



INTERFERENCE MANAGEMENT WITHIN 3GPP LTE ADVANCED

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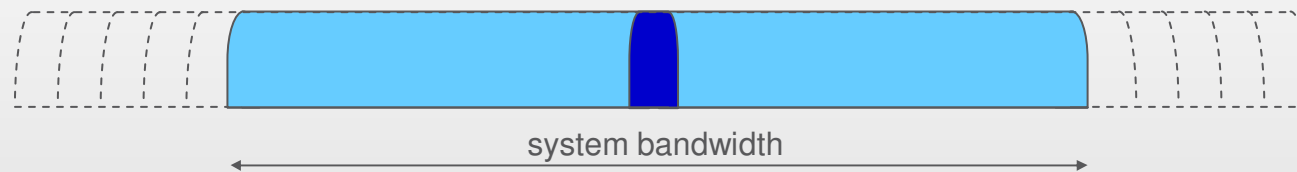
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OUTLINE

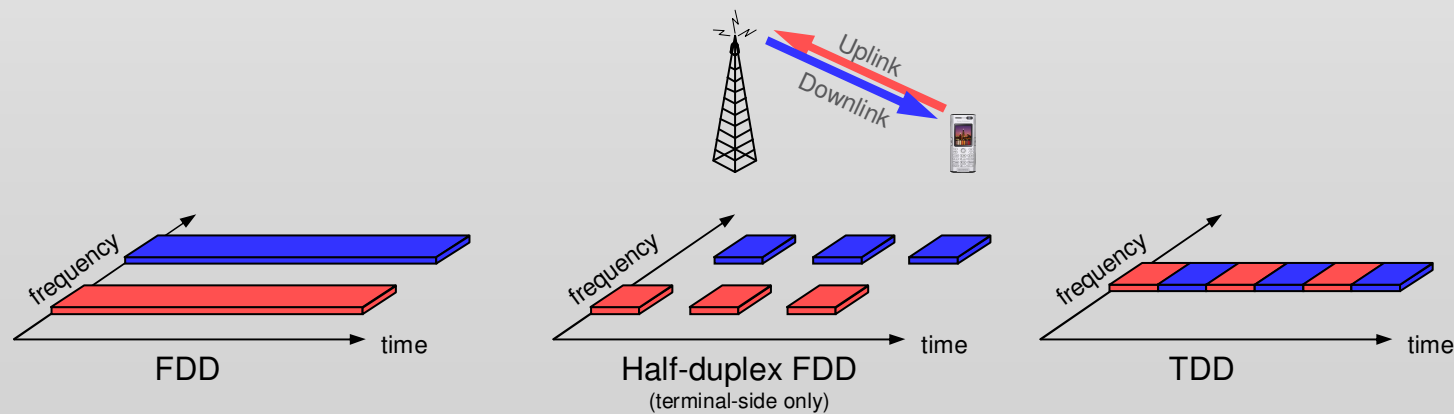
- 3GPP LTE (Advanced)
 - Short Introduction
- Interference Management
 - Goal of interference management in cellular systems
 - Sources of interference within 3GPP LTE Advanced
 - Inter-system Interference
 - Intra-LTE Interference
 - Inter-Cell Interference
- Inter-Cell Interference Coordination (ICIC)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

LTE – SPECTRUM FLEXIBILITY

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



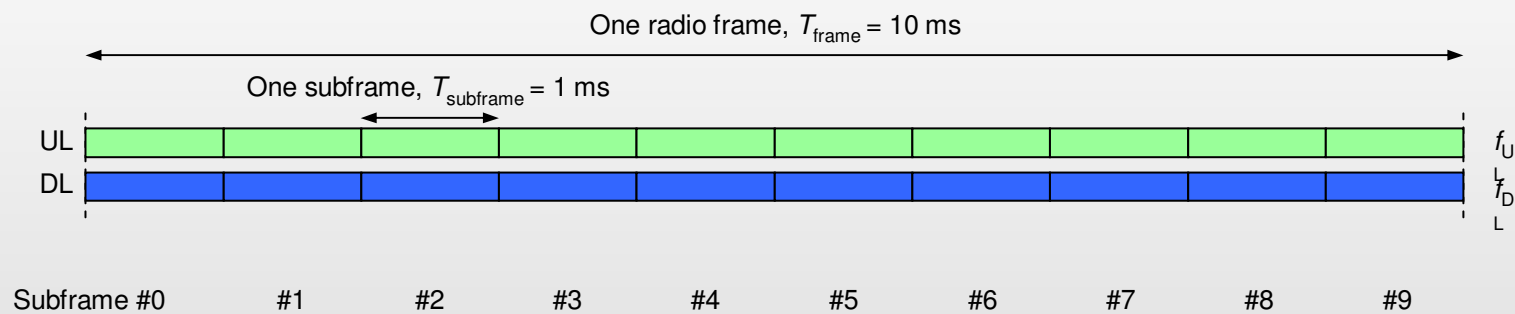
- › Support for paired *and* unpaired spectrum allocations



TIME-DOMAIN STRUCTURE

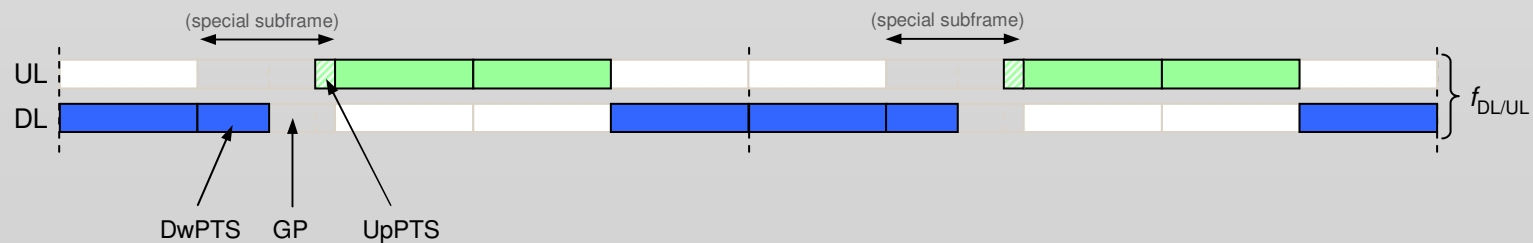
> FDD

- Uplink and downlink separated in frequency domain



> TDD

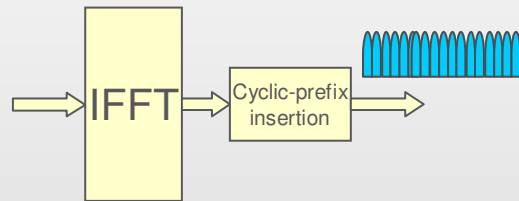
- Uplink and downlink separated in time domain ➔ "special subframe"
- Same numerology etc as FDD ➔ economy of scale



