INTERFERENCE MANAGEMENT WITHIN 3GPP LTE ADVANCED

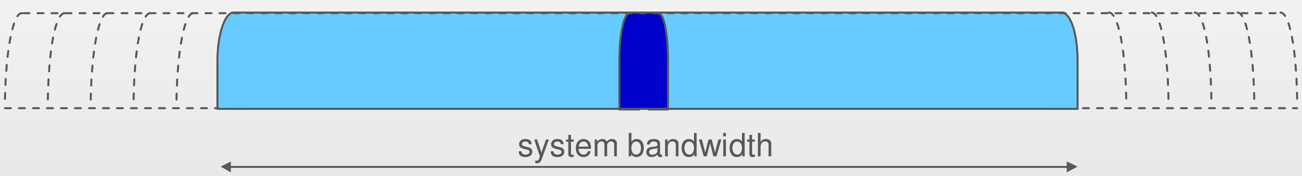
KONSTANTINOS DIMOU, PHD
SENIOR RESEARCH ENGINEER,
WIRELESS ACCESS NETWORKS, ERICSSON RESEARCH
konstantinos.dimou@ericsson.com

OUTLINE

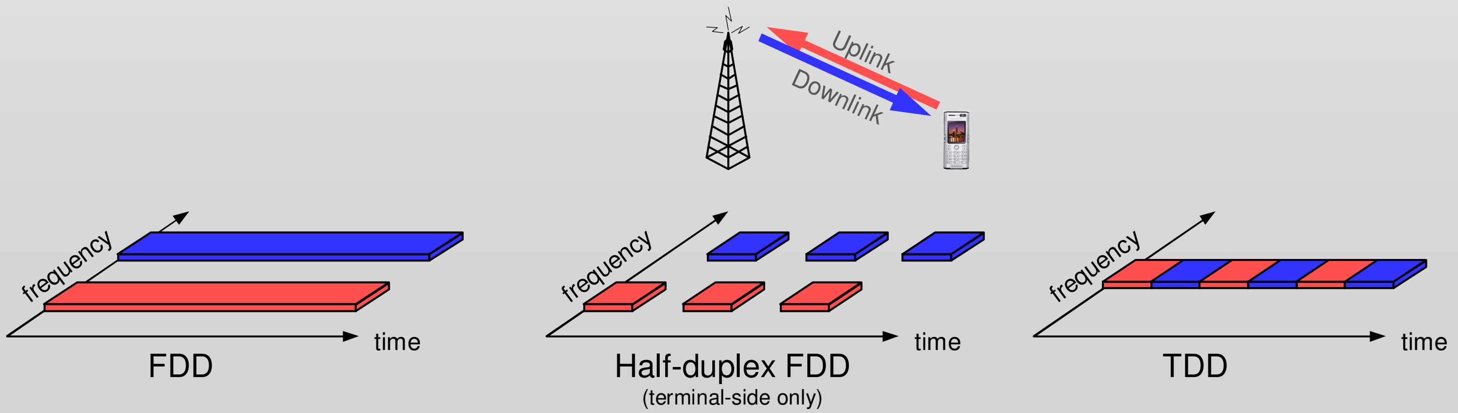
- 3GPP LTE (Advanced)
  - Short Introduction
- Interference Management
  - Goal of interference management in cellular systems
  - Sources of interference within 3GPP LTE Advanced
    - Inter-system Interference
    - Intra-LTE Interference
      - Inter-Cell Interference
- Inter-Cell Interference Coordination (ICIC)
  - Data Channels
    - Cell-autonomous schemes
    - Coordinated Schemes
- Summary

LTE – *Spectrum Flexibility*

- Operation in differently-sized spectrum allocations
  - From 1.4 MHz to 20 MHz

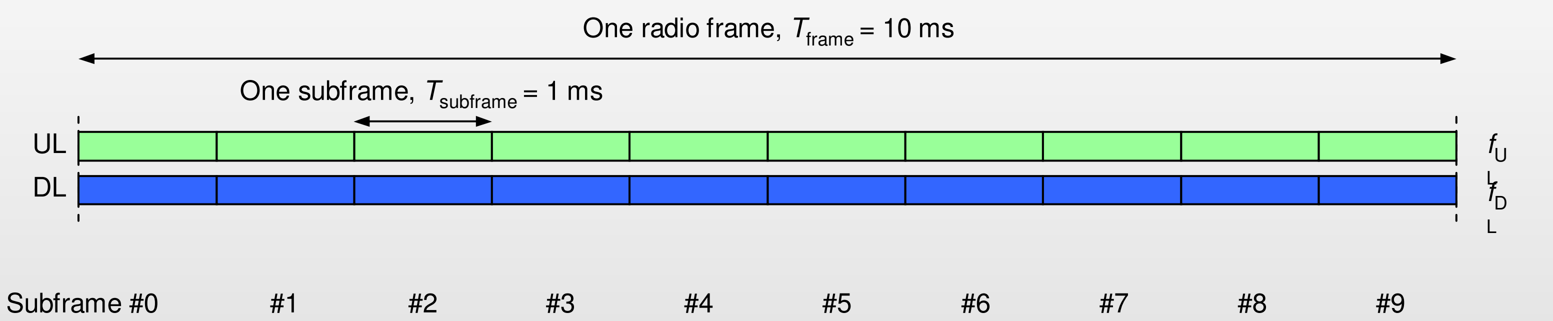


- Support for paired *and* unpaired spectrum allocations

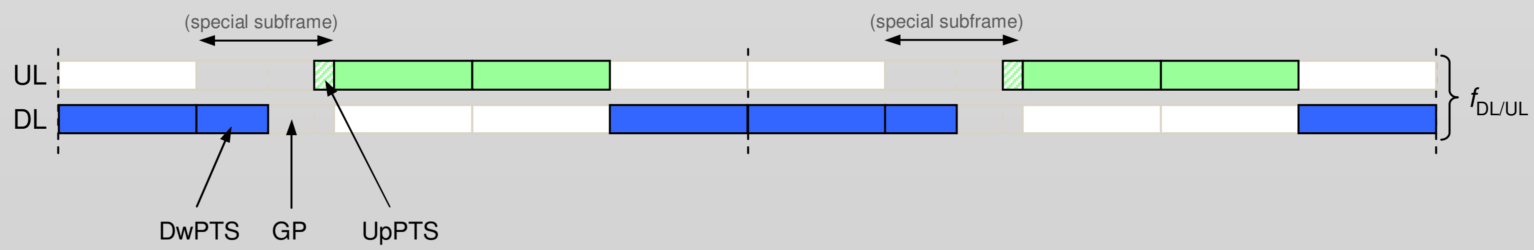


TIME-DOMAIN STRUCTURE

› FDD
  – Uplink and downlink separated in frequency domain



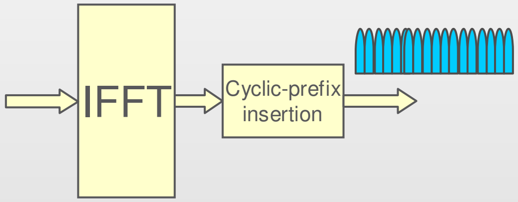
› TDD
  – Uplink and downlink separated in time domain ➡ ”special subframe”
  – Same numerology etc as FDD ➡ economy of scale



