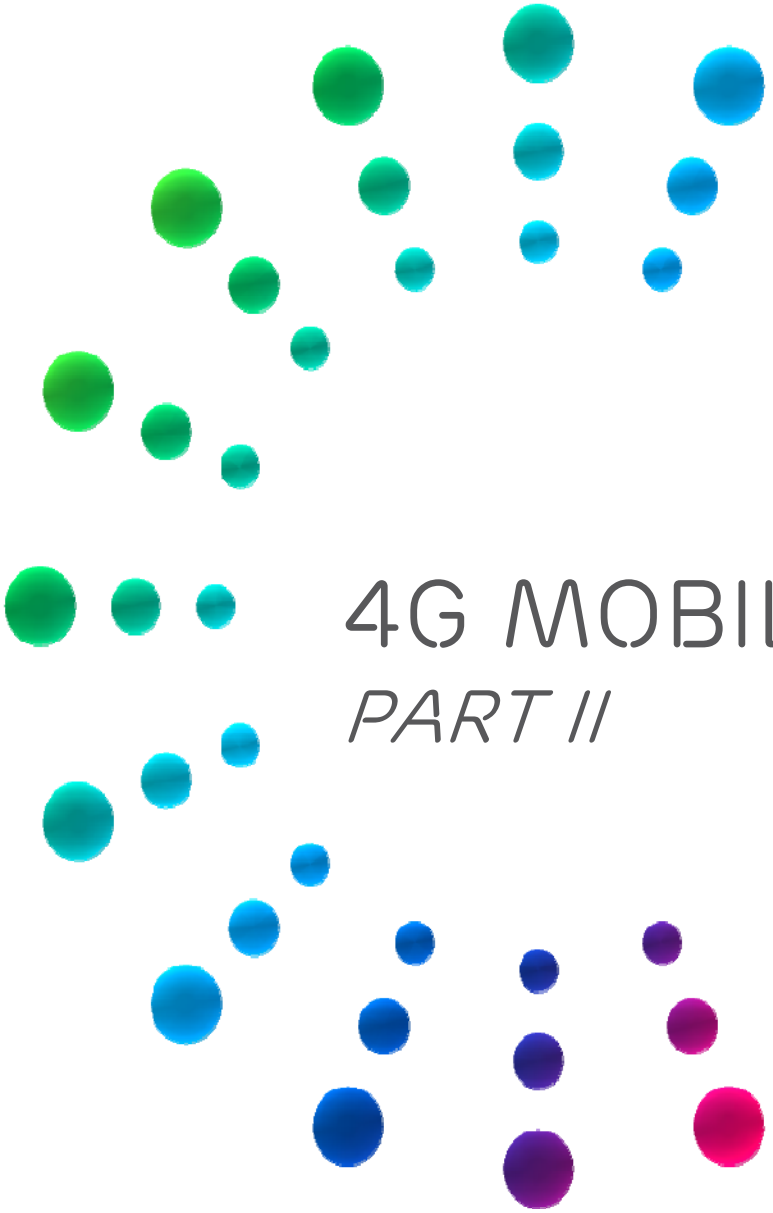

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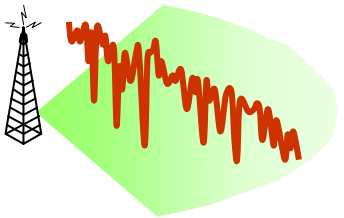
4G MOBILE BROADBAND – LTE

PART II

Dr Stefan Parkvall
Principal Researcher
Ericson Research

RECAP FROM FIRST SESSION



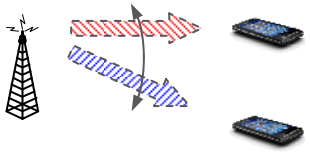
- Radio channel quality is time varying
- Traffic pattern is time varying

- ***Adapt to*** and ***exploit***…
  - variations in the radio channel quality
  - variations in the traffic pattern

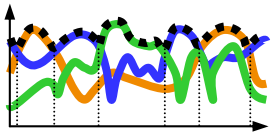
  …instead of combating them!

RECAP FROM FIRST SESSION

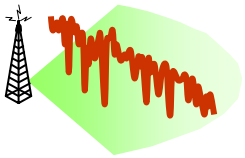
- Shared channel transmission



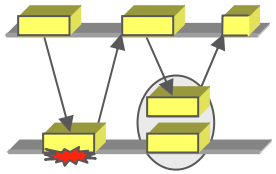
- Channel-dependent scheduling



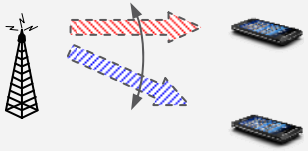
- Rate control

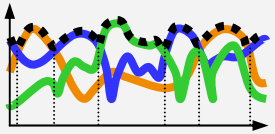


- Hybrid-ARQ with soft combining

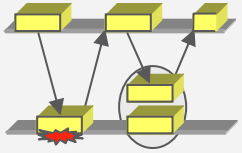


RECAP FROM FIRST SESSION





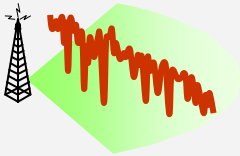
Channel-dependent scheduling



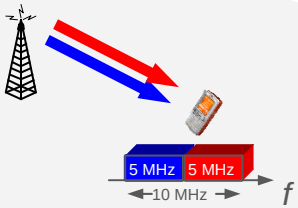
Hybrid ARQ

HSPA (“Turbo-3G”)

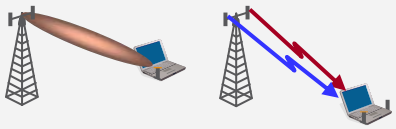
- Packet-data add-on to WCDMA
- First version ~2002, still evolving
- Using principles from first session



Rate control



Multi-carrier transmission



Multi-antenna support

OUTLINE

Series of three seminars

I. Basic principles
   - Channel and traffic behavior
   - Link adapation, scheduling, hybrid-ARQ
   - Evolving 3G, inclusion of basic principles in WCDMA

II. LTE
   - First step into 4G
   - Path towards IMT-Advanced

III. Standardization
   - How are HSPA and LTE created?
   - 3GPP, ITU, …

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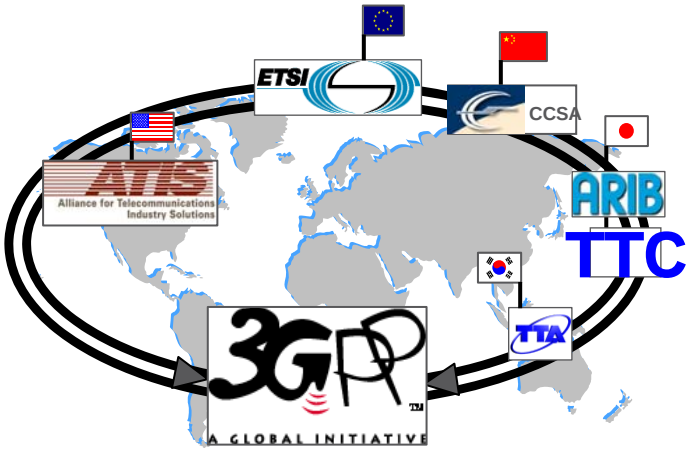
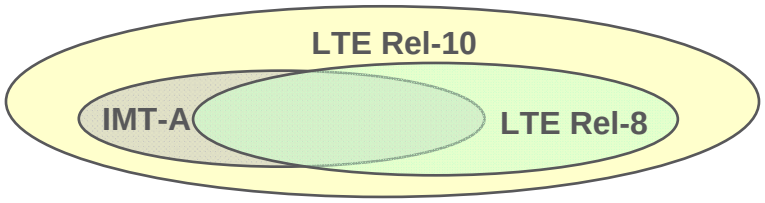
LTE

TECHNICAL OVERVIEW

LTE – 4G MOBILE BROADBAND



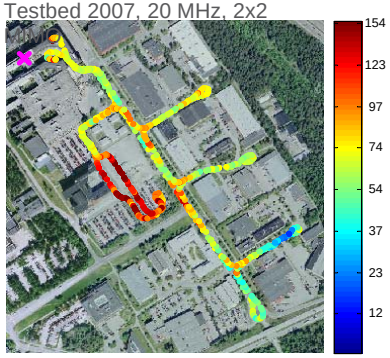
- Developed in 3GPP
  - 2005 LTE standardization started
  - 2008 First standard (Rel-8)
  - 2009 Commercial operation starts
- Packet-data only (no CS domain)
  - Rel-8 up to 300 Mbit/s DL 75 Mbit/s UL in 20 MHz
  - Rel-10 up to 3 Gbit/s DL 1.5 Gbit/s UL in 100 MHz
  - Low latency, 5 ms user plane, 50 ms control plane
- FDD *and* TDD
- Fulfills all IMT-Advanced requirements