TRANSMISSION SCHEME

Downlink – OFDM

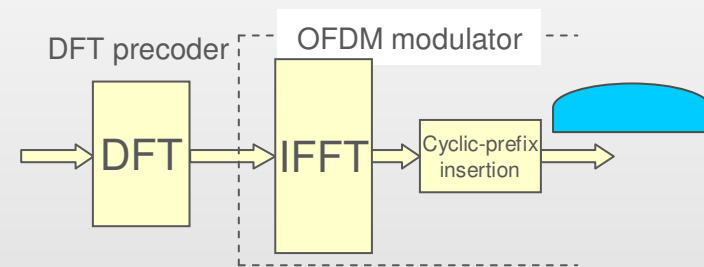
- › Parallel transmission on large number of narrowband subcarriers



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

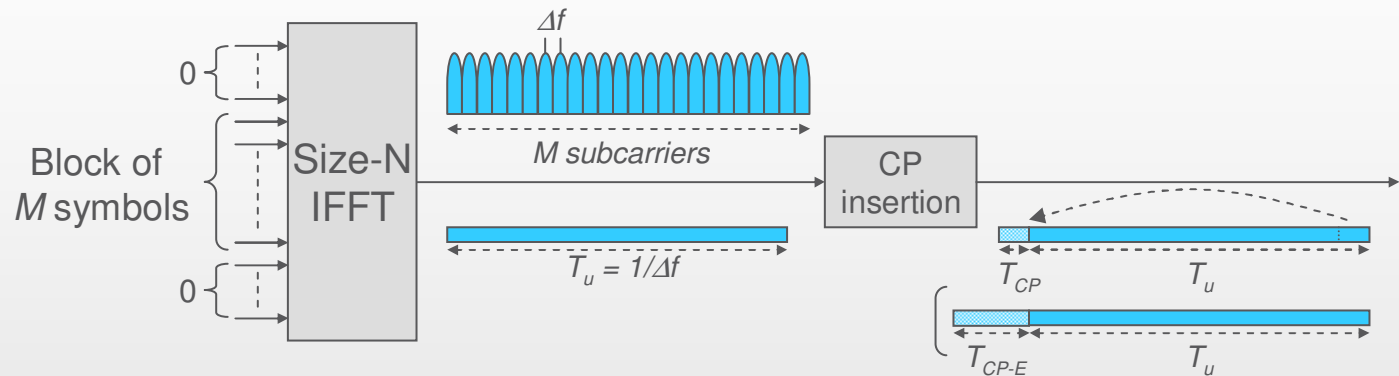
Uplink – DFTS-OFDM

- › 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**

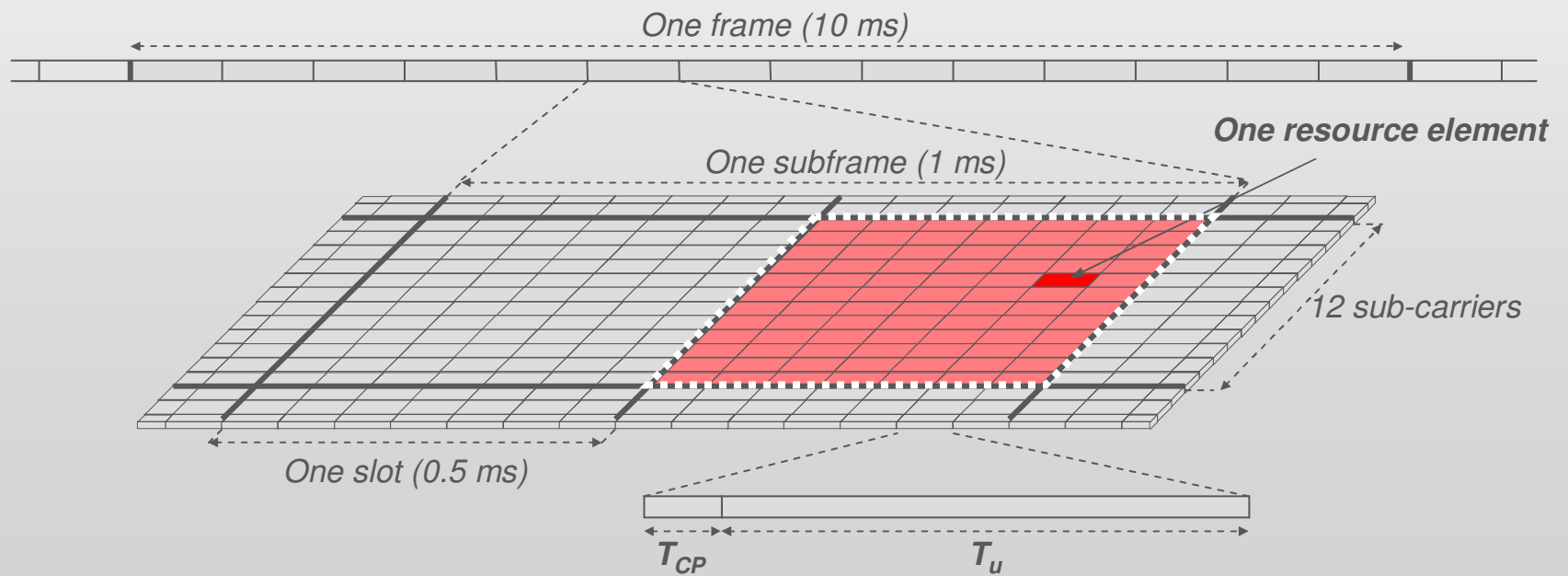
DOWNLINK – OFDM



- › 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	$\approx 4.7 \mu\text{s}$	7	
Extended	15 kHz	$\approx 16.7 \mu\text{s}$	6
	7.5 kHz	$\approx 33.3 \mu\text{s}$	3