TRANSMISSION SCHEME

Downlink – OFDM

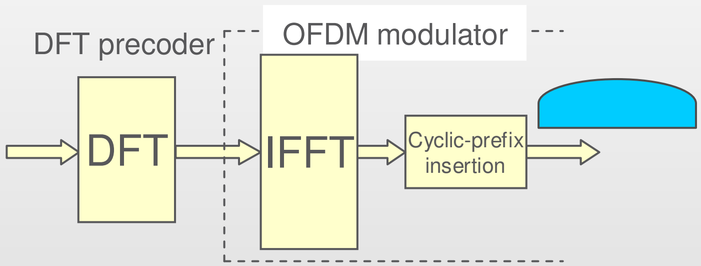
- Parallel transmission on large number of narrowband subcarriers



- Benefits:
  - Avoid own-cell interference
  - Robust to time dispersion
- Main drawback
  - Power-amplifier (PA) efficiency

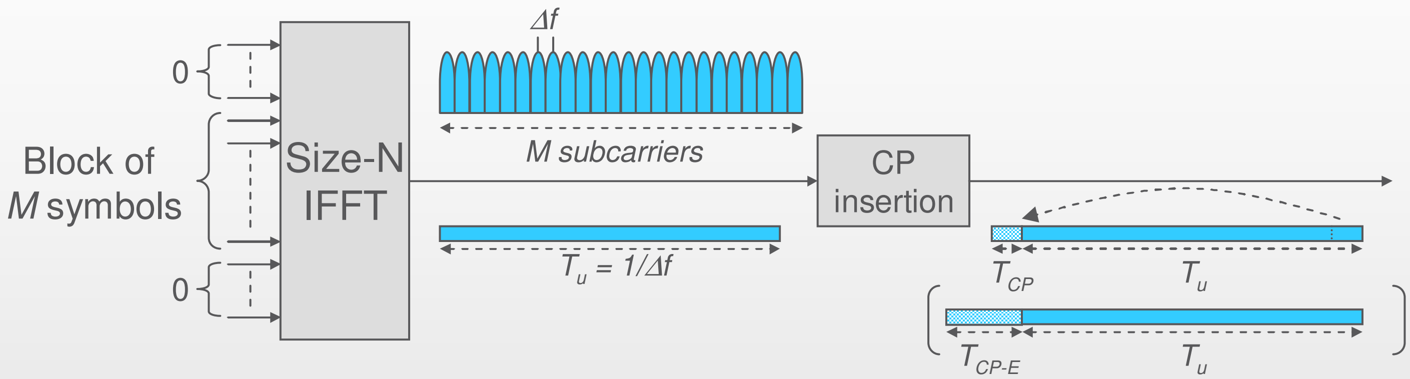
Uplink – DFTS-OFDM

- 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**

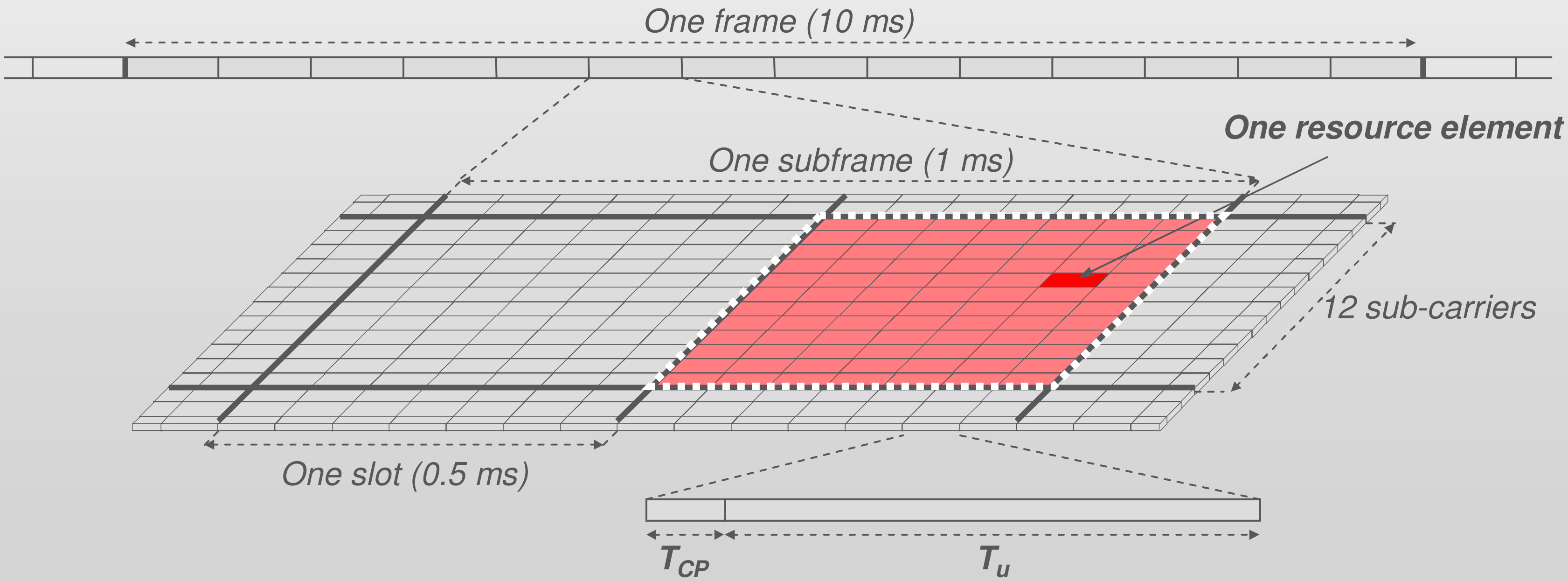
DOWNLINK – OFDM



- Parallel transmission using a large number of narrowband “sub-carriers”
- “Multi-carrier” transmission
  - Typically implemented with FFT
- Insertion of cyclic prefix prior to transmission
  - Improved robustness in time-dispersive channels – *requires CP > delay spread*
  - Spectral efficiency loss

Configuration, Δf		CP length	Symbols per slot
Normal	15 kHz	≈4.7 µs	7
Extended	15 kHz	≈16.7 µs	6
	7.5 kHz	≈33.3 µs	3