LTE – 4G MOBILE BROADBAND

From early studies…

Testbed 2007, 20 MHz, 2x2



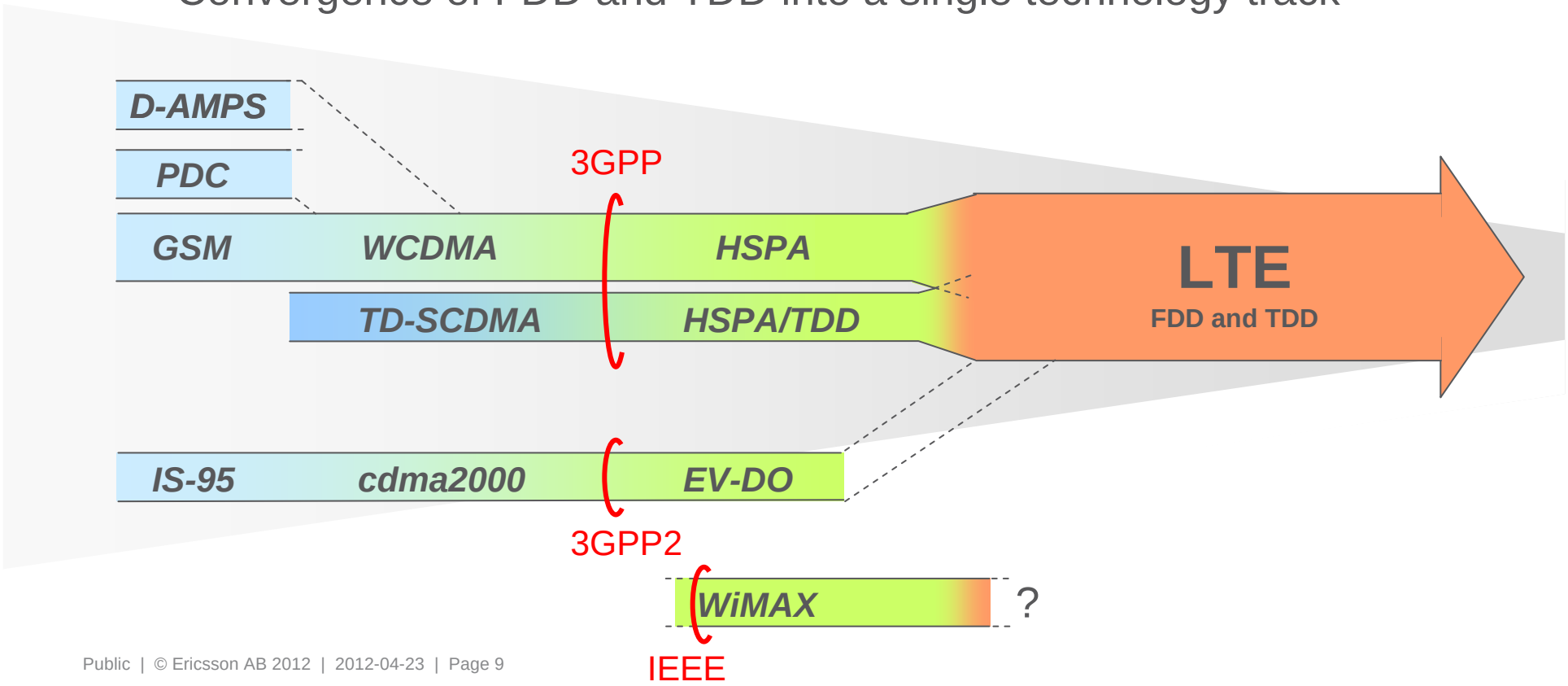
LTE Testbed 2007

…via trials…

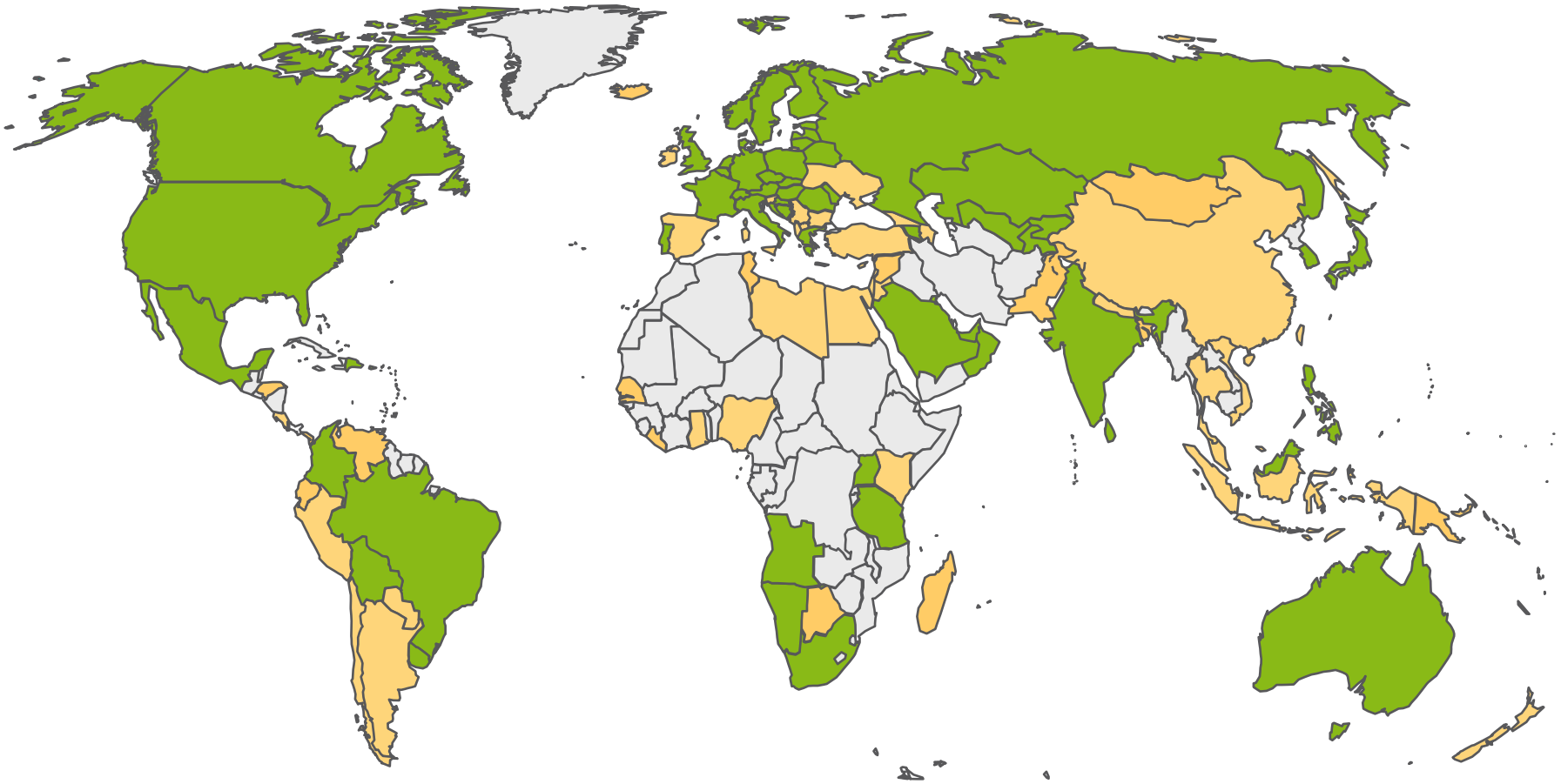
…to commercial operation!

GLOBAL CONVERGENCE

- LTE is the major technology for future mobile broadband
  - Convergence of 3GPP and 3GPP2 technology tracks
  - Convergence of FDD and TDD into a single technology track



LTE NETWORK COMMITMENTS



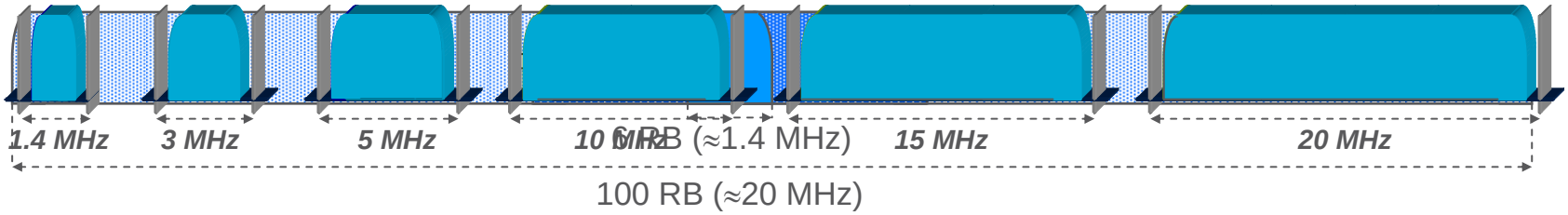
Countries with commercial LTE service

Countries with operators committed to and/or deploying LTE

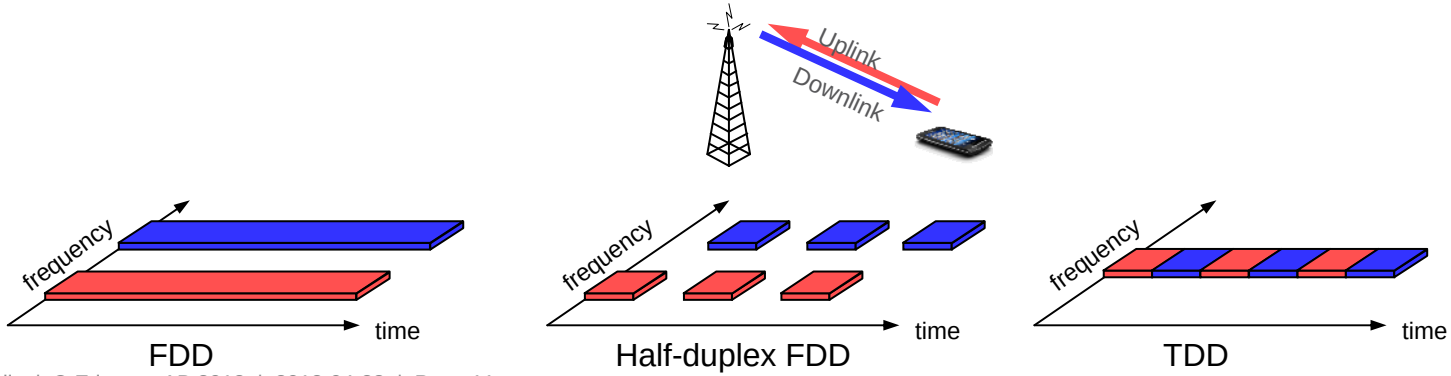
Sources: LTEmaps.org (Feb, 2013)

SPECTRUM FLEXIBILITY

- Operation in differently-sized spectrum allocations
  - Core specifications support any bandwidth from 1.4 to 20 MHz
  - Radio requirements defined for a limited set of spectrum allocations



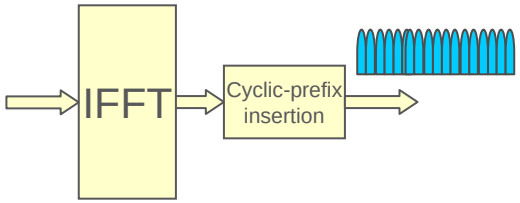
- Support for paired *and* unpaired spectrum allocations
  with a single radio-access technology ➡ economy-of-scale



TRANSMISSION SCHEME

Downlink – OFDM

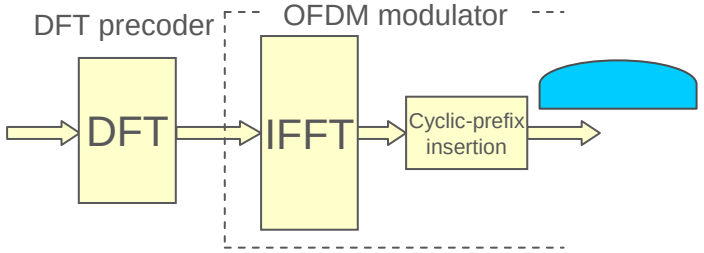
› Parallel transmission on large number of narrowband subcarriers



