



Interference Management in femto-overlaid LTE-A networks

**National and kapodistrian University of Athens
dept. of Informatics & Telecommunications**

**Dimitris Tsolkas, PhD candidate
dtsolkas@di.uoa.gr
March 2013**



Table of Contents

- **Interference Problem**
- **Interference Management issues**
- **Interference Management in femto-overlaid LTE-A networks**

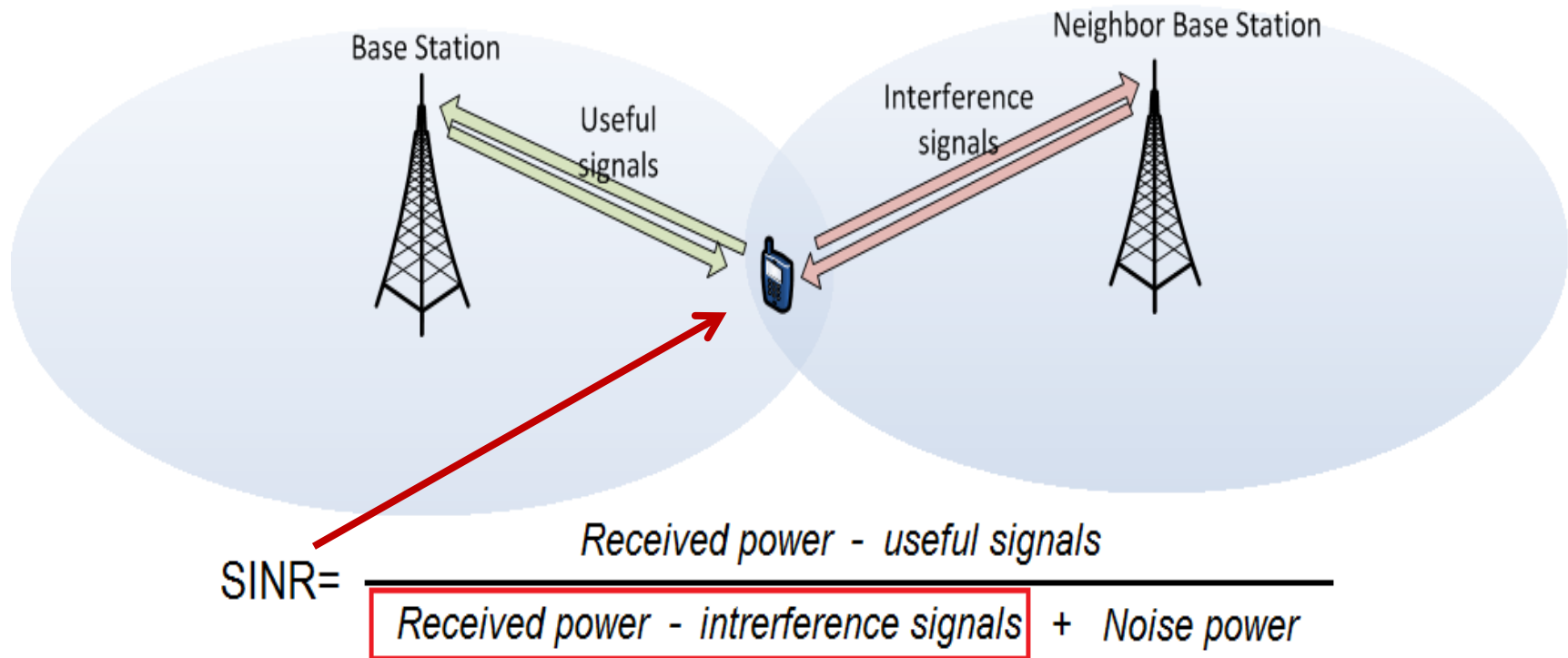


Interference problem

Interference problem

Traditional cellular networks

Interference at the receiver -> affects the SINR





Interference problem

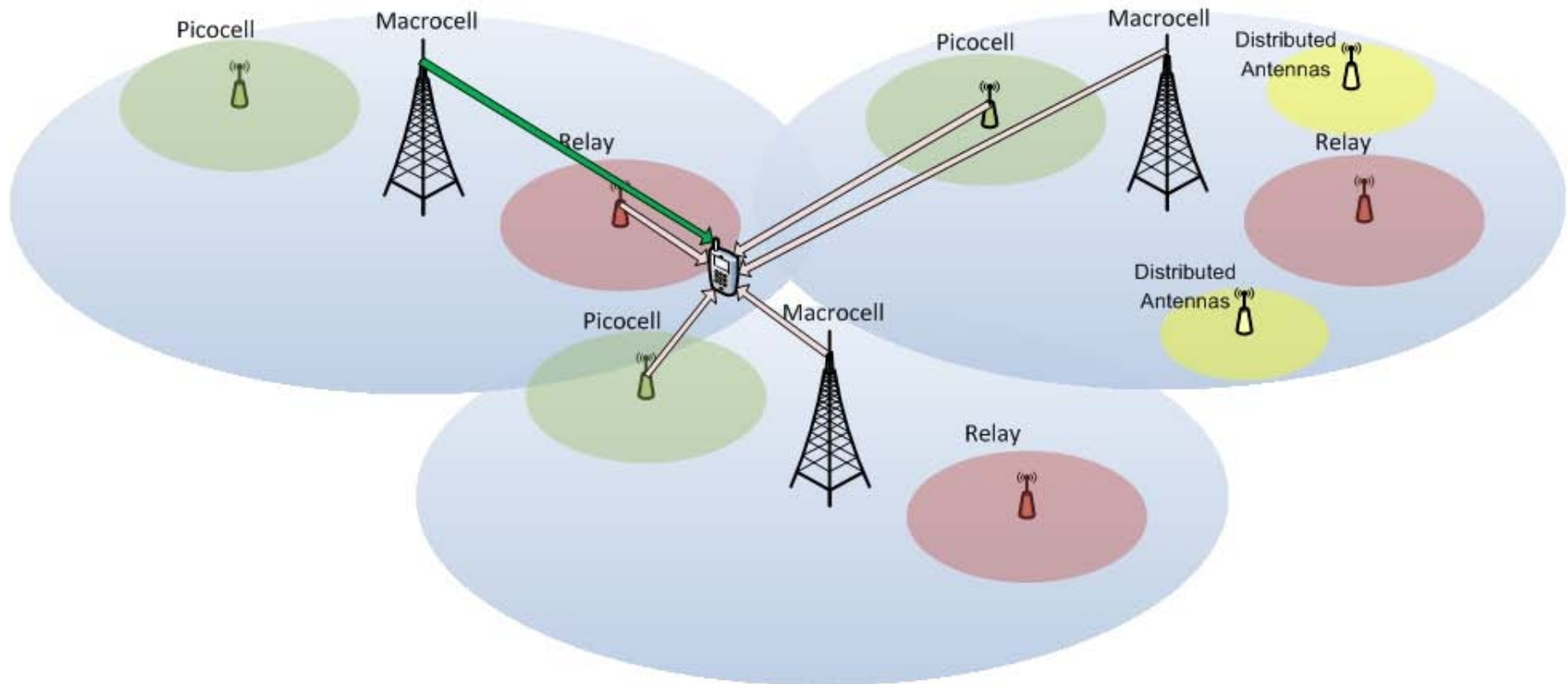
Current cellular networks

- **Macrocells**
 - They cover a large cell area providing services to operator's subscribers.
- **Picocells**
 - A picocell includes all the macrocell's functionality but covers smaller areas e.g. malls. It is also deployed by the operator providing services to all the operator's subscribers located inside its range.
- **Relay nodes**
 - They are practically picocells with a wireless backhaul connection.
 - A relay node is commonly to improve coverage under unplanned scenarios e.g. an exhibition. There are in-band relays that use the same spectrum band for their backhaul link and the access links and out-band relays that use different spectrum over backhaul and access link.
- **Distributed antennas (DA) - Remote radio headers (RRH)**
 - They are practically antennas with the minimum functionality needed to pass the traffic to the macrocell BS. Commonly, a fiber backhaul connection is used.

Interference problem

Current cellular networks

Multiple Transmitters -> higher Interference



Interference problem

Current cellular networks + femtocells

Why we need femtocells?

- **Spectrum is expensive and in scarcity, while the traffic increases rapidly.** Thus, more efficient spectrum utilization schemes are needed



Martin Cooper:

“The wireless capacity has doubled every 30 months over the last 104 years.”

- This enormous gain reaped mainly from smaller cell sizes arise from efficient spatial reuse of spectrum or, alternatively, higher area spectral efficiency

Thus, the spatial spectrum reuse seems to be the dominant technique for more efficient spectrum utilization



Interference problem

Current cellular networks + femtocells

Why we need femtocells? (continue..)

- In the near future more than 50% of data traffic, will originate from indoor users*

Thus, an efficient way to handle the indoor traffic is required

- **How about WiFi?**
 - Exploits the ever more crowded unlicensed spectrum
 - Coordination is more easy in femtocells
 - Theoretically femtocells provide more efficient setup, mobility, QoS, Interference management

* J. Cullen, "Radioframe presentation", in Femtocell Europe, London, UK, June 2008



Interference problem

Current cellular networks + femtocells

Why we need femtocells? (more..!)

