Multi-band Scheduling and Spectrum Aggregation

Fernando J. Velez

2nd workshop CReaTION project

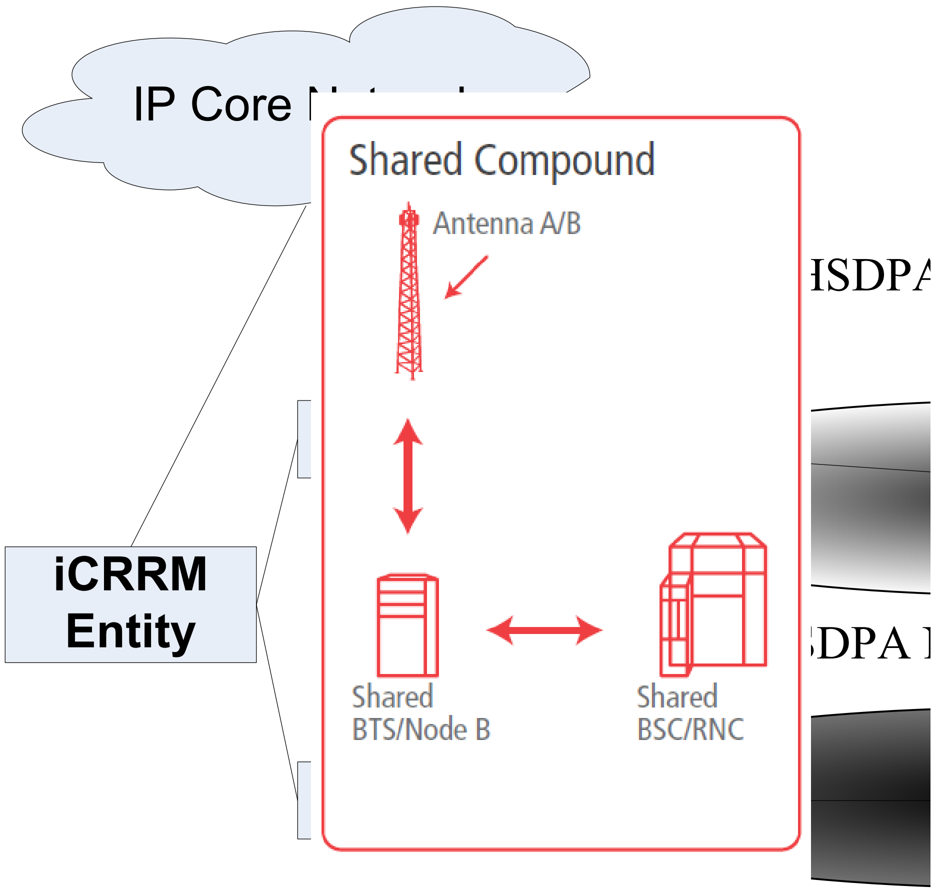
15th October, 2014

Porto, Portugal

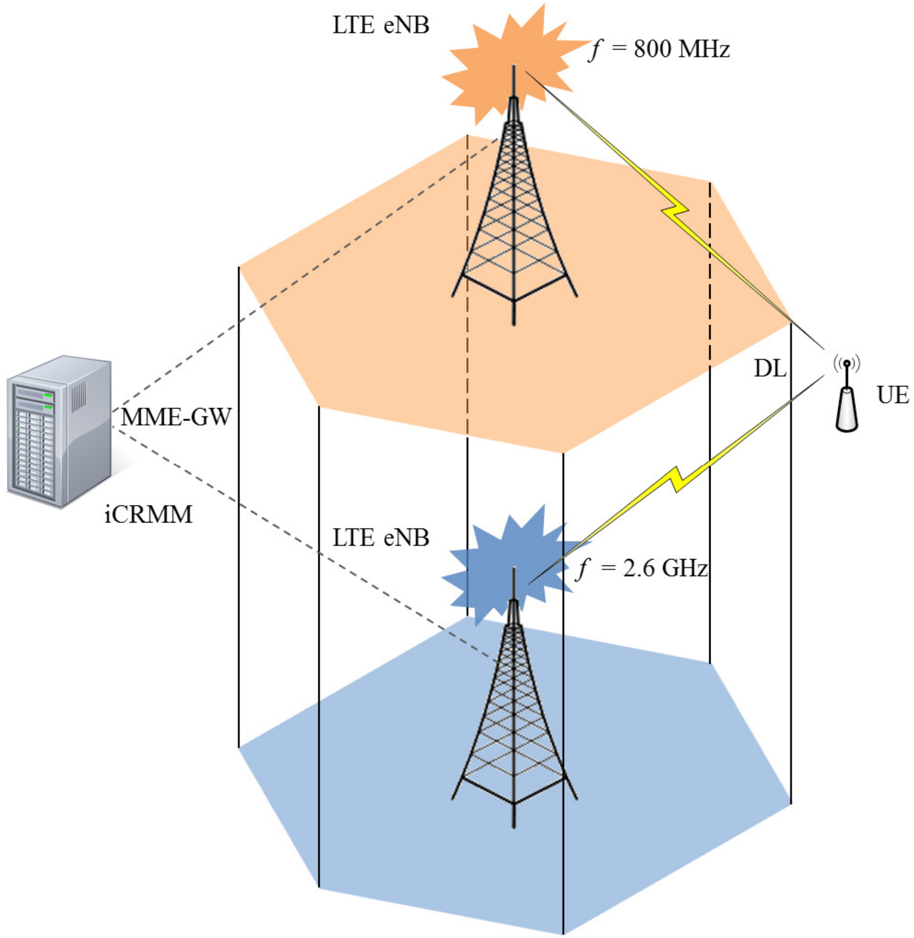
Outline

- Concept and scenarios
- Intra-band and inter-band carrier aggregation
- Some definitions
- Multi-band scheduling (MBS) algorithm in a IMT-Advanced scenario
- Results and discussion
- Road ahead and conclusions

