3G long-term evolution

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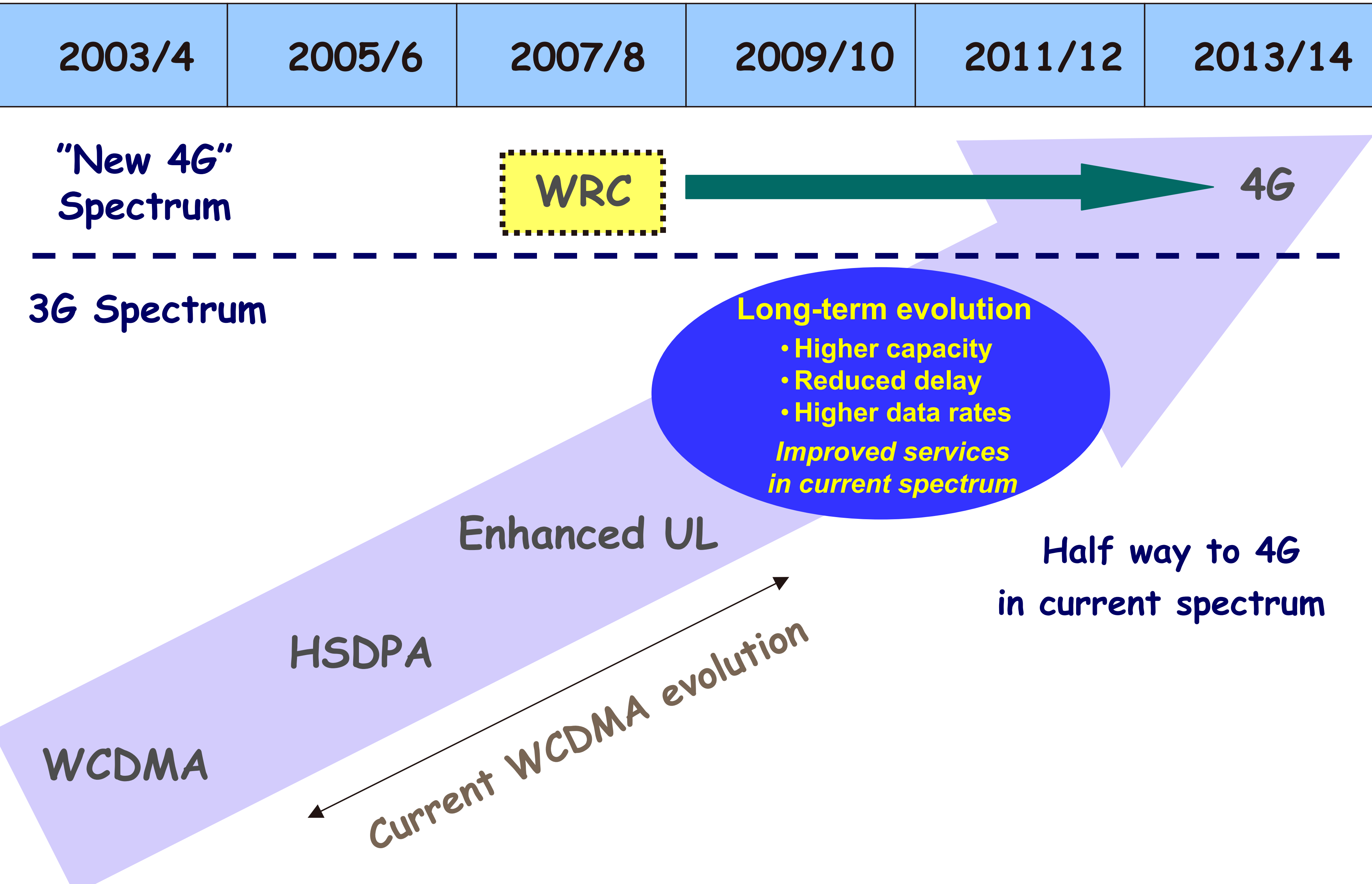
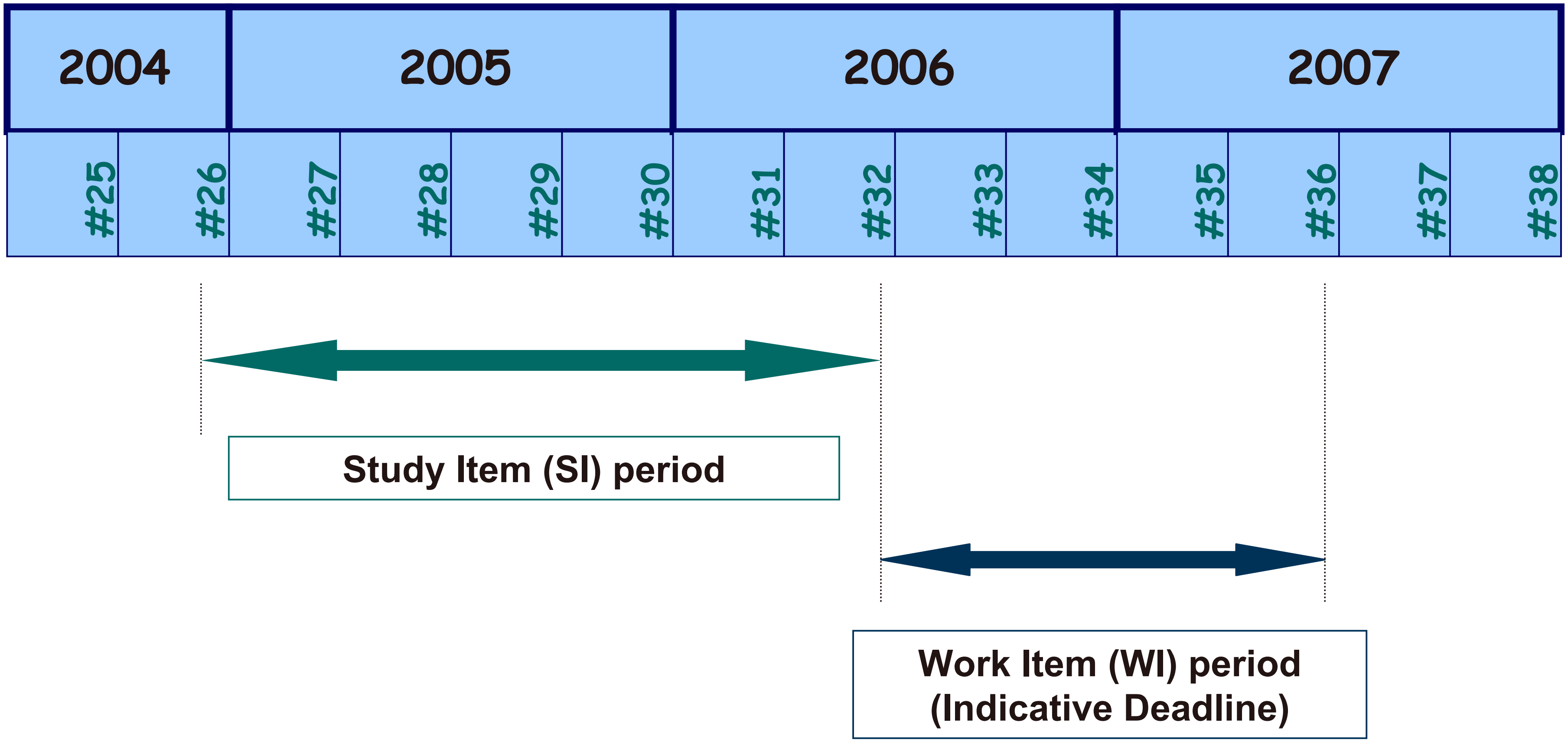

2003/4
2005/6
2007/8
2009/10
2011/12
2013/14
"New 4G" Spectrum
WRC
4G
3G Spectrum
Long-term evolution
• Higher capacity
• Reduced delay
• Higher data rates
Improved services in current spectrum
Enhanced UL
HSDPA
WCDMA
Current WCDMA evolution
Half way to 4G in current spectrum