- **Observations of the last 5 years show that**
 - 25X increase in traffic
 - and 2X increase in revenues (!)
- **Choices for the operators**
 - Strictly meter or restrict data usage, charge in proportion to bits consumed
 - Lose money and/or watch network collapse
 - > Decrease Euros/bit (exponentially)

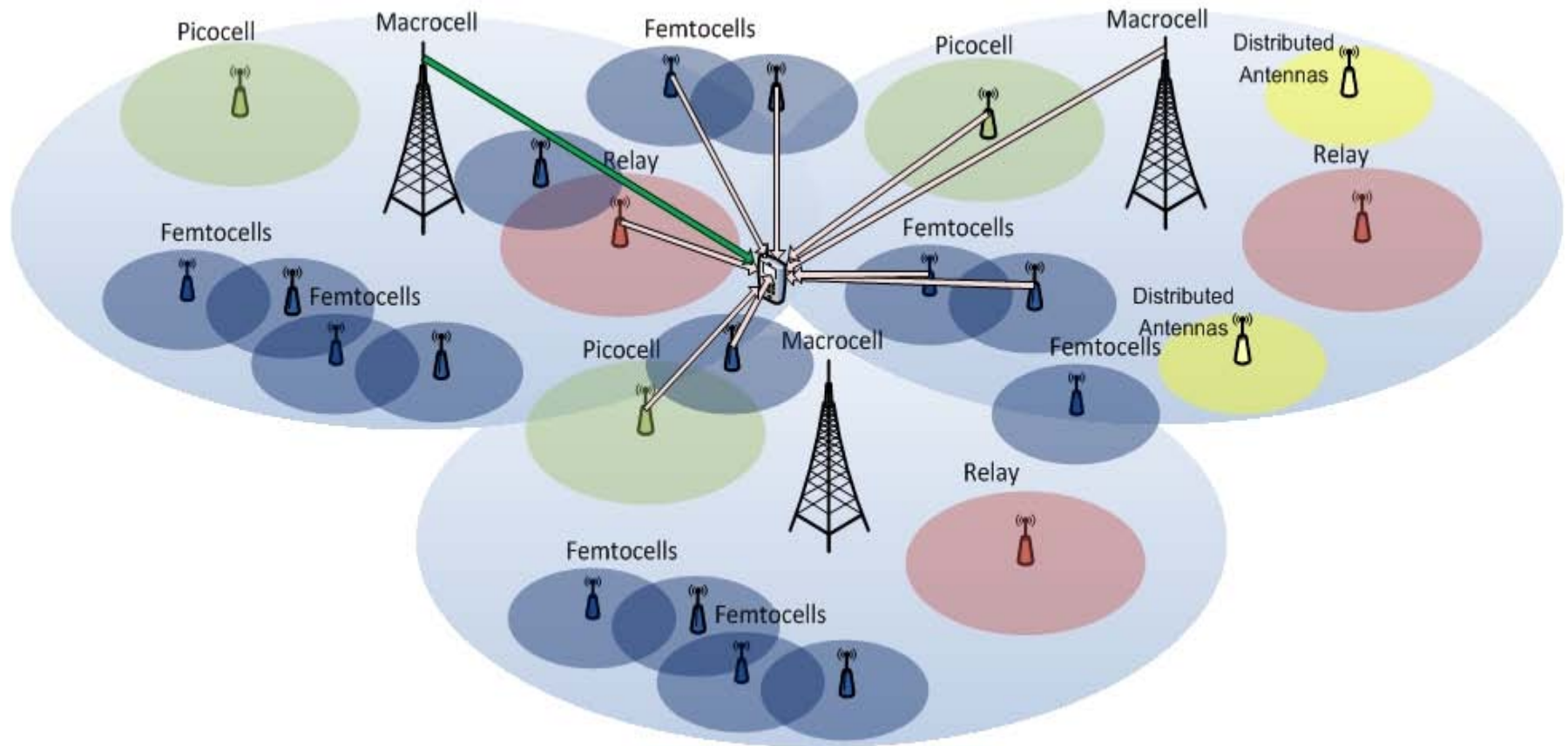
Femtocells capital expenditure and operational expenditure are low

End-users purchase the femtocell access points

New Femtozone Applications

Interference problem

Current cellular networks + femtocells





Interference problem

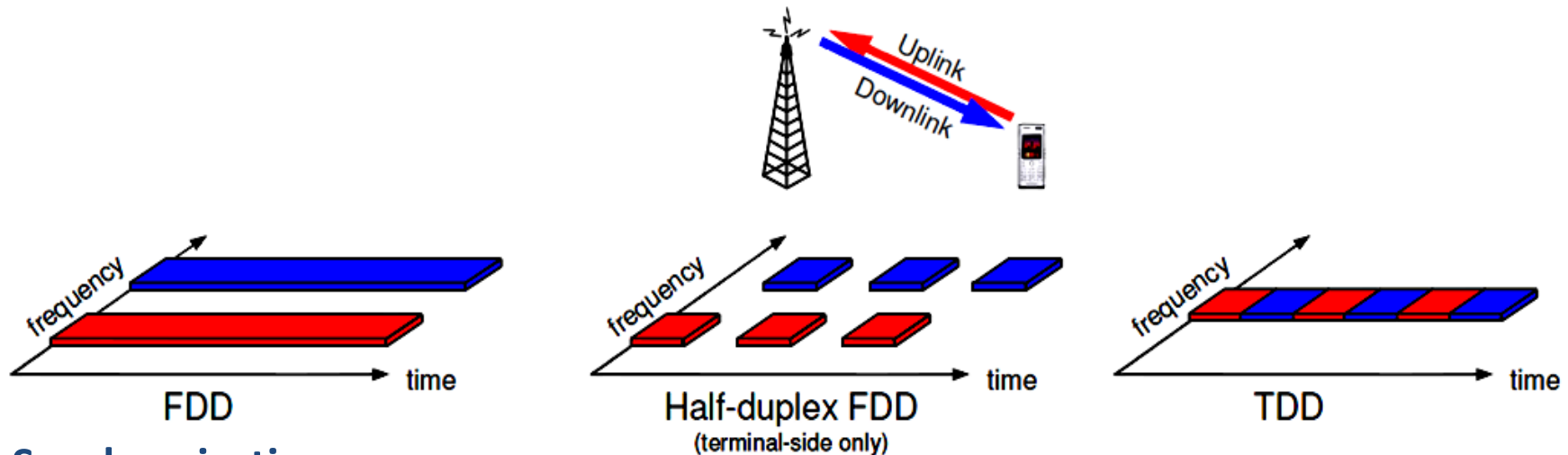
The role of network deployment

Interference in Femto-overlaid networks

- A highly heterogeneous and dense network is created
- Femtocells are deployed by the end-consumers i.e., in a random/unplanned deployment manner
- They are expected to spatially reuse licensed spectrum defining the co-channel deployment
- They can provide the option to serve only a limited set of subscribed users through the closed subscriber group (CSG) mode (no handover option for non-subscribed users)

Interference problem

The role of synchronization and duplex type



Synchronization

- If femtocells and macrocells are synchronized the interference problem is more manageable. However, **synchronization is an open issue since femtocells backhaul data through a broadband gateway.**

Duplex type

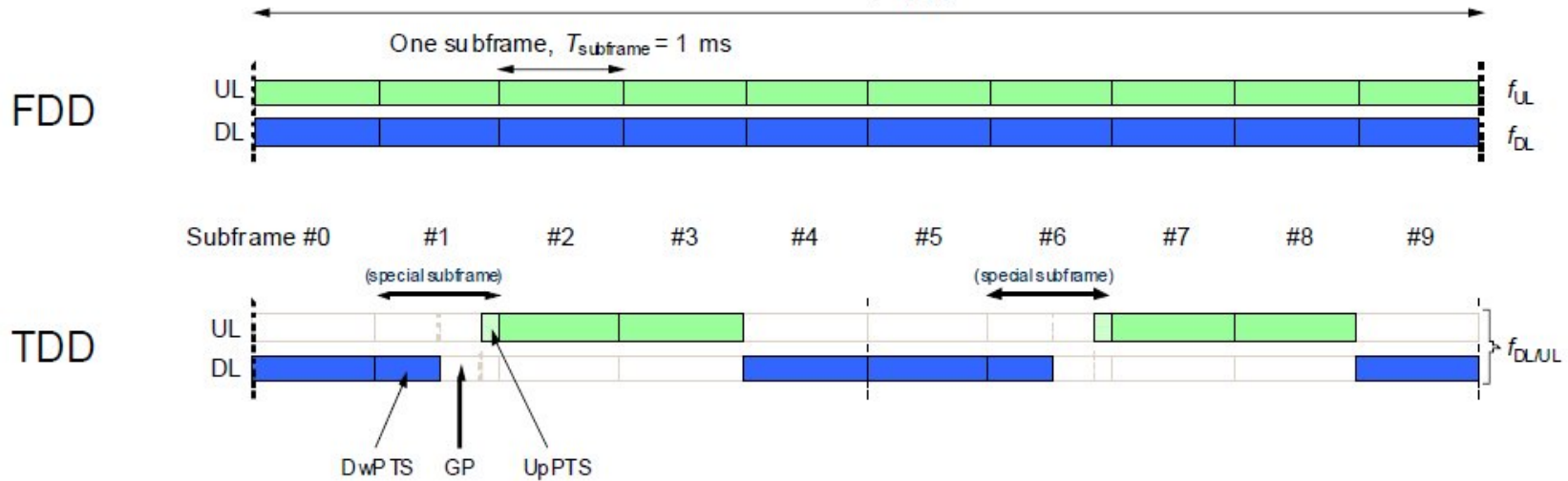
- In TDD mode different UL/DL configurations are available. Theoretically, each femtocell and macrocell can select a different one exacerbating the Interference problem.



LTE-A PHY

Available duplex types

One radio frame, $T_{\text{frame}} = 10 \text{ ms}$

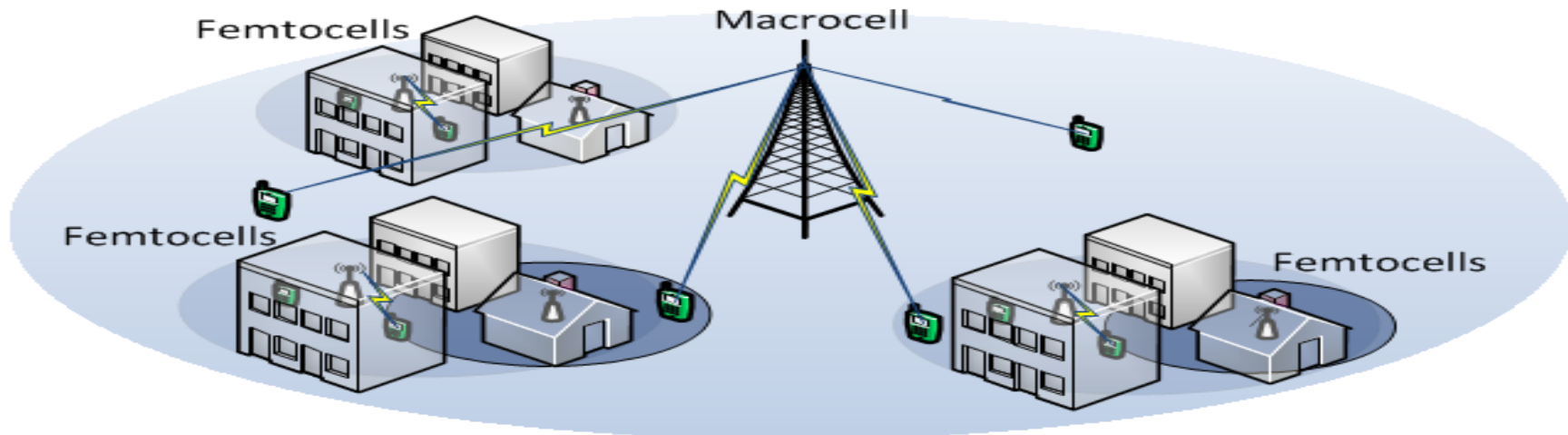


For TDD type LTE-A defines 7 different configurations for DL, UL and S subframes

		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

Interference Categories

*Assume synchronized femtocells/macrocells



Index	Aggressor	Victim	UL/DL	Cross/Co-tier
1	Macro User	Femto BS	UL	Cross-tier
2	Macro BS	Femto User	DL	Cross-tier
3	Femto User	Macro BS	UL	Cross-tier
4	Femto BS	Macro User	DL	Cross-tier
5	Femto User	Femto BS	UL	Co-tier
6	Femto BS	Femto User	DL	Co-tier

