average power ratio) achieves wide area coverage using limited transmission power
- Localized and/or distributed FDMA establishes intra-cell orthogonality in frequency domain
- Employs frequency domain equalizer with cyclic prefix to suppress MPI *

* D. Falconer, et al., "Frequency domain equalizer for single-carrier broadband wireless access," *IEEE Commun. Mag.*, vol. 40, no. 4, pp. 58 – 66, Apr. 2002.



DFT-Spread OFDM



Contiguous resource units are assigned to UE to maintain the single-carrier property

Major Radio Access Features in Rel-8 LTE (1)

■ Inter-Node B (cell) synchronization

- Radio interface supports **inter-Node B asynchronous mode as baseline**
- Utilize merits of synchronized operation for MBMS with SFN and inter-cell interference coordination (ICIC), etc.

■ Support of scalable transmission bandwidths

- 1.4, 3.0, 5, 10, 15, 20 MHz

■ Support of packet based radio access only

- Simple protocol architecture using **shared channel**
- Support VoIP capability

■ Cell search: Process to search for best cell with minimum path loss

- **SCH (Synchronization Channel)** and **Physical BCH (Broadcast Channel)** structures supporting unified cell search in scalable transmission bandwidth from 1.4 to 20 MHz
- **Hierarchical SCH structure**

■ Reference signal (RS): Used for channel estimation and channel-quality measurement

- **Orthogonal RSs** between transmitter antennas in MIMO

■ Application of essential techniques for packet radio access

- Frequency domain scheduling, AMC, Hybrid ARQ, Transmission power control, RACH, etc.

Major Radio Access Features in Rel-8 LTE (2)

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■ Efficient control signal structure

- **PBCH (Physical BCH) signal** with time diversity
- **DL L1 /L2 control signals:** PCFICH, PHICH, PDCCH
- **UL L1/L2 control signals:** PUCCH using intra-TTI frequency hopping

■ Application of MIMO channel transmission

- Baseline is 2-by-2 MIMO in DL and 1-by-2 SIMO in UL
- Single-user MIMO and multiuser MIMO (multiuser MIMO only in UL)

■ Shorter delay (latency)

- Reduce transmission and connection delays
- Achieve short control delay and interruption time during handover
 - ✓ Short TTI, Simplified RRC procedure, Simple RRC states

■ High-quality MBMS (Multimedia Broadcast Multicast Service)

- Synchronous transmissions from multiple cell sites and soft-combining reception at a UE in SFN using OFDM

■ Simple channel structures

- Decrease number of physical and transport channels
- Simple mapping between channels belonging to different layers

Targets for IMT-Advanced

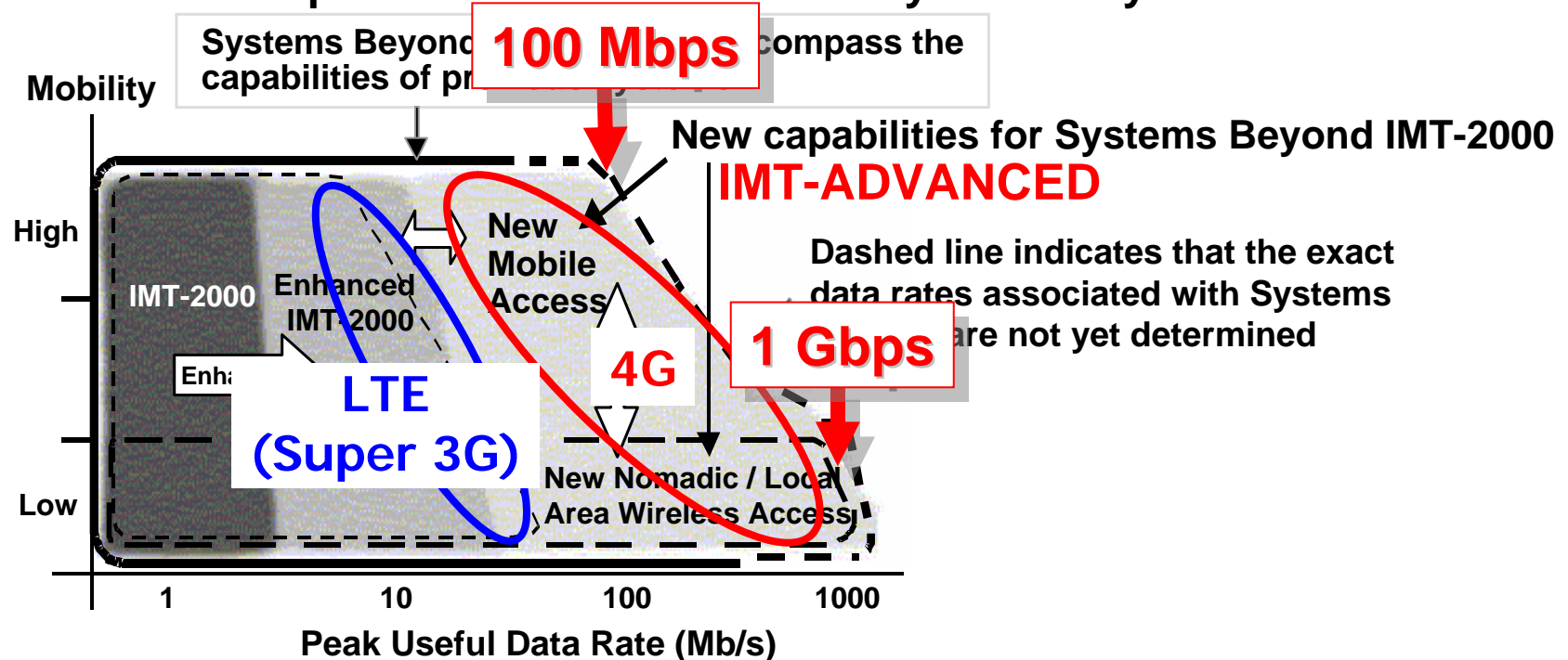
Targets for IMT-Advanced

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◆ Recommendation ITU-R M.1645