Shedule for Long-term evolution SI & WI



3G long-term evolution

Requirements/targets

3G long-term evolution – *Key targets*

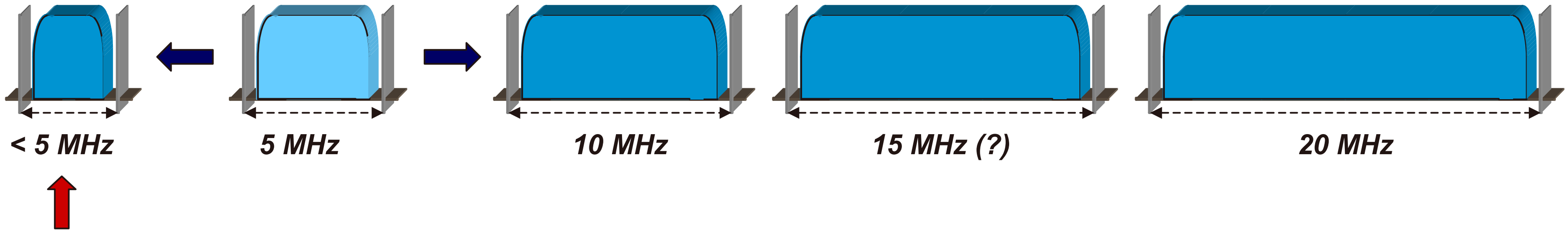
- **Packet-domain-services only (*including e.g. VoIP*)**
- **Much high data rates / user throughput**
- **Significantly reduced delay/latency**
- **Improved spectrum efficiency (*unicast as well as broadcast*)**
- **Reduced Radio-access-network cost as well as cost-effective migration from earlier 3GPP releases**
- **Spectrum flexibility**

Long-term evolution – *Spectrum flexibility*

- Operation in all cellular bands
  - *2100 MHz, 1900 MHz, 1700 MHz, 2600 MHz, 900 MHz, 800 MHz, 450 MHz, etc*

… *as well as other frequency bands*

- Efficient operation in differently-sized <u>spectrum allocations</u>
  - *Up to 20 MHz to enable very high data rates*
  - *Less than 5 MHz to enable smooth migration of e.g. 2G spectrum*



Current 3GPP assumption: 1.25 MHz and/or 2.5 MHz

Important to identify relevant spectrum allocations !

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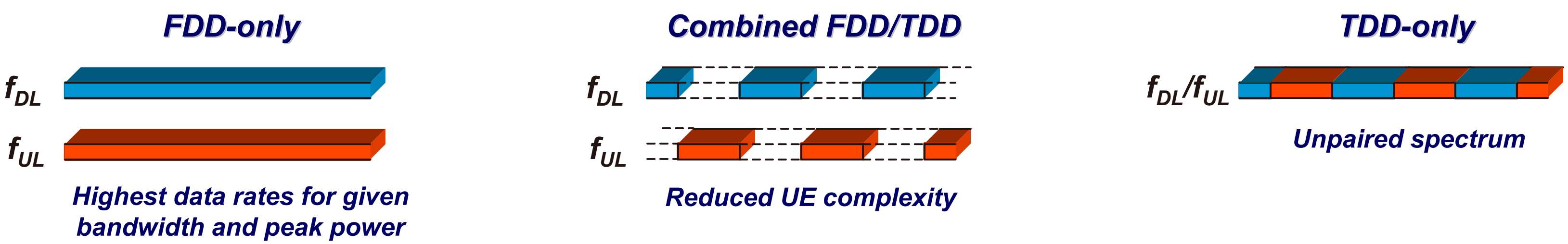
Evolved UTRA – *Duplex arrangement*

- *Operation in paired and unpaired spectrum "without unnecessary technology fragmentation"*

  ➡ *Support for FDD and TDD operation*
  - FDD-only: ***Simultaneous*** *uplink/downlink in* ***different*** *frequency bands*
  - TDD-only: ***Non-simultaneous*** *uplink/downlink in the* ***same*** *frequency band*

- Consider FDD extension to combined FDD/TDD ("*half-duplex FDD*")
  - ***Non-simultaneous*** *uplink/downlink in* ***different*** *frequency bands*
  - *Simplifies multi-band terminals (relaxed duplex-filter requirements)*
  - *Trade-off max data rate vs. terminal complexity*



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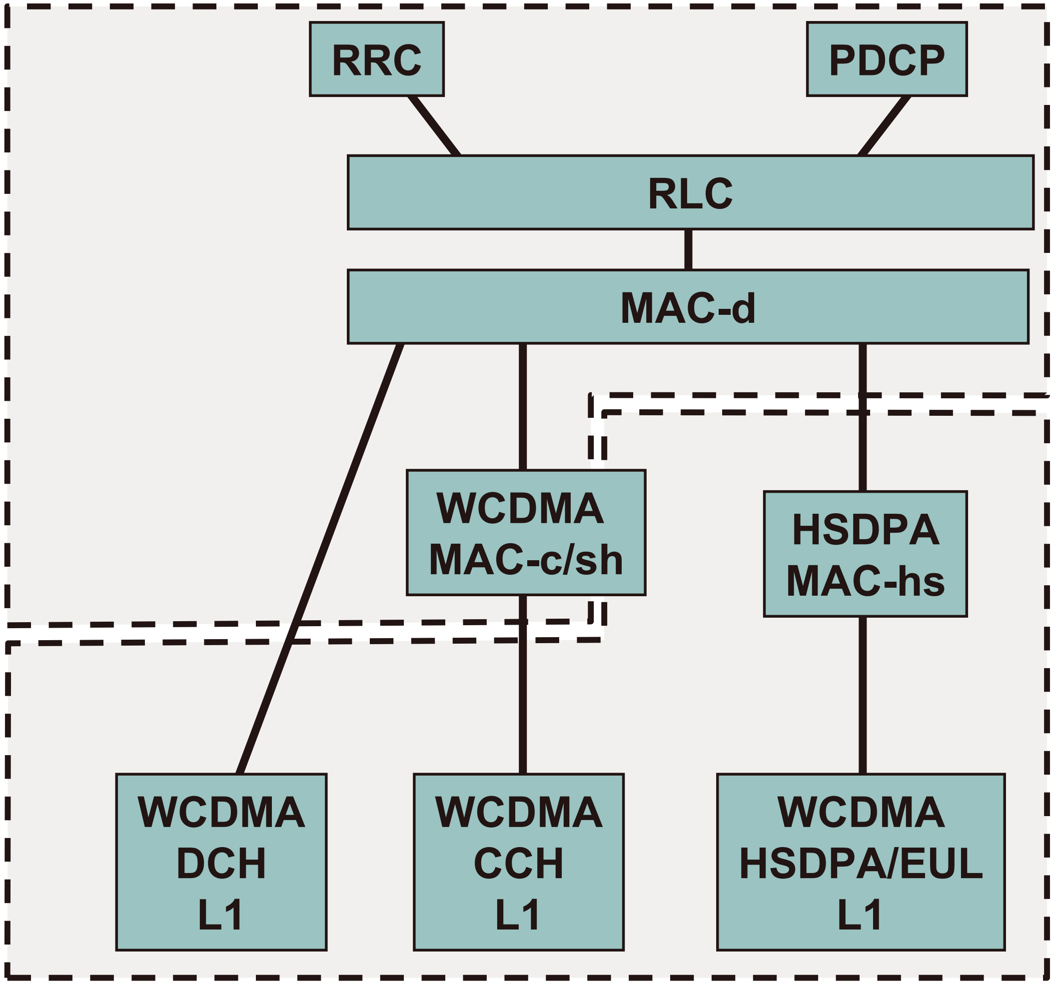
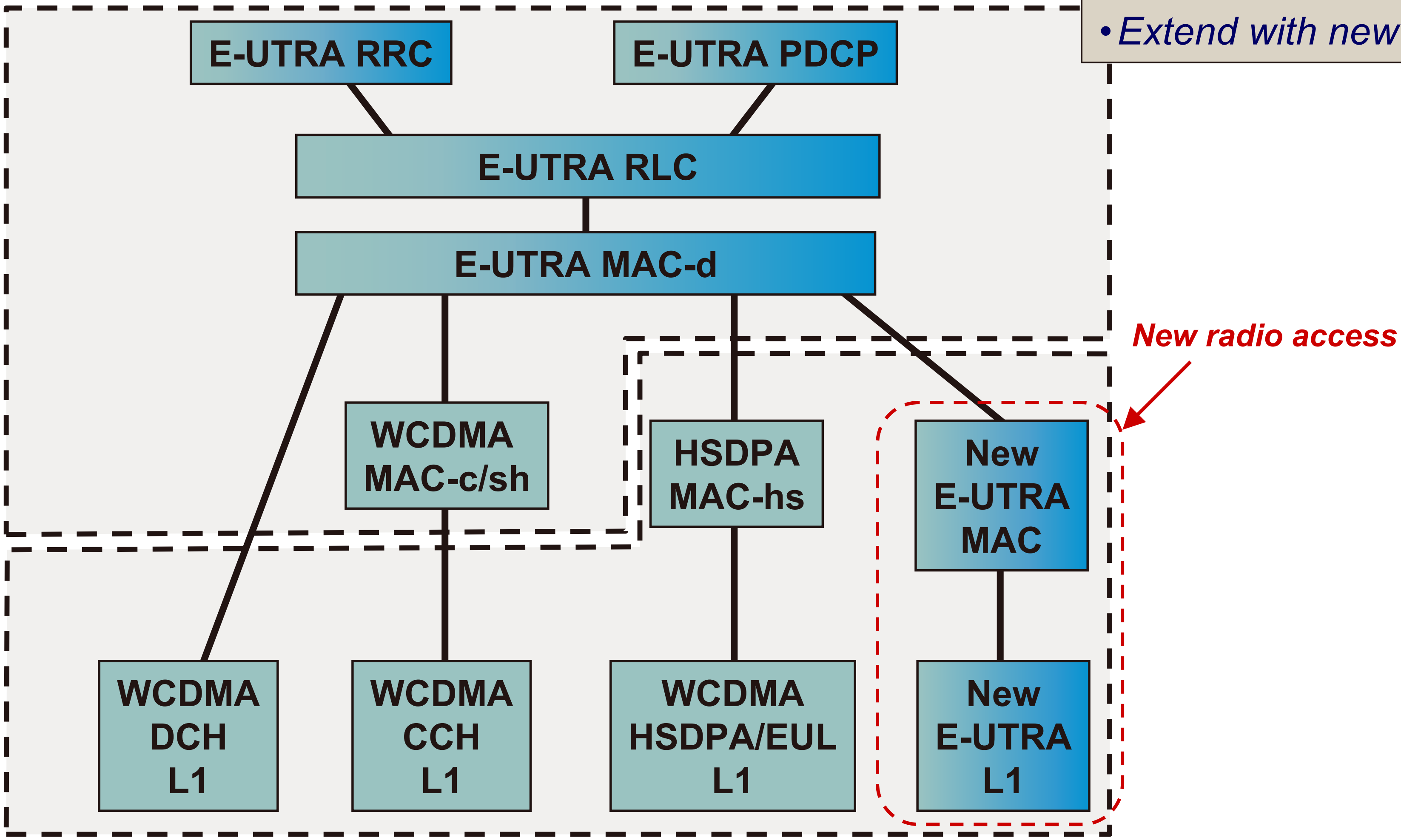
Current UTRA Protocol Stack