Interference problem

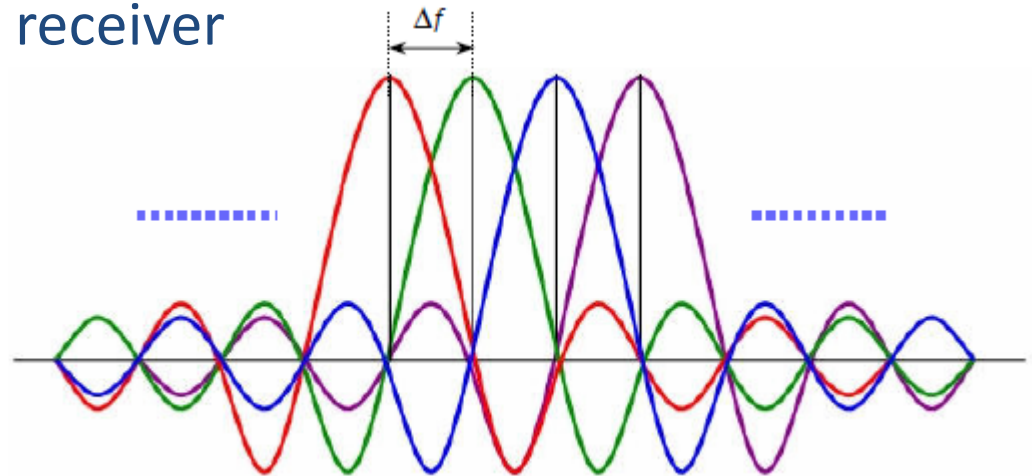
The role of the hardware

Co-channel interference and Adjacent channel interference

Adjacent channel interference caused by:

hardware imperfections at the transmitter resulting in:

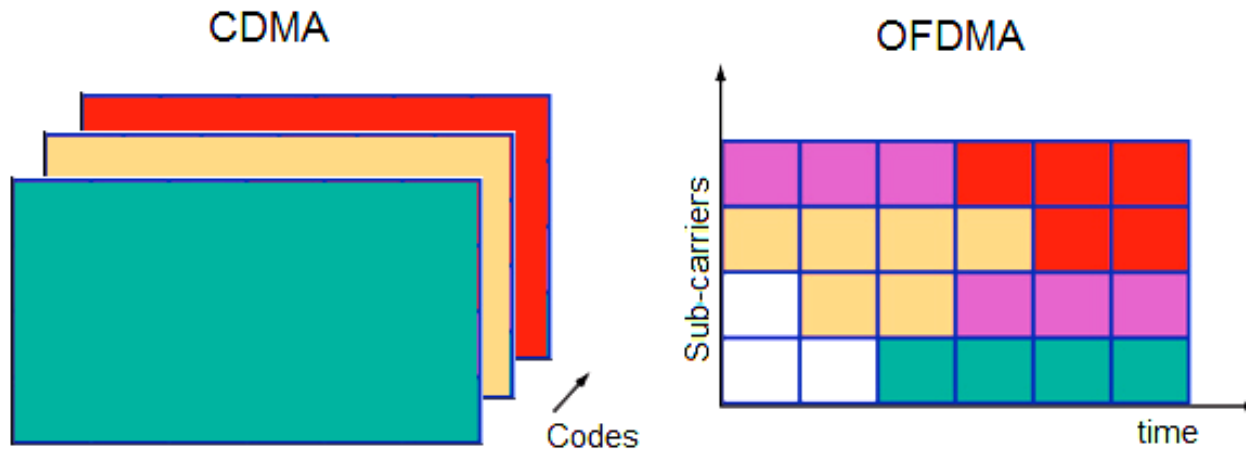
- Out of Band/Spurious emissions
- Adjacent Channel Leakage
- Non-perfect filter at the receiver



Interference problem

The role of the PHY

(Multiplexing – Multiple Access)

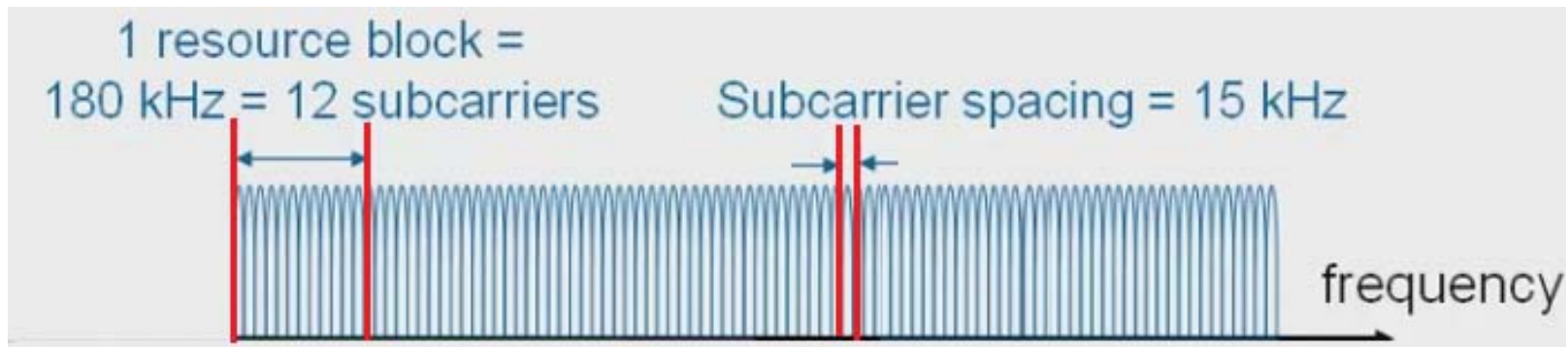


The interference is strongly correlated with the adopted PHY

- **CDMA - Orthogonal Codes**
 - average freq. distortion
 - difficult MIMO, equalization
- **OFDMA - Frequency and time regions**
 - easy MIMO, dynamic allocation, Flexible resource allocation
 - Inter-carrier interference

LTE-A PHY

Frequency domain structure





LTE-A PHY

Frequency domain structure

- There are 6 different bandwidths
- Each bandwidth is divided into subcarriers of 180 KHz each and
- 12 adjacent subcarriers compose a Resource Block (RB)

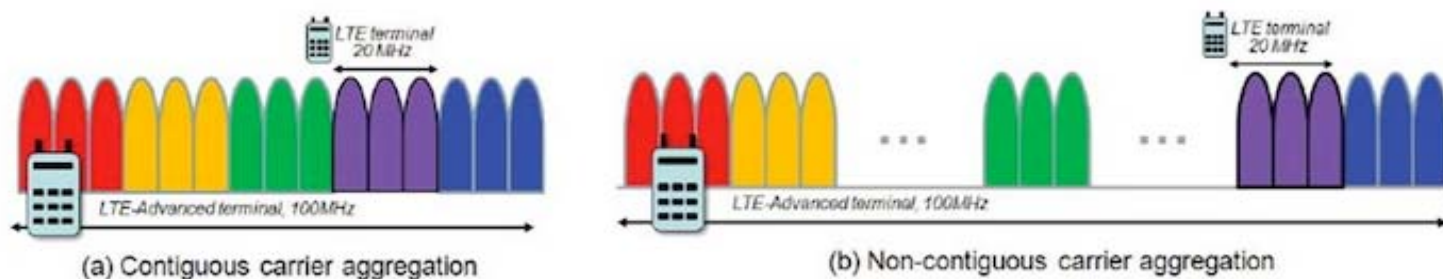
Channel bandwidth BW_{Channel} [MHz]	1.4	3	5	10	15	20
Number of resource blocks	6	15	25	50	75	100