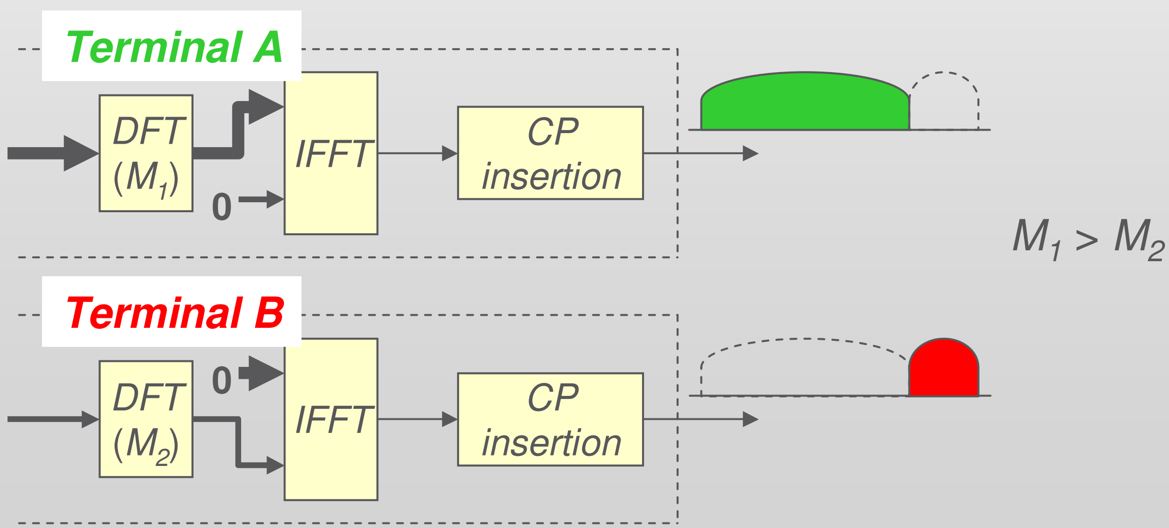
PHYSICAL RESOURCES



UPLINK – DFT-SPREAD OFDM ('SC-FDMA')

- 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

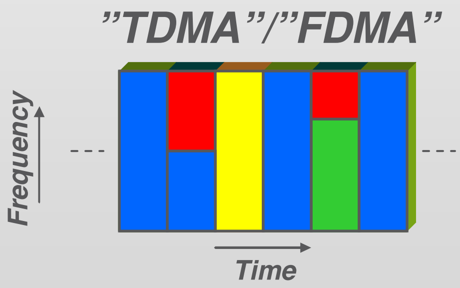
- Uplink numerology aligned with downlink numerology



UPLINK – DFT-SPREAD OFDM ('SC-FDMA')

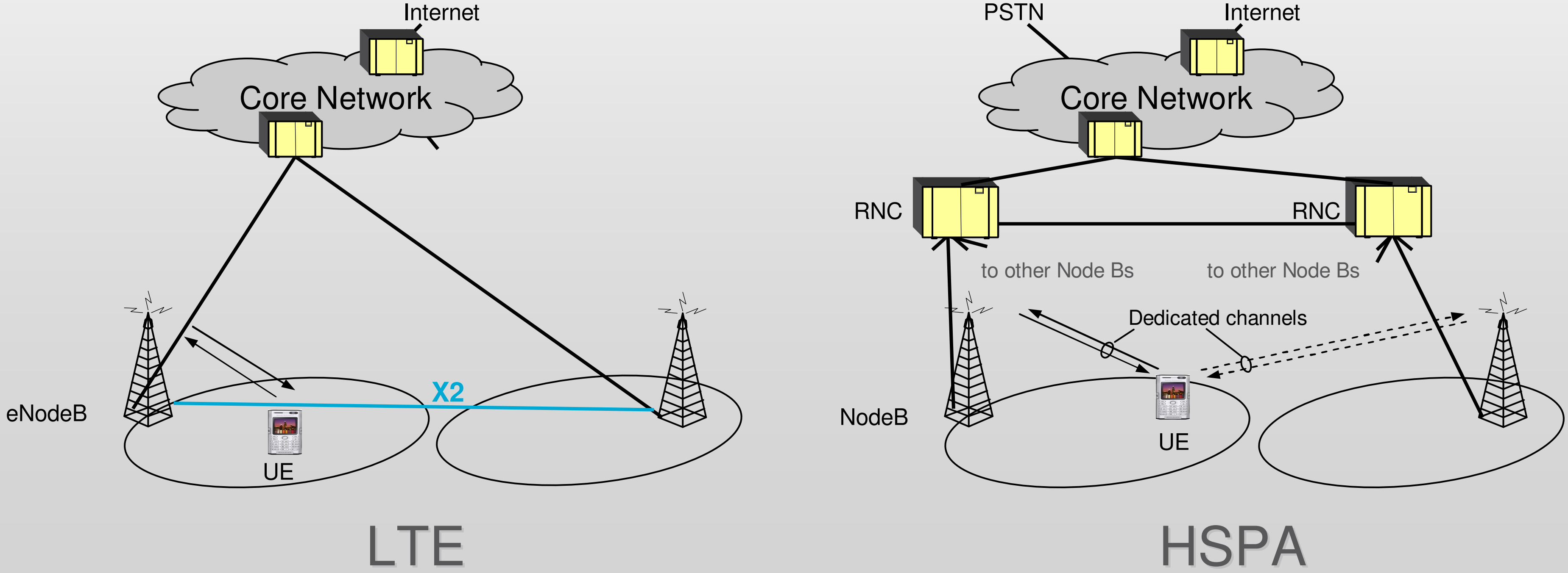
- Combined TDMA/FDMA ➡ intra-cell orthogonality
  - Scheduled uplink – NodeB scheduler controls resource allocation
  - Orthogonal uplink ➡ no intra-cell interference
  - Orthogonal uplink ➡ relaxed need for fast closed-loop power control

- Why FDMA component?
  - To support small payloads
  - To handle the case of power limitations