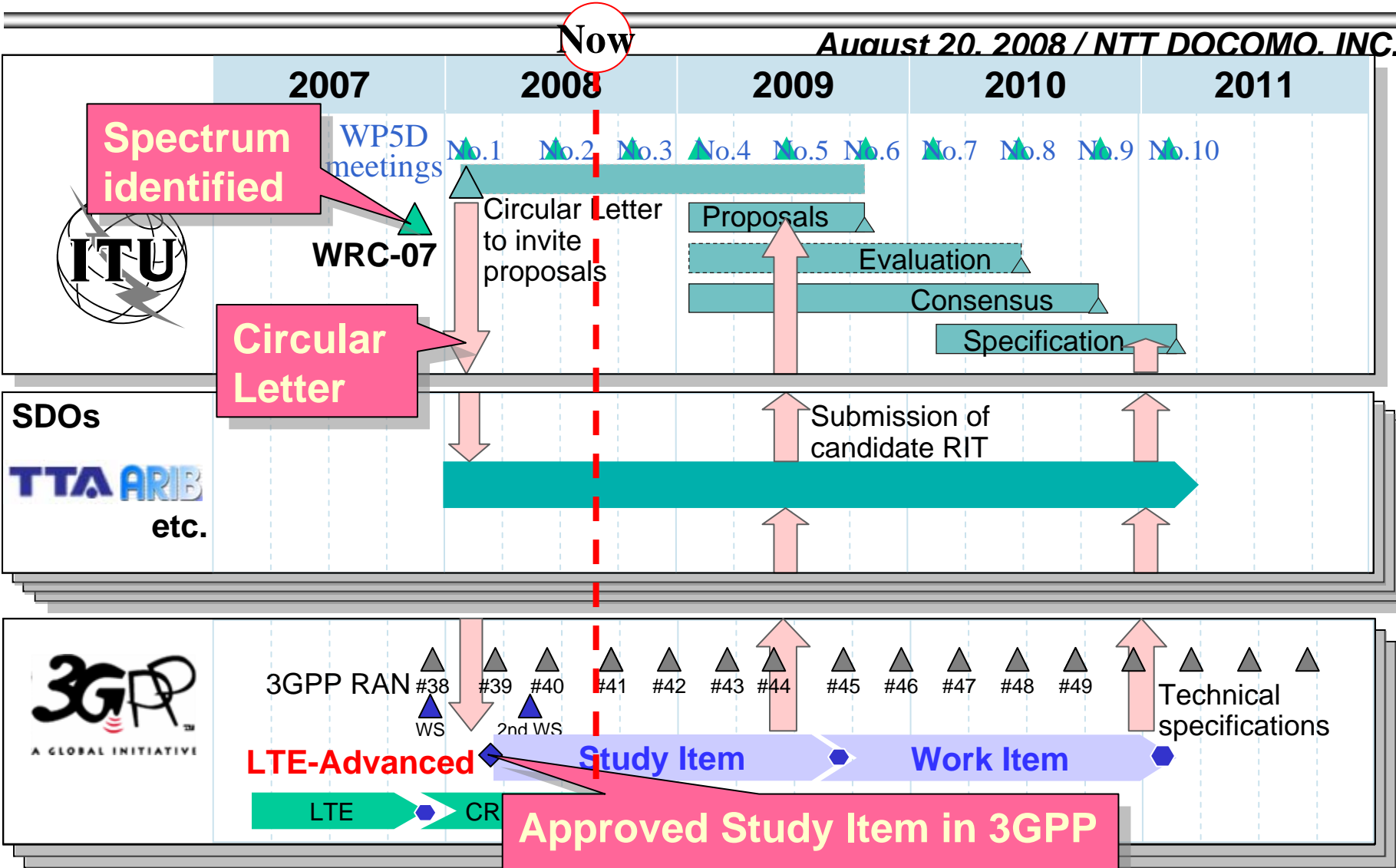
Framework and overall objectives for the future development of IMT-2000 and systems beyond IMT-2000

Illustration of capabilities for IMT-2000 and systems beyond IMT-2000



Schedule for IMT-Advanced

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- In 3GPP, LTE-Advanced is regarded as IMT-Advanced
- DOCOMO continues to contribute to IMT-Advanced

Requirements for LTE-Advanced

High-Level Requirements for LTE-Advanced

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- LTE-Advanced should be real broadband wireless networks that provide peak data rates equal to or greater than those for wired networks, i.e., FTTH (Fiber To The Home), while maintaining equivalent QoS
 - Requires complete backward compatibility, i.e., full support of Rel-8 LTE and its enhancement in LTE-Advanced
 - High-level requirements
 - Reduced network cost (cost per bit)
 - Better service provisioning
 - Compatibility with 3GPP systems
-
- Minimum requirement for LTE-Advanced is to meet or exceed IMT-Advanced requirements within ITU-R time plan
 - Furthermore, LTE-Advanced targets performance higher than that for Rel-8 LTE in order to satisfy future user demand and to be a competitive mobile communications system

Radio Access Requirements

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- **Full support of Rel-8 LTE and its enhancement within the same spectrum**
 - ➔ **Basically same radio parameters and multi-access schemes**
- **Lower latencies in C-plane and U-plane compared to those in Rel-8 LTE**
- **Improve system performance**
 - **Peak spectrum efficiency**
 - **Capacity (average spectrum efficiency)**
 - **Cell edge user throughput**
 - **VoIP capacity ➔ Higher capacity than in Rel-8 LTE**
 - **Mobility ➔ Improve system performance in low mobility up to 10 km/h**
 - **Coverage ➔ Equal or wider coverage than in Rel-8 LTE**

Performance Requirements (1)

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■ Peak data rate

- Need higher peak data rates in LTE-Advanced than those for LTE in order to satisfy future traffic demands

	LTE (Rel-8)		LTE-Advanced
DL	300 Mbps	x3.3	1 Gbps
UL	75 Mbps	x6.6	500 Mbps

- Wider transmission bandwidth
- Higher-order MIMO

■ Peak spectrum efficiency

- Must reduce bit cost per Hertz and improve user throughput particularly in local areas
- Higher peak spectrum efficiency is beneficial to achieving higher peak data rate with limited available transmission bandwidth

	LTE (Rel-8)		LTE-Advanced
DL	15 bps/Hz (4 streams)	x2.0	30 bps/Hz (8 streams)
UL	3.75 bps/Hz (1 stream)	x4.0	15 bps/Hz (4 streams)

- Higher-order MIMO etc.

Performance Requirements (2)

■ Capacity (Average spectrum efficiency)

- Need higher capacity to reduce further network cost per bit

	LTE (Rel-8)		LTE-Advanced
DL	1.69 bps/Hz/cell (2-by-2 MIMO)	x2.2	3.7 bps/Hz/cell (4-by-4 MIMO)
UL	0.735 bps/Hz/cell (1-by-2 SIMO)	x2.7	2.0 bps/Hz/cell (2-by-4 MIMO)

- Wider transmission bandwidth
- OFDM in uplink
- Higher-order MIMO
- Multi-cell transmission/reception
- Advanced receiver

■ Cell edge user throughput

- Need higher cell edge user throughput compared to that for LTE to provide better services

	LTE (Rel-8)		LTE-Advanced
DL	0.05 bps/Hz/cell (2-by-2 MIMO)	x2.4	0.12 bps/Hz/cell (4-by-4 MIMO)
UL	0.028 bps/Hz/cell (1-by-2 SIMO)	x2.5	0.07 bps/Hz/cell (2-by-4 MIMO)

- Higher-order MIMO
- Multi-cell transmission/reception
- Advanced receiver

* Target values are for Case 1 scenario in 3GPP, which is similar to Base Coverage Urban scenario in IMT.EVAL

Expect to satisfy these target values by

- increasing number of Rx antennas (approximately 1.5 times)
- increasing number of Tx antennas (approximately 1.1 times)
- employing other new/enhanced techniques (approximately 1.4 – 1.6 times)