- Carrier Aggregation allows the expansion of the bandwidth to 100MHz

LTE-A PHY

Carrier Aggregation

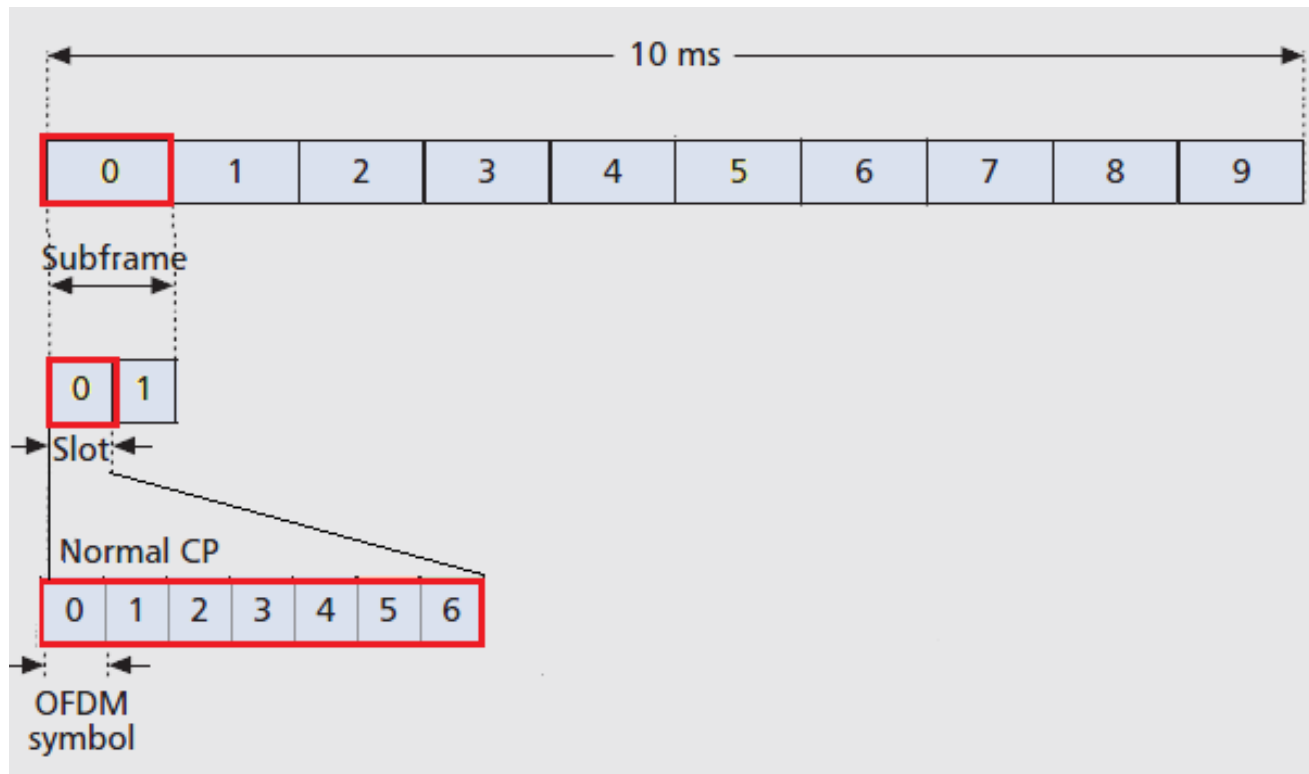
- Scalable expansion from 20MHz to 100MHz by aggregating carriers, each group of carrier is referred to as a component carrier CC.
- The available bandwidths of each CC are 10 MHz and 20 MHz
- continuous (adjacent) or non-continuous CC located in the same or different spectrum bands can be aggregated
- There are two categories:
 - **Primary component carrier:** This is the main carrier in any group. (a primary downlink CC and an associated uplink primary CC)
 - **Secondary component carrier:** There may be one or more secondary component carriers





LTE-A PHY

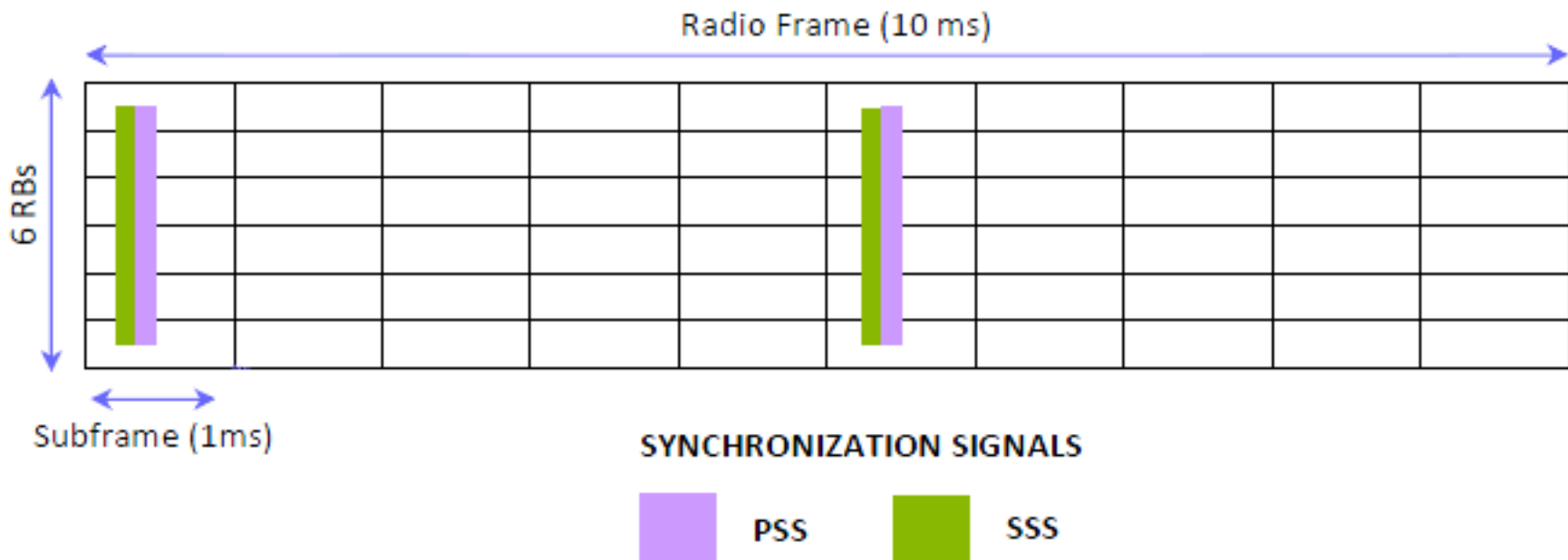
Time domain structure



LTE-A PHY

Time domain structure

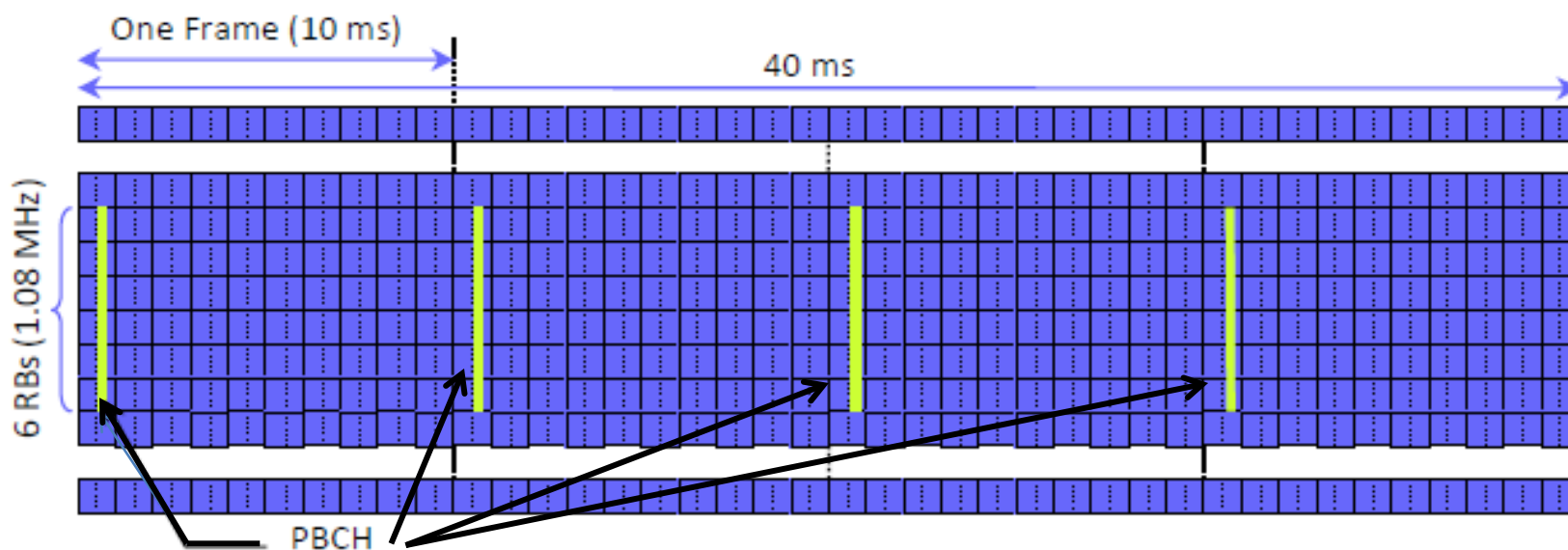
Primary Synchronization Sequence (PSS) and **Secondary Synchronization Sequence (SSS)**. The detection of these signals allows the UE to complete time and frequency synchronization and to acquire useful system parameters such as cell identity, cyclic prefix length, and access mode (FDD/TDD).

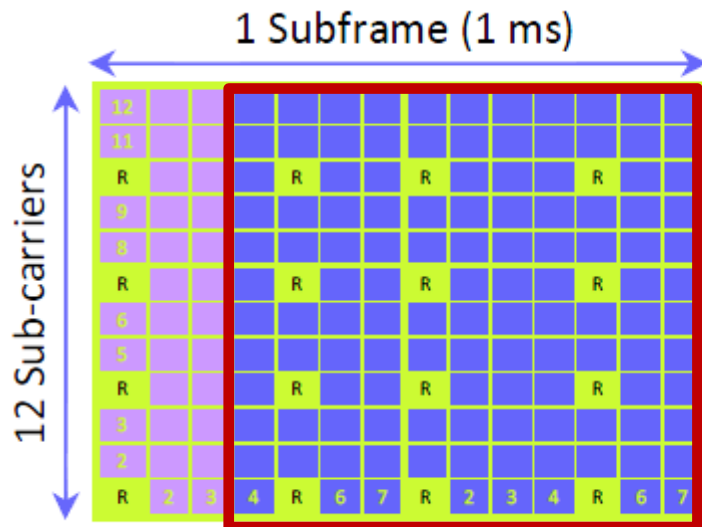


LTE-A PHY

Time domain structure

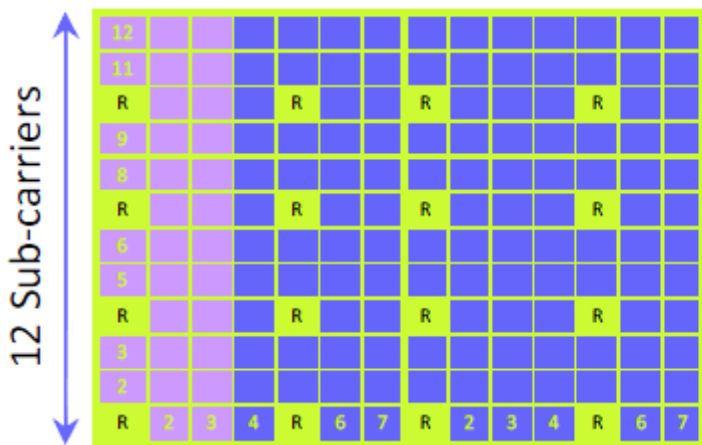
Physical Broadcast Channel (PBCH). The PBCH broadcasts a limited number of parameters essential for initial access of the cell such as downlink system bandwidth, the Physical Hybrid ARQ Indicator Channel structure, and the most significant eight-bits of the System Frame Number.