› Benefits:
  – Avoid own-cell interference
  – Robust to time dispersion
› Main drawback
  – Power-amplifier efficiency

Uplink – DFTS-OFDM

› DFT-precoded OFDM

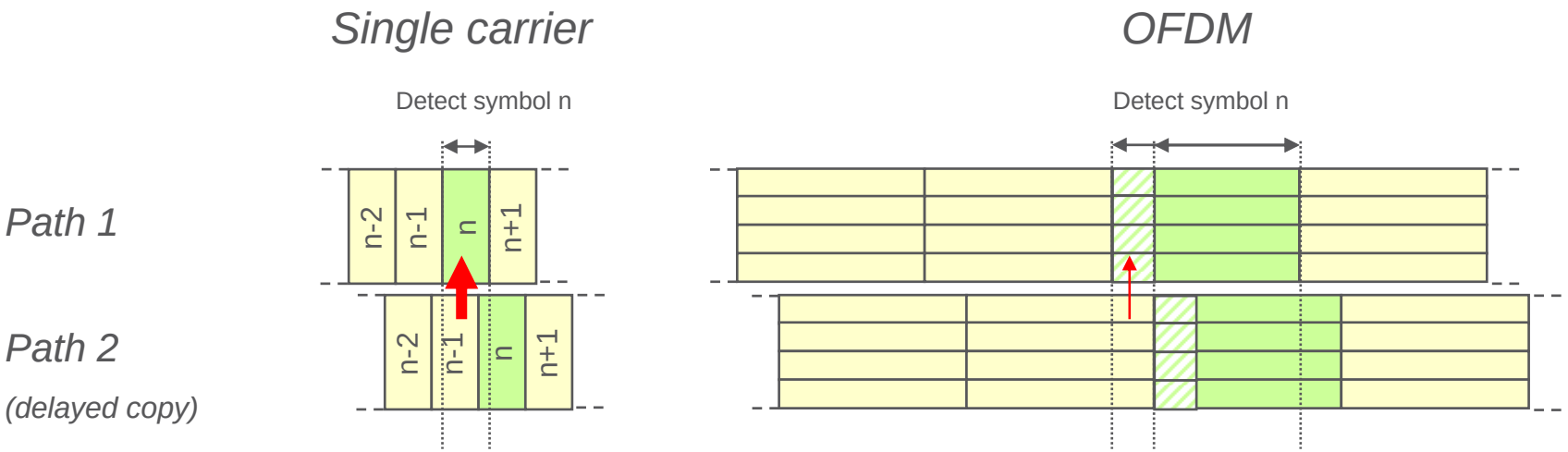


› Tx signal has single-carrier properties
  ⇨ *Improved power-amplifier efficiency*
  – Improved battery life
  – Reduced PA cost
  – **Critical for uplink**
› Equalizer needed ⇨ Rx Complexity
  – **Not critical for uplink**

OFDM AND TIME DISPERSION

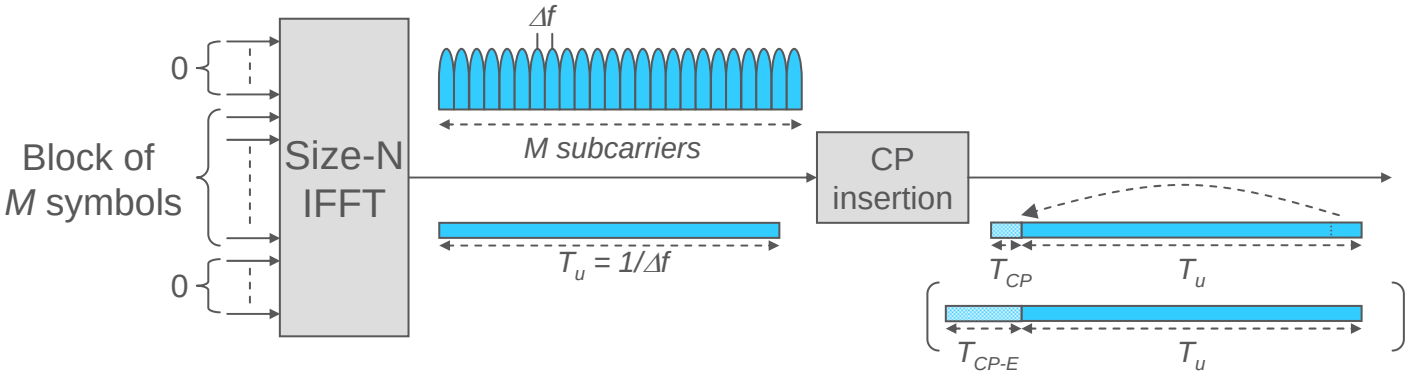
- Time dispersion ➡ inter-symbol interference
  - Requires receiver-side processing (equalization)

- OFDM – transmission uses multiple ‘narrowband’ subcarriers
  - Including of cyclic prefix completely mitigates time dispersion (up to CP) at the cost of additional overhead ➡ simple receiver



DOWNLINK – OFDM

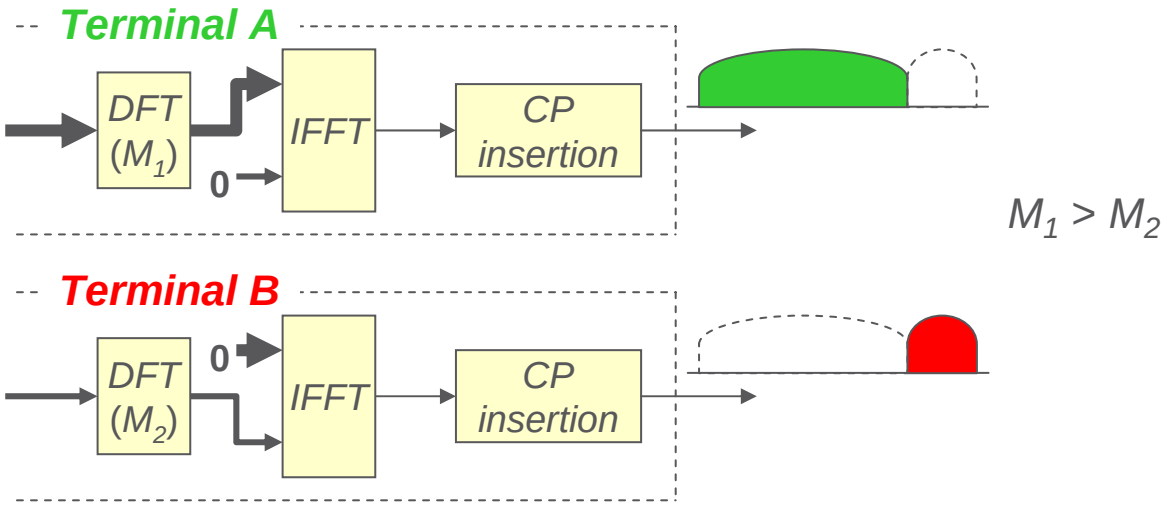
- Parallel transmission using a large number of narrowband “sub-carriers”
  - Typically implemented with FFT
  - 15 kHz subcarrier spacing
- Insertion of cyclic prefix prior to transmission
  - Two CP lengths supported, ≈4.7 µs and ≈16.7 µs
  - Improved robustness in time-dispersive channels – *requires CP > delay spread*
  - Spectral efficiency loss



UPLINK – DFT-SPREAD OFDM

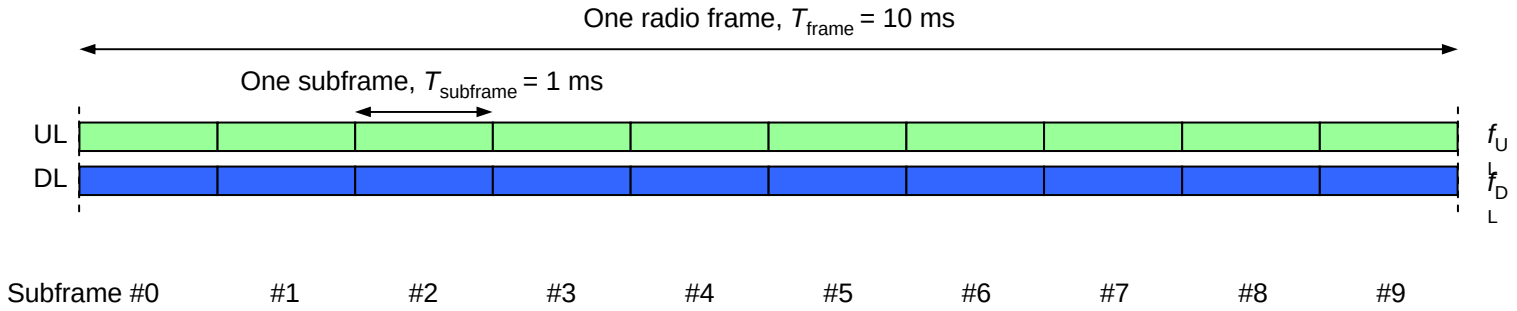
- Single-carrier uplink transmission ➡ efficient power-amplifier operation ➡ improved coverage
  - OFDM requires larger back-off than single-carrier
  - DFT-spread OFDM – OFDM with DFT precoder to reduce PAR