Radio Access Techniques for LTE-Advanced

Proposed Techniques for LTE-Advanced

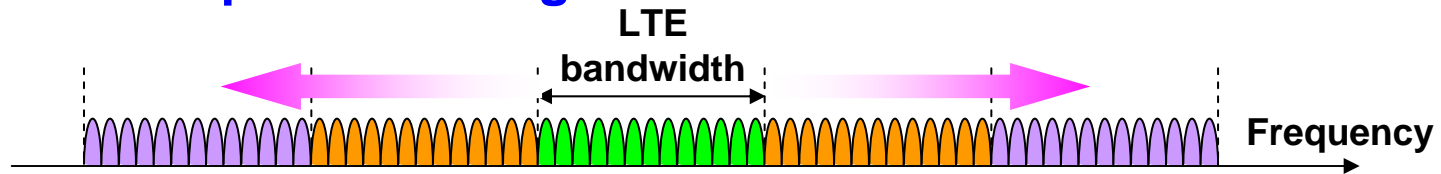
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- **Proposed radio access techniques for LTE-Advanced**
 1. **Asymmetric wider transmission bandwidth**
 2. **Layered OFDMA multi-access**
 3. **Advanced multi-cell transmission/reception techniques**
 4. **Enhanced multi-antenna transmission techniques**
 5. **Enhanced techniques to extend coverage area**

Asymmetric Wider Transmission Bandwidth

Support of Wider Bandwidth

- Require wider transmission bandwidth near 100 MHz to reduce bit cost per Hertz and to achieve peak data rate higher than 1 Gbps
- Continuous and discontinuous spectrum allocations
- **Continuous spectrum usage**



- ✓ Can simplify eNB and UE configuration
- ✓ Possible frequency allocation in new band, e.g., 3.4 – 3.8 GHz band
- ✓ **In this case, the same sub-carrier separation should be maintained over the entire system bandwidth** → Simple UE with single FFT
- **Discontinuous spectrum usage**
- ✓ Requires spectrum aggregation → UE has multiple RF receivers and multiple FFTs
- ✓ Hence, UE capability for supportable spectrum aggregation should be specified so that increases in UE size, cost, and power consumption are minimized



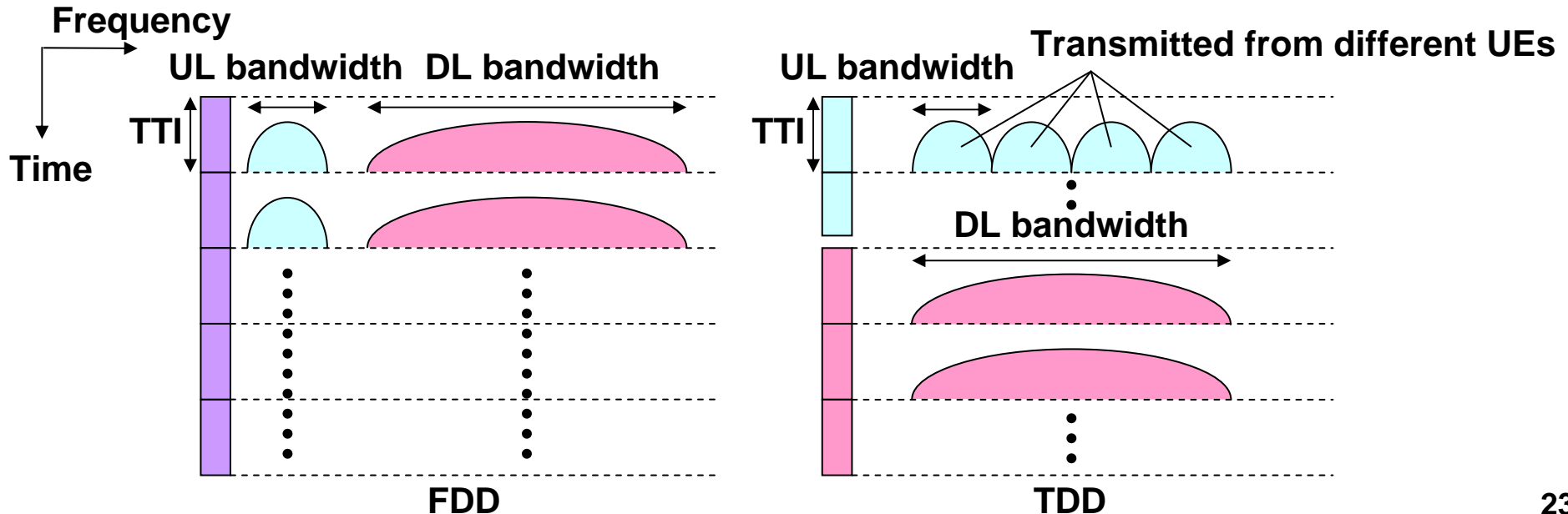
Asymmetric Transmission Bandwidth

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■ Asymmetric transmission bandwidth

- Required bandwidth in uplink will be much narrower than that in downlink considering current and future traffic demands in cellular networks
- In FDD, asymmetric transmission bandwidth eases pair band assignment
- In TDD, narrower transmission bandwidth is beneficial in uplink, since an excessively wider transmission bandwidth degrades accuracies of channel estimation and CQI (Channel Quality Indicator) estimation

→ Propose asymmetric transmission bandwidth in both FDD and TDD (e.g., near 100 MHz in DL and near 40 MHz in UL)



Layered OFDMA Multi-access

Layered OFDMA

■ Requirements for multi-access scheme

- Support of transmission bandwidth wider than 20 MHz, i.e., near 100 MHz, to achieve peak data rate requirements, e.g., higher than 1 Gbps
- Coexist with Rel-8 LTE in the same system bandwidth as LTE-Advanced
- Optimize tradeoff between achievable performance and control signaling overhead
 - ✓ Obtain sufficient frequency diversity gain when transmission bandwidth is approximately 20 MHz
 - ✓ Control signaling overhead increases according to increase in transmission bandwidth
- Efficient support of scalable bandwidth to accommodate various spectrum allocations



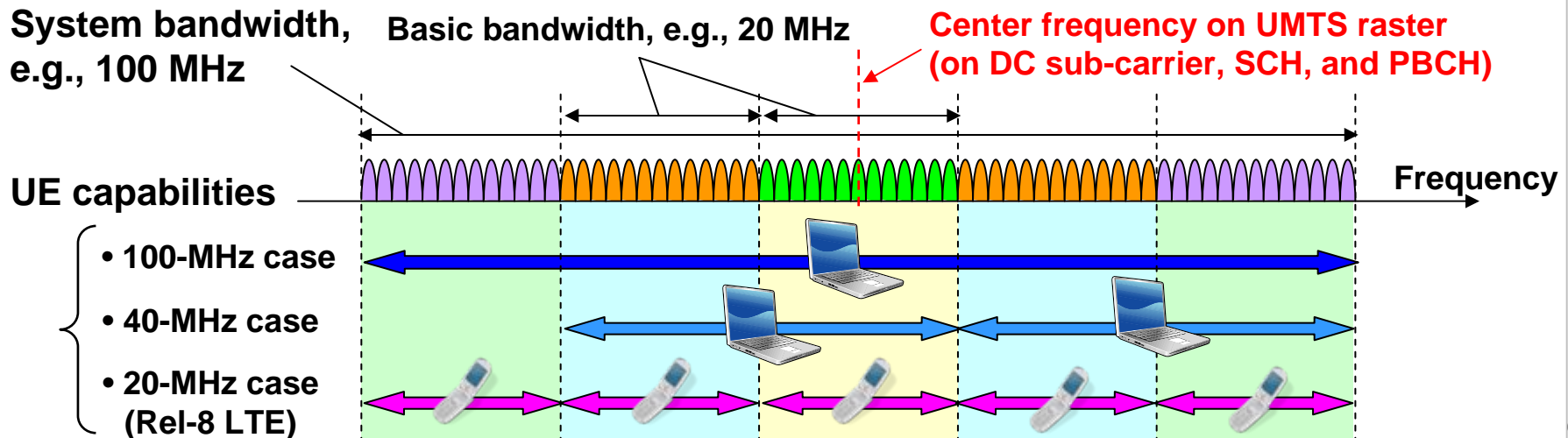
■ Propose Layered OFDMA radio access scheme in LTE-Advanced