Evolved UTRA Protocol Stack

- *Evolve current 3GPP protocol stack*
- *Extend with new L1+MAC*



Evolved UTRA

New radio access

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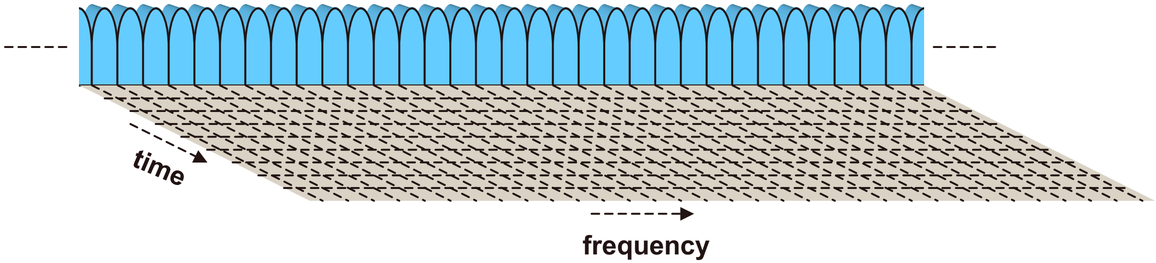
Evolved UTRA downlink – *Key requirements*

- Good link performance in diverse channel conditions
  - *Time-dispersive environments*
  - *High mobility*
- Good system performance
  - *High capacity*
  - *Good coverage*
- Low transmission delay (*to achieve very low RAN RTT*)
- Well-matched to multi-antenna techniques including MIMO
- Efficient for broadcast
- Spectrum flexibility

Evolved UTRA downlink – *OFDM*

- Good link performance in time-dispersive environments (*without equalizer*)
  - *More critical in case of MIMO*
- Access to frequency domain
  - *Enables frequency-domain adaptation*
  - *Interference co-ordination/avoidance* (*two-dimensional "playground"*)
- Broadcast efficiency
- Straightforward to extend to different transmission bandwidth
  - *From a baseband point-of-view – RF is still a potential major issue*



Conventional OFDM
- *Square-shaped pulses*
- *Cyclic prefix*
- ***Current assumption***

or

Pulse-shaped OFDM
- *Non-square-shaped pulses*
- *No cyclic prefix*
- ***Under consideration***

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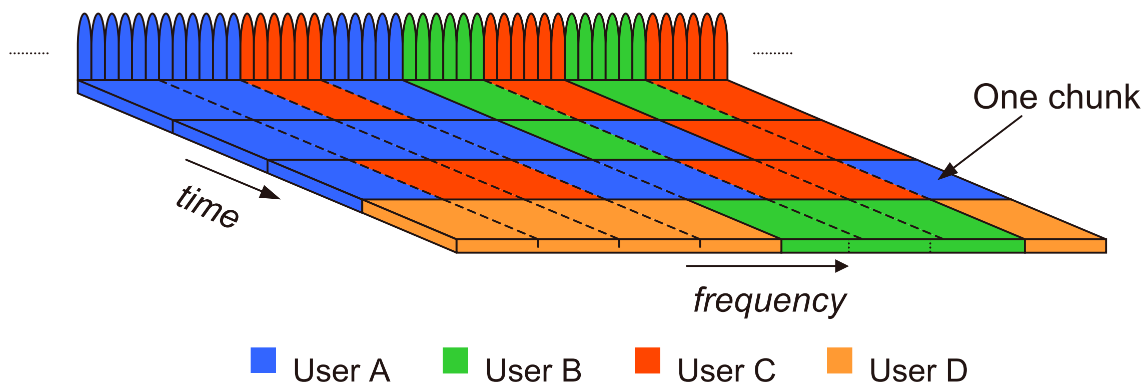
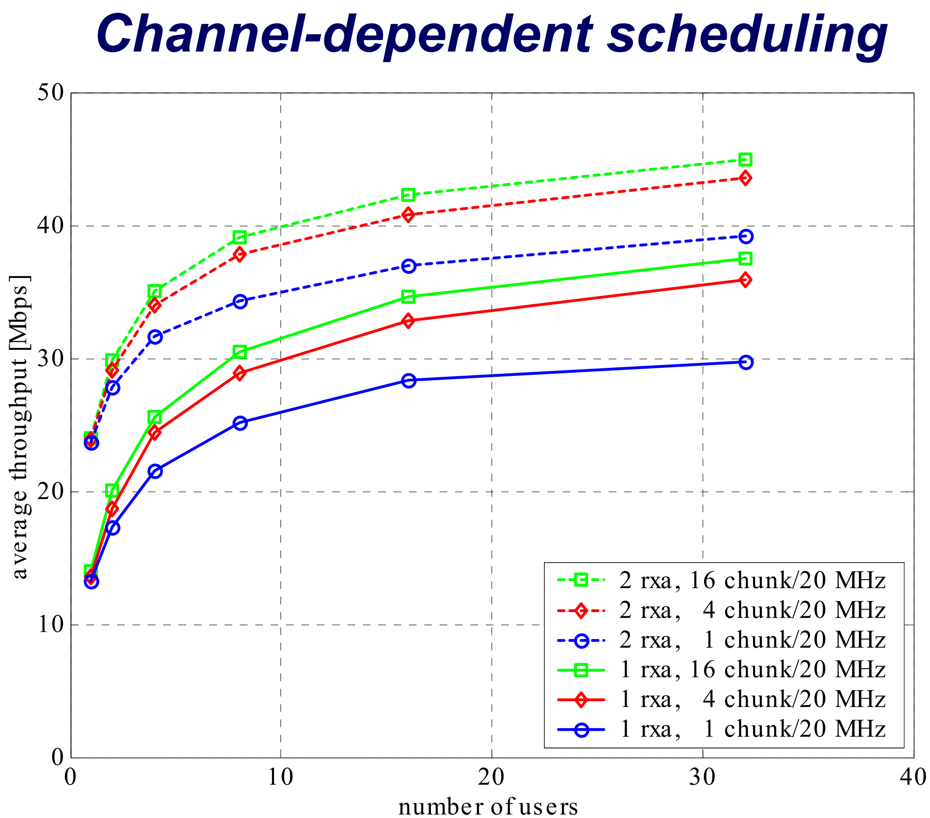
Evolved UTRA – *Frequency-domain adaptation*