- Uplink numerology aligned with downlink numerology

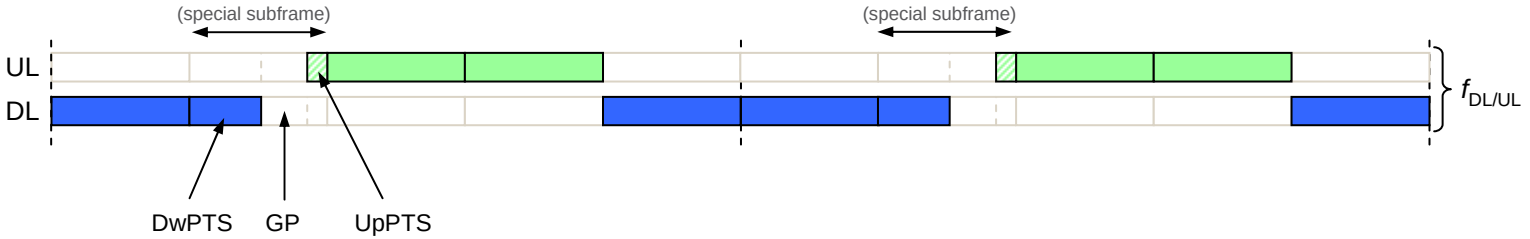


TIME-DOMAIN STRUCTURE

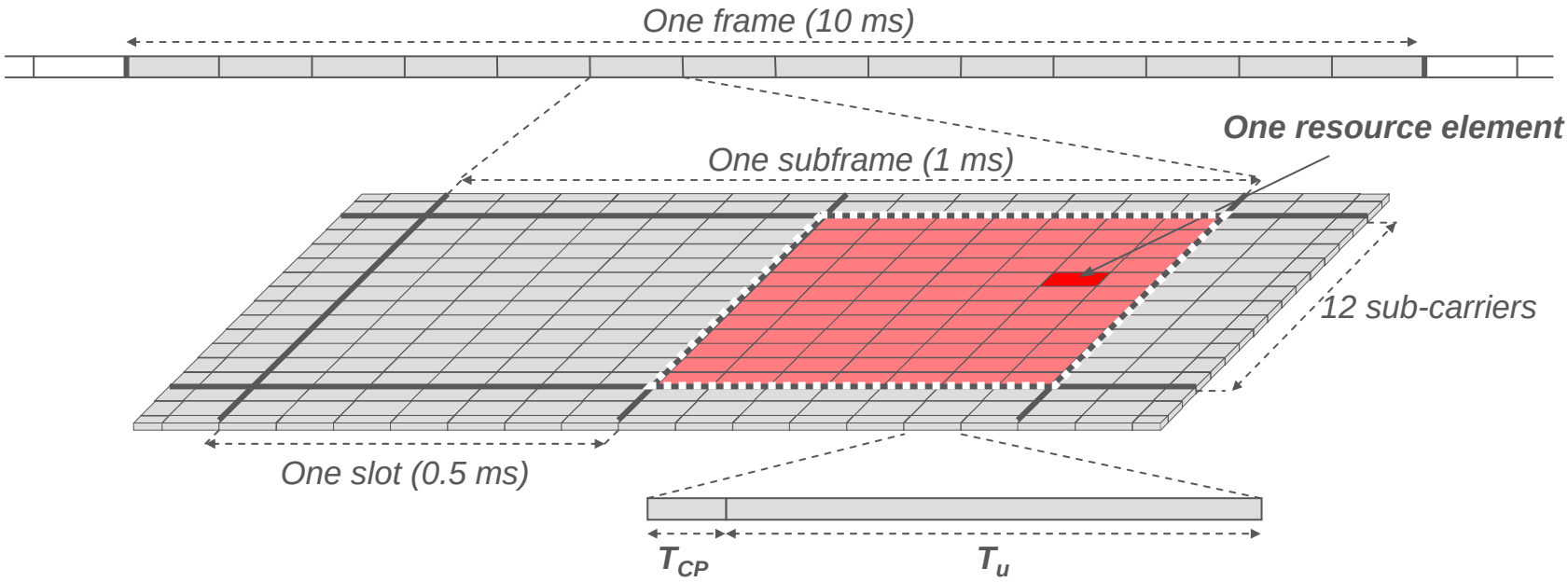
- FDD
  - Uplink and downlink separated in frequency domain



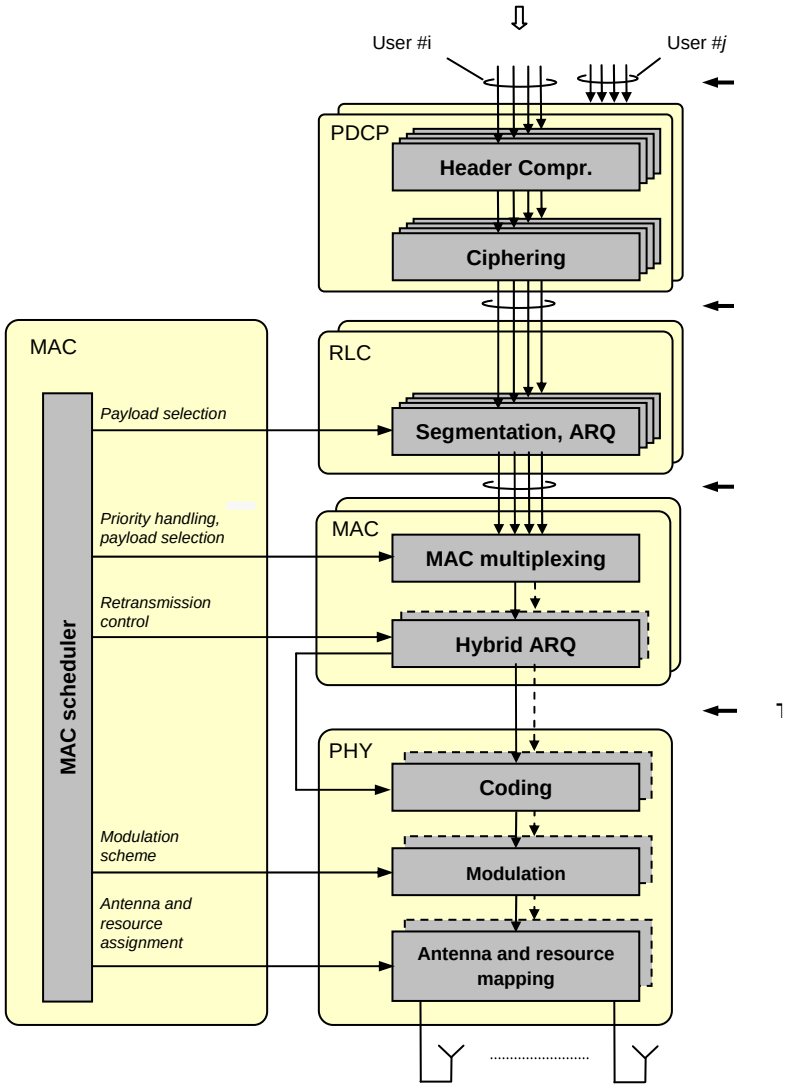
- TDD
  - Uplink and downlink separated in time domain ➡ ”special subframe”
  - Same numerology etc as FDD ➡ economy of scale



PHYSICAL RESOURCES



PROTOCOL ARCHITECTURE

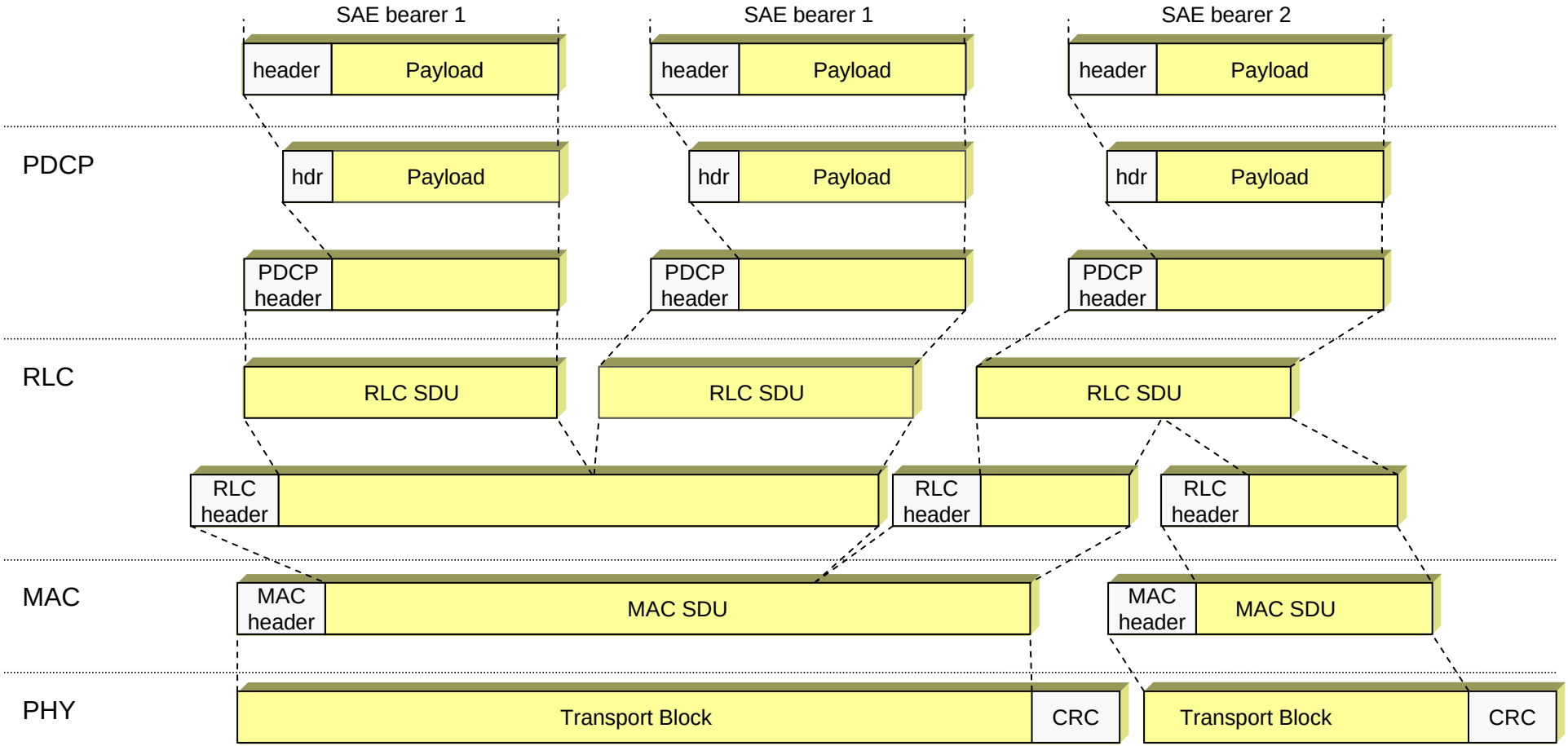


› RLC – *Radio Link Control*
  – Segmentation/concatenation
  – RLC retransmissions

› MAC – *Medium Access Control*
  – Multiplexing of radio bearers
  – Hybrid-ARQ retransmissions