- ✓ Layered transmission bandwidth
- ✓ Support of layered environments
- ✓ Layered control signal formats

Layered Transmission Bandwidth (1)

■ Layered transmission bandwidths

- Layered structure comprising multiple basic frequency blocks
 - ✓ Entire system bandwidth comprises multiple basic frequency blocks
 - ✓ Bandwidth of basic frequency block is, e.g., 15 – 20 MHz
 - Principle of UE access method
 - ✓ LTE-A UE with different capability and Rel.8-LTE UE can camp at any basic frequency block(s)
- ➔ Our concept was adopted in agreements at RAN WG1#53bis as carrier aggregation comprising two or more component carriers (corresponding basic frequency block)

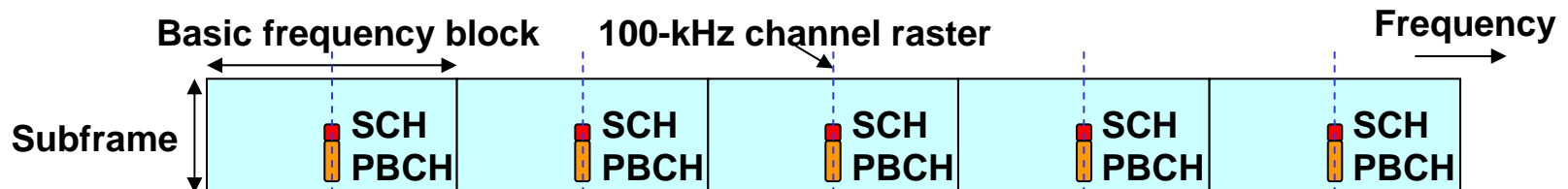


Layered Transmission Bandwidth (2)

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■ Layered transmission bandwidths

- ✓ Center frequency of each component carrier (basic frequency block) should be located on 100-kHz UMTS channel raster
- ✓ Synchronization Channel (SCH) and Physical Broadcast Channel (PBCH) are transmitted from all component carriers
 - ➔ Rel-8 LTE UE can camp at any component carriers in LTE-Advanced frequency band
- For continuous spectrum usage, reduce number of sub-carriers based on bandwidths defined in Rel-8 LTE or insert sub-carriers between component carriers to satisfy the two conditions

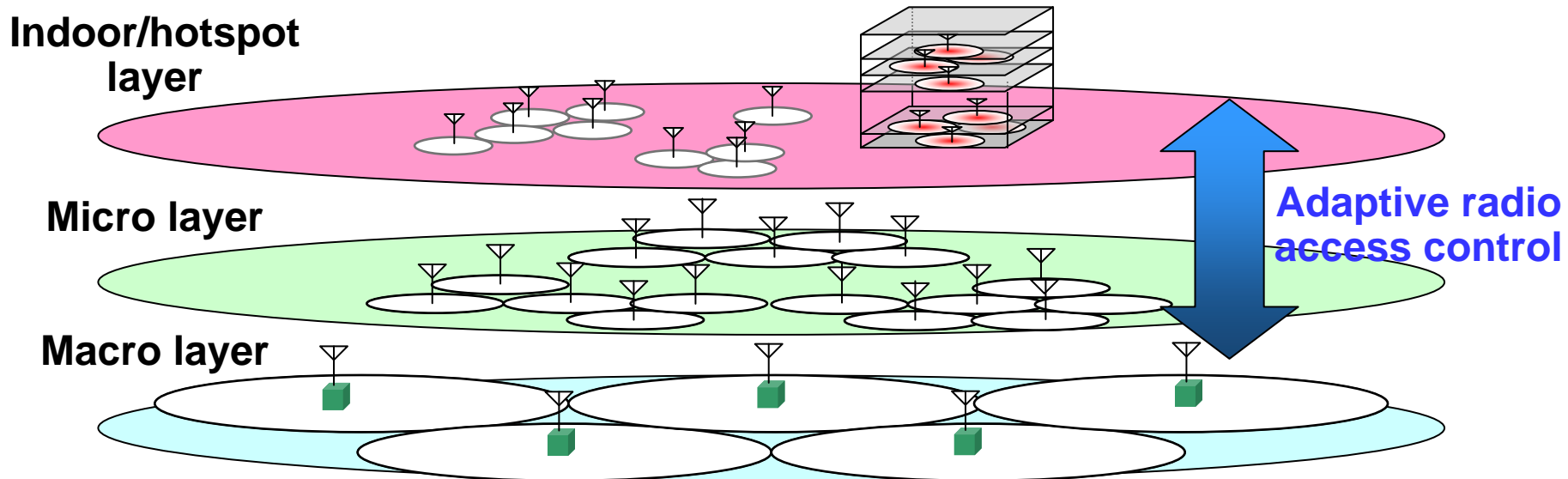


Support of Layered Environments

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■ Support of layered environments

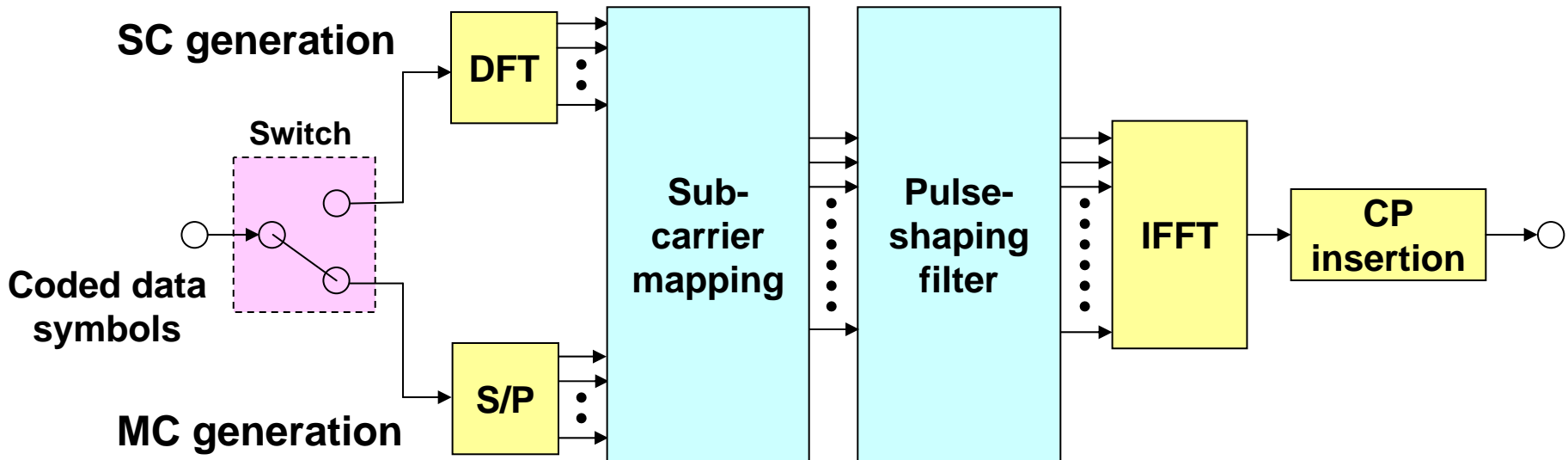
- Achieves highest data rate (user throughput) or widest coverage according to respective radio environments such as macro, micro, indoor, and hotspot cells and required QoS
 - MIMO channel transmission (MIMO multiplexing/MIMO diversity) with high gain should be used particularly in local areas
- ➔ Adaptive multi-access control according to radio environment