LTE-A PHY DL subframe

Minimum Allocation unit PRB



- Data
- Reference symbols (two antenna ports)
- Control resource elements



Interference Categories

*LTE-A PHY

Data /Control / Reference / Synchronization / broadcast channels

- The content of control channels is very important, bad control signals can lead to link/access failure – in contrast, bad data signal can lead to lower signal quality
- No retransmission available in some Control Signals
- No flexibility in Resource allocation – specific spectrum regions are used for control signals
- Fixed location for the reference/synch/broadcast signals



Interference problem

The role of network deployment

-> Femtocell characteristics – multiple/unplanned interference

The role of Synchronization

-> UL/DL configuration – inter-slot Interference

The role of hardware

-> adjacent channel interference

The role of PHY layer

-> OFDMA in LTE-A – frequency selective Interference

The role of channel content

-> Control/reference/broadcast and data channel interference



Interference Management issues



Interference Management issues

1. Interference Detection
2. Interference Coordination
3. Interference Avoidance
4. Interference Mitigation
5. Interference Cancelation
6. Interference Exploitation (!)



Interference Management

Interference detection

Directly- Measurements

A base station or a user can measure the surrounding environment and estimate the level of perceived interference

- A deteriorated useful signal is an evidence

Indirectly- Messages

- A Base station can use neighbor information or specific messages reported by users or other Base stations
e.g. An attempt for handover from a victim user

➤ Challenges

- How frequent measurements and in which spectrum portions
- Reliability in indirect detection – false detection
- Reduce signaling



Interference Management

Interference Coordination

Use of Interference Indicators

exchanging of interference messages

- **Proactive interference coordination**

messages that inform neighbor base stations for the near future resource and power allocations

- **Reactive interference coordination**

messages are exchanged if interference (via measurements) or an interfered node are detected

- Challenges

- How to mitigate signaling

- Signaling reliability – over the air ? Fiber?



Interference Management

Interference Avoidance

Static or dynamic split of the spectrum

- **Static:** predefined different spectrum portions are allocated to macros and femtos
 - + Interference avoidance
 - Inefficient – spectrum is in scarcity
 - What about interference between femtos?
- **Dynamic:** different spectrum portions are dynamically allocated to macros and femtos
 - + Reactive Interference avoidance / better spectrum utilization
 - complex solution – What about dense femto-overlaid networks

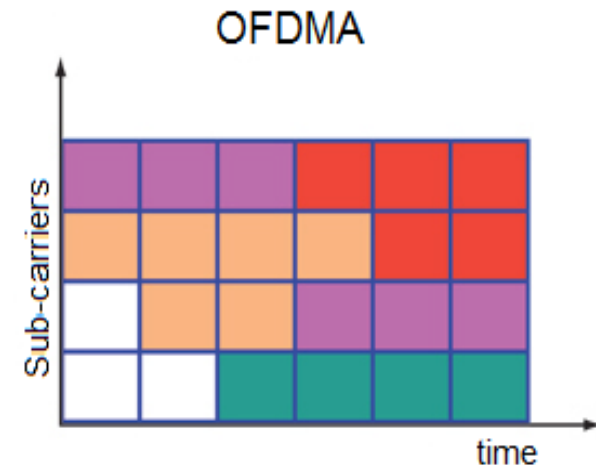
Interference Management

Interference Avoidance

Dynamic resource allocation

Applicable to OFDMA systems

- Femto and Macro base stations allocate appropriately the resources to users towards avoiding interference
 - + Dynamic, can be reactive and proactive
 - Coordination or measurements are needed
 - Difficult to applied for cross-tier interference avoidance



Interference Management

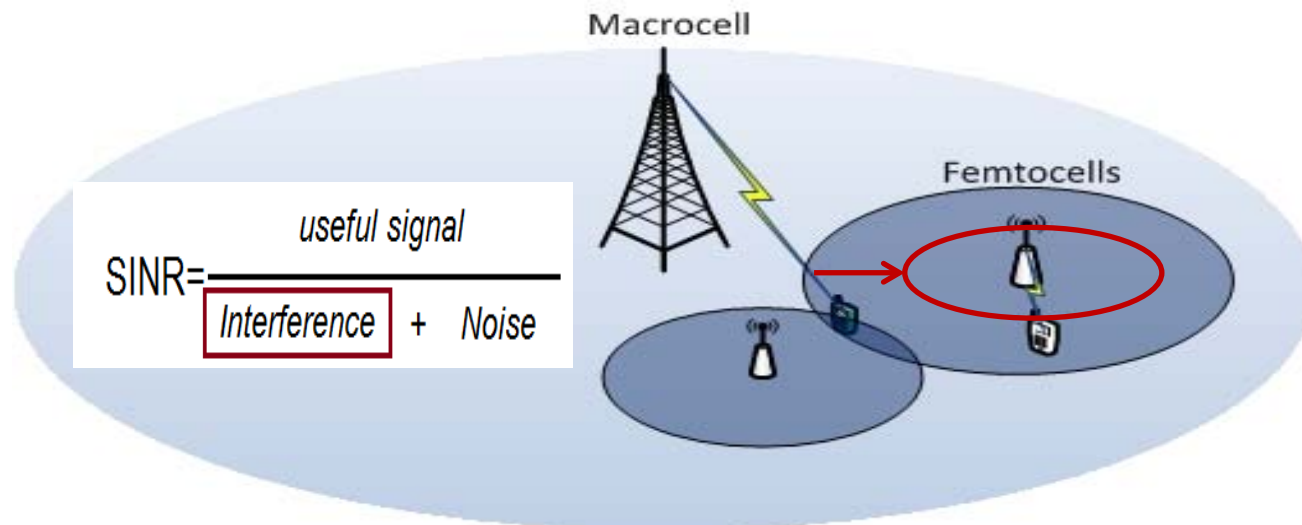
Interference Mitigation

Power Control

Reduce the transmit power of the interference aggressor

➤ Challenge

- avoid false alarm for interference protection
- Protection of the serving users is needed



Interference Management

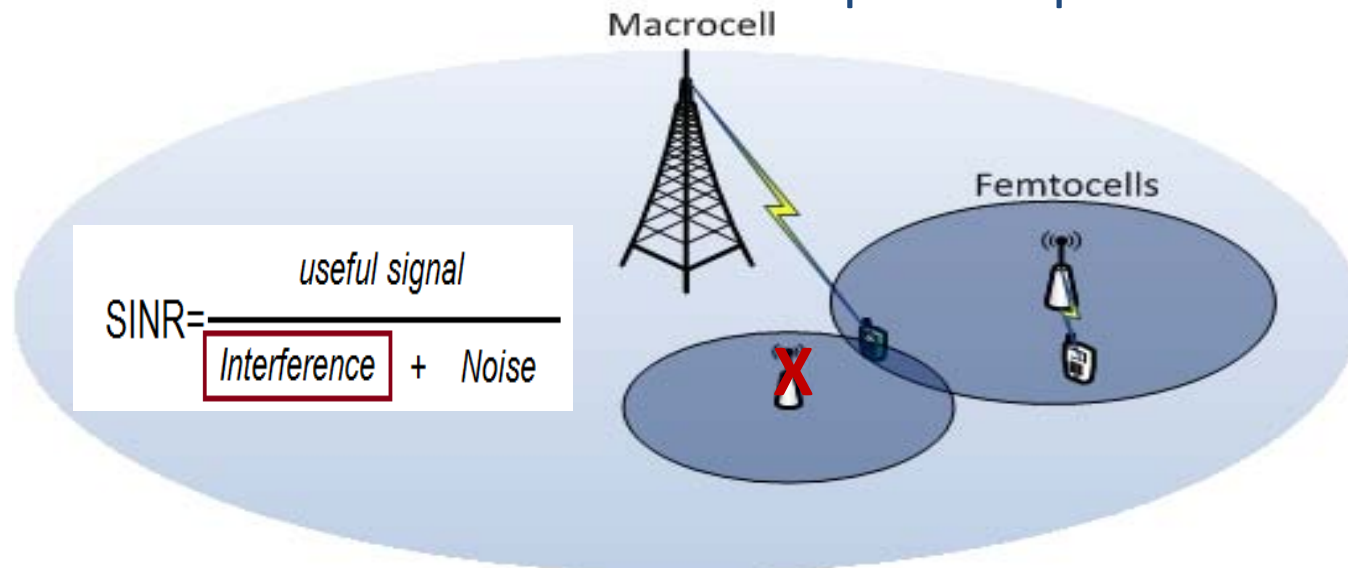
Interference Mitigation

Discontinuous Transmissions

Switch off dynamically some of the HeNBs

➤ Challenges

- Use of interference detection/ coordination/ measurement
- Silence and transmit duration are important parameters





Interference Management

Interference Cancellation

Interference is cancelled after the signal is received
(signal processing approach)

➤ Challenges

- Reduce the cost
- knowledge of the characteristics of the interfering signal
- **Successive interference cancellation (SIC)**
 - Detects one user per stage. The strongest received signal is detected first, then the next strongest...
 - Complex if there are many users



Interference Management

Interference Cancelation

- **Parallel interference cancellation (PIC)**
 - detects all users simultaneously
 - detection is repeated and this process is repeated over several stages
- **Multistage SIC**
 - A group of users are detected in parallel, and then has their aggregate interference subtracted from the composite received signal, and then another group is detected in parallel.