Muti-band Scheduling and Spectrum Aggregation

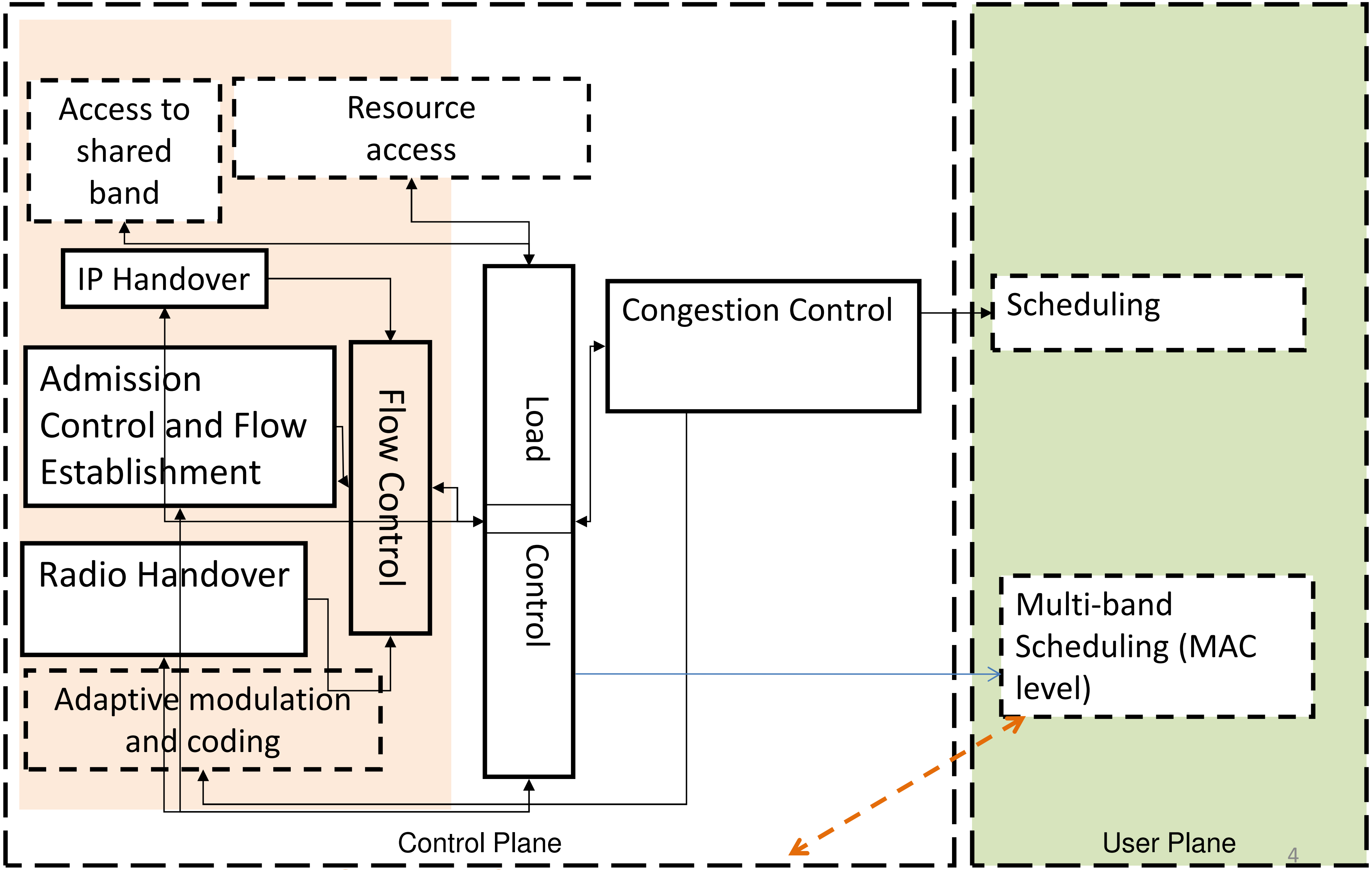


Full RAN Sharing



MME
Mobility Management Entity