UL Hybrid Radio Access Scheme (1)

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- Propose **SC/MC hybrid radio access**, i.e., to introduce **OFDM** in addition to **DFT-Spread OFDM** in uplink
 - ➔ Introduction of OFDM as complement to DFT-Spread OFDM is under discussion in RAN WG1 meeting
 - Universal switching of SC/MC based access using frequency domain multiplexing/de-multiplexing



UL Hybrid Radio Access Scheme (2)

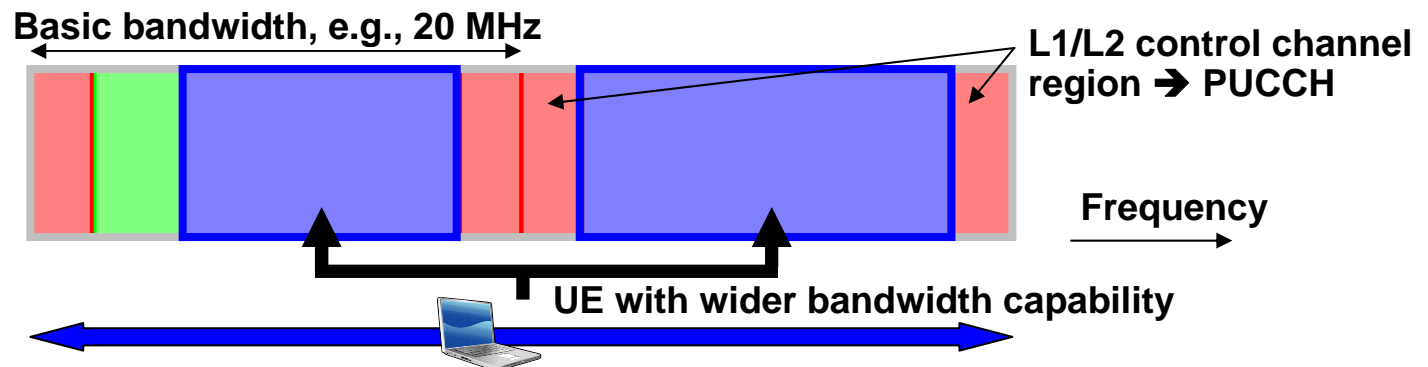
■ Merits of SC/MC hybrid radio access in uplink

• High gain in user throughput

- ✓ OFDM has higher robustness against MPI than DFT-Spread OFDM
→ OFDM provides higher user throughput than DFT-Spread OFDM when MIMO transmission is employed
- ✓ Radio interface should be designed to support any kind of receiver → OFDM provides much higher gain in MLD-based signal detection than SIC etc.

• Flexibility of resource assignment

- ✓ SC-FDMA with DFT-Spread OFDM provides inefficient resource assignment when wideband transmission UE is assigned (e.g., PUCCH is transmitted in the middle of transmission bandwidth)
→ Requires more flexible resource assignment using non-contiguous RB allocation



UL Hybrid Radio Access Scheme (3)

One deployment scenario to introduce SC/MC hybrid radio access

■ Performance improvement

- Optimization of PAPR (coverage) and achievable peak data rate according to inter-site distance, cell structure, and QoS requirements
- High affinity to UL MIMO transmission

■ Reduction in number of implementation options

- Fewer options for implementation and testing

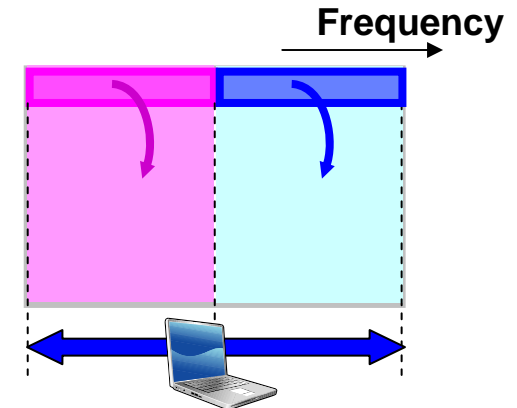
➔ Reduce variations in UE categories

	Transmission bandwidth of less than 20 MHz	Transmission bandwidth wider than 20 MHz
One stream (rank 1)	<ul style="list-style-type: none"> • Clustered DFT-Spread OFDM ➔ Add clustered function to Rel-8 LTE 	<ul style="list-style-type: none"> • Clustered DFT-Spread OFDM ➔ Add clustered function to Rel-8 LTE
Two streams (rank 2)	<ul style="list-style-type: none"> • OFDM ➔ Add OFDM function (and/or) • Clustered DFT-Spread OFDM ➔ Add clustered function to Rel-8 LTE 	<ul style="list-style-type: none"> • OFDM ➔ Add OFDM function

Layered Control Signal Formats (1)

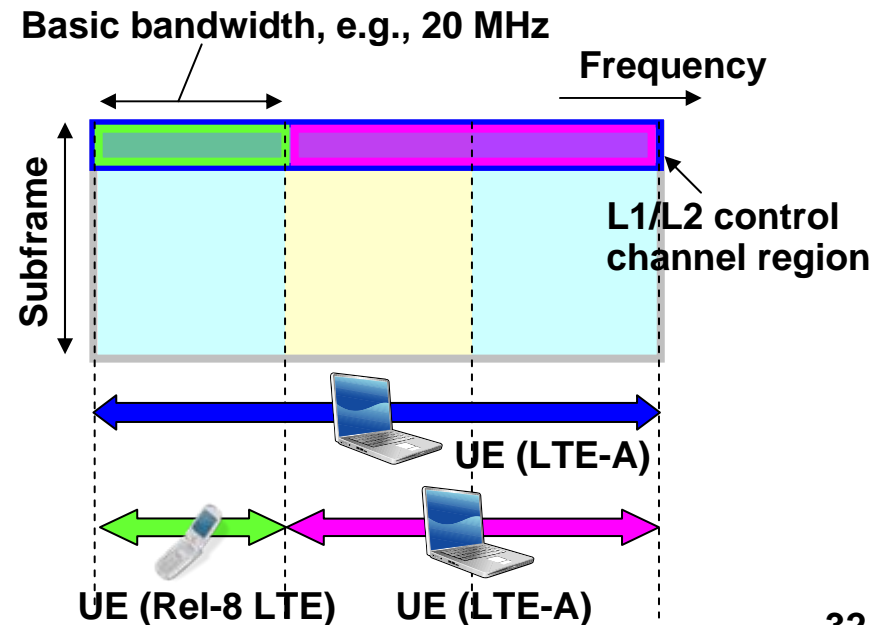
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- **Straightforward extension of L1/L2 control signal format of Rel-8 LTE to LTE-Advanced**
- Independent control channel structure for each component carrier
- Control channel supports only shared channel belonging to the same component carrier