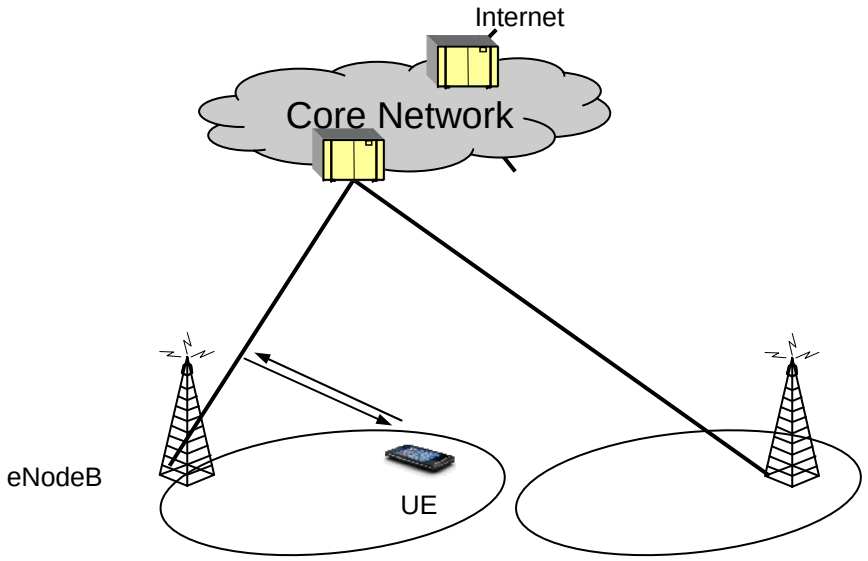
› PHY – *Physical Layer*
  – Coding, Modulation
  – Multi-antenna processing
  – Resource mapping

DATA FLOW IN LTE

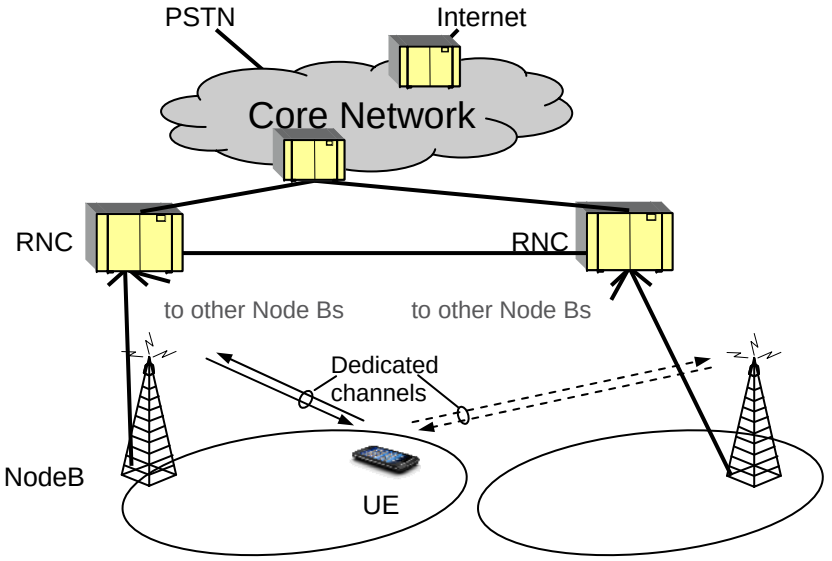


ARCHITECTURE

- Core network evolved in parallel to LTE
  - EPC – Evolved Packet Core
- Flat architecture, single RAN node, the eNodeB
  - Compare HSPA, which has an RNC



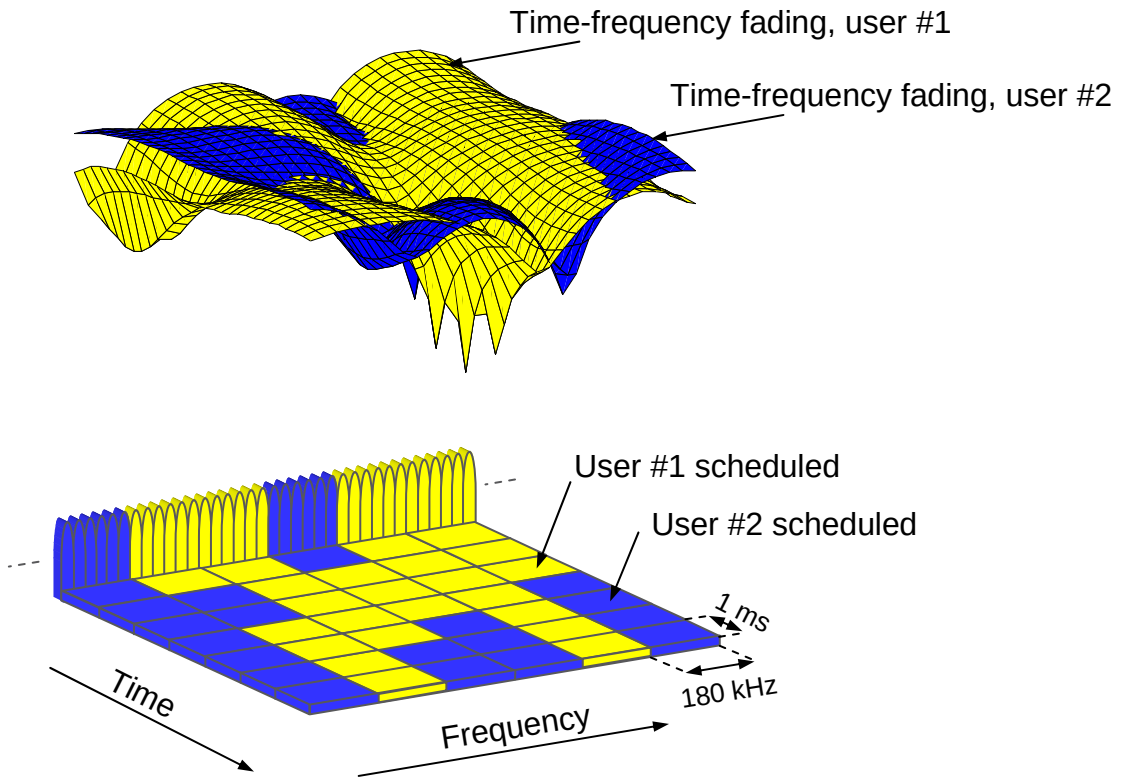
LTE



HSPA

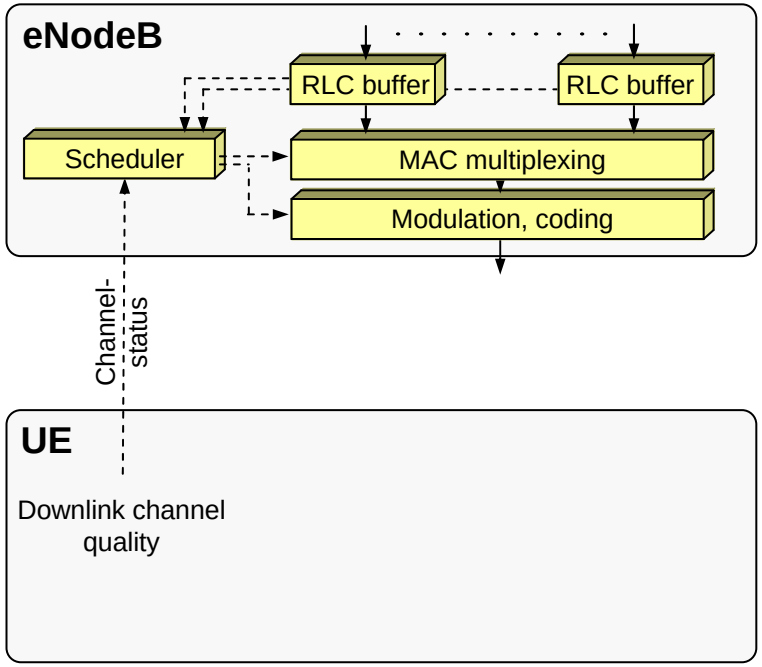
CHANNEL-DEPENDENT SCHEDULING

- LTE – channel-dependent scheduling in time *and* frequency domain
  - HSPA – scheduling in time-domain only

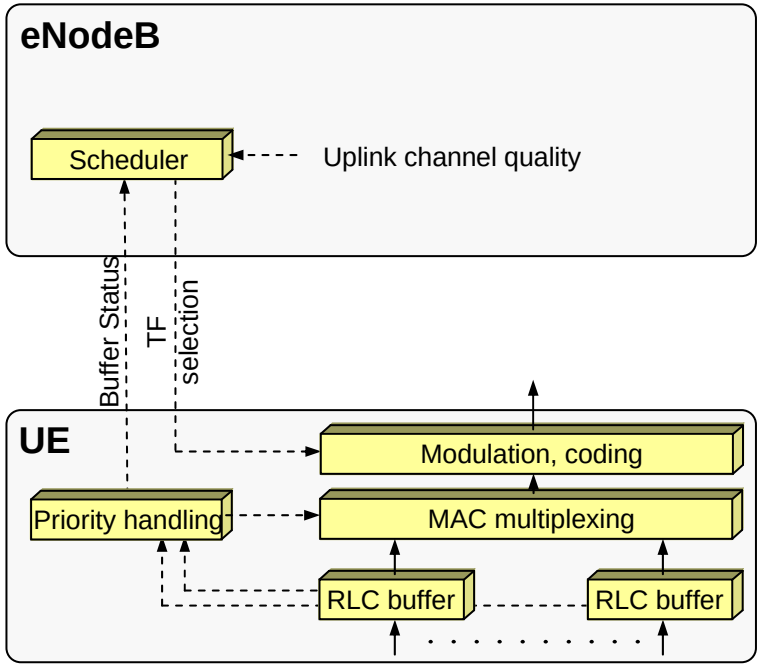


UPLINK SCHEDULING

- Base station mandates data rate of terminal
  - Unlike HSPA where terminal selects data rate [limited by scheduler]
  - Motivated by orthogonal LTE uplink vs non-orthogonal HSPA uplink