Interconnectivity of Cooperative Functions



… but Spectrum/Carrier Aggregation is done at different layers

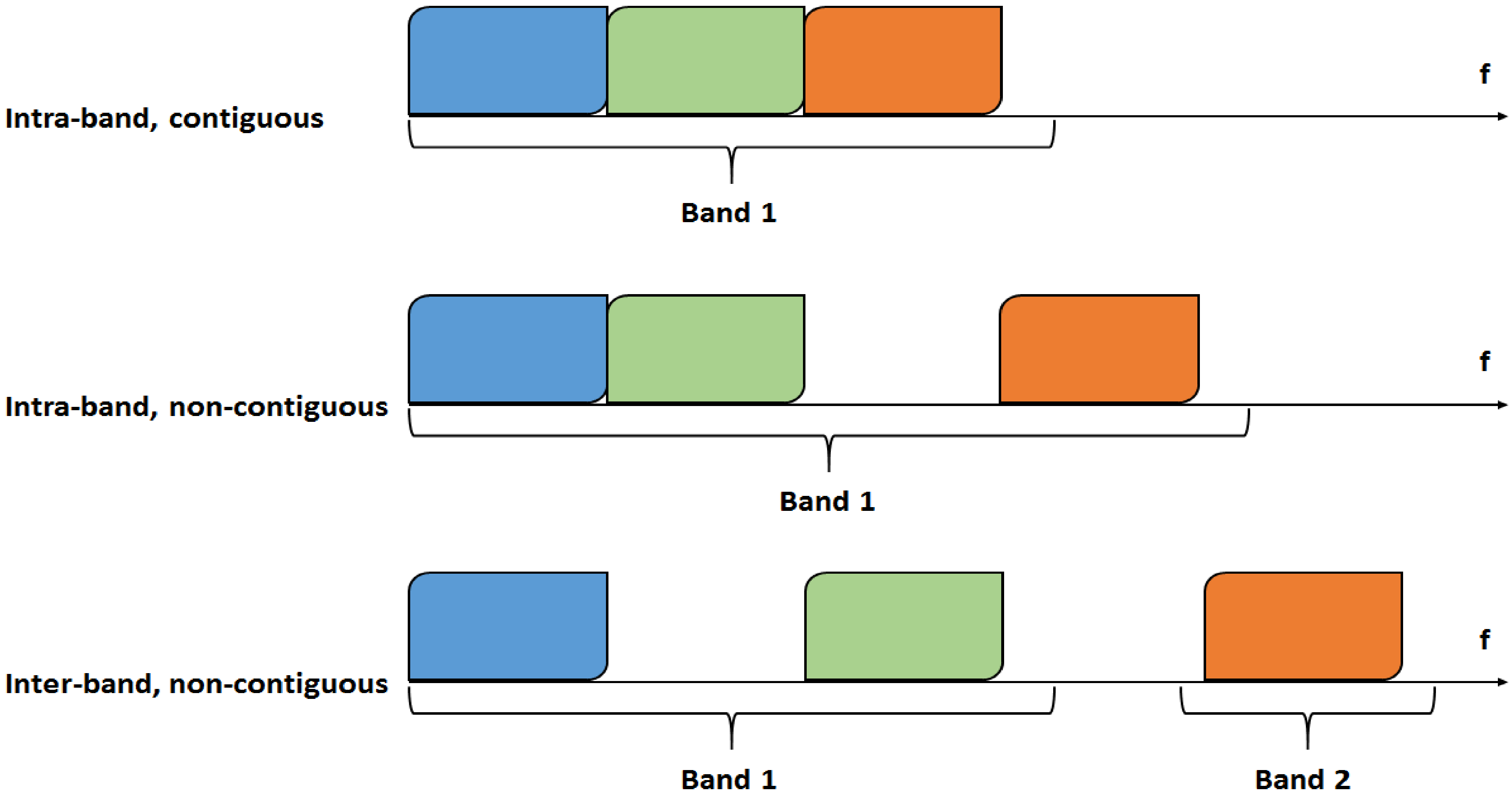
Component carriers (CCs)