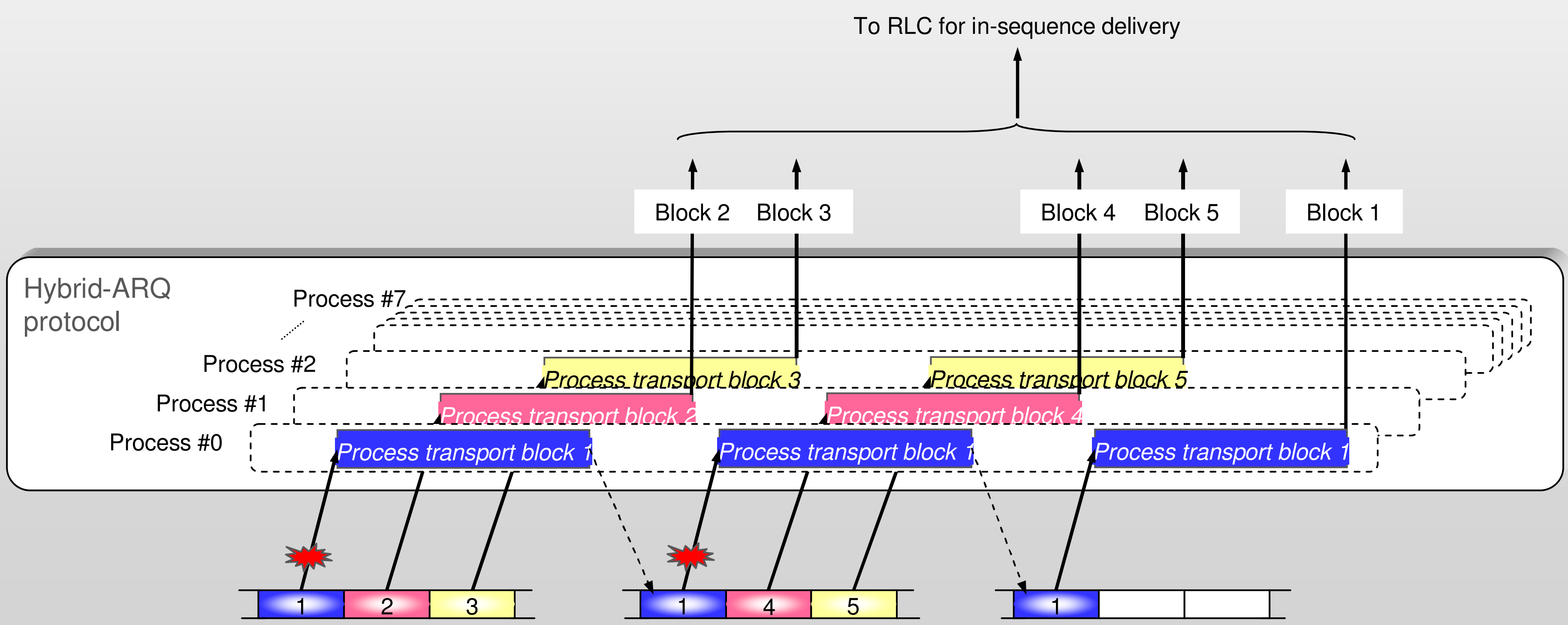
ARCHITECTURE

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



HYBRID-ARQ WITH SOFT COMBINING

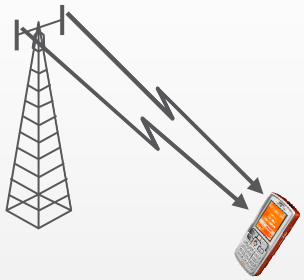
- Same basic structure as HSPA
  - Parallel stop-and-wait processes
  - 8 processes ➡ 8 ms roundtrip time



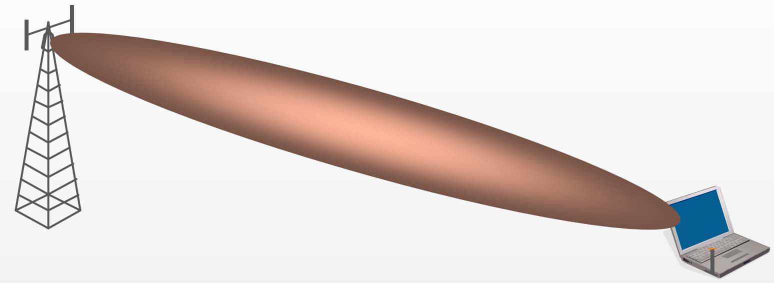
INTERACTION WITH RLC

- 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
- Hybrid-ARQ and RLC *complement* each other

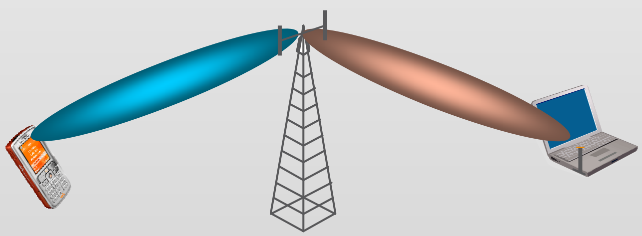
MULTI-ANTENNA TRANSMISSION TECHNIQUES



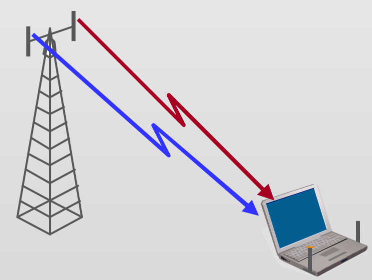
Diversity for improved
system peformance



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



SDMA for improved capacity
(more users per cell)