Examples of layered multiplexing of L1/L2 control signals

- **Propose layered L1/L2 control signal formats**
- Achieve **high commonality** with control signal formats in Rel-8 LTE
- Use **layered L1/L2 control signal formats** according to assigned transmission bandwidth to achieve efficient control signal transmission for **LTE-Advanced**



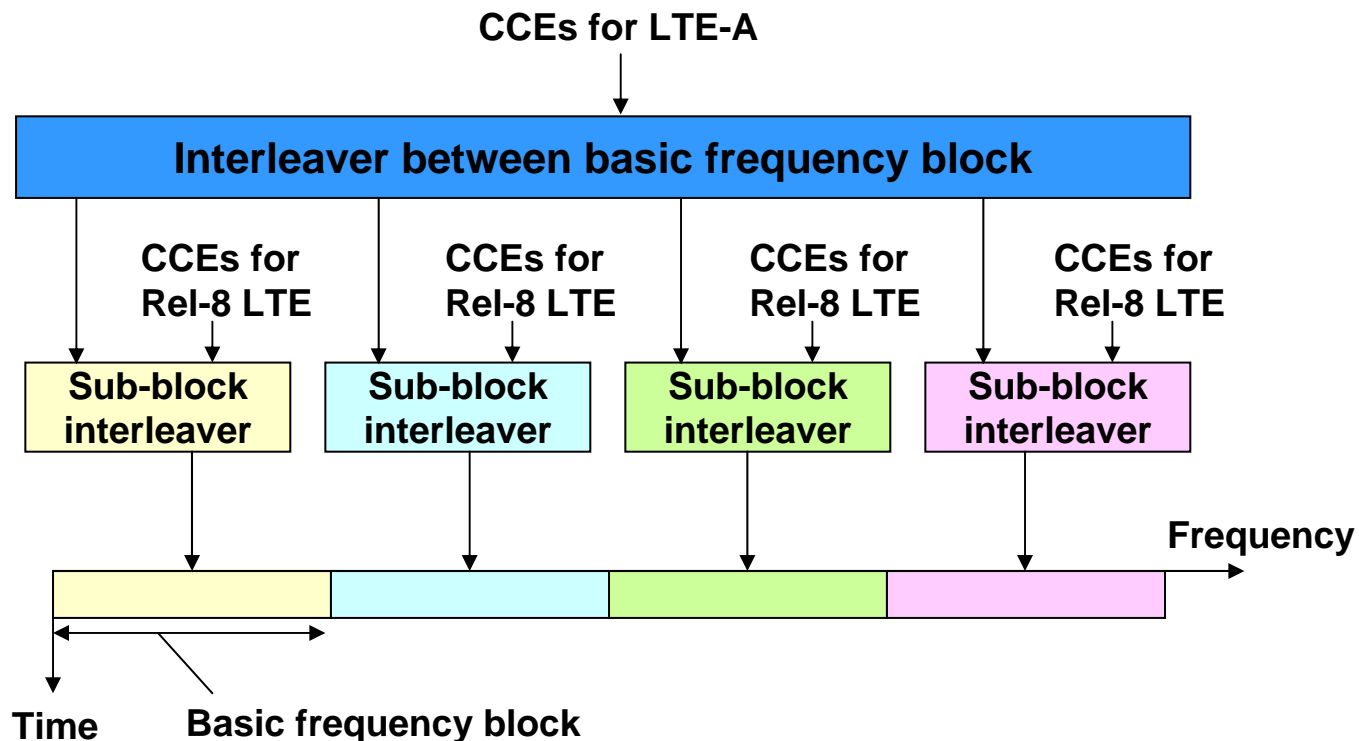
Layered Control Signal Formats (2)

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■ Interleaver structure for layered control signal formats

Require new interleaver / mapping scheme to support layered L1/L2 control signal structure

- Control Channel Elements (CCEs) for Rel-8 LTE are mapped to one component carrier
- CCEs for LTE-A are mapped to multiple component carriers

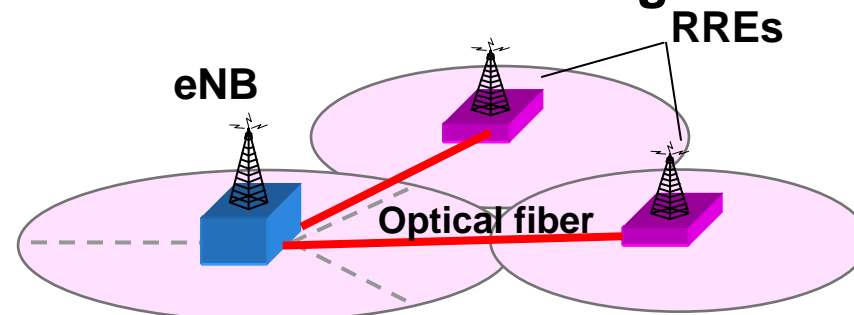


Advanced Multi-cell Transmission/Reception Techniques

Advanced Multi-cell Transmission/Reception Techniques

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- **Use of advanced multi-cell transmission/reception techniques**
 - Use advanced multi-cell transmission/reception, i.e., coordinated multipoint transmission/reception, to increase frequency efficiency and cell edge user throughput
 - Proposed techniques –
 - ✓ **Fast inter-cell interference (ICI) management (i.e., inter-cell interference coordination (ICIC)) aiming at inter-cell orthogonalization**
 - ✓ **Fast handover at different cell sites**
- **Use cell structure employing sets of remote radio equipment (RREs) more actively in addition to cell structure employing independent eNB**
 - RREs are beneficial to both ICI management and fast handover