- CA is considered as a key enabler for LTE-A [3GPP_R10], which can meet or even exceed the IMT-Advanced requirement for large transmission bandwidth (40 MHz-100 MHz) and high peak data rate (500 Mbps in the uplink and 1 Gbps in the downlink)
- Each aggregated carrier is referred to as component carrier, CC
- The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of **five** CCs can be aggregated and can also be of different bandwidths
- The maximum aggregated bandwidth is 100 MHz
- In this context, user equipment (UE) may simultaneously receive or transmit data on one or multiple CCs, whereas in the 3GPP Rel-8 specifications [3GPP_R10], each UE uses only one CC to communicate at one time

Enabling Spectrum Aggregation …

- The easiest way to arrange aggregation would be to use contiguous component carriers within the same operating frequency band (as defined for LTE), so called intra-band contiguous
- However, in practice, such a large portion of continuous spectrum is rarely available
- Carrier Aggregation, where multiple Carrier Components (CCs) of smaller bandwidth are aggregated, is an attractive alternative to increase data rate
- By aggregating non-contiguous carriers, fragmented spectrum can be more efficiently utilized

Intra-band and inter-band Carrier Aggregation alternatives



Efficiency increase

- Additional advantages are offered by CA in terms of spectrum efficiency, deployment flexibility, backward compatibility, and more
- By aggregating non-contiguous carriers, fragmented spectrum can be much more efficiently utilized

Some definitions

- **Aggregated Channel Bandwidth:** The radio frequency (RF) bandwidth in which a UE transmits and receives multiple contiguously aggregated carriers
- **Aggregated Transmission Bandwidth Configuration (ATBC):** The number of resource block (RB) allocated within the aggregated channel bandwidth
- **Carrier aggregation:** Aggregation of two or more component carriers in order to support wider transmission bandwidths
- **Carrier aggregation band:** A set of one or more operating bands across which multiple carriers are aggregated with a specific set of technical requirements

Some definitions (cont.)

- **Carrier aggregation bandwidth class:** A class defined by the aggregated transmission bandwidth configuration and maximum number of component carriers supported by a UE. In R10 and R11 three classes are defined, A, B and C, whereas classes D, E and F are at the time in the study phase

CA bandwidth classes (extracted from [3GPP, TR 36.807 (2012-07])

CA bandwidth class	ATBC, N_{RB_agg} [RBs]	Number of CC's
A	$N_{RB\_agg} \leq 100$	1
B	$N_{RB\_agg} \leq 100$	2
C	$100 < N_{RB\_agg} \leq 200$	2
D	$[200] < N_{RB\_agg} \leq [300]$	3
E	$[300] < N_{RB\_agg} \leq [400]$	Under study
F	$[400] < N_{RB\_agg} \leq [500]$	Under study