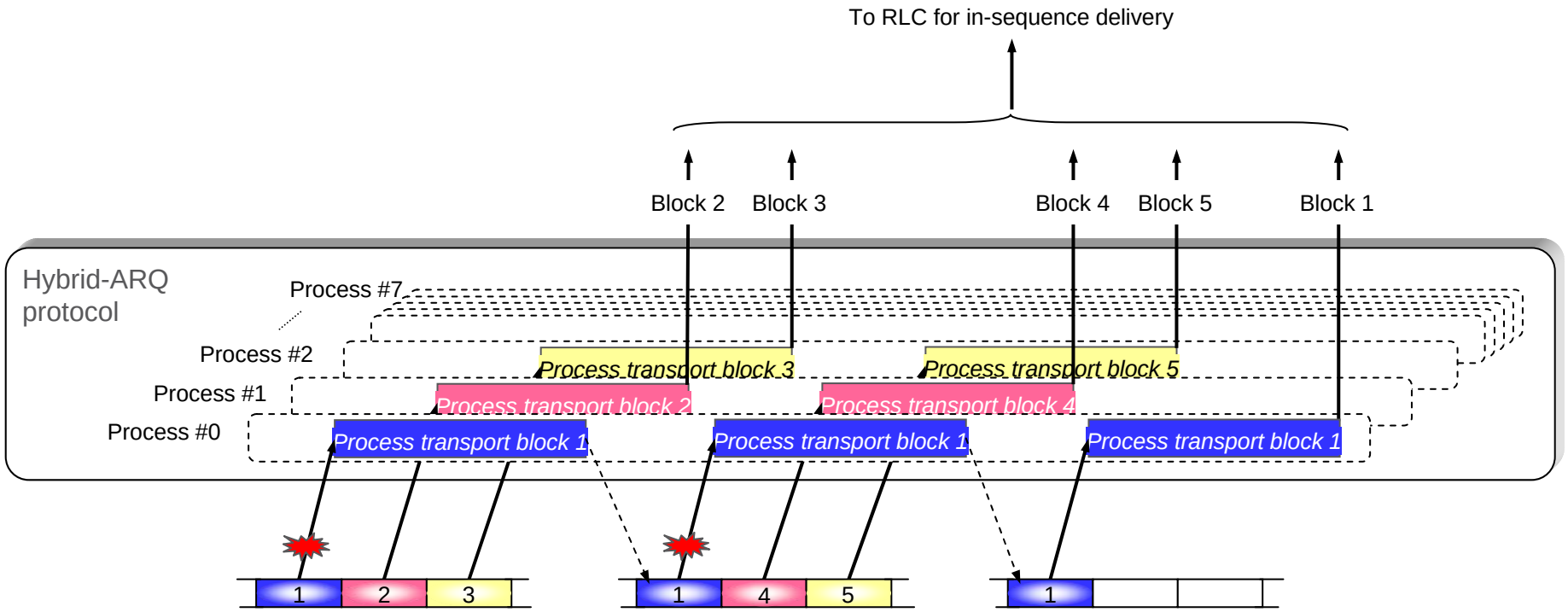
Downlink



Uplink

HYBRID-ARQ WITH SOFT COMBINING

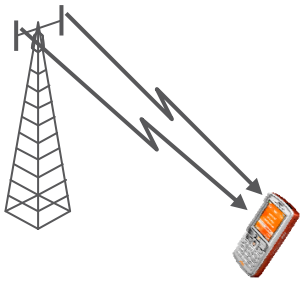
- Parallel stop-and-wait processes
  - 8 processes ➡ 8 ms roundtrip time



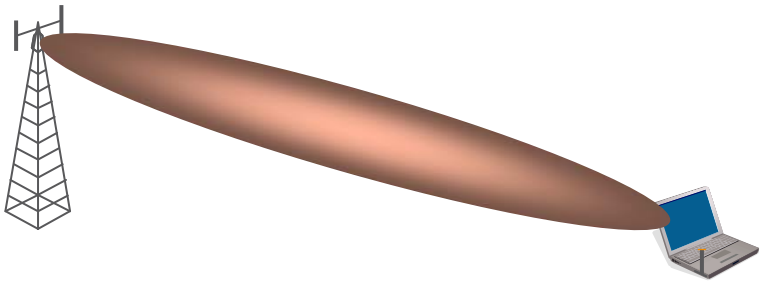
INTERACTION WITH RLC

- Why two transmission mechanisms, RLC and hybrid-ARQ?
  - Retransmission protocols need feedback
- Hybrid ARQ [with soft combining]
  - Fast retransmission, feedback every 1 ms interval
  - Frequent feedback ➡ need low overhead, single bit
  - Single, uncoded bit ➡ errors in feedback (~10^{-3})
- RLC
  - Reliable feedback (sent in same manner as data)
  - Multi-bit feedback ➡ less frequent transmission [overhead aspects]
- Hybrid-ARQ and RLC *complement* each other

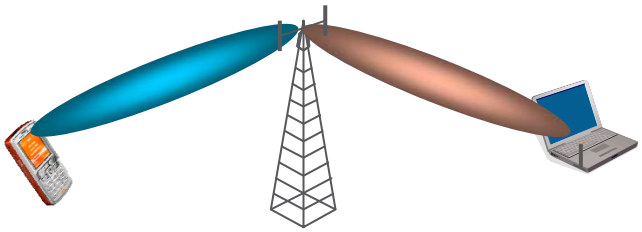
MULTI-ANTENNA TRANSMISSION TECHNIQUES



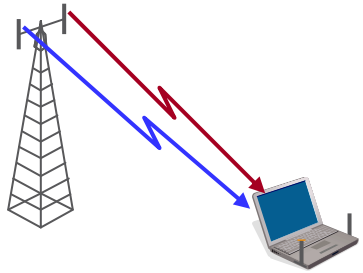
Diversity for improved system peformance



Beam-forming for improved coverage (less cells to cover a given area)



SDMA for improved capacity (more users per cell)

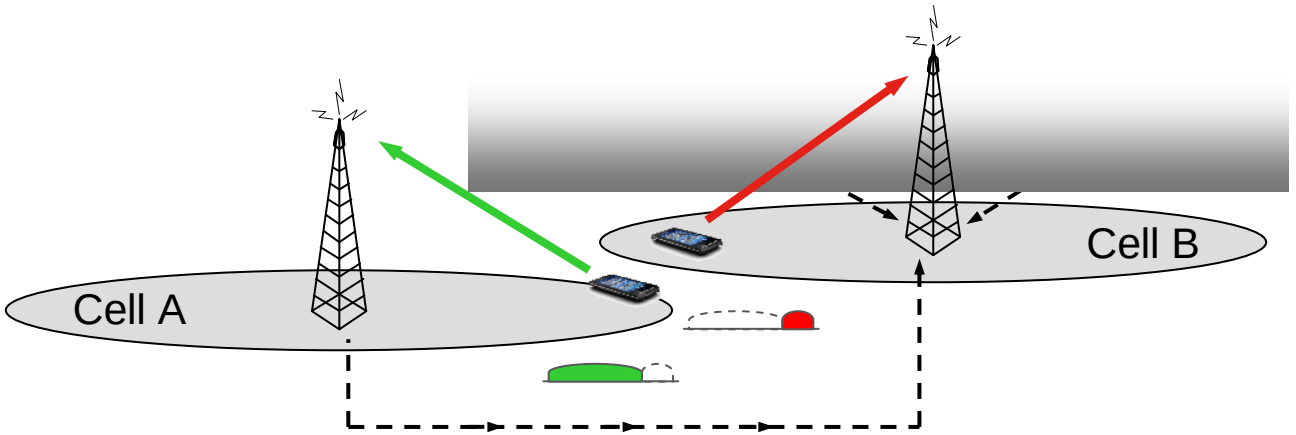


Multi-layer transmisson (”MIMO”) for higher data rates in a given bandwidth

The multi-antenna technique to use depends on what to achieve

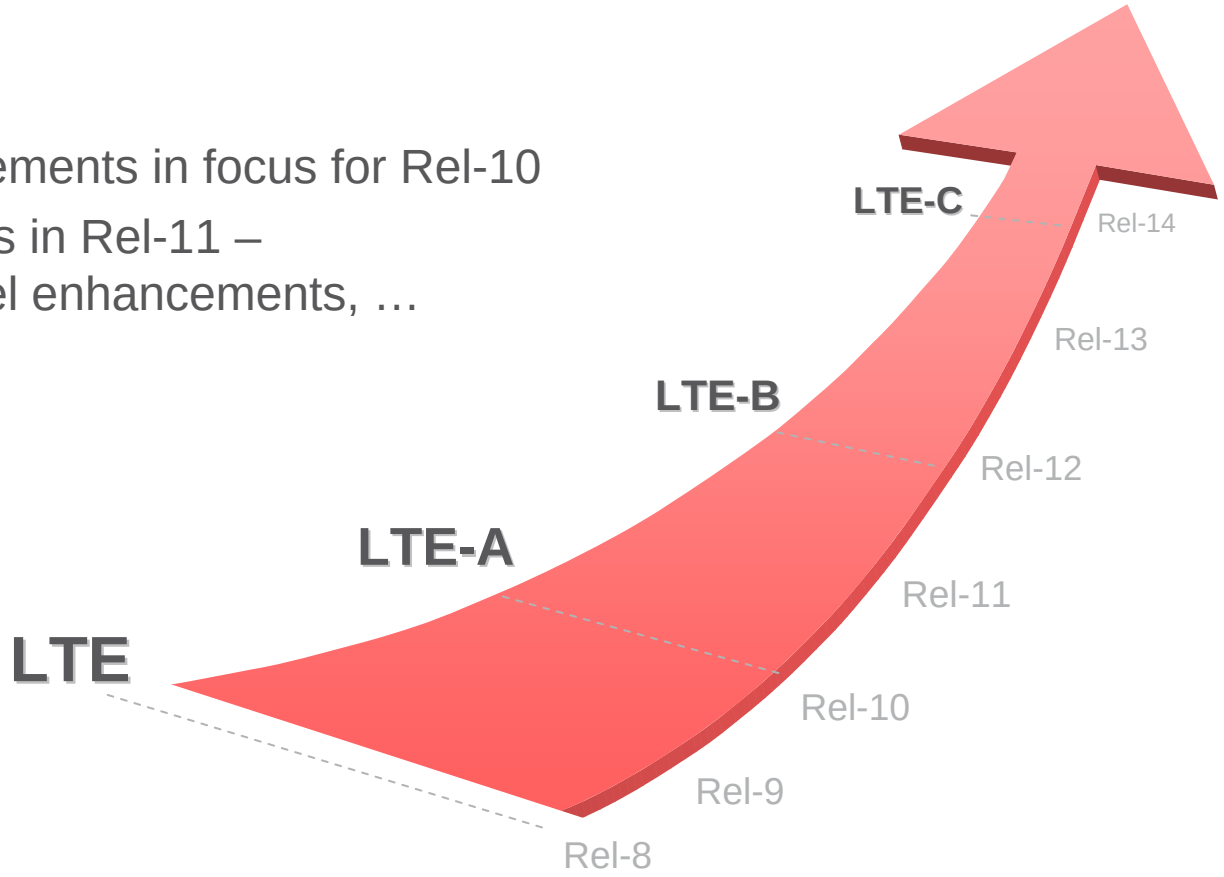
SCHEDULING AND INTERFERENCE HANDLING

- Scheduling strategy strongly influences system behavior
  - Trade-off between capacity and uniform service provisioning
  - Can take inter-cell interference into account
    - Improve cell-edge data rates...at the cost of system throughput
    - Autonomous handling complemented by exchange of coordination messages between base stations