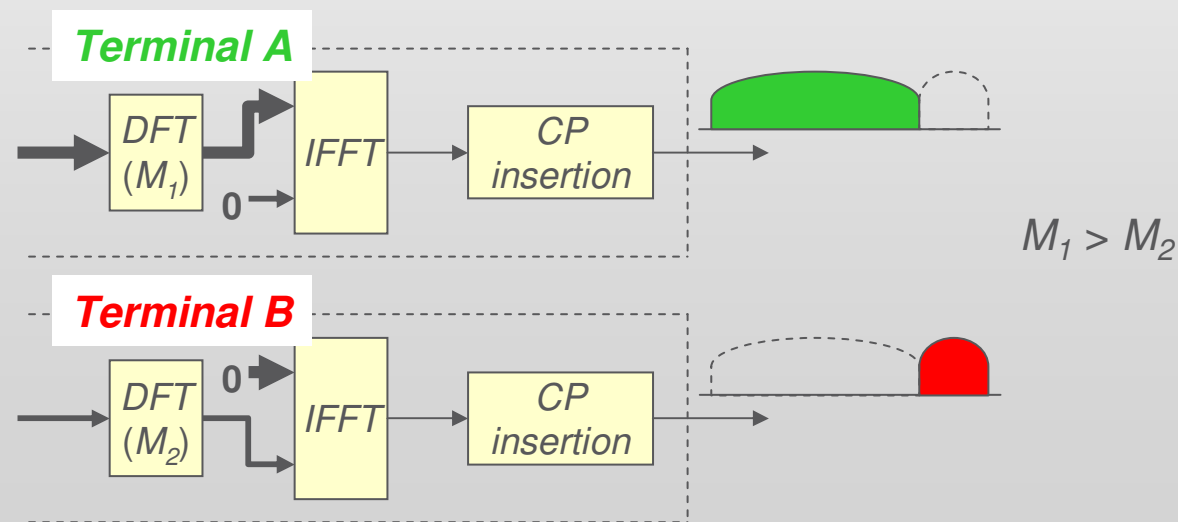
PHYSICAL RESOURCES



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

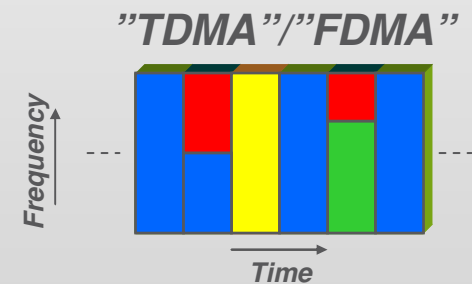
- › Uplink numerology aligned with downlink numerology



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

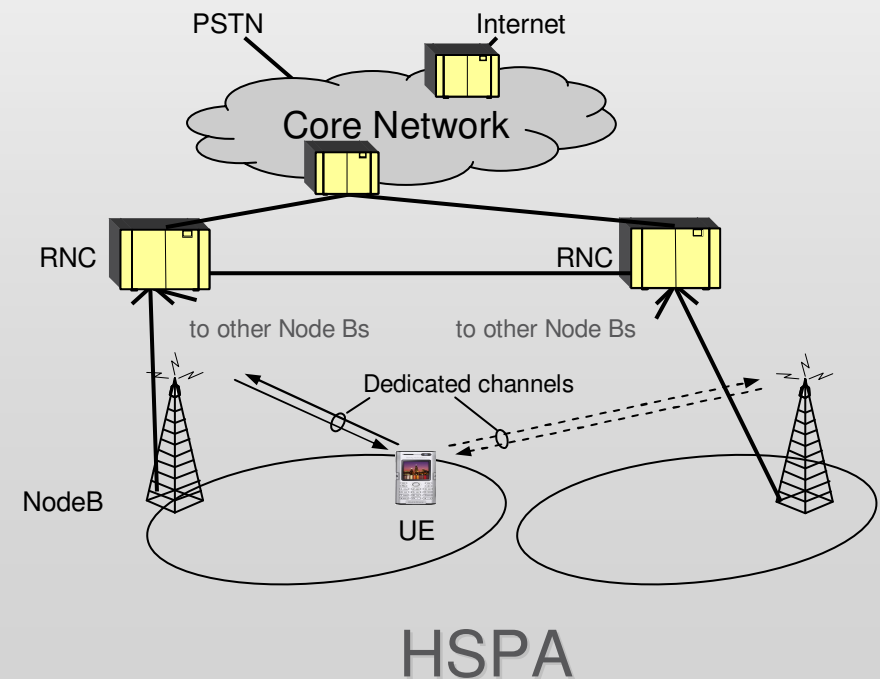
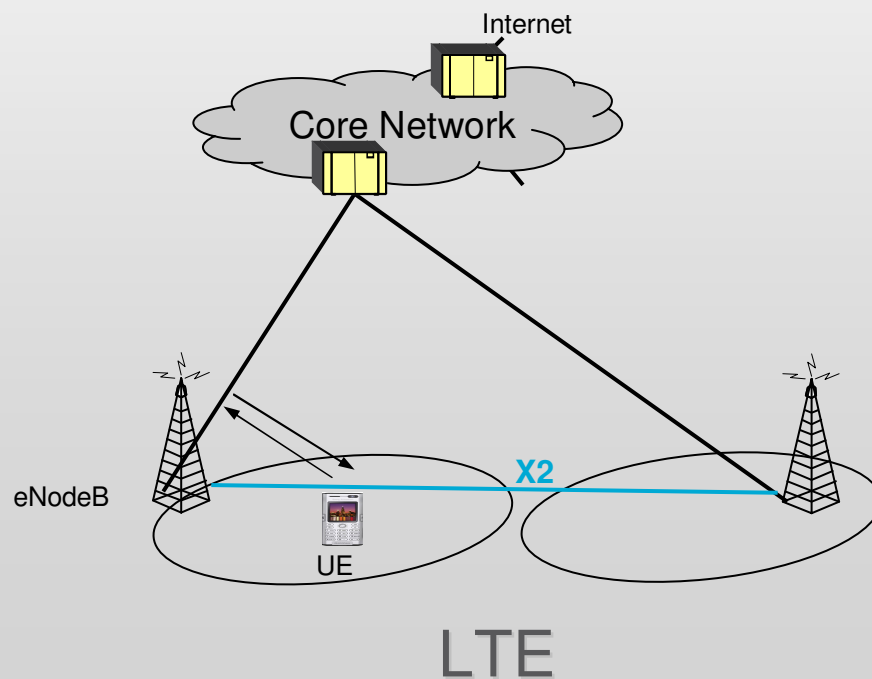
- › Why FDMA component?
 - To support small payloads
 - To handle the case of power limitations