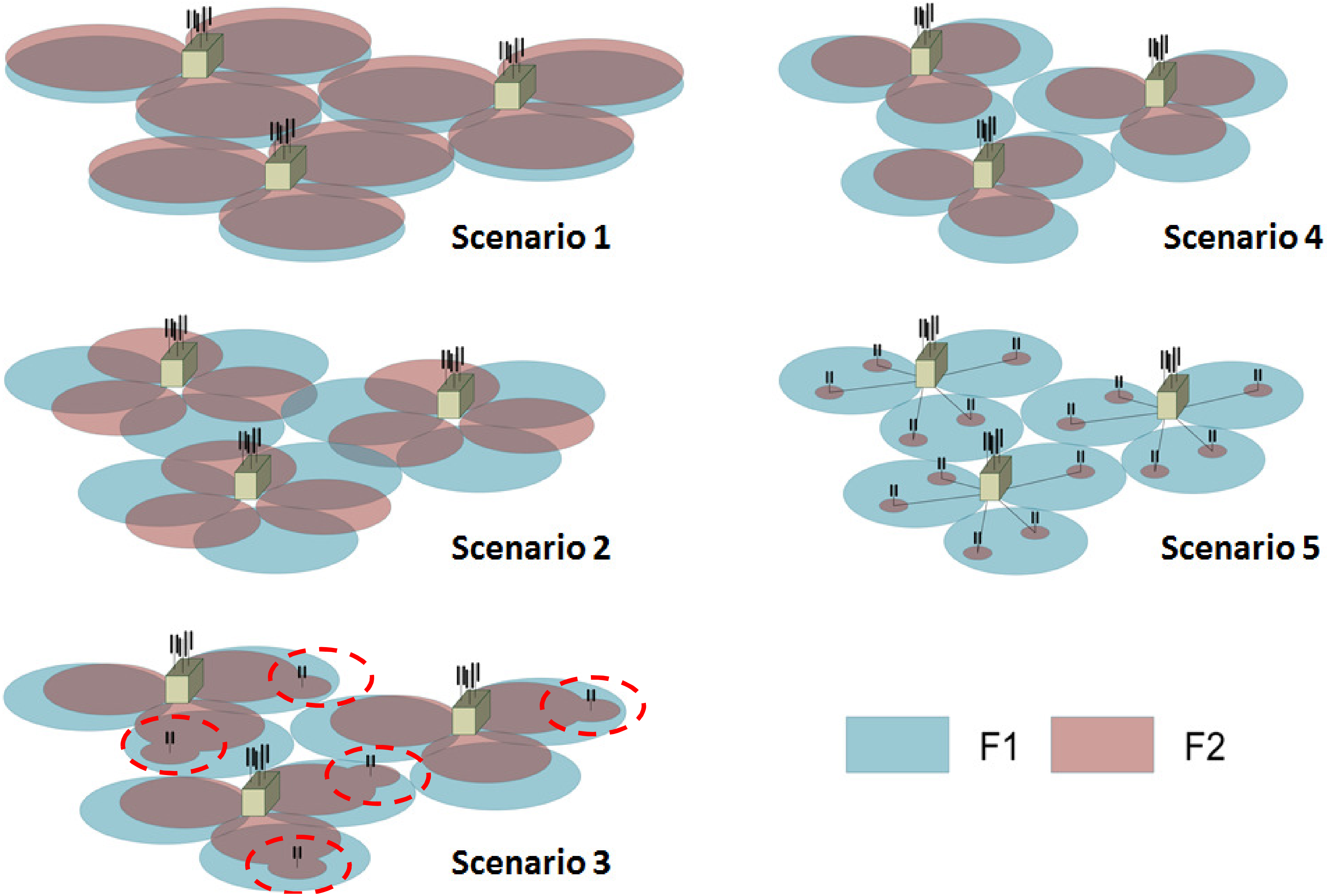
N_{RB_agg} is the number of aggregated RBs in which a UE can transmit (receive) simultaneously

N_{RB_agg} is defined as the sum of the transmission bandwidth configurations (N_{RB}) of the CCs.