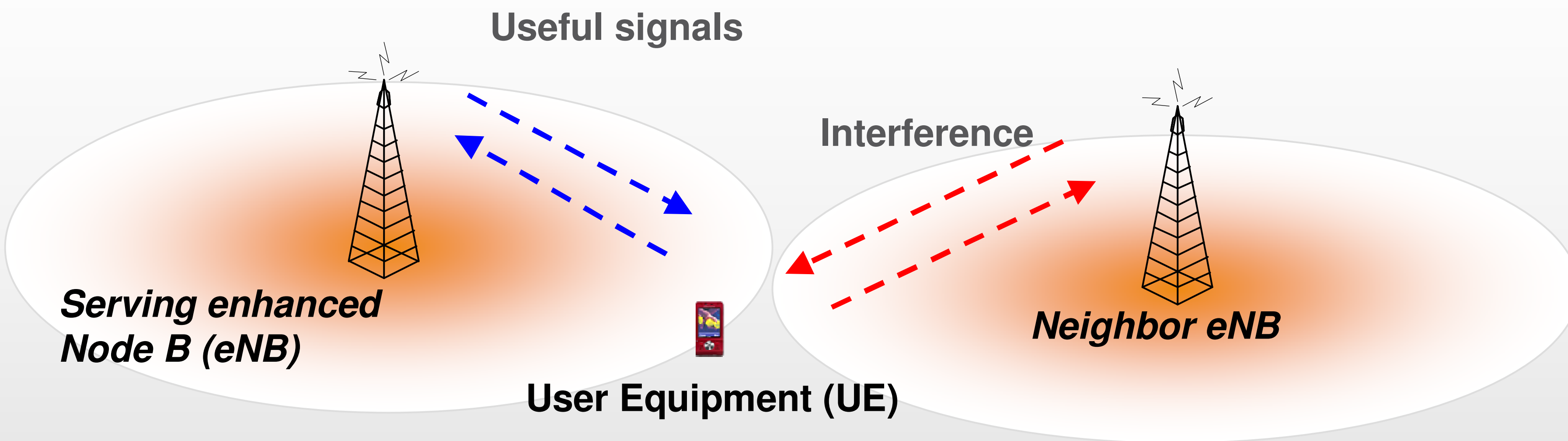


Multi-layer transmisson (”MIMO”)
for higher data rates in a given bandwidth

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

GOAL OF INTERFERENCE MANAGEMENT

INTERFERENCE WITHIN CELLULAR SYSTEMS



$$SINR = \frac{S}{I + N}$$

Useful Signal

Noise

Interference

Downlink

- Interference @ the UE

Uplink

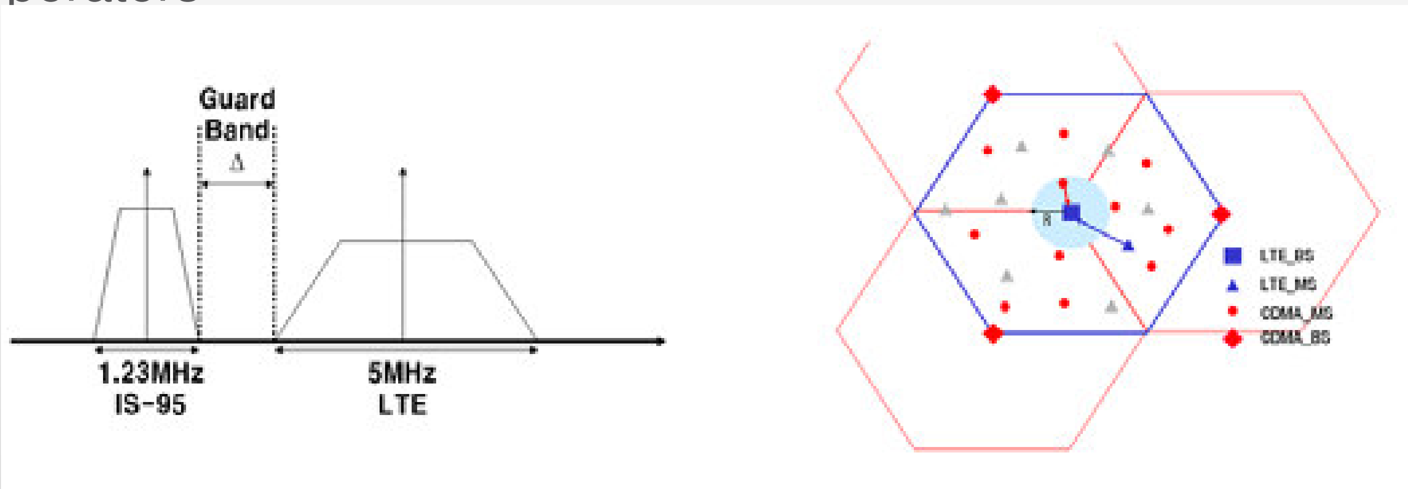
- Interference @ the eNB

Reduce interference so as to increase SINR

SOURCES OF INTERFERENCE

SOURCES OF INTERFERENCE WITHIN LTE

› Inter-system interference
  – From other cellular systems
    › E.g. from WCDMA, IS-95 or from bands belonging to other LTE operators



  – From other types of systems
    › E.g. TV or other broadcasting systems, satelite communications, radars

› Intra-LTE Interference
  – Inter-cell Interference

INTER-SYSTEM INTERFERENCE

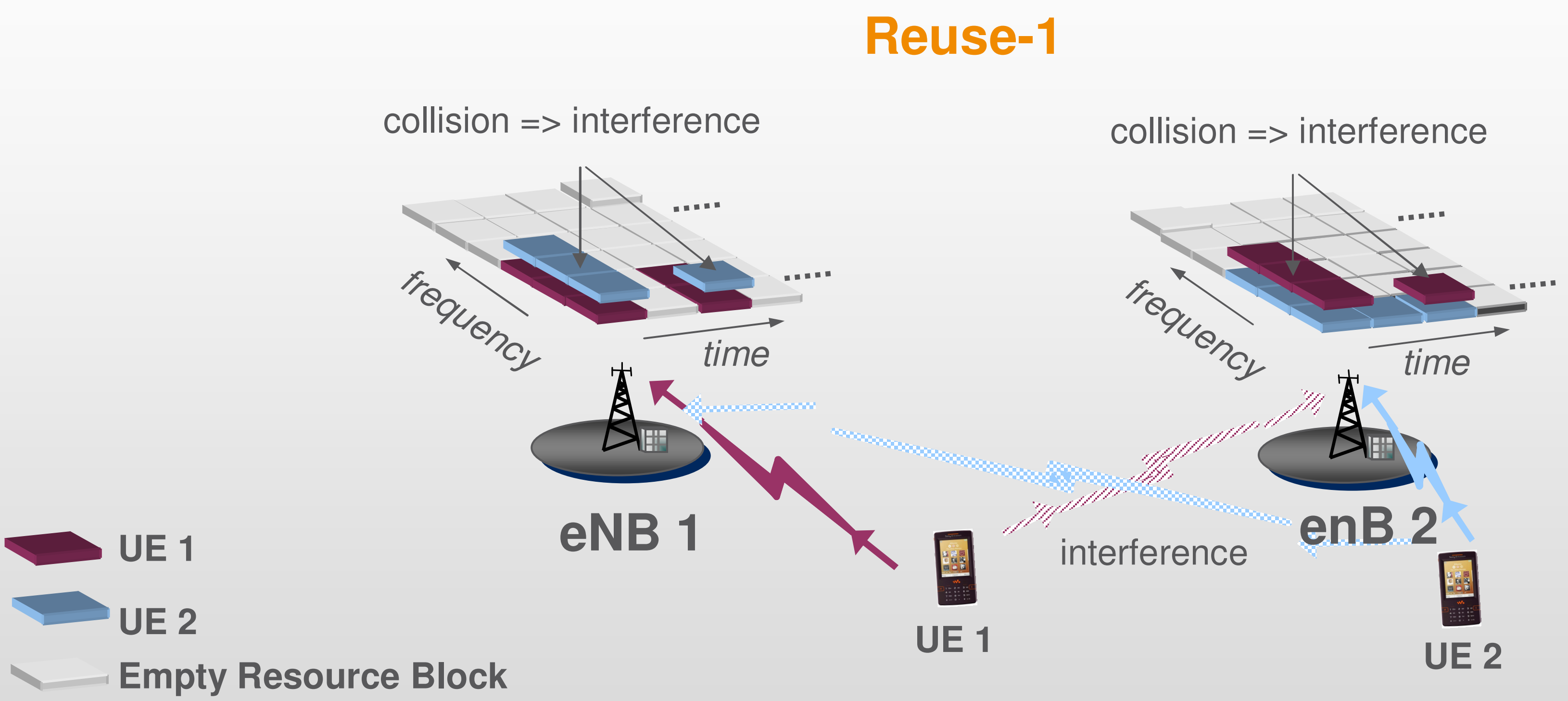
- Inter-system interference
  - Typically of steady nature
    - Exception: interference created by radars transmiting pulses/signals on certain time instants
  - Either on the same frequency
    - "Co-channel interference" or
  - On adjacent frequencies
    - "Adjacent channel interference"
      - Created by
        - hardware imperfections at the transmitter resulting in:
          - Out of Band/Spurious emissions
          - Adjacent Channel Leakage
        - Non-perfect filter at the receiver

SOLUTIONS TO INTER-SYSTEM INTERFERENCE

- Adjacent channel interference
  - Receiver blocking
    - Filtering
  - Guard bands
- Co-channel interference
  - Receiver Desensitization
  - Network Planning
  - Inter-system coordination