ARCHITECTURE

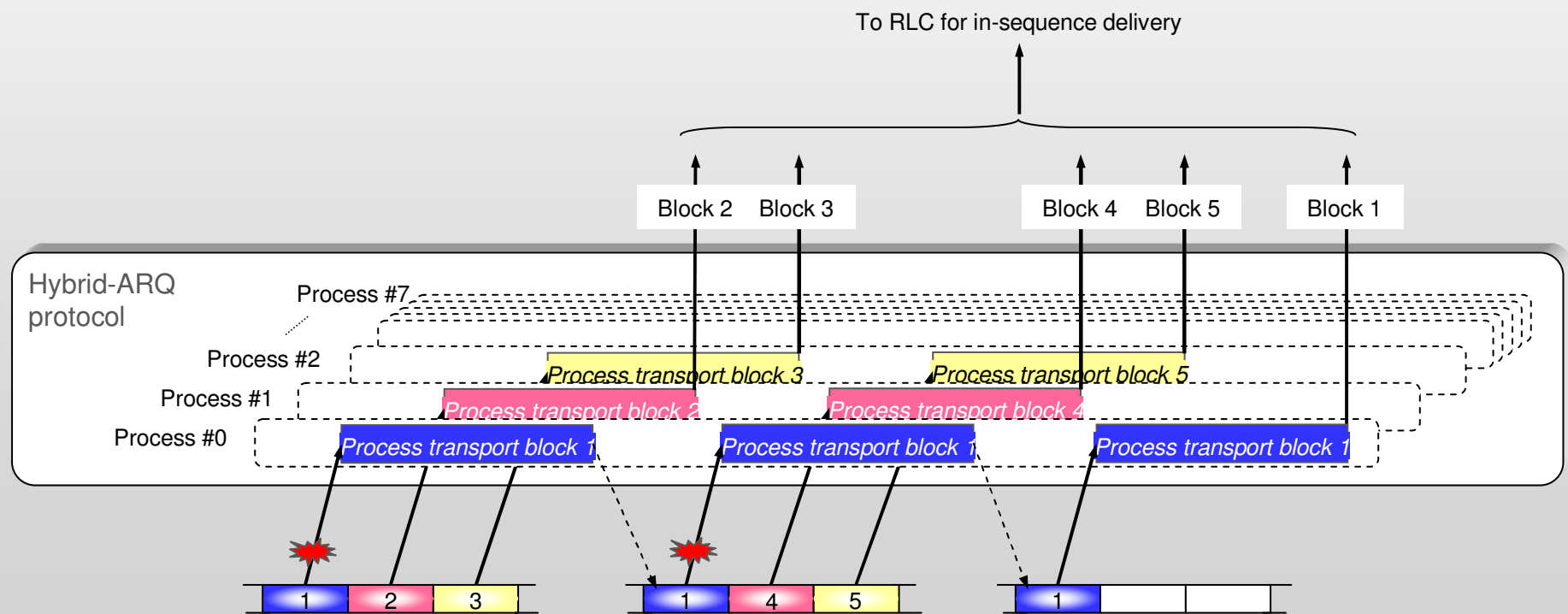
- › Core network evolved in parallel to LTE
 - EPC – *Evolved Packet Core*

- › Flat architecture, single RAN node, the *eNodeB*
 - Compare HSPA, which has an RNC



HYBRID-ARQ WITH SOFT COMBINING

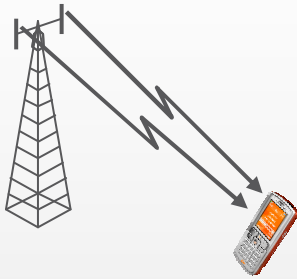
- › Same basic structure as HSPA
 - Parallel stop-and-wait processes
 - 8 processes ➔ 8 ms roundtrip time



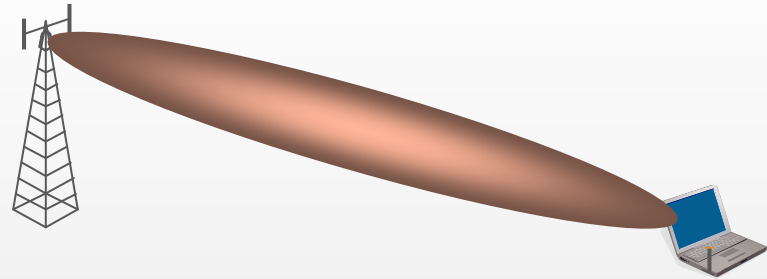
INTERACTION WITH RLC

- › 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 ($\sim 10^{-3}$)
- › RLC
 - Reliable feedback (sent in same manner as data)
 - Multi-bit feedback ➔ less frequent
- › Hybrid-ARQ and RLC *complement* each other

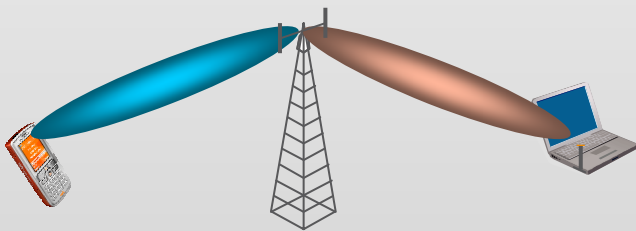
MULTI-ANTENNA TRANSMISSION TECHNIQUES



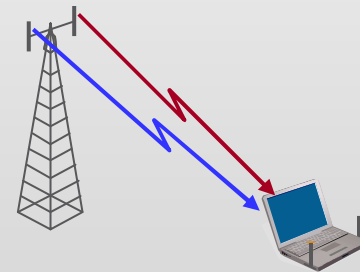
Diversity for improved system performance



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



SDMA for improved capacity (more users per cell)