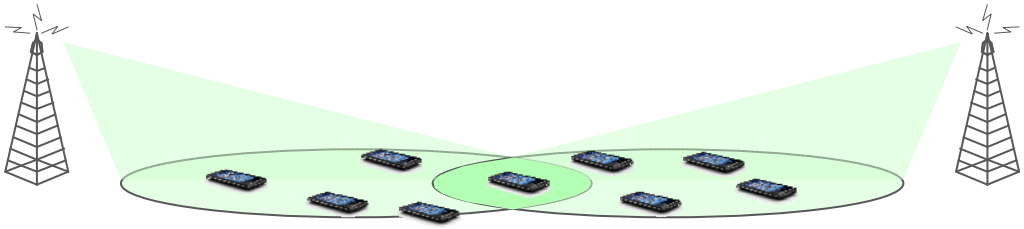
LTE EVOLUTION

- LTE
  - Basics in Rel-8, some enhancements in Rel-9
- LTE-A
  - IMT-Advanced requirements in focus for Rel-10
  - Further enhancements in Rel-11 – CoMP, control channel enhancements, …
- LTE-B
  - Next major release



MBSFN OPERATION
REL-9

- Multicast-Broadcast Single Frequency Network
  - Synchronized transmission from multiple cells
  - Seen as multipath propagation by terminal ➡ combining gain ‘for free’



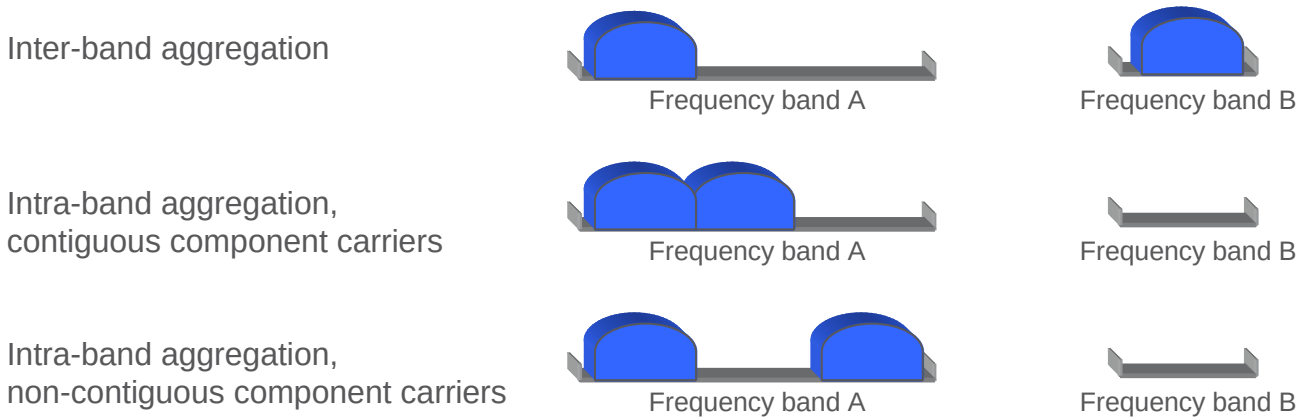
- MBSFN for content known to have many viewers
  - News, sport events, …

On demand
Personalized content

Big events
Known in advance to have many users

CARRIER AGGREGATION
REL-10

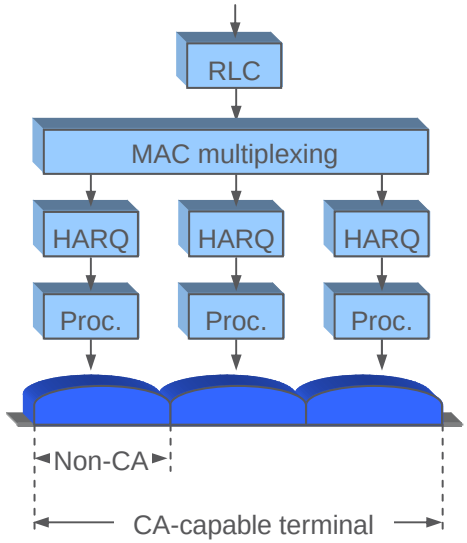
- What is it?
  - Multiple component carriers operating in parallel



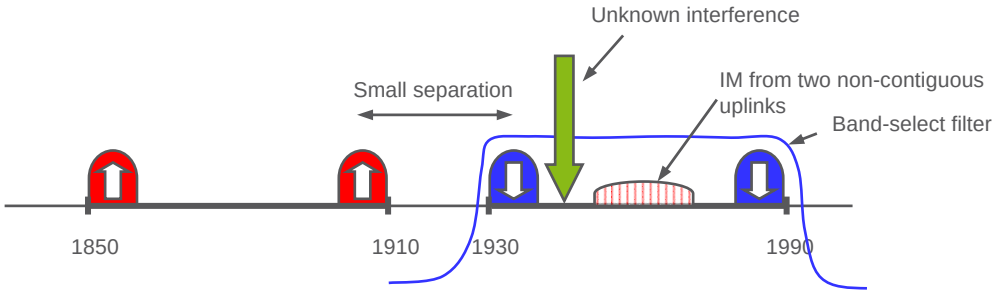
- Why?
  - Exploitation of fragmented spectrum
  - Higher bandwidth ➡ higher data rates

CARRIER AGGREGATION
REL-10

- Baseband implementation
  - Processing per component carrier
  - Relatively straightforward,
    Complexity ~ aggregated data rate

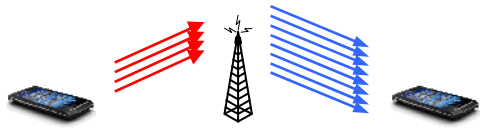


- RF implementation
  - Challenging, especially on the terminal side
    - *True for any radio-access technology!*
  - Complexity highly dependent on band combinations
  - Insertion loss, harmonics, intermodulation, …



MIMO ENHANCEMENTS
REL-10

- Enhanced downlink MIMO – up to 8 layers
- Uplink MIMO – up to 4 layers

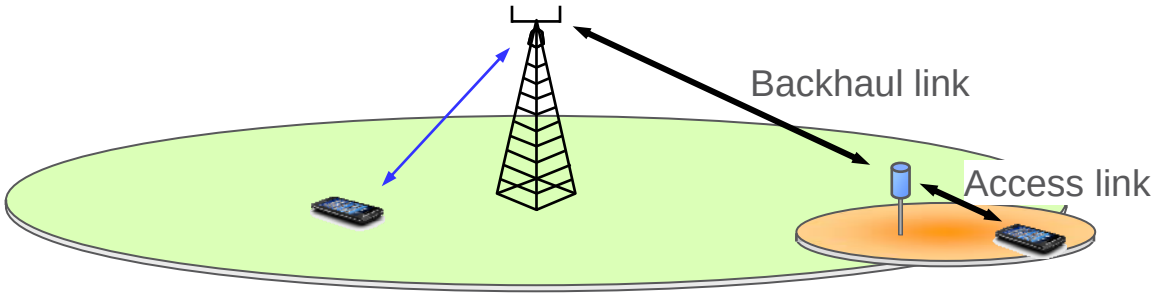


- Trend – focus on UE-specific reference-signal structures (DM-RS)
  - Enabling novel multi-antenna structures
  - Improved beamforming, heterogeneous deployments, CoMP, …
  - Rel-11 extends DM-RS support to control signaling

RELAYING
REL-10

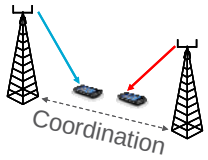
- Relay – small low-power base station
  - Creates new cells – can serve Rel-8 terminals
  - Uses LTE spectrum/air interface for backhaul transport (”self-backhauling”)

- Main usage scenario
  - When fiber/microwave backhaul is more expensive than LTE spectrum

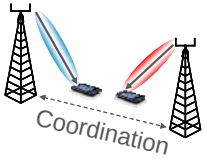


COMP
REL-11

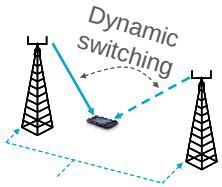
› Numerous schemes under discussion…



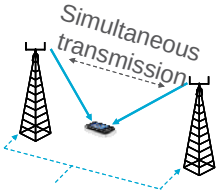
Coordinated Scheduling



Coordinated Beamforming

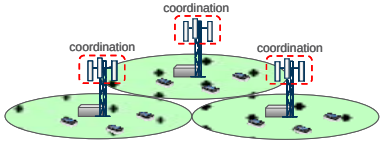


Dynamic Point Selection

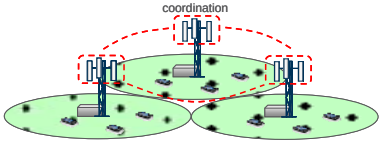


Joint Transmission

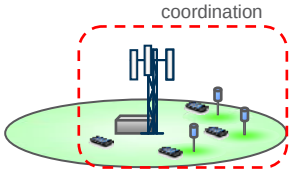
› Different deployment scenarios under investigation…



Intra-site coordination



Inter-site coordination



Heterogeneous deployment

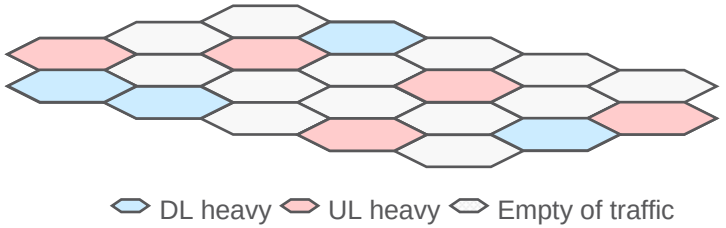
› Challenges – *robustness* and *overhead*

HETEROGENEOUS DEPLOYMENTS

- Increasing data rate and capacity demands ➡ densification
  - Strong trend towards *complementing* macro nodes with picos
- Possible already in Rel-8, enhancements in later releases
- Later releases provide tools *improving* heterogeneous deployments
  - Range expansion – *increase pico uptake area*
  - Soft Cell – *macro-assisted pico layer*
  - Relay – *pico backhaul*
  - …

ADDITIONAL EXAMPLES
REL-11 AND BEYOND

- Flexible TDD allocations
  - Adapt to traffic variations [in small cells]