INTRA LTE INTERFERENCE

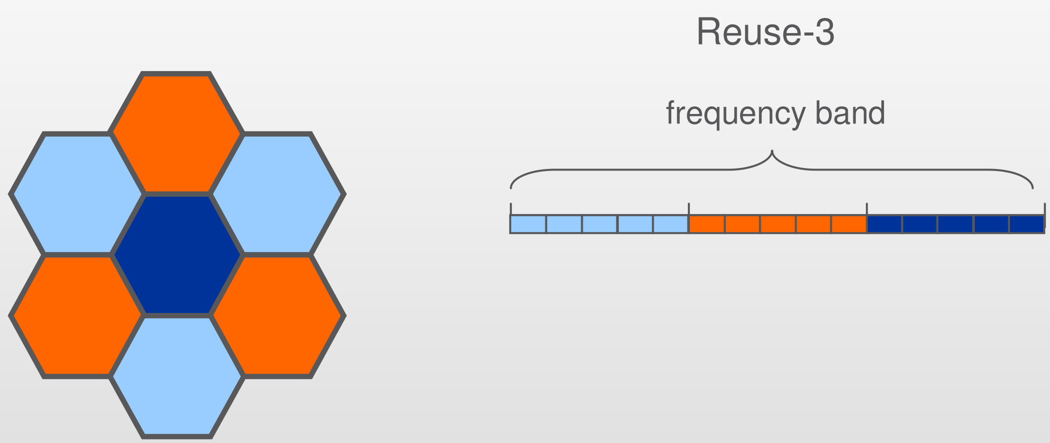
➢ Other-cell interference



- Independent scheduler operation may result in collisions
- For data: A collision typically leads to some SINR degradation; it does not necessarily mean information loss
  - Collisions more harmful to cell edge users

HOW CAN A COLLISION BE AVOIDED?

- Radio Resource Management (RRM)
  - Frequency Reuse (FR)



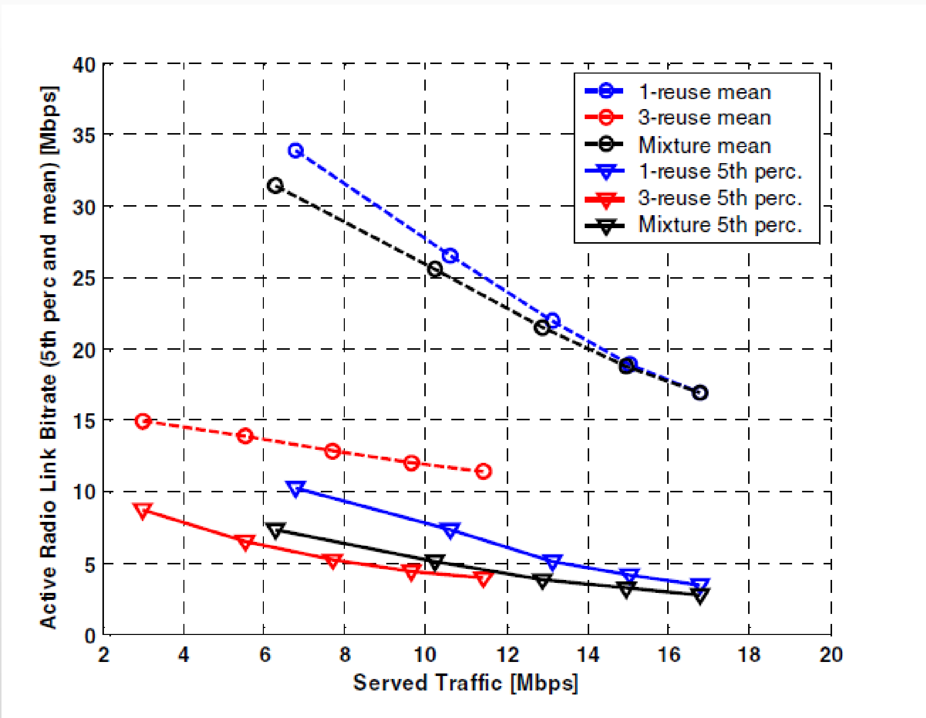
- Coordinated RRM
  - Joint scheduling

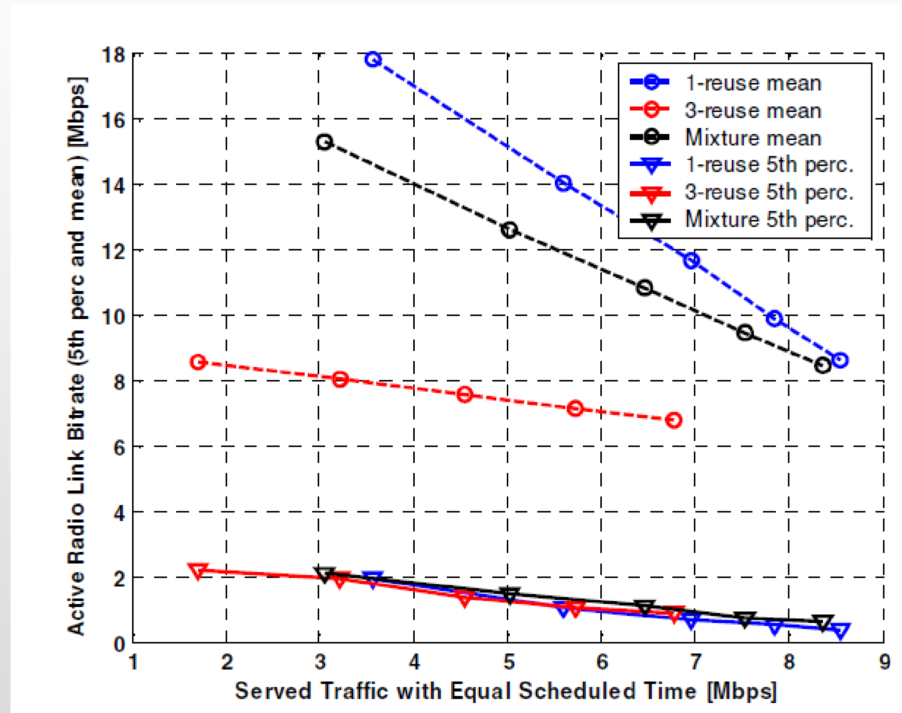
ICIC FOR DATA CHANNELS "COST" TRADE-OFF ANALYSIS

- "Cost" of a "collision"
  - Fewer user data bits can be carried in one PRB, as the link adaptation needs to select lower modulation order and/or lower coding rate to compensate the lower SINR
  - More HARQ retransmissions may be needed for successful data delivery (due to BER degradation)

- "Cost" of avoiding a collision
  - Bandwidth restriction: colliding PRBs may need to be banned from use in the neighbor cell or may be used only with restrictions (e.g., with lower power)
  - Delayed scheduling: the scheduling of some UEs (interfering or interfered UEs) may need to be postponed.

WHAT IS THIS RESULT OF THIS TRADE-OFF?