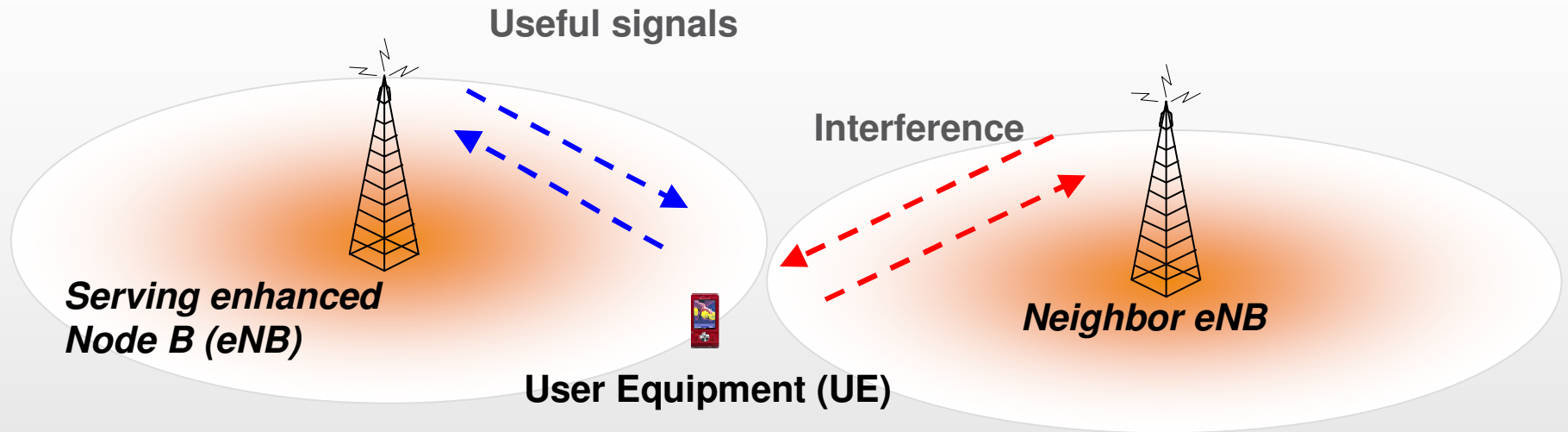
Multi-layer transmission ("MIMO") for higher data rates in a given bandwidth

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 (points to S)
 Interference (points to I)
 Noise (points to N)

Downlink

> Interference @ the UE

Uplink

> Interference @ the eNB

Reduce interference so as to increase SINR



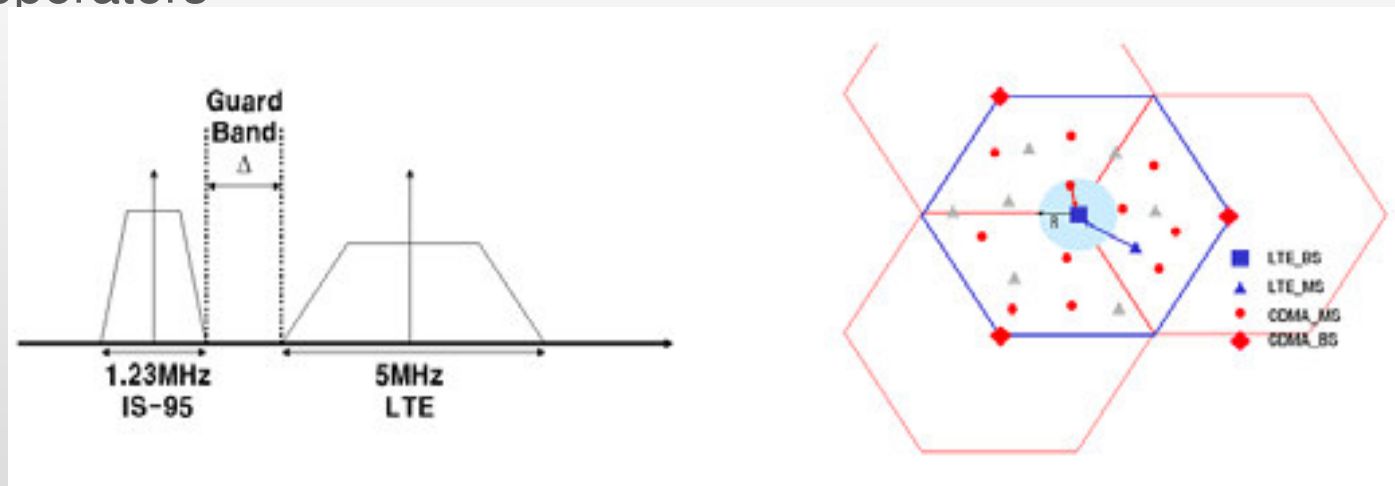
SOURCES OF INTERFERENCE

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, satellite communications, radars

> Intra-LTE Interference

– Inter-cell Interference

INTER-SYSTEM INTERFERENCE

➤ Inter-system interference

- Typically of steady nature
 - Exception: interference created by radars transmitting 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