- HSDPA: *Channel-dependent scheduling and rate control in time domain*
  - *Substantial benefits in system performance*
- Freq. Domain adaptation:
  - *Channel-dependent scheduling and link adaptation (rate and/or power control) in time <u>and</u> frequency domain*
  - *Scheduler assigns a number of (possibly non-contiguous) chunks to a user*
  - *Per-chunk rate and/or power assignment ?*



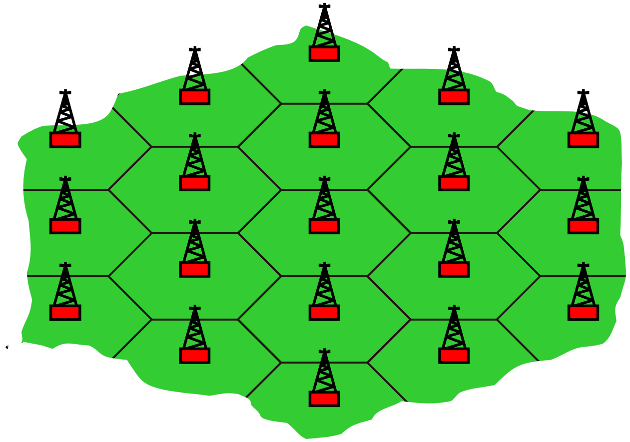
Channel-dependent scheduling – *Performance potential*

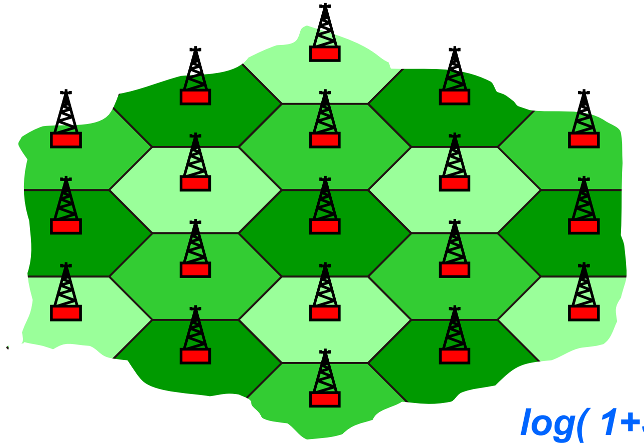


- General case: *Frequency-domain power control*

Evolved UTRA – *Frequency reuse*

- Requirement: High data rates in a limited spectrum allocation
  - *Entire spectrum must be available in each cell*
    ➡ ***One-cell frequency reuse***
- Reduced inter-cell interference with frequency reuse > 1
  ➡ *Increased throughput at cell edge*



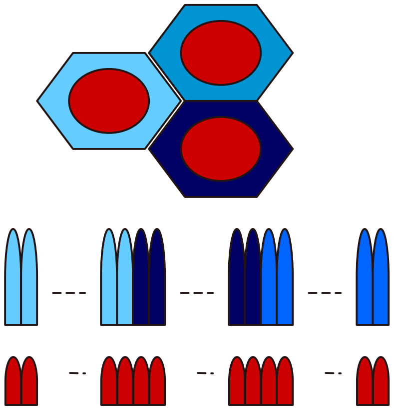


$\log(1+SNR_3) > 3 \times \log(1+SNR_1)$

Flexible reuse

Evolved UTRA – *Flexible reuse*

- Primary and secondary frequency bands
- Primary band: *Reuse > 1, higher transmit power*
- Secondary bands: *Remaining spectrum*
- Cell-edge users: *Use primary band* ➡ *Good SIR*
- Cell-centre users: *Use entire band* ➡ *High data rates*



- Supported by means of frequency-domain scheduling
- Central or distributed control

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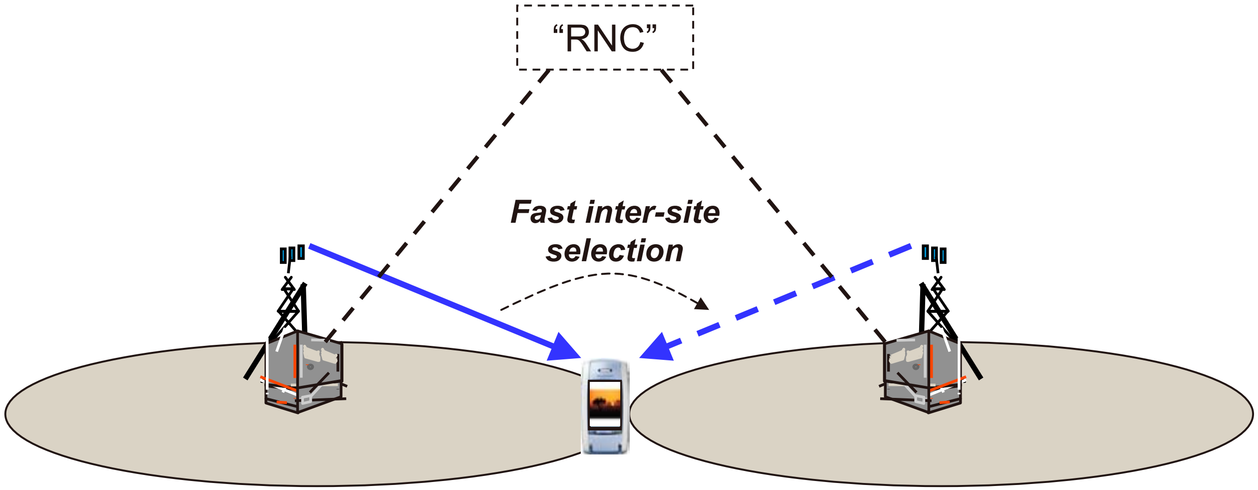
Evolved UTRA – *Downlink macro diversity*

- Downlink soft handover not needed for unicast transmission
- Downlink macro diversity by means of fast cell/sector selection
  - *Very fast sector (intra-site) selection*
  - *Somewhat slower (but still fast) inter-site selection*
  - *Relation to Evolved UTRAN architecture*



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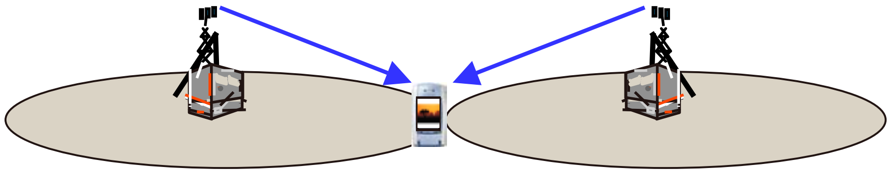
Evolved UTRA – *MBMS*

- Radio-link combining very beneficial for broadcast/ multicast
  - *Capture more energy at cell edge*
  - *Adopted for release 6 MBMS*



- Further benefits in case of OFDM (+ *content-dependent scrambling*)
  - *"invisible" soft combining – Captures all energy*
  - *Avoids inter-cell interference*
  - *Note! Similar benefits with WCDMA + common scrambling + equalizer*
- Very long cyclic prefix needed
  - *To cover path-delay difference + time-dis-alignment*
  - *Current estimate: In the order of 20 μs or more* (depends on deployment structure)

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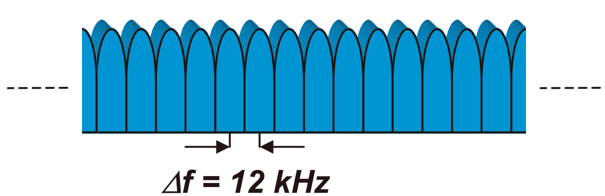
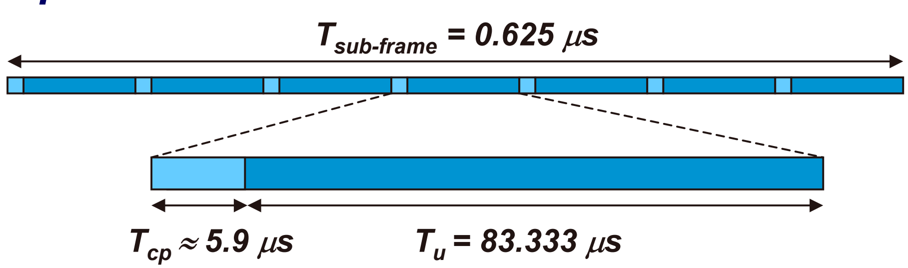
OFDM parameters