Interference Management

Interference Exploitation

Use Multiple Antennas to take advantage of self-interference

single user MIMO

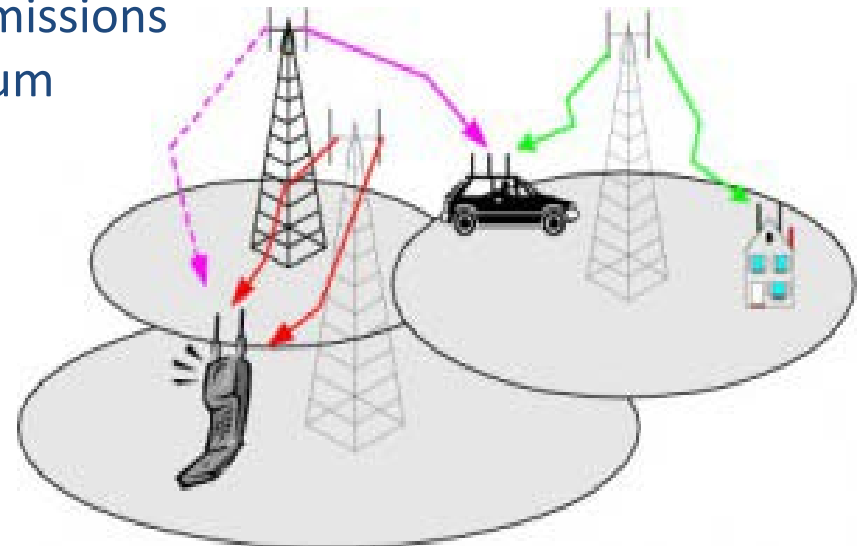
A good solution for self-interference exploitation

Self –interference = interference through the multipath effect

multi user MIMO

Useful for broadcasting - Multicast transmissions

to different users using the same spectrum



Interference Management

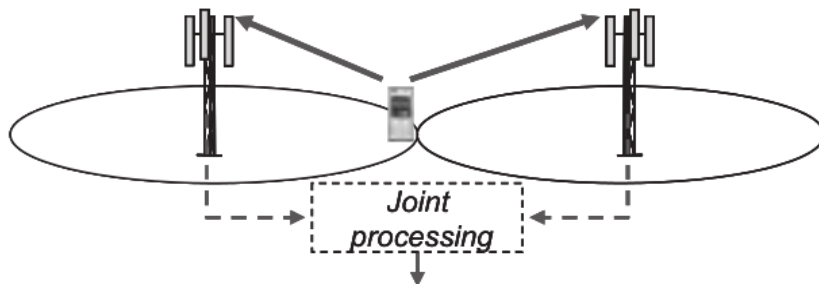
Interference Exploitation

multi cell MIMO – CoMP

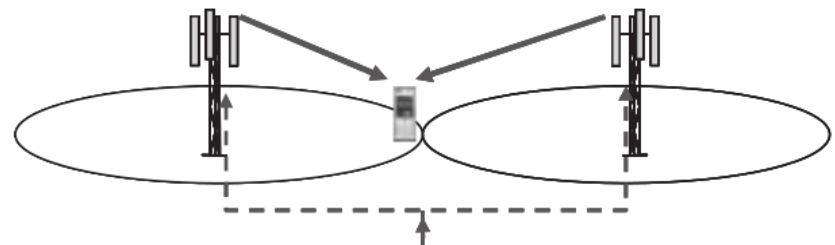
Use Multiple Antennas to Improve resistance to interference

- A good solution for the scenario of distributed antennas
- Launches the Idea of Coordination Multipoint (CoMP) transmission and reception

Joint receiver processing



Joint transmission



➤ Challenges

- Fast connections required – practically applicable only for DA



Interference Management in femto-overlaid LTE-A networks



Interference Management in LTE-A networks

LTE-A standardized tools

1. Measurements
2. X2 Interference indicators
3. Carrier Aggregation (with Cross carrier scheduling)
4. Almost blank subframes



Measurements

Collected through:

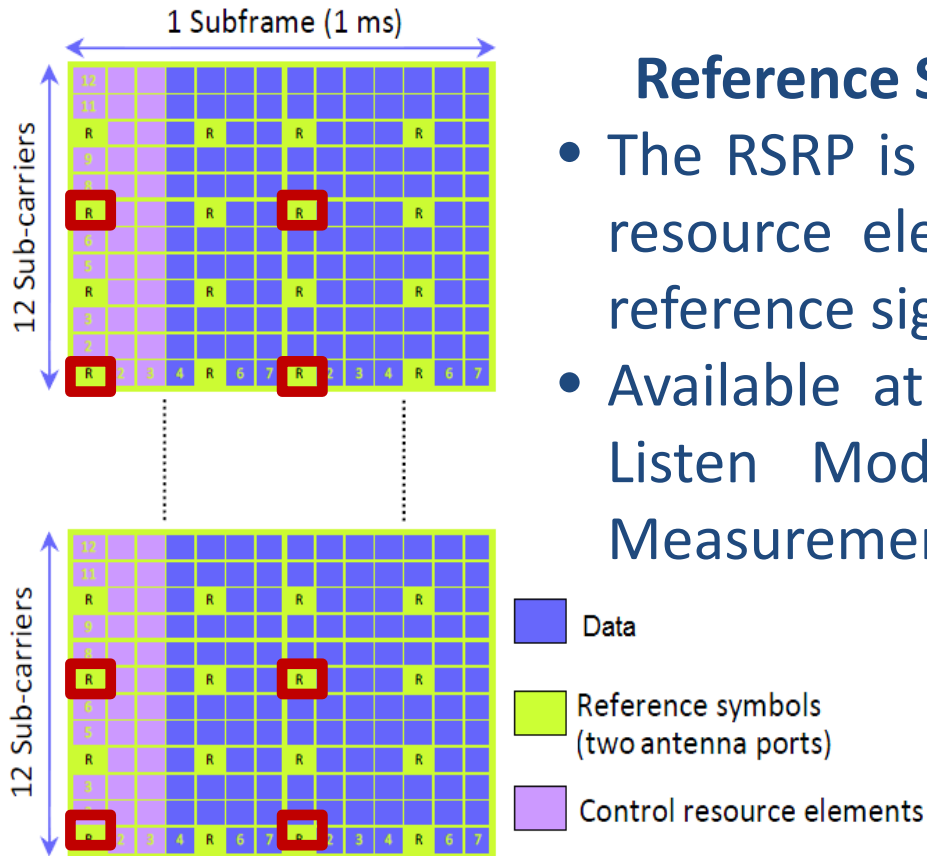
- Connected Mode UEs attached to (H)eNB
- UL Receiver function and DL Receiver function within (H)eNB – (Network Listen Mode (NLM), Radio Environment Measurement (REM) or "HeNB Sniffer")

Some of the most useful measurement for IM are:

- Reference Signal Received power (RSRP)
- Reference Signal received Quality (RSRQ)
- Received Interference Power (RIP)
- Reference Signal Transmission Power
- Physical and Global Cell ID

Measurements and IM

- Measurements can be used for power Control



Reference Signal Received Power (RSRP)

- The RSRP is the average of the power of all resource elements which carry cell-specific reference signals over the entire bandwidth
- Available at the UEs and HeNBs (Network Listen Mode (NLM), Radio Environment Measurement (REM) or "HeNB Sniffer")



Measurements and IM

- Measurements can be used for power Control

Power Control at HeNBs

- refers to power assignment for DL and UL transmissions
- This procedure is open to operators and different approaches can be used; However one of the proposed by 3GPP approaches is:

$$P_{tx} = \text{median} (P_{eNB-HeNB} + PL_{HeNB-MUE}, P_{max}, P_{min})$$

Where

P_{tx} represent the transmit power of the eHeNB

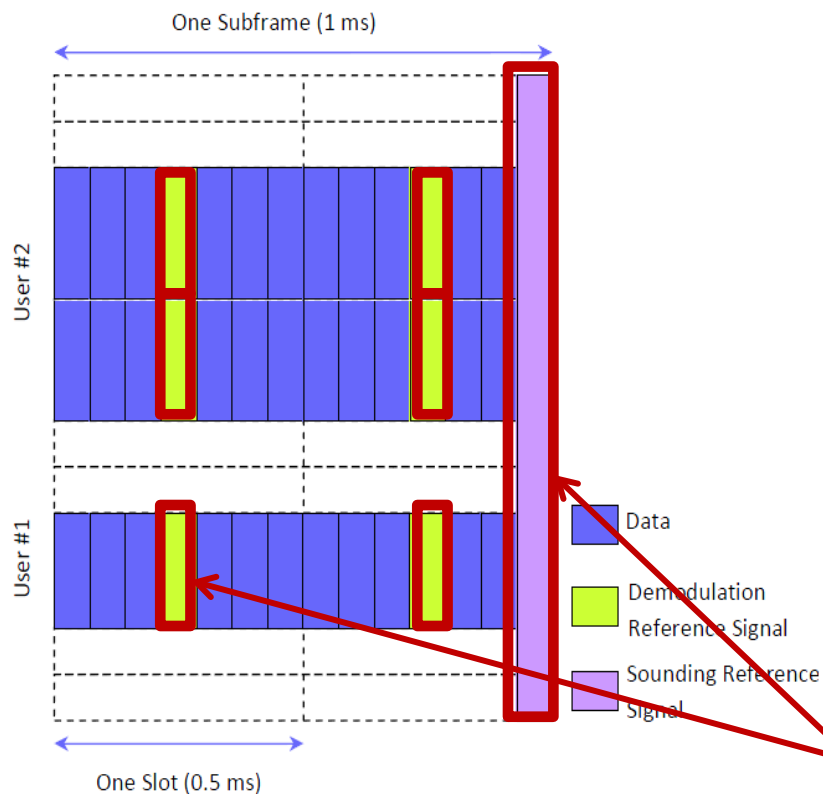
$P_{eNB-HeNB}$ the measured RSRP from the eNB

$PL_{HeNB-MUE}$ depicts the pathloss between the HeNB and victim MUE.

P_{max} and P_{min} parameters refer to predefined maximum and minimum transmit power settings, respectively.