Inter-cell Orthogonalization

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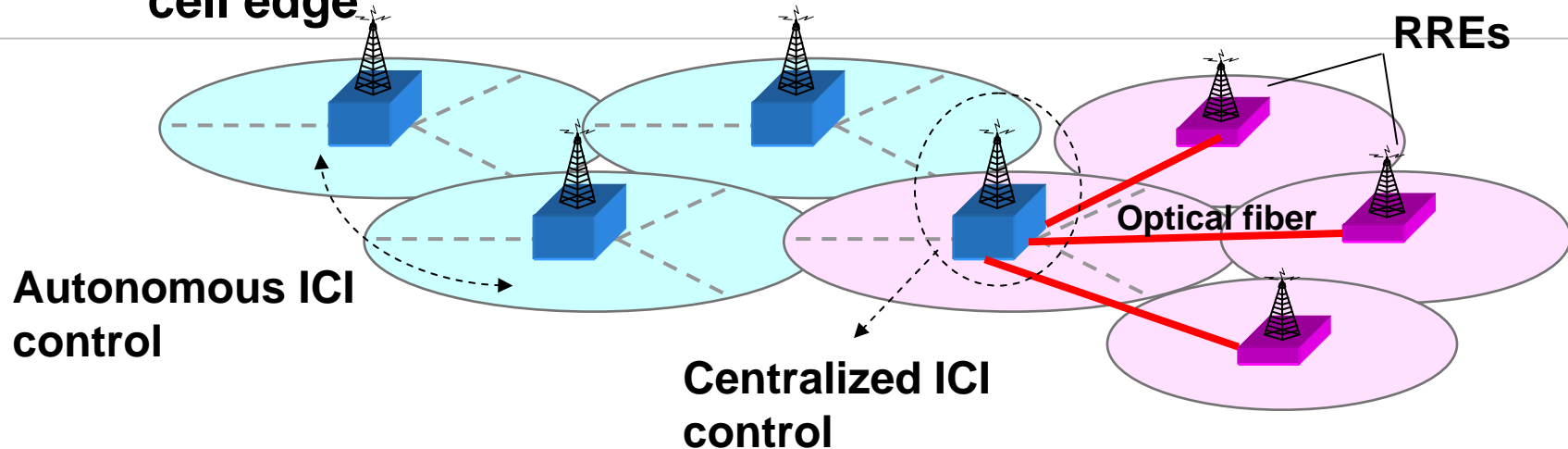
- **One-cell frequency reuse**
 - **Baseline is one-cell frequency reuse** to achieve high system capacity
- **Intra-cell orthogonalization**
 - Achieves intra-cell orthogonal multi-access (multiplexing) in both links as well as in Rel-8 LTE
- **Inter-cell orthogonalization**
 - Although ICIC is adopted in Rel-8 LTE, it only introduces fractional frequency reuse at cell edge with slow control speed using control signals via backhaul
 - **Inter-cell orthogonality will be established in LTE-Advanced to achieve high frequency efficiency and high data rate at cell edge**

		W-CDMA	LTE (Rel-8)	LTE-Advanced
Intra-Cell Site	DL	(Partially) orthogonal	Orthogonal	Orthogonal
	UL	Non-orthogonal	Orthogonal	Orthogonal
Inter-Cell Site	DL	Non-orthogonal	Non-orthogonal	(Quasi)-orthogonal
	UL	Non-orthogonal	Non-orthogonal	(Quasi)-orthogonal

Fast Radio Resource Management for Inter-cell Orthogonalization

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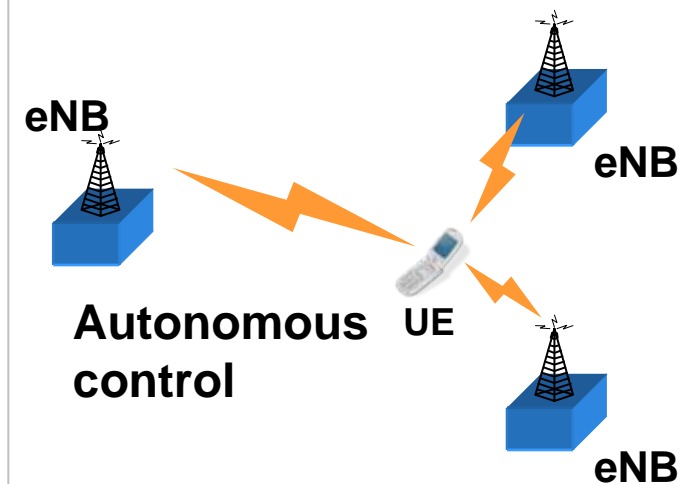
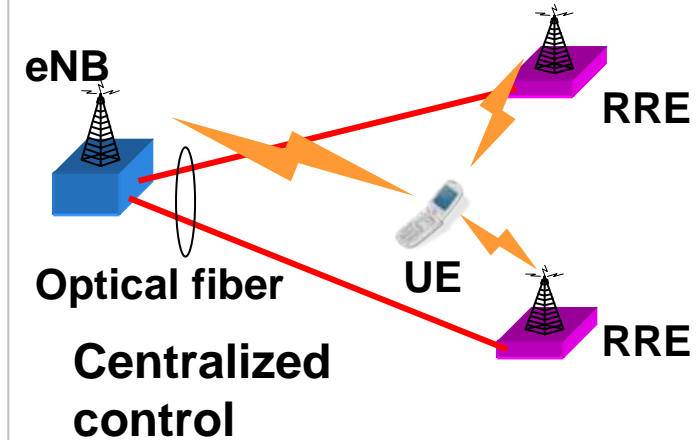
- Achieve inter-cell orthogonality through fast inter-cell interference (ICI) management
- **Centralized control:** ICI management among **RRE cells** using scheduling at central eNB
 - Achieves **complete inter-cell orthogonality**
- **Autonomous control (similar to Rel-8 LTE method):** ICI management among independent eNBs using control signals via backhaul and/or air
 - Achieves inter-cell quasi-orthogonality through faster control compared to Rel-8 LTE to achieve fractional frequency reuse at cell edge



Enhanced Macro Diversity and ICI Management Schemes to Achieve Inter-cell Orthogonalization

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- **Centralized control using remote radio equipment (RRE)**
 - ✓ DL
 - **Fast cell selection (FCS) in L1**
 - ✓ UL
 - **Multicell reception (MCR) with diversity combining at central eNB**
- **Autonomous control among independent eNBs**
 - ✓ DL
 - **Faster cell selection than that for Rel-8 LTE, i.e., as fast as possible, in L1 using bicast/forwarding in L2/L3**
 - ✓ UL
 - **Simultaneous reception at multiple cells or faster cell selection than that for Rel-8 LTE**



Enhanced Multi-antenna Transmission Techniques

Benefits of Higher-Order MIMO

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Necessity of higher-order MIMO channel transmissions

■ Traffic demand in the era of LTE-Advanced

- Requires higher peak frequency efficiency than that for Rel-8 LTE to satisfy the increased traffic demand in LTE-Advanced era
 - ➔ Increased number of antennas directly contributes to achieving higher peak spectrum efficiency

■ Local area optimization

- Since LTE-Advanced will focus on local area, higher peak frequency efficiency also contributes to increase in average frequency efficiency
- Higher-order MIMO is more practical in local areas

Number of Antennas Considered for LTE-Advanced

- User throughput is significantly improved according to the increase in the number of transmitter and receiver antennas, i.e., more effective than increasing modulation level
- Proposals for the number of supported antennas

	LTE (Rel-8)	LTE-Advanced
DL	Baseline: 2-by-2 MIMO Max: 4-by-4 MIMO	Baselines: 2-by-2, 4-by-2, and 4-by-4 according to UE categories and eNB types (optimization condition is FFS) Max: 8-by-8 MIMO
UL	Baseline: 1-by-2 SIMO	Baselines: 2-by-2 and 2-by-4 according to eNB types Max: 4-by-4(8) MIMO