- ***Sub-carrier spacing Δf:*** Sufficiently large to allow for high-speed operation
  - *Δf = 10-15 kHz sufficient (reduced performance at very high speed)*
- **Cyclic prefix T_{CP}** : Sufficiently large to cover typical delay spread
  - *3-4 μs sufficient in most cases*
  - *Longer CP for broadcast and very-large-cell scenarios*
- Exact parameters should be well-matched to WCDMA chip rate
  - *Dual-mode terminals and RBS platforms*

Preliminary assumptions





Evolved UTRA

Uplink transmission scheme

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Evolved UTRA – *Uplink-related requirements and their implications*

- Good coverage
  - *Diversity (time/frequency/space)*
  - *Reduce interference Uplink intra-cell orthogonality desirable*
- Low delay (*U-plane and C-plane*)
  - *Short TTI and fast access (e.g. avoid slow power ramping)*
- Low cost terminal and long battery life
  - *High PA efficiency* ➡ *Low-PAPR transmission desirable*
- Avoid unnecessary base-station complexity
  - *Cyclic prefix to simplify equalization*
  - *Beneficial regardless of transmission scheme*

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Uplink interference

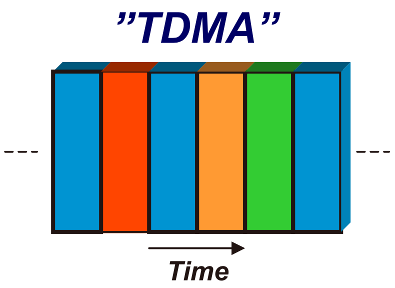
- WCDMA uplink capacity and coverage often limited by interference
  - *Intra-cell interference*
  - *Inter-cell interference*
- Possibility for intra-cell orthogonality
- Inter-cell-interference reduction, e.g. by means of partial reuse

Note!

- Orthogonality implies dimension limits
- Interference can be suppressed at receiver side
  - *Interference suppression/cancellation*
  - *Additional antennas*
- ***Fundamentally, non-orthogonality is probably superior but …***

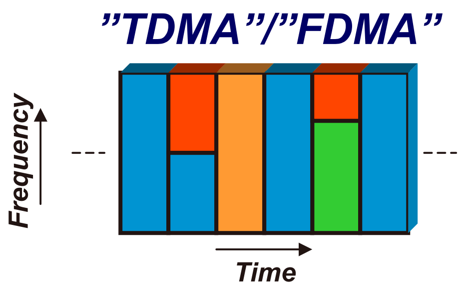
Intra-cell orthogonality

- Time-domain orthogonality
  - *Time-domain scheduling, TDMA*
  - *Partly already in Rel6 (Enhanced UL)*



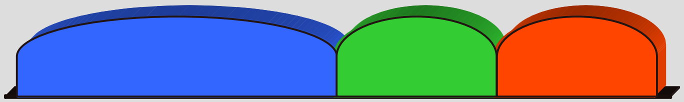
- Issue: *Potentially inefficient bandwidth utilization*
  - *Limited payload and/or power-limited UE ➡ Bandwidth not fully utilized*

- Additional support for ***frequency-domain orthogonality***
  - *Frequency-domain scheduling, FDMA*
  - *Flexible bandwidth allocation*

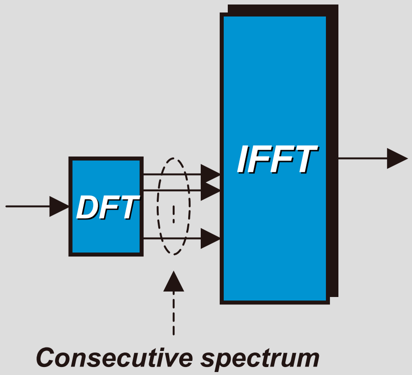


FDMA – Localized vs. Distributed

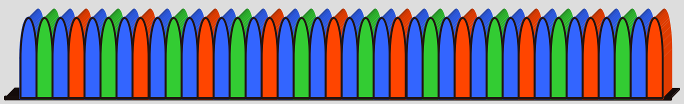
Localized FDMA



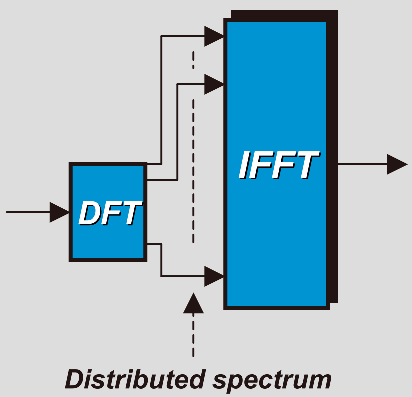
- *Each user transmission localized in the frequency domain*
- *Low-PAPR by single-carrier transmisssion*
- *Flexible transmission bandwidth*
- *Channel-dependent scheduling in frequency domain*



Distributed FDMA



- *Each user distributed in the frequency domain*
- *Low PAPR by means of IFDMA ("single-carrier")*
- *Flexible number of "sub-carriers" (different IFDMA repetition factors)*
- *Frequency diversity*
- *Sensitive to frequency errors, user synchronization required*



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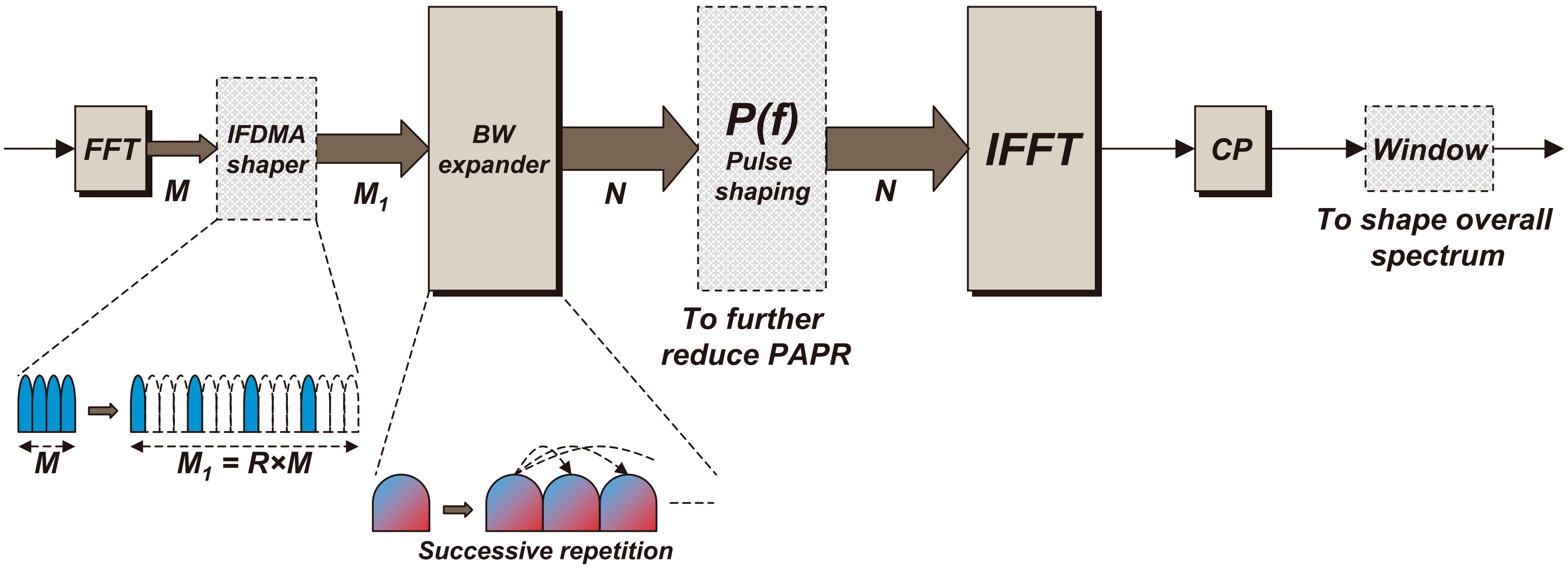
Uplink transmission scheme (*unified scheme*)

Frequency-domain description



Can also be seen as pre-coded OFDM
”DFT-spread OFDM”

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IFDMA vs. DFT-spread OFDM ?