SOLUTIONS TO INTER-SYSTEM INTERFERENCE



➤ Adjacent channel interference

- Receiver blocking
 - Filtering
- Guard bands

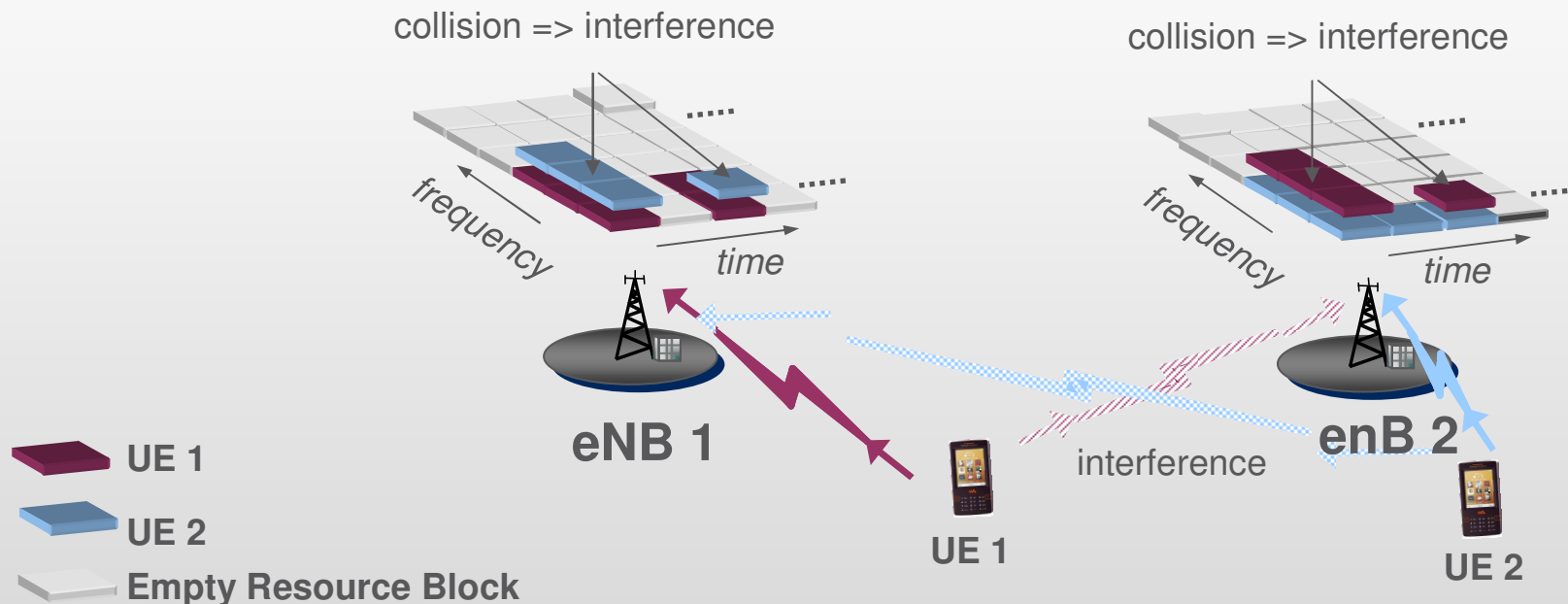
➤ Co-channel interference

- Receiver Desensitization
- Network Planning
- Inter-system coordination

INTRA LTE INTERFERENCE

➤ Other-cell interference

Reuse-1



- 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

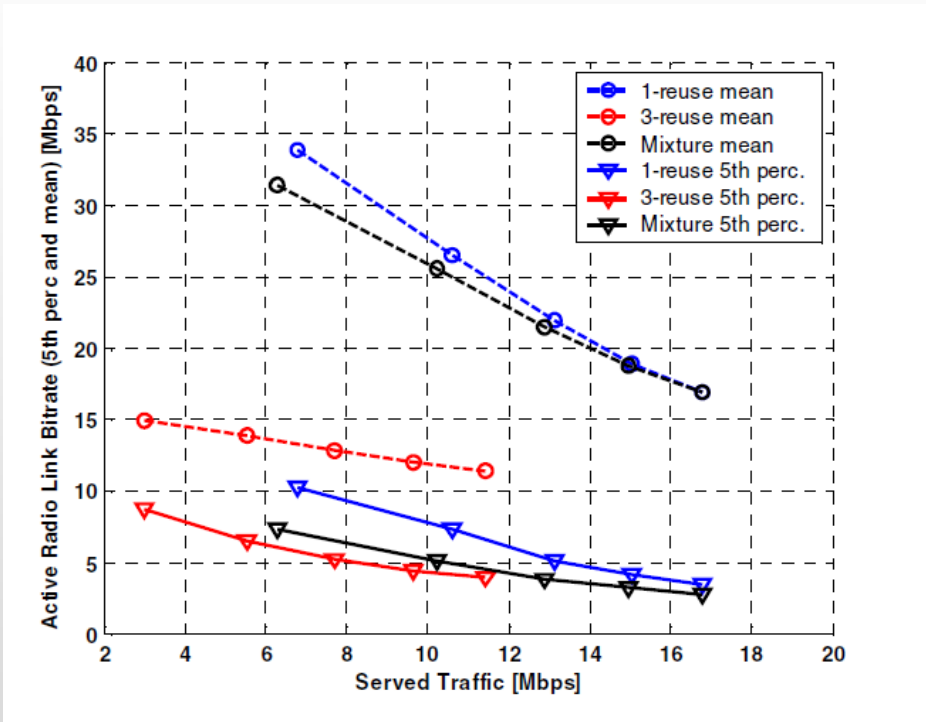
> "Cost" of a "collision"

- 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)

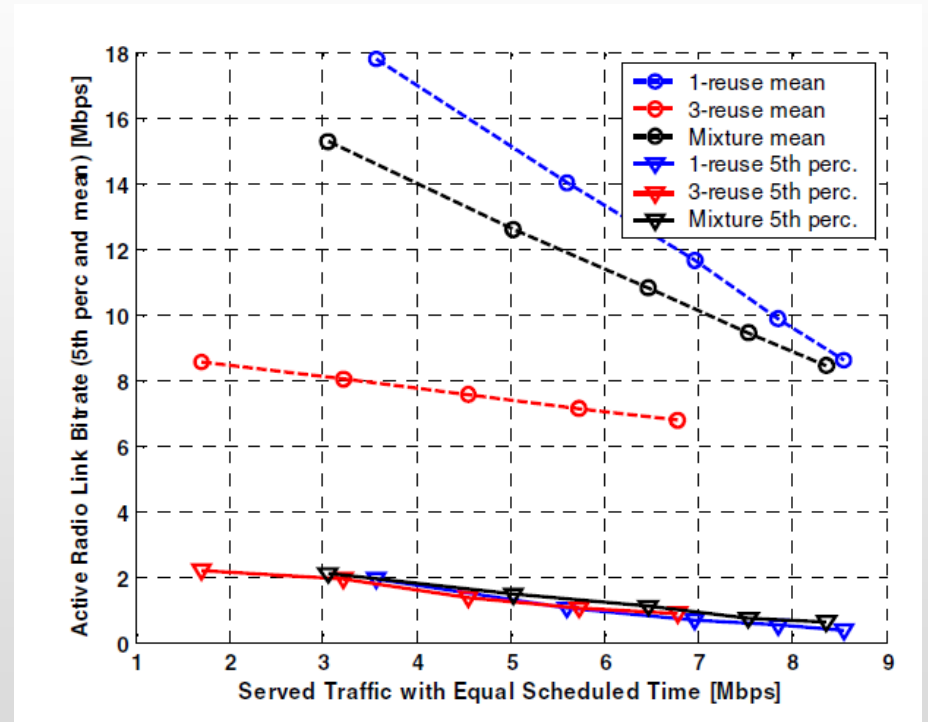
> "Cost" of avoiding a collision

- 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)