Measurements and IM

- Measurements can be used for detection of victim UEs

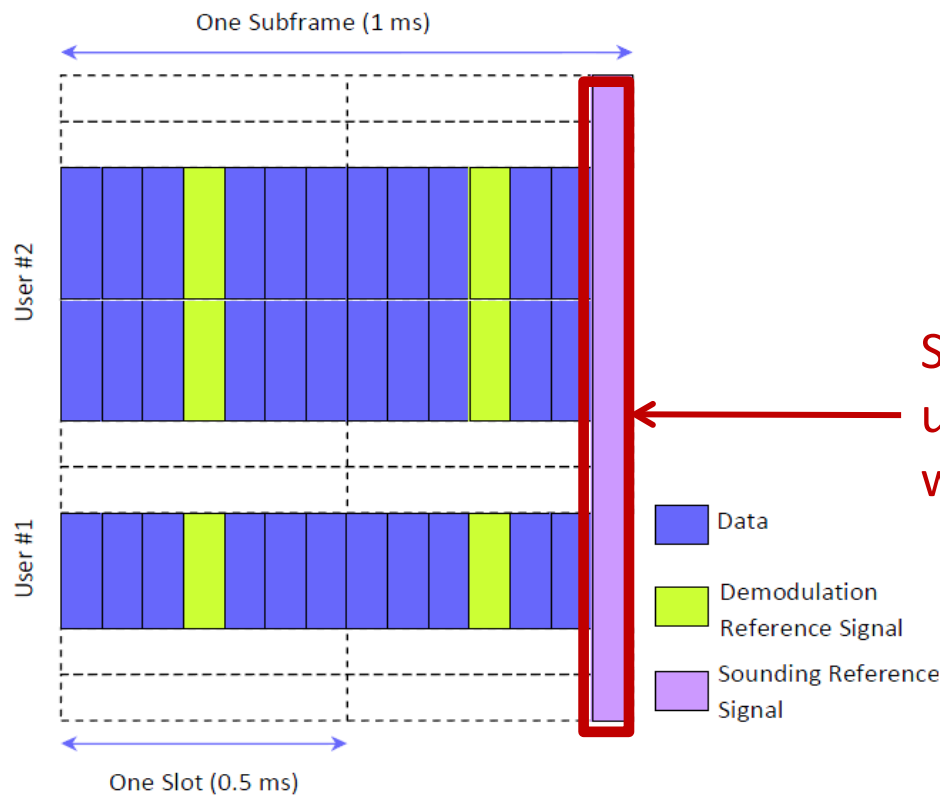


- RIP** value larger than a pre-defined threshold would mean that at least an MUE which is interfered by a HeNB is close to the HeNB and that the MUE's Tx power would cause interference towards the HeNB.
- This measurement value may be used in calculating path loss between the HeNB and the MUE assuming that a single MUE dominates the interference.

the properties of the uplink reference signals can be used

Measurements and IM

- Measurements can be used for Interference-aware RA

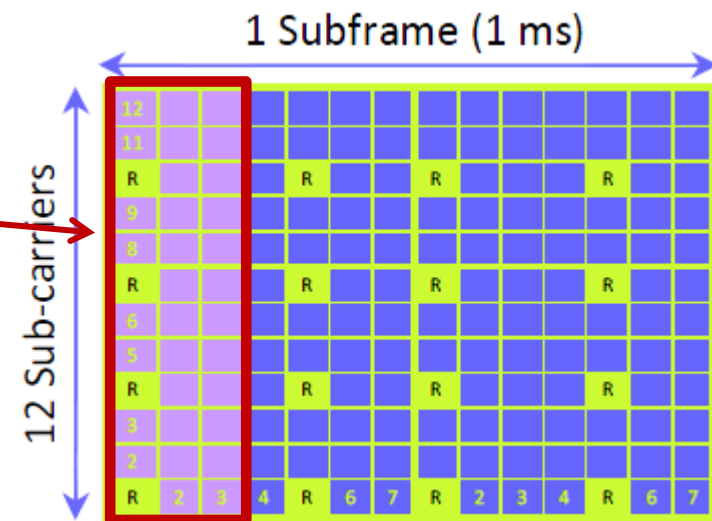


Sounding reference signals can be used for allocating UEs to resources with the lower interference

Measurements and IM

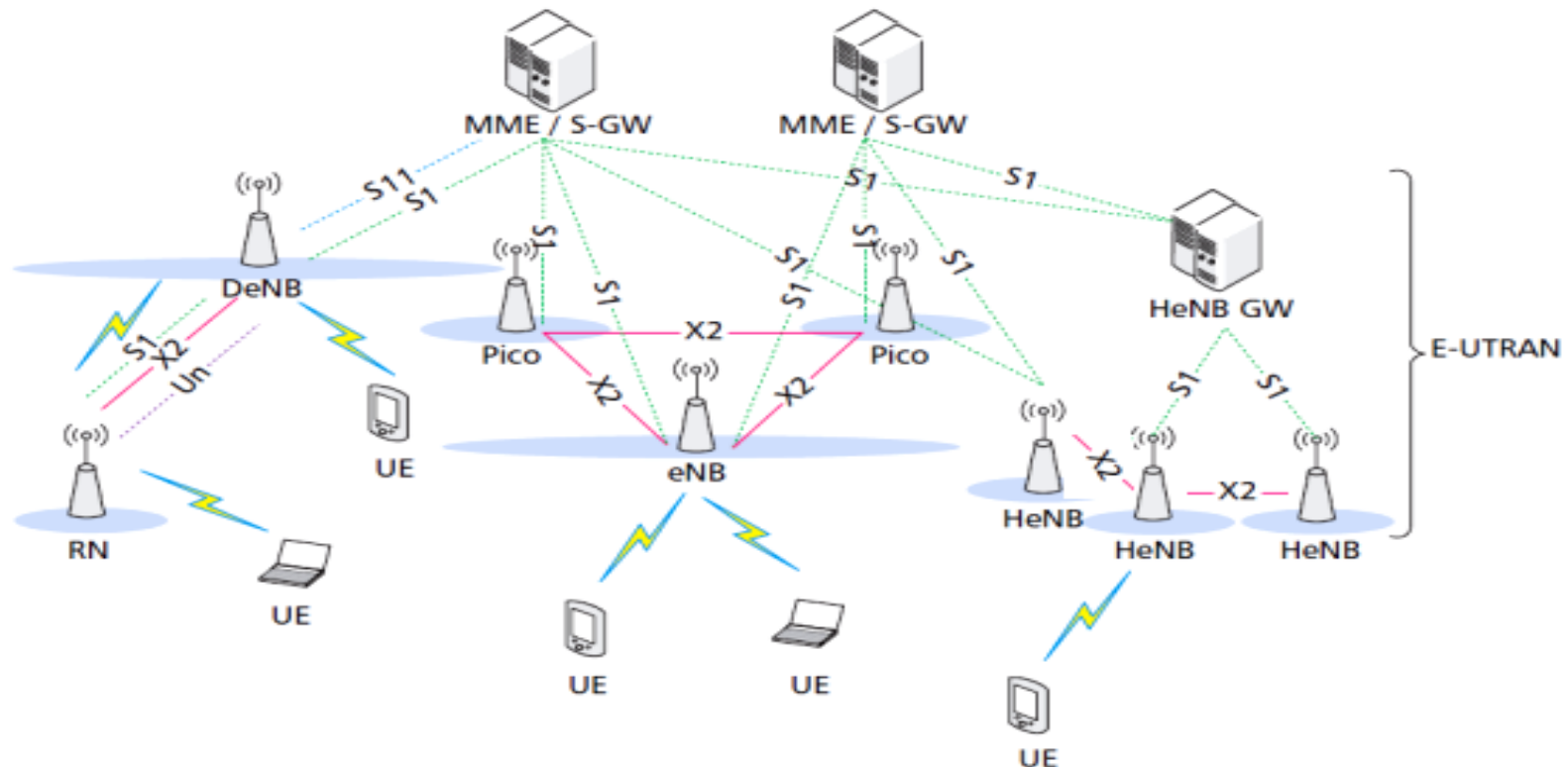
- Measurements can be used for control channel protection
e.g. **Cell ID manipulation for control channel protection**

Specific location of Control channels based on cell ID value



X2 interference indicators

LTE-A Architecture



- X2 interface is used for exchanging interference indicators
- Unfortunately, X2 is not available between eNBs and HeNBs

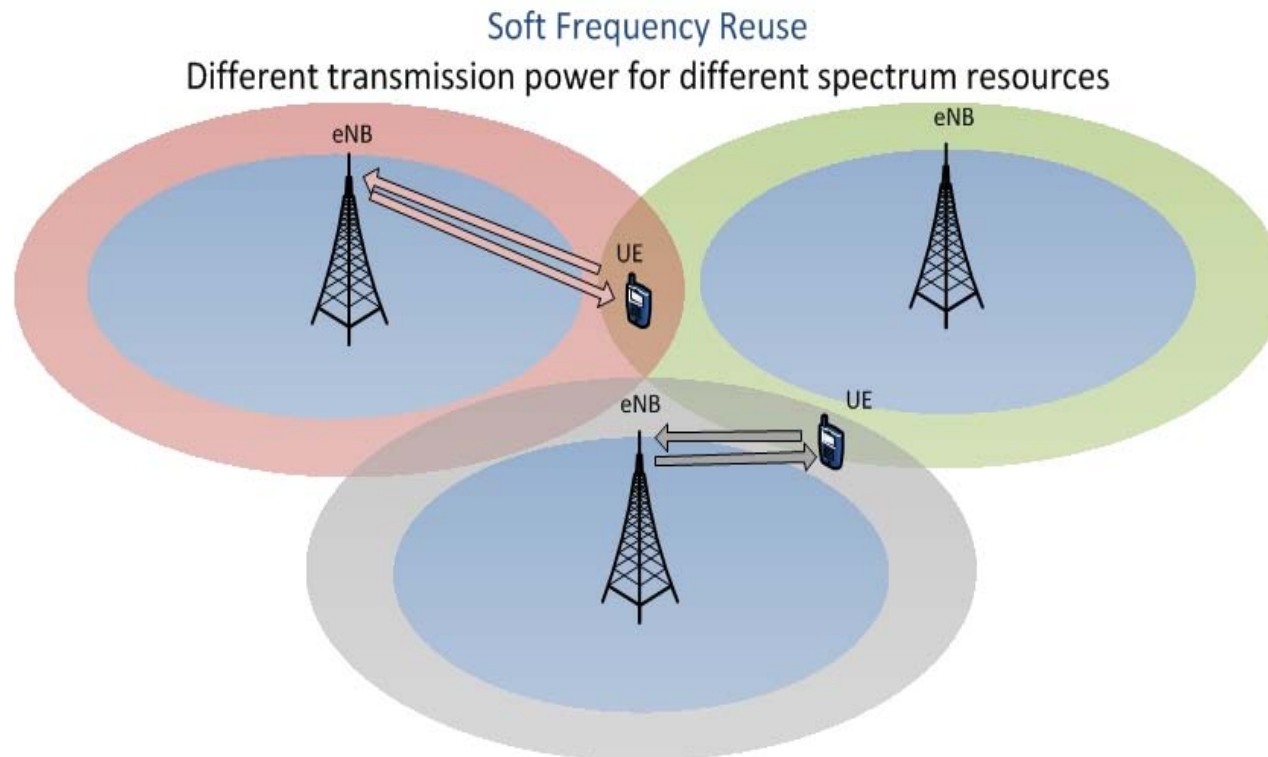


X2 interference indicators

- **Relative Narrowband Transmit Power Indicator (RNTP)**
 - This message contains information about the transmission power level that will be used in each resource block (RB) for the DL transmission.
 - One bit per RB indicates if it is expected the transmission power to exceed a predefined threshold. (every 200ms)
- **High Interference Indicator (HII)**
 - HII can be considered as an RNTP indicator for the UL transmissions.
 - One bit per PB indicates if a neighbor (H)eNB should expect high interference power in the near future. (every 20 ms)
- **Overload Indicator (OI)**
 - OI is referred to the UL transmissions, however it is triggered only when high-interference is detected by an (H)eNB (every 20 ms)

X2 interference indicators

- Use of X2 Interference Indicators for Inter-Cell Interference Coordination (ICIC)
- **ICIC example:** Adaptive Soft Frequency Reuse





Interference indicators lack of X2 interface

Over the air - directly between eNB and HeNB

- **Pros**
 - low latency in comparison to information exchanging through the wired backhaul connection – it gives the opportunity for coordinated scheduling and resource allocation
- **Cons**
 - uncertainty in over-the-air connection between eNB and HeNB



Interference indicators lack of X2 interface

Over the air - UEs as intermediate nodes

UEs are used to transit interference information between BSs

- **Pros**

- the downlink transmission of the (H)eNB would not need to be interrupted to receive the interference information (UE transmits the message during the next UL period).