- Fundamentally very similar or even the same
- IFDMA “assumes” time-domain generation
  - *Block-wise repetition + user-specific rotation*
- DFTS OFDM “assumes” frequency-domain generation
- Pulse-shaping
  - *Typically assumed for IFDMA*
  - *Typically not assumed for DFTS-OFDM*
  - $PAPR_{IFDMA} < PAPR_{DFTS\text{-}OFDM} < PAPR_{OFDMA}$

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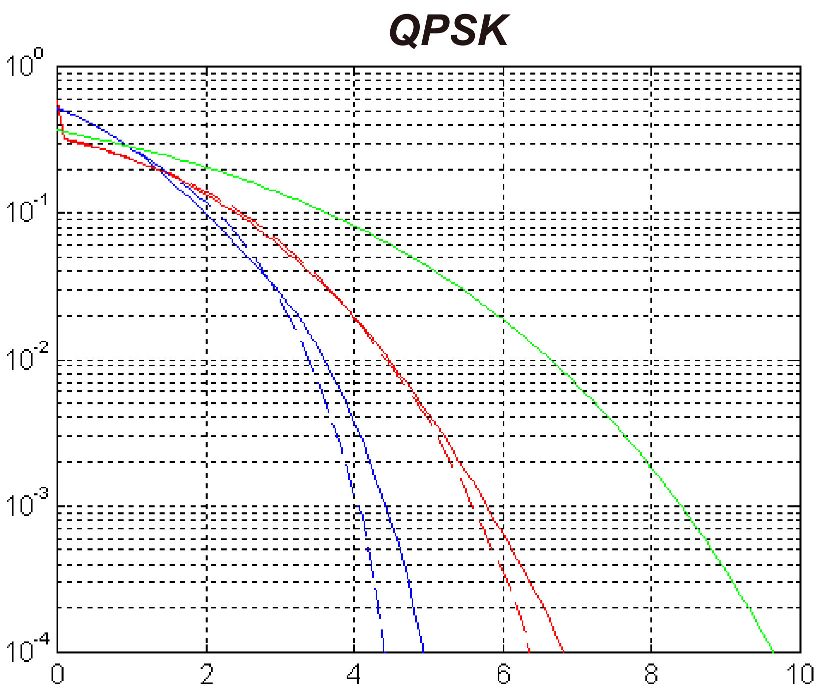
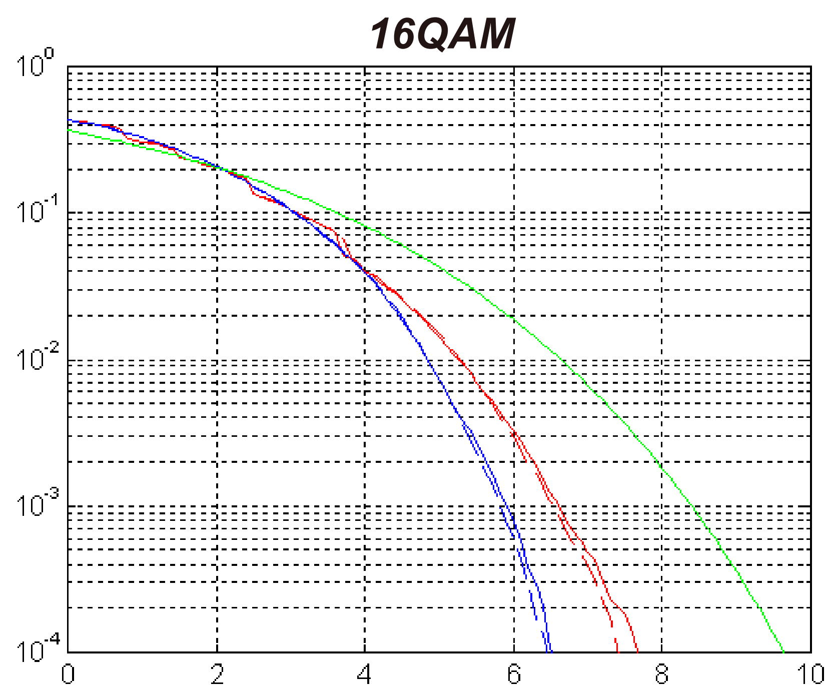
Power distribution

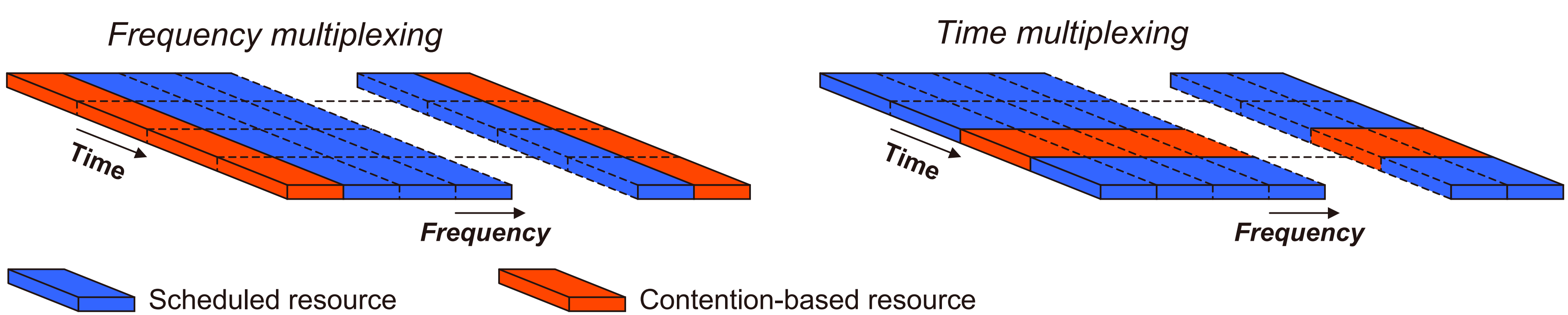




Green: OFDM *Red: Single-carrier, no pulse-shaping* *Blue: Single-carrier, pulse-shaping (α=0.22)*

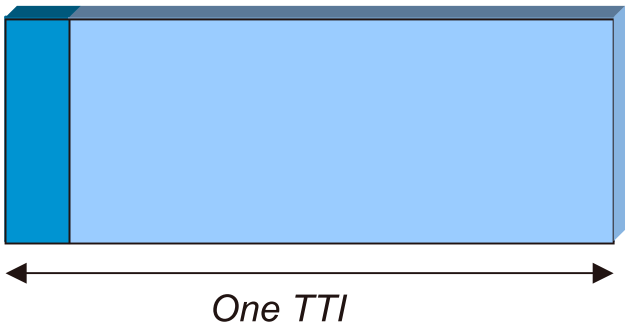
Scheduled vs. contention-based access

- Scheduled uplink access should be main mode of operation
  - *At least for high-load scenarios*
  - *UEs request for uplink resources*
  - *Network response including resource allocation (set of chunks)*
- Also need for contention-based access
  - *At least for random-access and scheduling requests*
  - *Possibly also for smaller data payload and at low load (reduced delays)*
- Orthogonality between scheduled and contention-based resources



Uplink reference-signal structure

- Time-multiplexed “pilot”
- One or several receiver FFT blocks

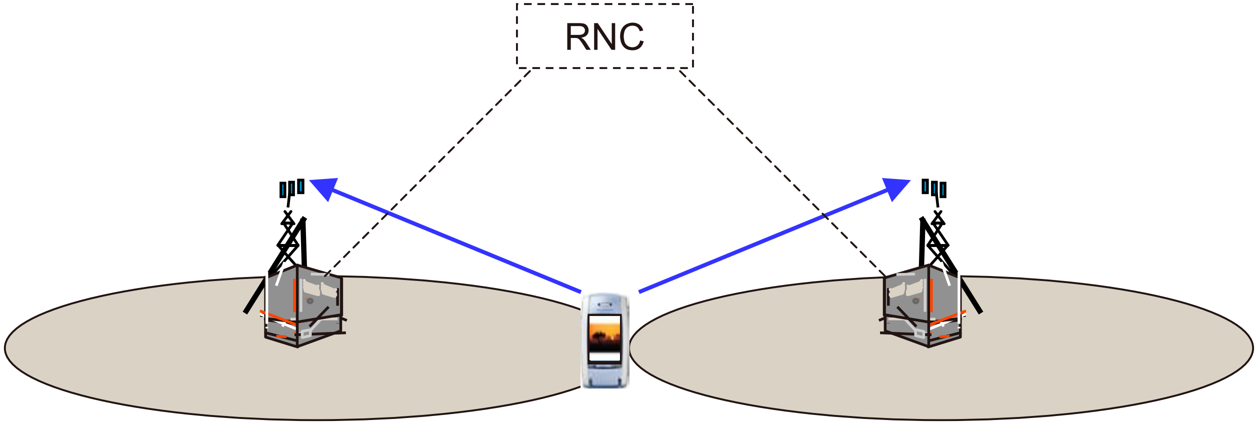


- Need for sequence with constant envelope in time ***and*** frequency, e.g. CAZAC sequences [1]