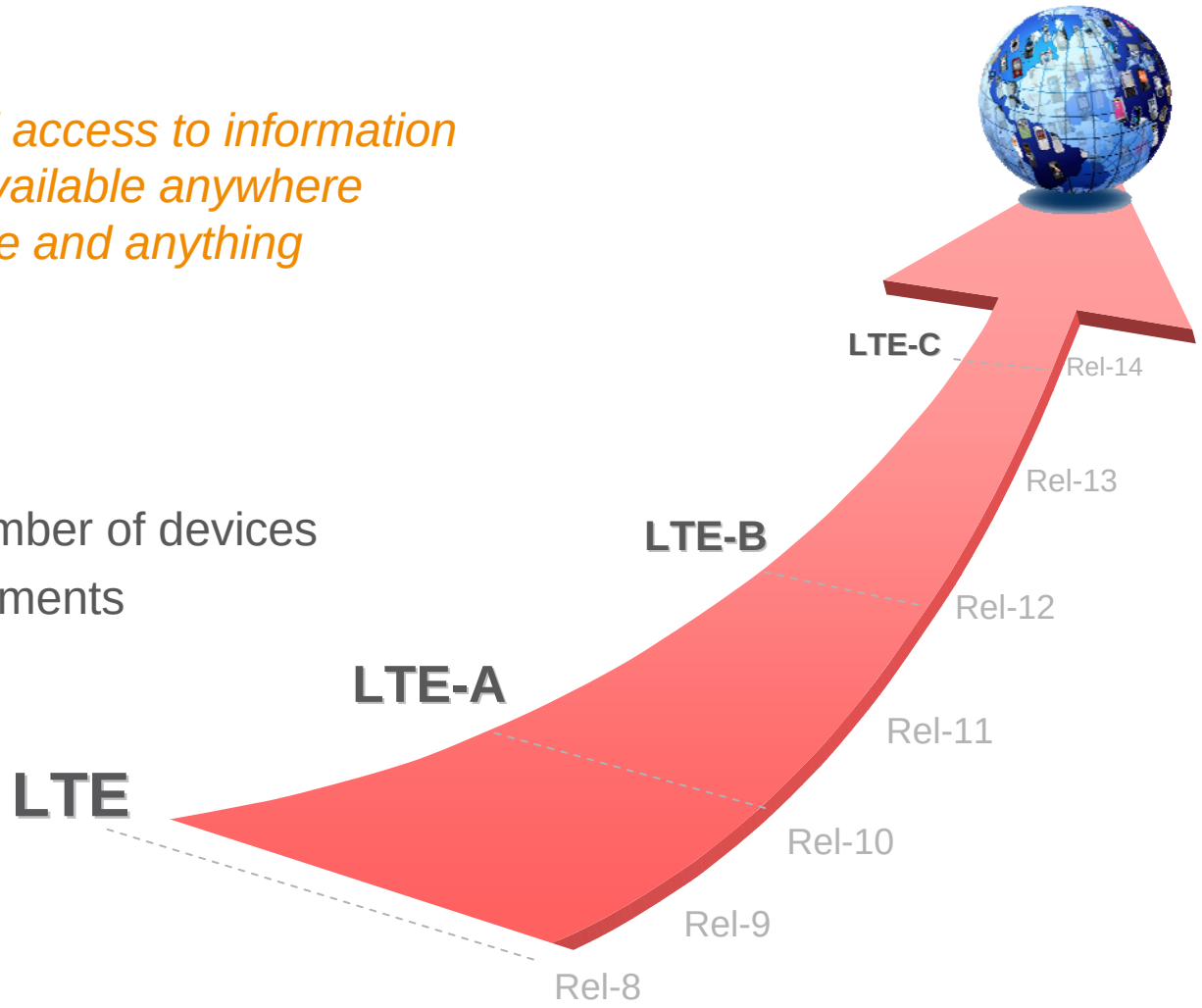
- Machine-type communication
  - Possible in Rel-8
  - Enhancements in later releases – number of connections, low-cost terminals, …

- Enhancements of existing features
  - Additional band combinations
  - Carrier aggregation enhancements
  - Receiver improvements
  - …

FURTHER INTO THE FUTURE

- Vision
  - *A world with unlimited access to information and sharing of data available anywhere and anytime to anyone and anything*

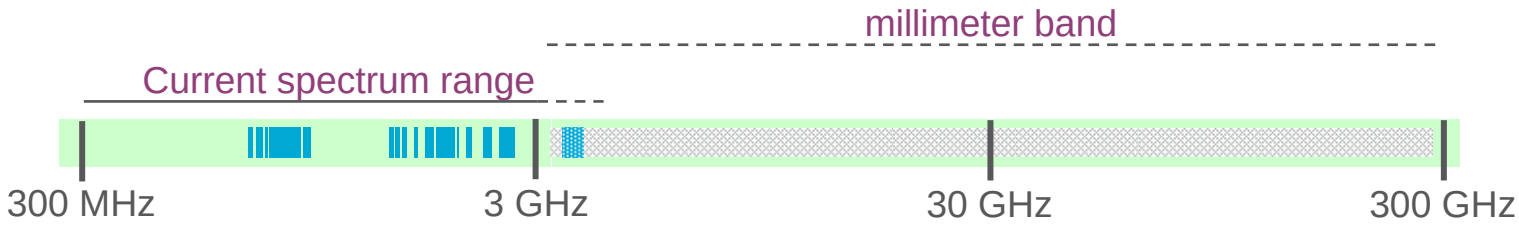
- Challenges
  - Massive traffic growth
  - Massive growth in number of devices
  - Wide range of requirements and use cases



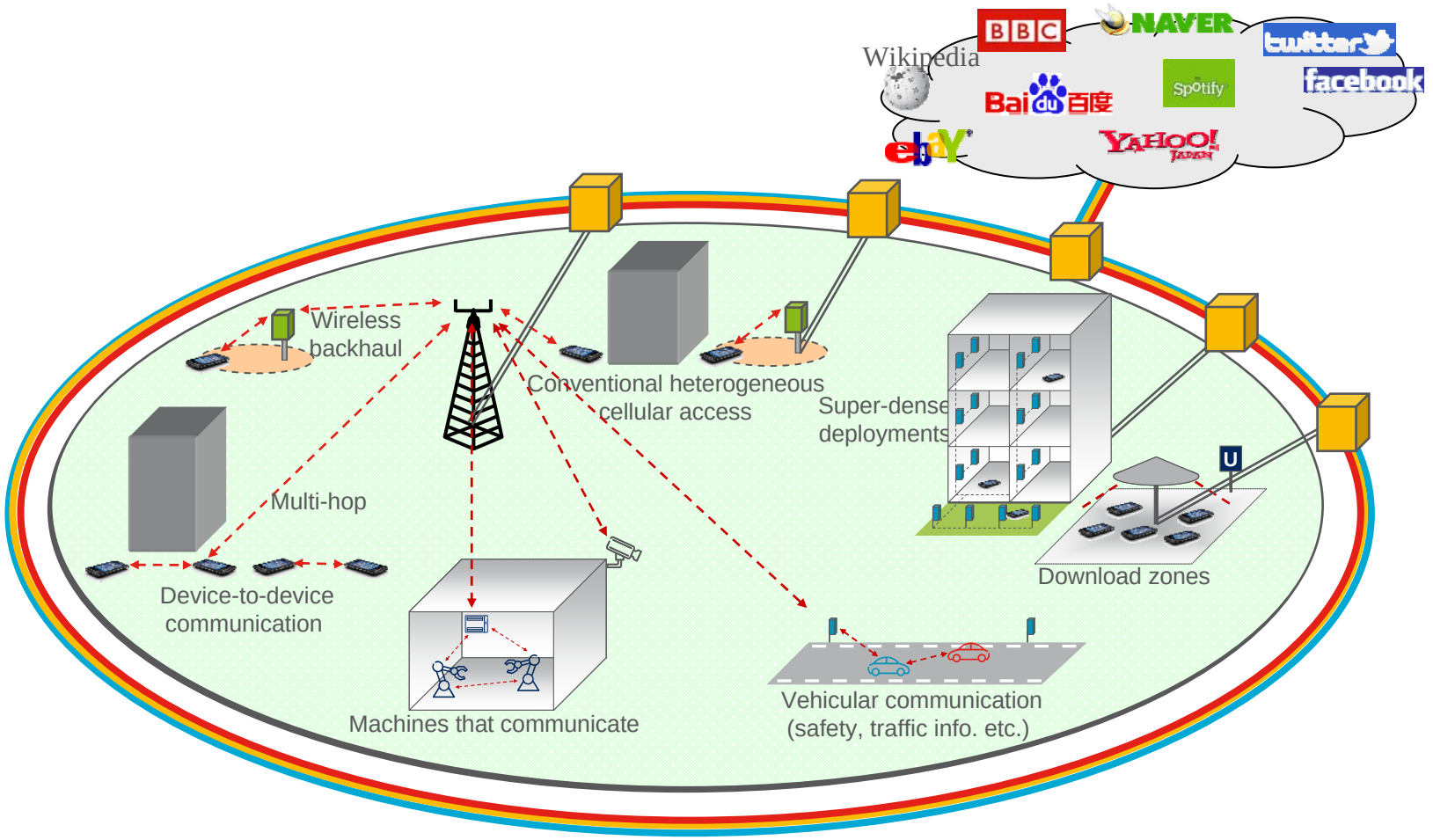
FURTHER INTO THE FUTURE

- No reason to radically deviate from LTE track
  - *Evolution continues – inter-site coordination, energy efficiency, …*
  - *LTE capable of handling massive increase in capacity*

- New scenarios, e.g. usage of *very high frequency bands*?
  - Lots of spectrum available ➡ Extreme capacity and data rates
  - Small wave length ➡ Possibilities for massive antenna solutions

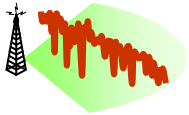


FURTHER INTO THE FUTURE



SUMMARY

› Fundamental principle – *adapt to* and *exploit* variations in…



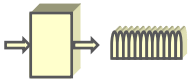
…radio channel quality

…traffic pattern

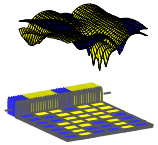
› LTE - some building blocks

Bandwidth flexibility

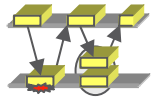
FDD *and* TDD



OFDM



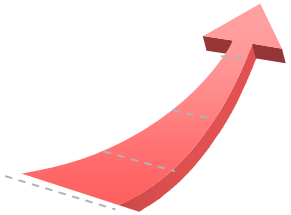
Scheduling



Hybrid ARQ

Multi-antenna

› Evolution continues



FOR FURTHER INFORMATION...

Open the 3GPP specifications...

...or read The Book!

Available in English, Chinese, Korean and Japanese.

ERICSSON