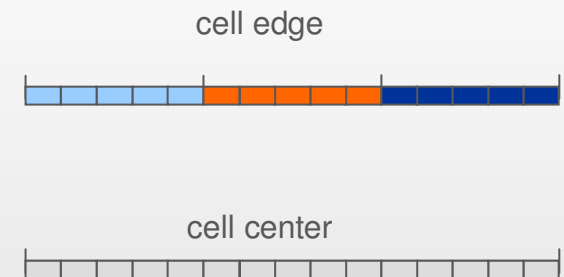
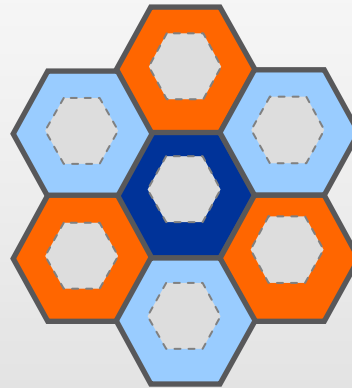
Avoiding a collision results in higher loss in radio resource usage than the gain in interference reduction

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



- › Radio Resource Management (RRM)

- Scheduling
- Fractional Frequency Reuse (FFR)



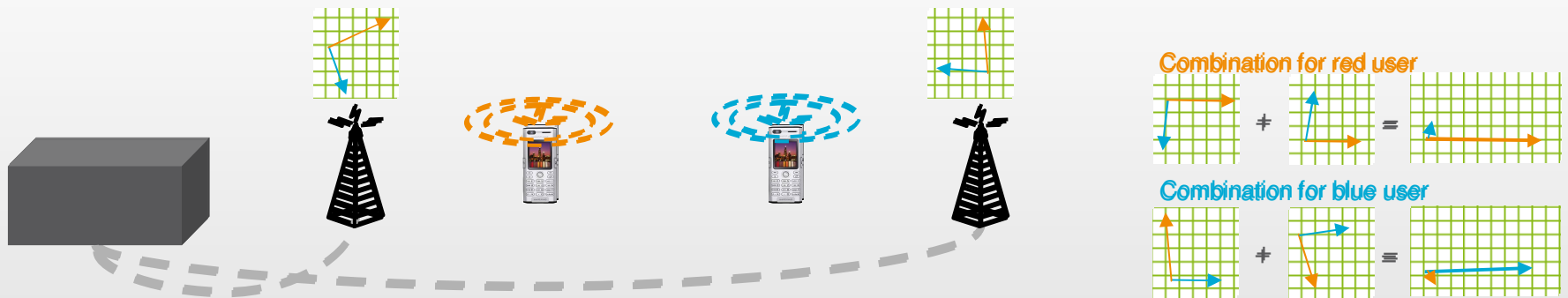
- Fractional Power Control (FPC)

- › 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

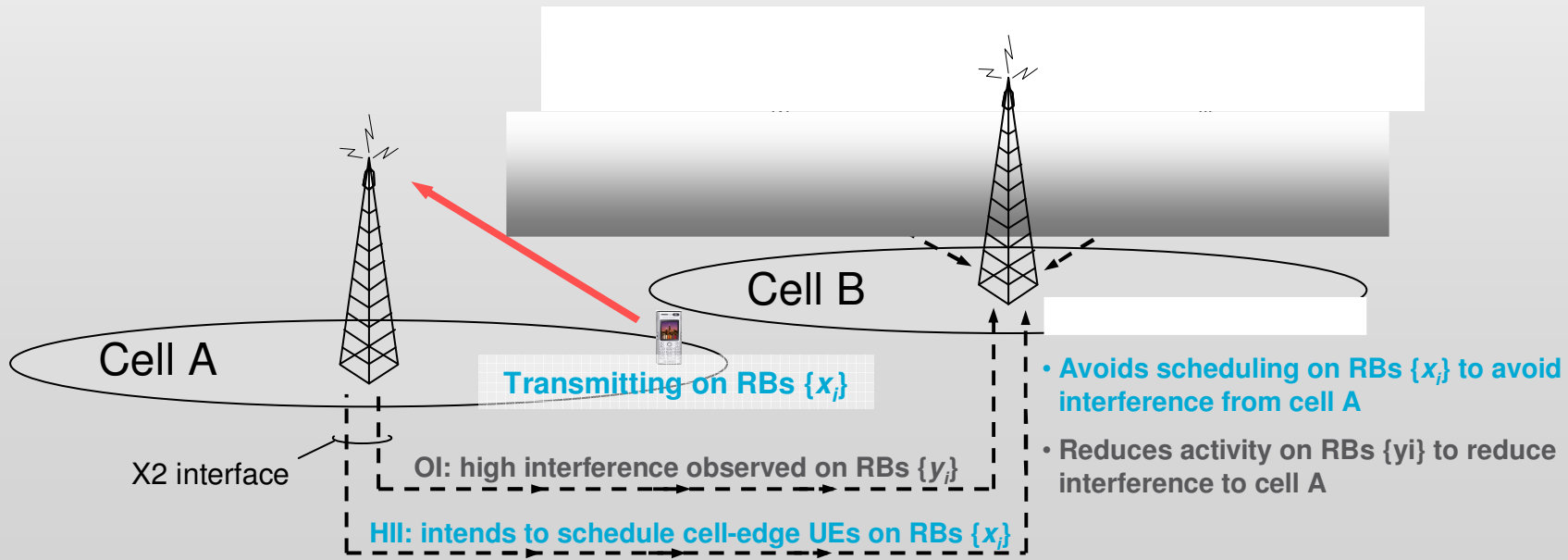
- › Coordinated schemes
 - Hardware complexity, higher processing power
 - Backhaul cost
 - › Requirements on
 - Latency
 - Capacity