[1] A. Czylwik, “Low Overhead Pilot-Aided Synchronization for Single Carrier Modulation with Frequency Domain Equalization”

Evolved UTRA – *Uplink macro diversity*

- Uplink transmission received at multiple cell sites
  - *Always beneficial (power gain, diversity gain)*
  - *Improved uplink coverage is a key requirement for evolved UTRA*
- Uplink power control from multiple cell sites
  - *N/A for Evolved UTRA (no closed-loop power control)*
- **Current assumption:** ***Support for uplink reception at multiple cell sites***



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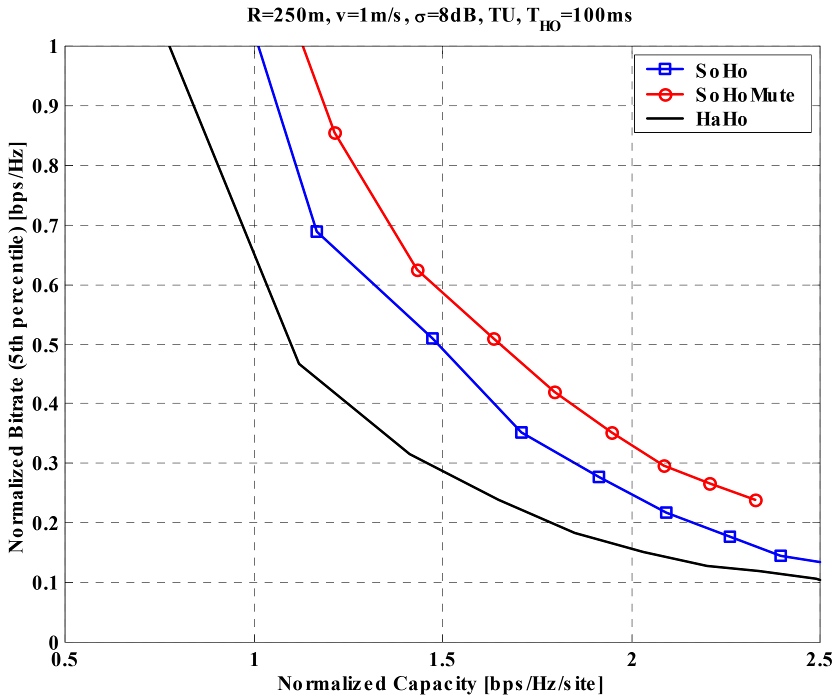
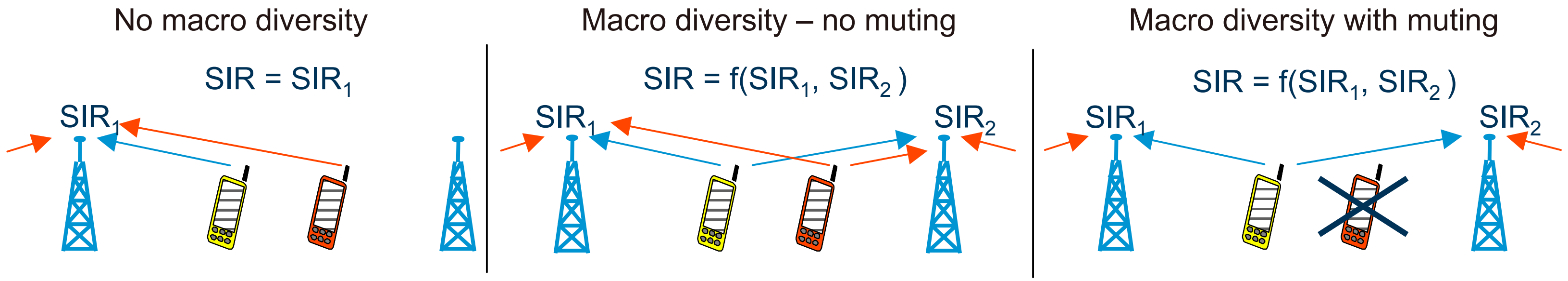
Evolved UTRA – Uplink macro diversity

- Soft HO (with muting) vs. Hard HO
  - *100% larger coverage area*
  - *40% higher capacity*
  - *100% higher cell edge bitrate*





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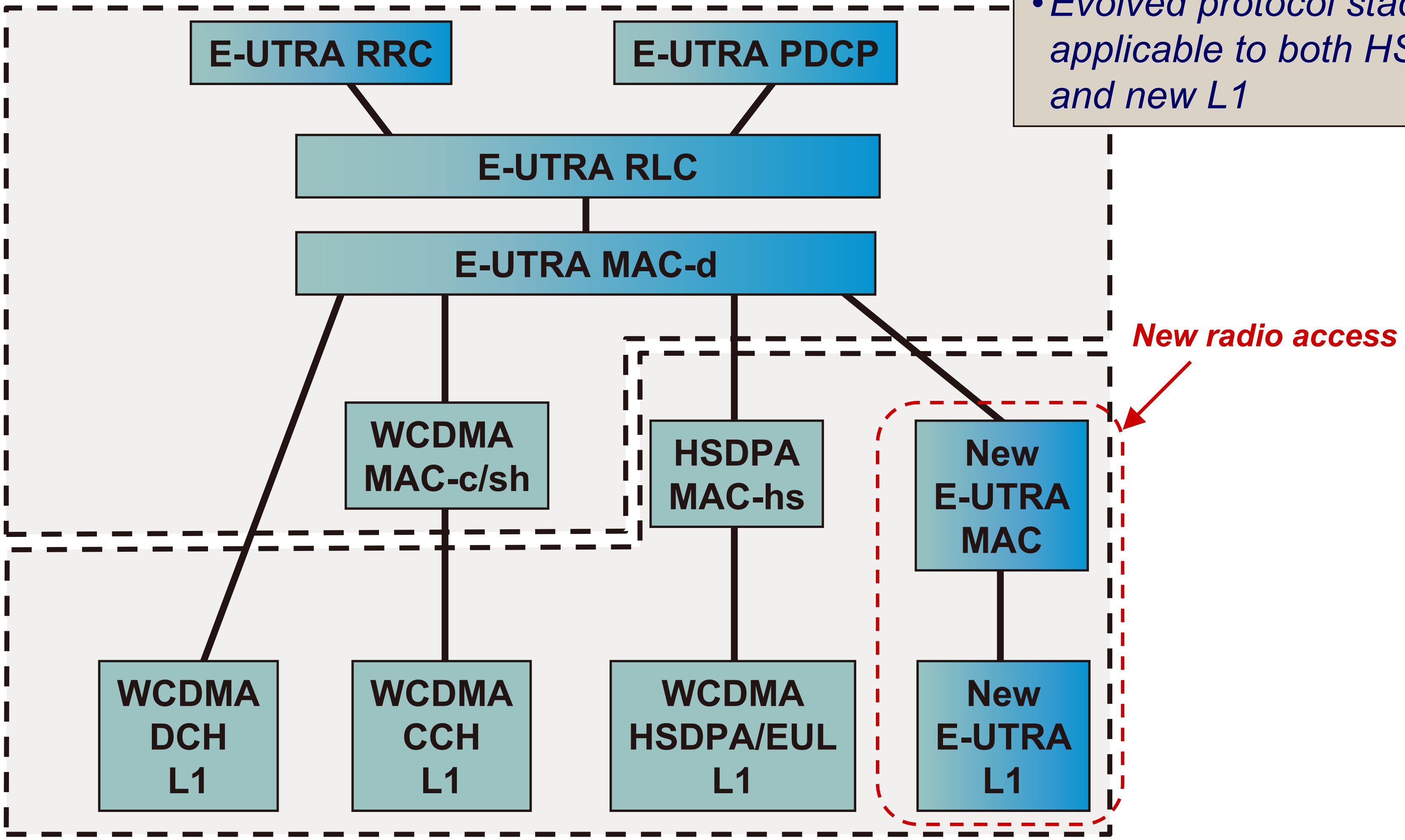
Evolved UTRA