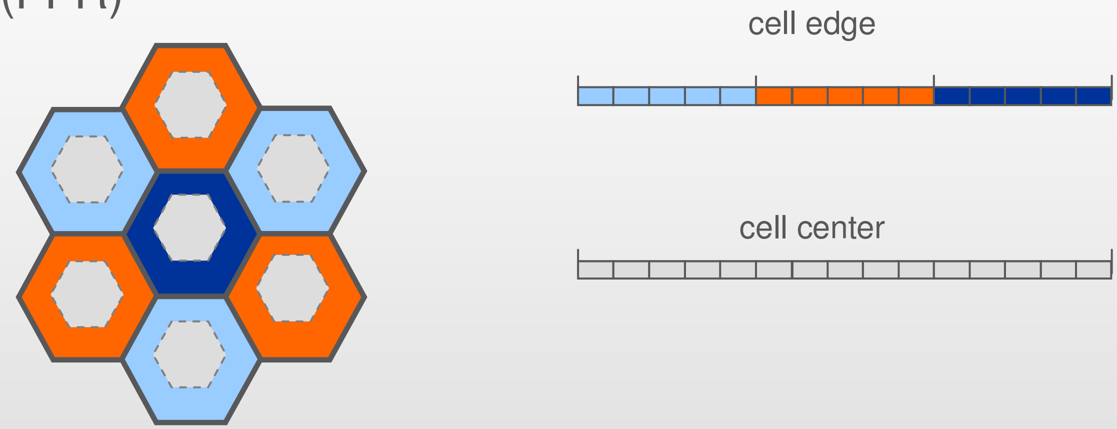
Downlink: 2X2, Maximum Ratio Combining (MRC)

Uplink: 1X1, Single Input Single Output (SISO)

Avoiding a collision results in higher loss in radio resource usage than the gain in interference reduction

HOW CAN THE EFFECTS OF A COLLISION BE MINIMIZED? - 1

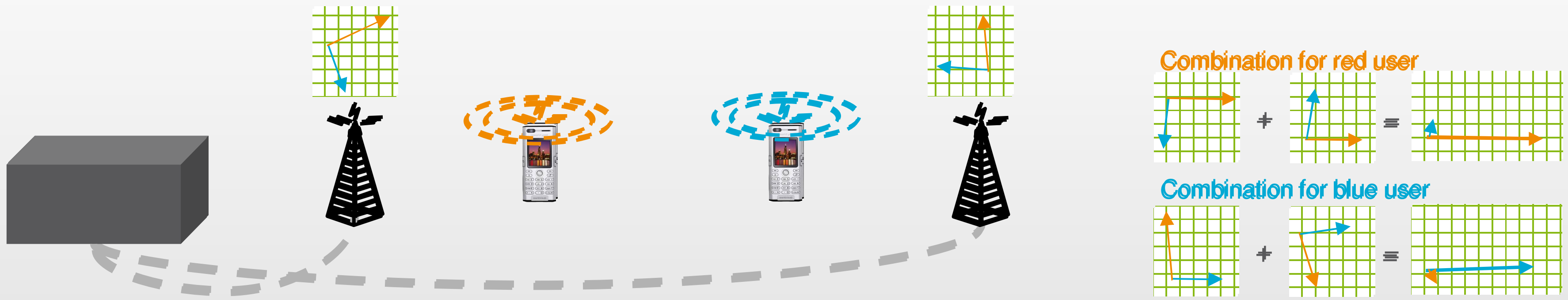
- Radio Resource Management (RRM)
  - Scheduling
  - Fractional Frequency Reuse (FFR)



  - Fractional Power Control (FPC)
- Coordinated RRM
  - Joint scheduling
  - Joint power control

HOW CAN THE EFFECTS OF A COLLISION BE MINIMIZED? - 2

- Advanced Receivers, e.g.
  - Interference Rejection Combining (IRC)



Weighted signals combined to maximize SINR (reject interference and amplify desired signal)

- Coordinated RRM Combined with Advanced Receivers aka as Coordinated Multipoint Transmission & Reception (COMP)
  - IRC
  - Successive Interference Cancellation (SIC)

"COST" FOR REDUCING THE EFFECTS OF A COLLISION

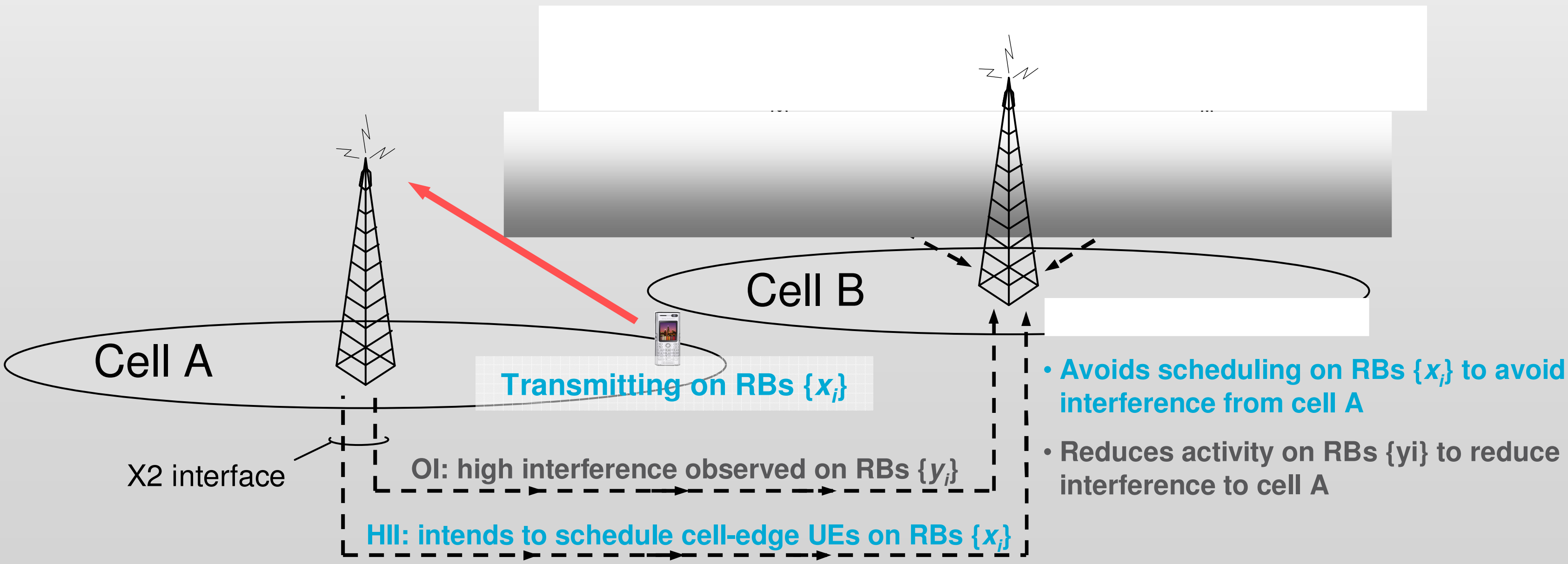
- Advanced receivers
  - Hardware complexity, higher processing power, cost

- Coordinated schemes
  - Hardware complexity, higher processing power
  - Backhaul cost
    - Requirements on
      - Latency
      - Capacity