- **Cons**

- higher latency than the eNB – HeNB connection
- no backwards compatibility is achieved for LTE Rel.8 UEs and at the same time changes to eNBs and HeNB implementation are required



Interference indicators lack of X2 interface

Through S1 interface

- **Pros**
 - higher accuracy of information received at destination while in contrast to X2 interface S1 based connection is already standardized between (H)eNBs and (H)eNB
- **Cons**
 - increases load to core network and especially to MME entity, the high latency



Carrier Aggregation and IM

Carrier Aggregation = more Spectrum

+

Each femtocell will serve few users



Enhanced Frequency Partitioning schemes for Femto-to Femto
interference management

Find ways for allocating different (primary) CC to neighboring HeNBs



Carrier Aggregation and IM

Centralized Approach

Resources are assigned by a central controller

- + More efficient resource utilization than the distributed approach
- Needs extra signaling between the BSs and the controller
- High computational complexity at the controller

Distributed Approach

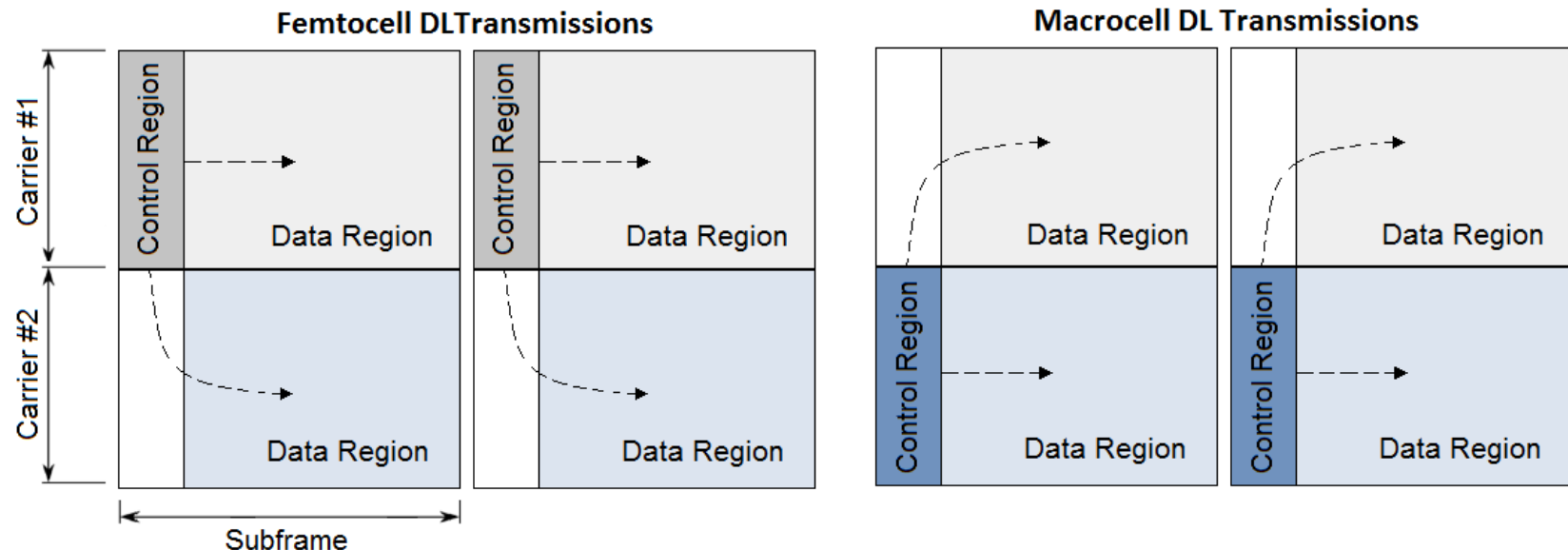
Resources are assigned autonomously by BSs

- + Less complexity
- High signaling overhead
- Requires long time period to reach a stable resource allocation
- Low resource efficiency

CA with Cross-Carrier Scheduling

- Refers to the ability to schedule a UE transmission/reception in multiple secondary CCs, while the allocation (control) messages are transmitted in a particular primary CC

Control channel protection





CA with Cross-Carrier Scheduling

Advantages

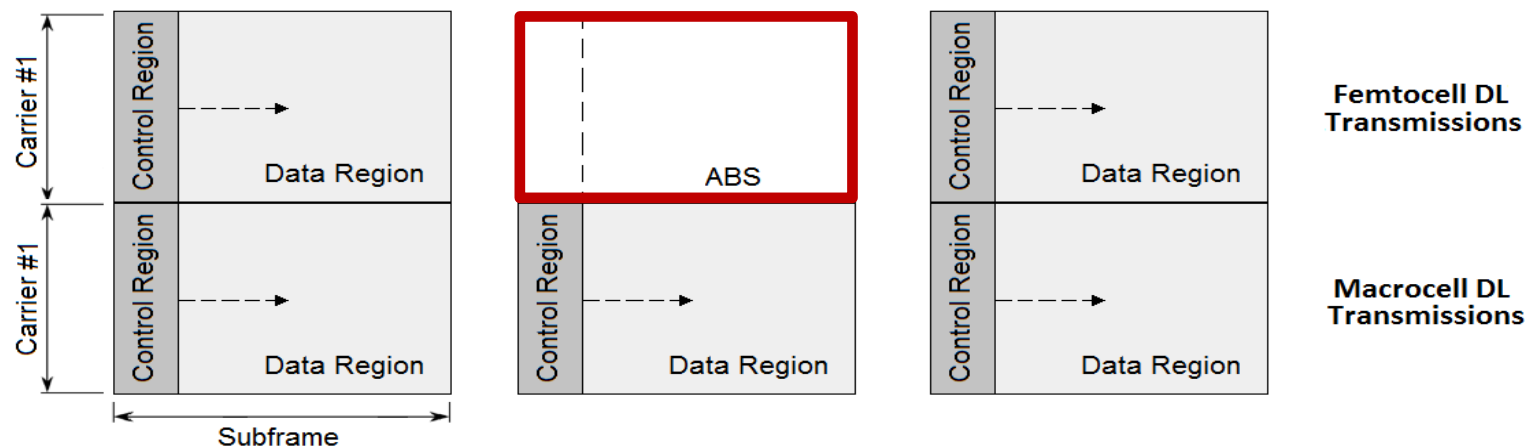
- Interference avoidance in the very important control channels with no decrease in the available spectrum

Disadvantages

- The same as in the Frequency partitioning schemes
- Problems on mapping the PDCCH of multiple CC in the control region of the primary CC
- Backwards incompatible (Rel.8,9 UEs can not take advantage of this technique)

Almost Blank Subframes

- ABSs can be constructed either by configuring the multicast/broadcast over single-frequency network (MBSFN) subframes or by avoiding to schedule unicast traffic in certain subframes
- **Data and control channels are not included**, making room for interference-free transmissions/receptions by victim UEs





Almost Blank Subframes

- The neighbor (H)eNBs can be informed for the ABS transmissions in order to transmit control signals and/or allocate resources for victim UEs in these subframes

Advantages

- Interference-free resources for control and data channels

Disadvantages

- Lose of resources for the (H)eNB that transmits the ABSs
- channel measurements made by UEs deteriorate including in their average estimations measurements of non-transmitting (blank) subframes



Almost Blank Subframes

Two types of ABS bitmap patterns can be exchanged through the X2 interface to configure ABSs among (H)eNBs

– ABS Pattern

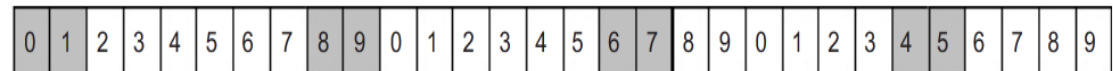
referred to as the time-domain Relative Narrow-Band Transmit Power (RNTP) indicator

– Measurement Subset,

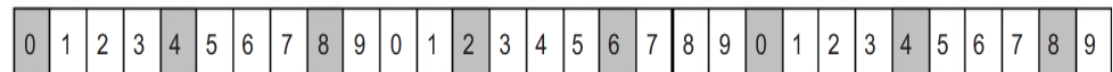
informs the receiving (H)eNBs on the set of subframes that can be used for measurements



(a) Normal ABS: 1 ABS out of 8 subframes, Periodicity = 40 ms



(b) Normal ABS: 2 ABS out of 8 subframes, Periodicity = 40 ms



(c) Normal ABS: 2 ABS out of 8 subframes, Periodicity = 40 ms



(d) MBSFN ABS: 3 MBSFN ABS out of 20 subframes, Periodicity = 40 ms



Almost Blank Subframe (ABS)



Summary

LTE-A - Standardized IM tools

- In LTE-A PHY, special measurements are introduced for interference management
- X2 interface is mainly used for ICIC
- Frequency domain IM - CA technique
- Time Domain IM - ABS technique

These standardized tools can be exploited by:

- POWER CONTROL schemes
- RESOURCE ALLOCATION schemes



Thank you!