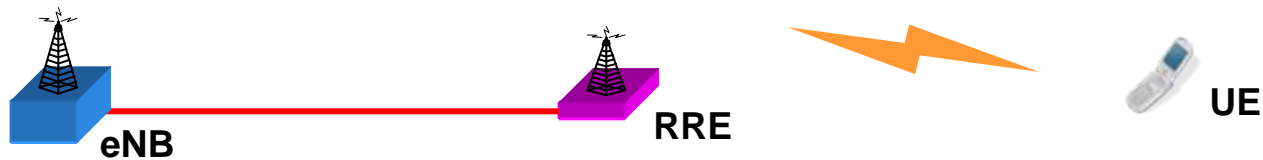
- All Rel-8 LTE MIMO channel techniques should be enhanced and applied to LTE-Advanced
 - MIMO transmission mode control according to different requirements/targets
 - Adaptive rank control according to channel conditions
 - Adaptive rate control through modulation and coding rates
 - Codebook based precoding

Enhanced Techniques to Extend Coverage Area

Enhanced Techniques to Extend Coverage (1)

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- **RREs using optical fiber** (“sector” belonging to the same eNB)
 - Effective in implementation of small size of eNB
 - Should be used in LTE-Advanced as effective technique to extend cell coverage



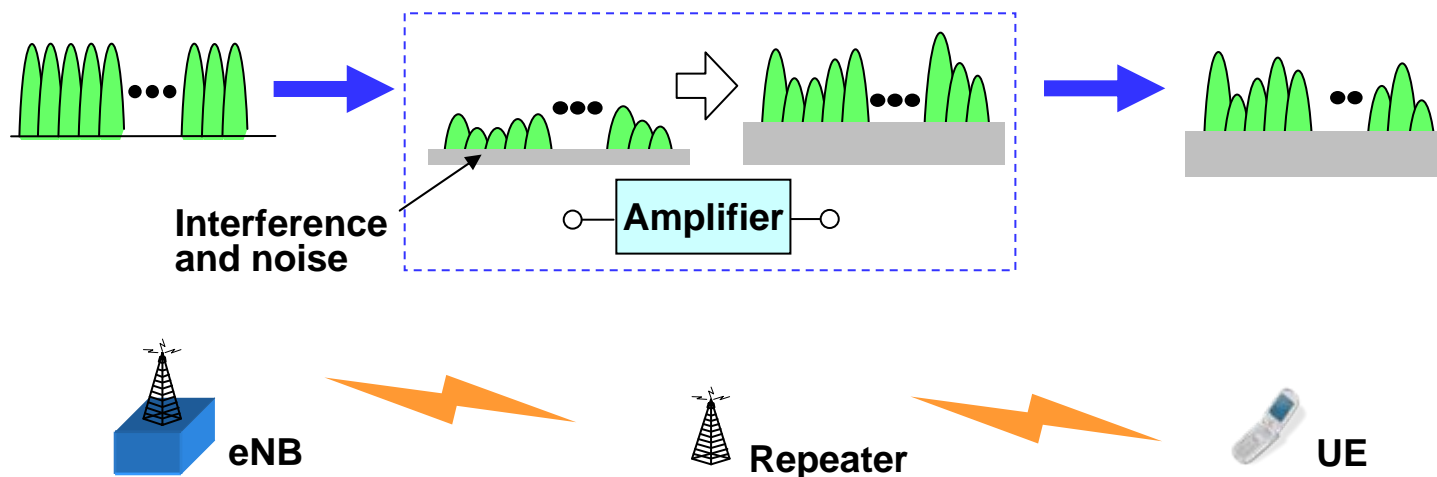
Enhanced Techniques to Extend Coverage (2)

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■ Relays using radio

• L1 relays with non-regenerative transmission, i.e., repeaters

- ✓ Use the same (or different) frequency/time resources
- ✓ Repeaters are effective in improving coverage in existing cells
- ✓ Since delay is shorter than cyclic prefix duration, no distinct additional change to radio interface is necessary
- ✓ Should be used as well as in 2G/3G networks



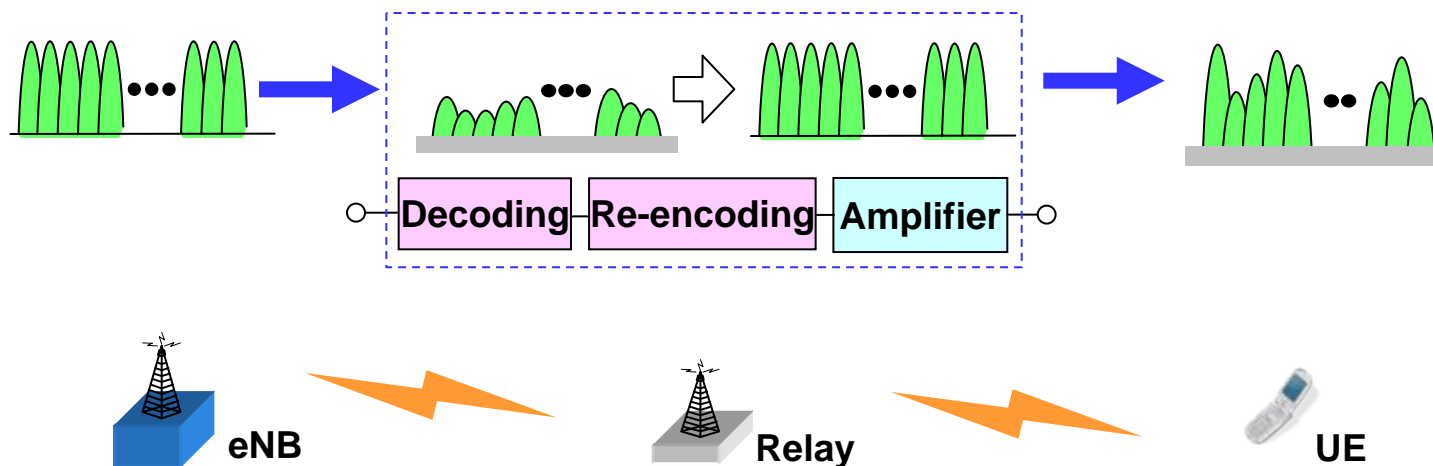
Enhanced Techniques to Extend Coverage (3)

August 20, 2008 / NTT DOCOMO, INC.

■ Relays using radio

• L2 and L3 relays

- ✓ Use different frequency/time resources
- ✓ L2 and L3 relays can achieve wide coverage extension via increase in SNR
- ✓ Problems to be solved are efficient radio resource assignment to signals to/from relay station, and long delay due to relay, etc.



Conclusion

■ Rel-8 LTE

- Commercial equipment is under development

■ Targets for LTE-Advanced

- Minimum requirement is to meet or exceed ITU-R requirements within ITU-R time plan
- LTE-Advanced targets higher performance than that for Rel-8 LTE

■ Proposed radio access techniques for LTE-Advanced

- **Asymmetric wider transmission bandwidth** to reduce network cost per bit and to achieve required peak data rate
- **Layered OFDMA** using layered physical channel structure with adaptive multi-access control to support layered environments and to achieve high commonality with Rel-8 LTE
- **Advanced multi-cell transmission/reception techniques** with inter-cell orthogonalization and fast handover
- **Enhanced multi-antenna transmission techniques** including higher-order MIMO channel transmission using larger number of antennas
- **Efficient modulation/detection and coding techniques**
- **Enhanced techniques to extend coverage area** such as RREs and relays using radio including repeaters