REL. 8-9 SUPPORT FOR ICIC

UPLINK ICIC

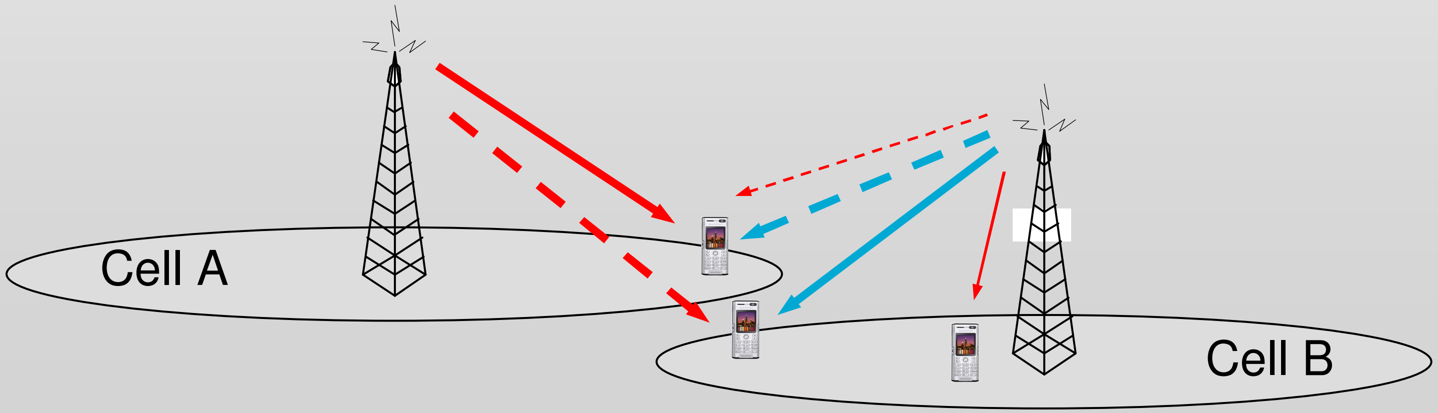
- Overload Indicator – OI (*"Reactive" mechanism*)
  - Bit map per resource block sent over X2 to neighbor cells
  - Signals if cell experiences low, medium, or high interference
- High Interferance Indicator – HII (*"Proactive" mechanism*)
  - Bit map per resource block sent over X2 to neighbor cells
  - Indicates intention to schedule cell edge users in specific bands



DOWNLINK ICIC

› Less beneficial compared to uplink
  - Enough power available also for wide bandwidth transmission
  - Cost in DL data rate from power limitation

› Relative Narrow band TX Power Indicator (RNTPI)
  - Own intention to limit DL TX power in e.g red subband (per RB)
  - Soft intention that can be broken in case if needed



ICIC ALGORITHMS

AUTONOMOUS-COORDINATED SCHEMES

- ICIC schemes can be either:
  - cell autonomous or
  - Coordinated between eNBs (aka "X2-based")

- Cell autonomous schemes
  - No coordination between neighbor cells

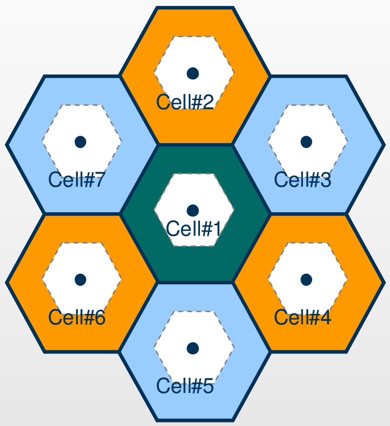
- Coordination schemes
  - exchanging scheduling information between cells
    - time scale of information exchange depends on the backhaul latency

AUTONOMOUS ICIC

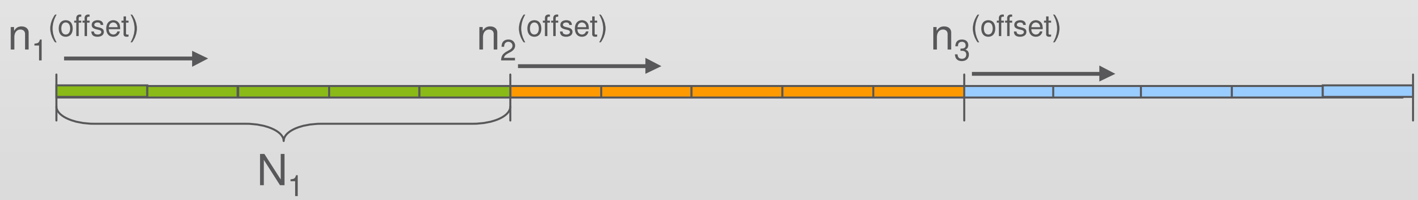
EXAMPLE OF AUTONOMOUS ICIC ALGORITHMS

STARTING OFFSET-BASED

- Offset based allocation order



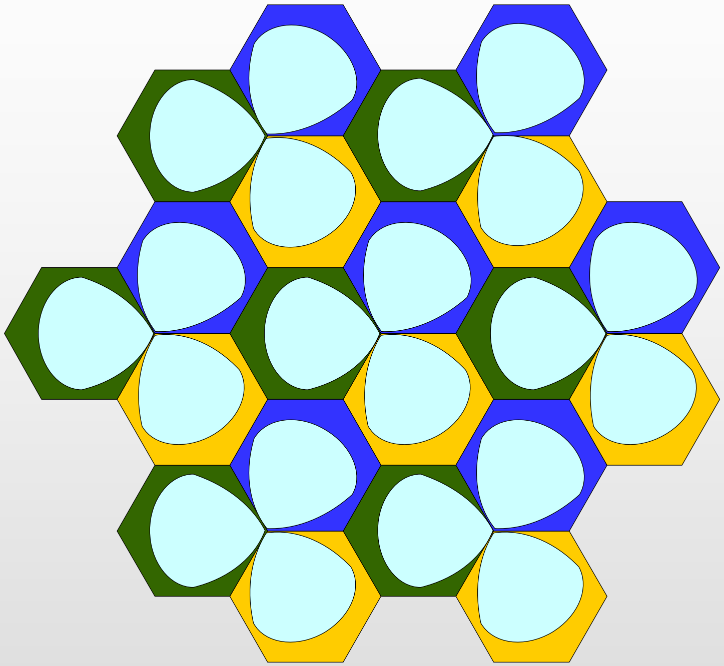
Offset based allocation order

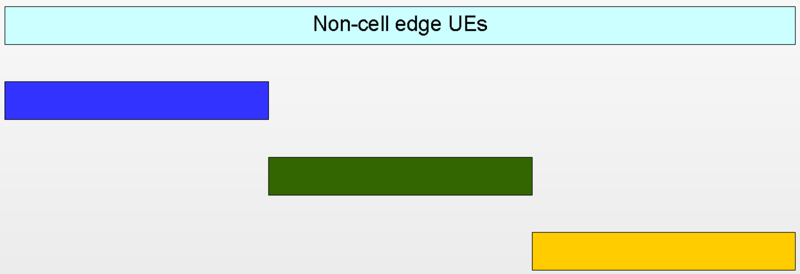


- Random Start index
  - Starting PRB selected randomly

Well performing schemes @ low loads

ICIC BASED ON FFR





› Cell edge user determined by averaged geometry