REL. 8-9 SUPPORT FOR ICIC

UPLINK ICIC

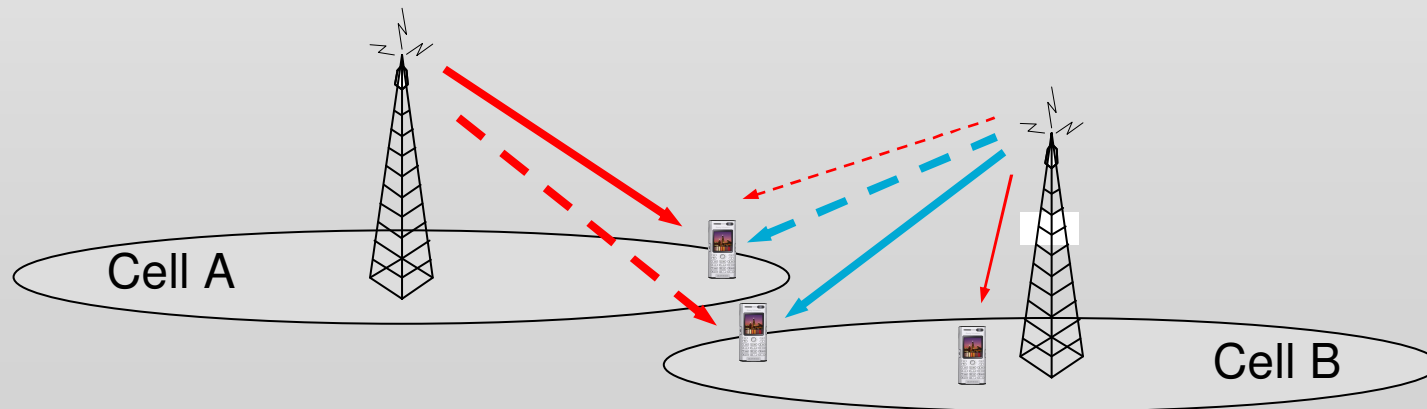
- > Overload Indicator – OI (*"Reactive" mechanism*)
 - Bit map per resource block sent over X2 to neighbor cells
 - Signals if cell experiences low, medium, or high interference
- > High Interference Indicator – HII (*"Proactive" mechanism*)
 - Bit map per resource block sent over X2 to neighbor cells
 - 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

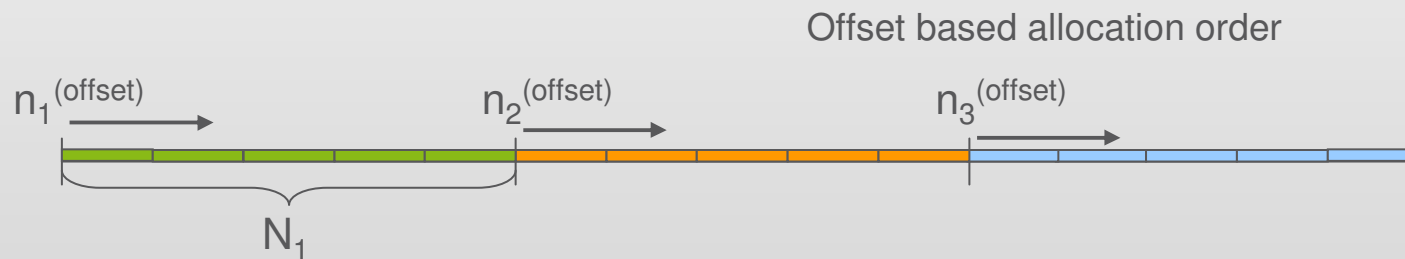
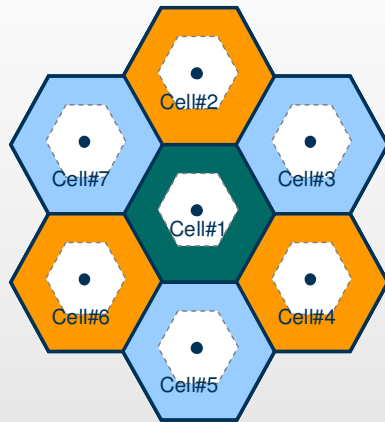


AUTONOMOUS ICIC

EXAMPLE OF AUTONOMOUS ICIC ALGORITHMS

STARTING OFFSET-BASED

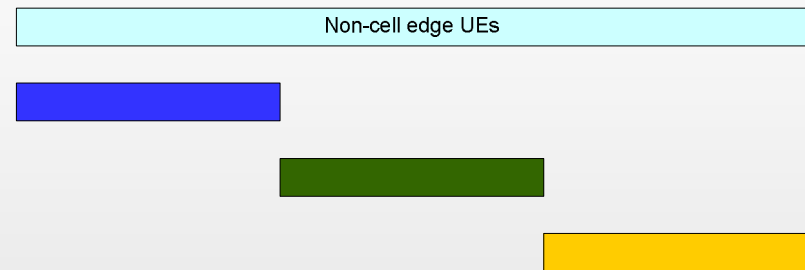
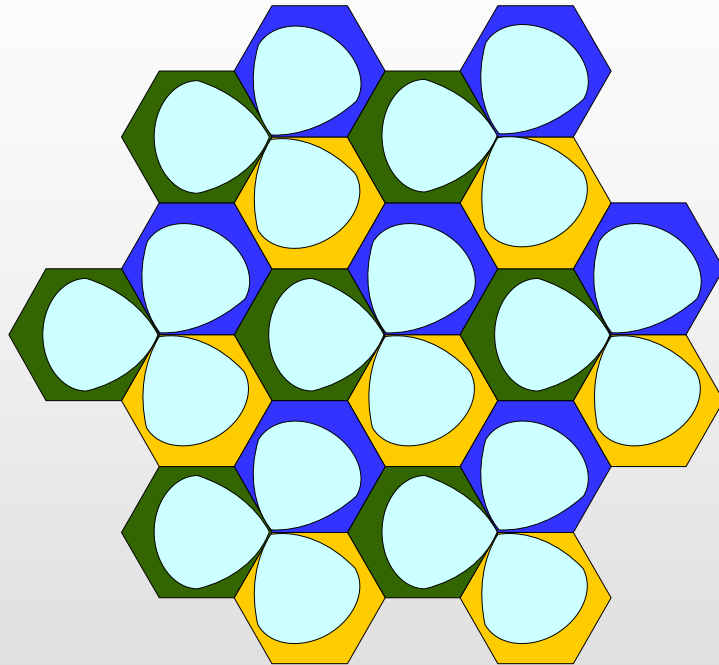
- Offset based allocation order



- Random Start index
 - Starting PRB selected randomly

Well performing schemes @ low loads

ICIC BASED ON FFR



- › Cell edge user determined by averaged geometry



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