- Evolved protocol stack
- Extend with new L1+MAC
- Evolved protocol stack applicable to both HSDPA and new L1



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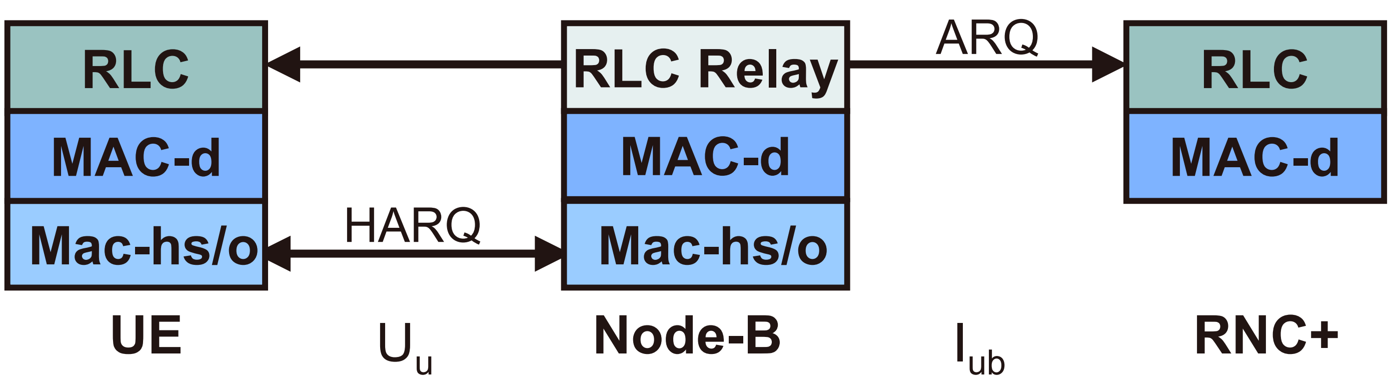
Evolution of RLC and MAC

- Improvements to RLC and MAC are required to improve throughput and latency
- Candidate Solution: 2 ARQ layers
  - *RLC Protocol: RNC+ is Central Mobility and Security Anchor Point*
  - *MAC-o Protocol: Fast, Local Retransmissions*
- Packet centric RLC is considered
  - *IP Packet = RLC SDU ⇒ Variable PDU size, No Padding*
  - *RLC Relay: Local Error Recovery on Iub*
- MAC-o: HARQ based on Incremental Redundancy
  - *Autonomous Re-Transmissions*
  - *Soft ARQ Feedback*



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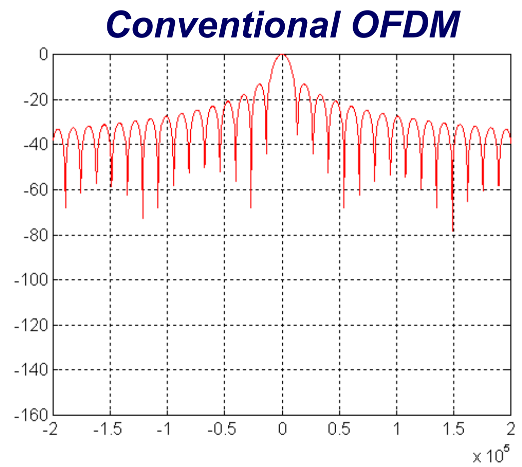
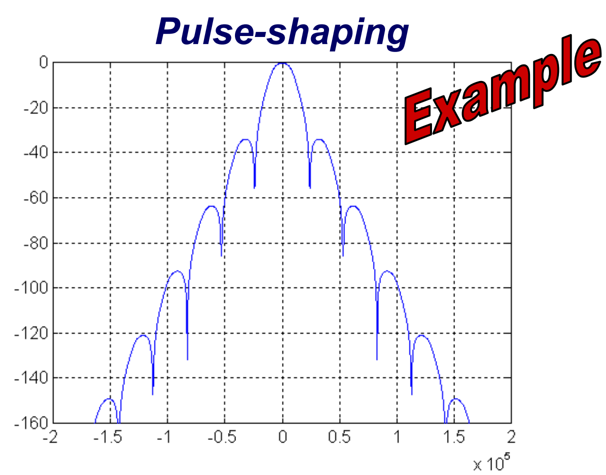
TAKING YOU FORWARD

Thank you !

Pulse-shaped OFDM

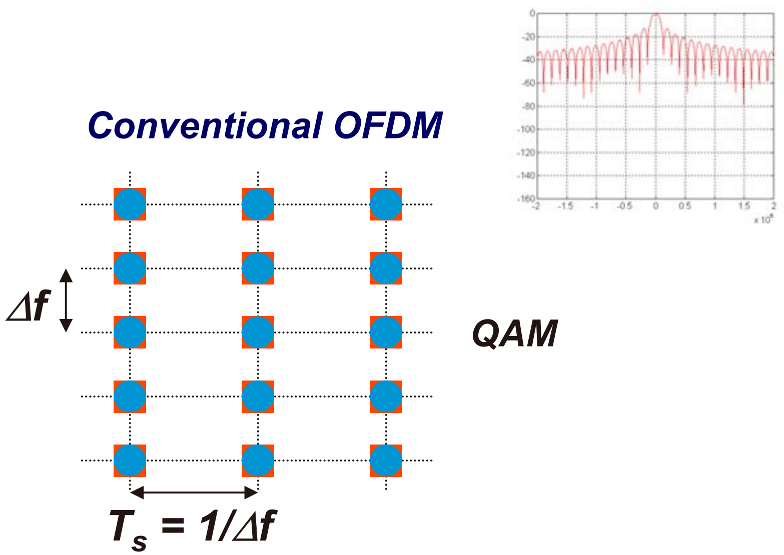
- OFDM-OQAM *(see e.g. [1])*
- Benefits
  - *No cyclic prefix (reduced overhead)*
  - *Improved spectrum properties*
  - *Less sensitive to frequency/phase impairments*
- Identified issues
  - *Channel estimation*
  - *MIMO performance/complexity*
- ***Under consideration but further studies needed !***

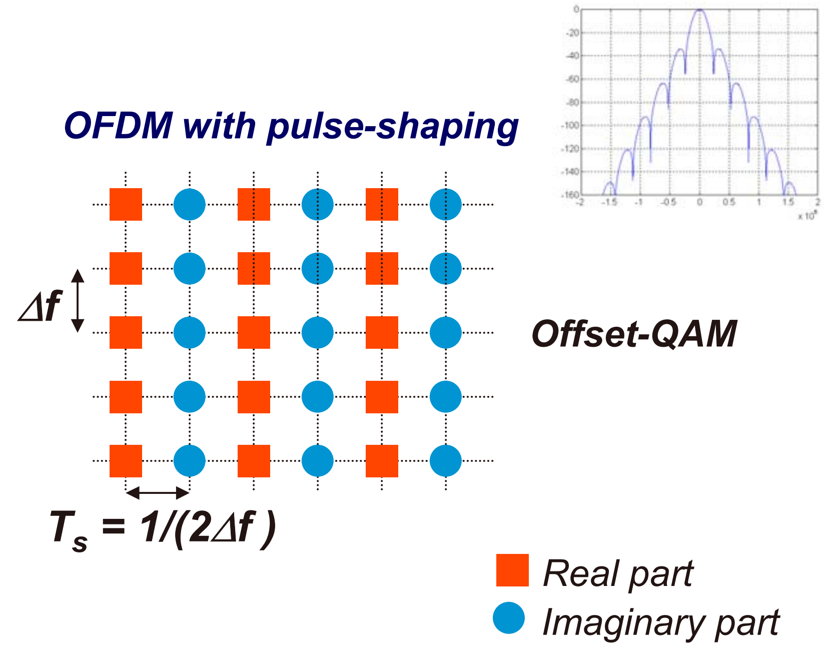




[1] Le Floch et al, "Coded orthogonal frequency division multiplex," Proceedings of the IEEE, vol. 83, Jun 1995.

OFDM-OQAM





- Inter-symbol orthogonality relies on perfect phase relation
  - *Channel-estimation ? ISI on pilot*
  - *MIMO performance/complexity ? Inter-stream interference*