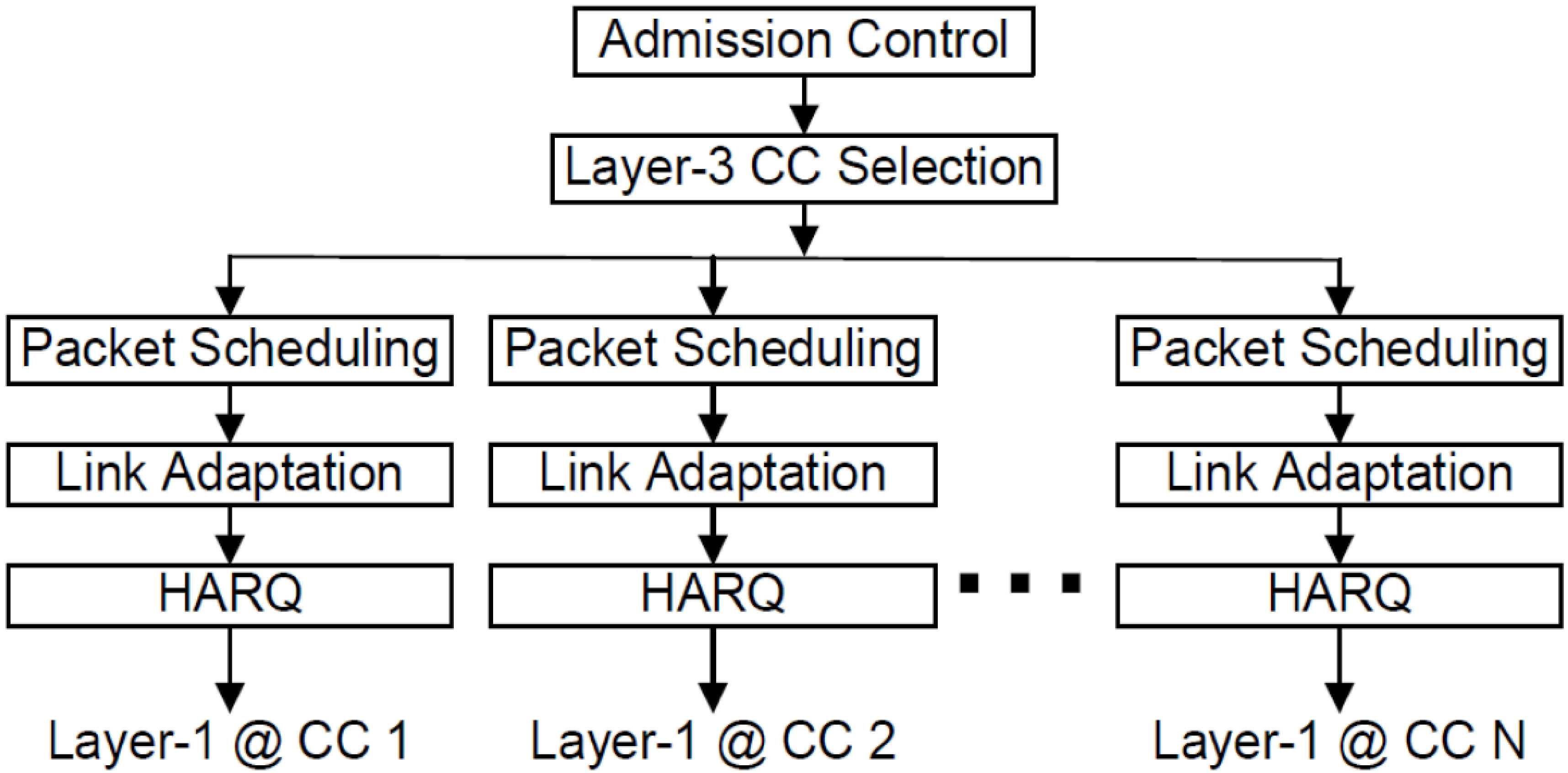
Primary/Secondary Component Carriers

- When carriers are aggregated, each carrier is referred to as a CC and they can be classified in two categories:
  - **Primary component carrier**: This is the main carrier in any group. There will be a primary downlink carrier and an associated uplink primary component carrier.
  - **Secondary component carrier**: There may be one or more secondary component carriers.
- 3GPP does not define which carrier should be used as a primary component carrier
- Different UE may use different carriers
- The configuration of the primary component carrier is UE/terminal specific and depends of the loading on the various carriers and other relevant parameters

CA deployment scenarios



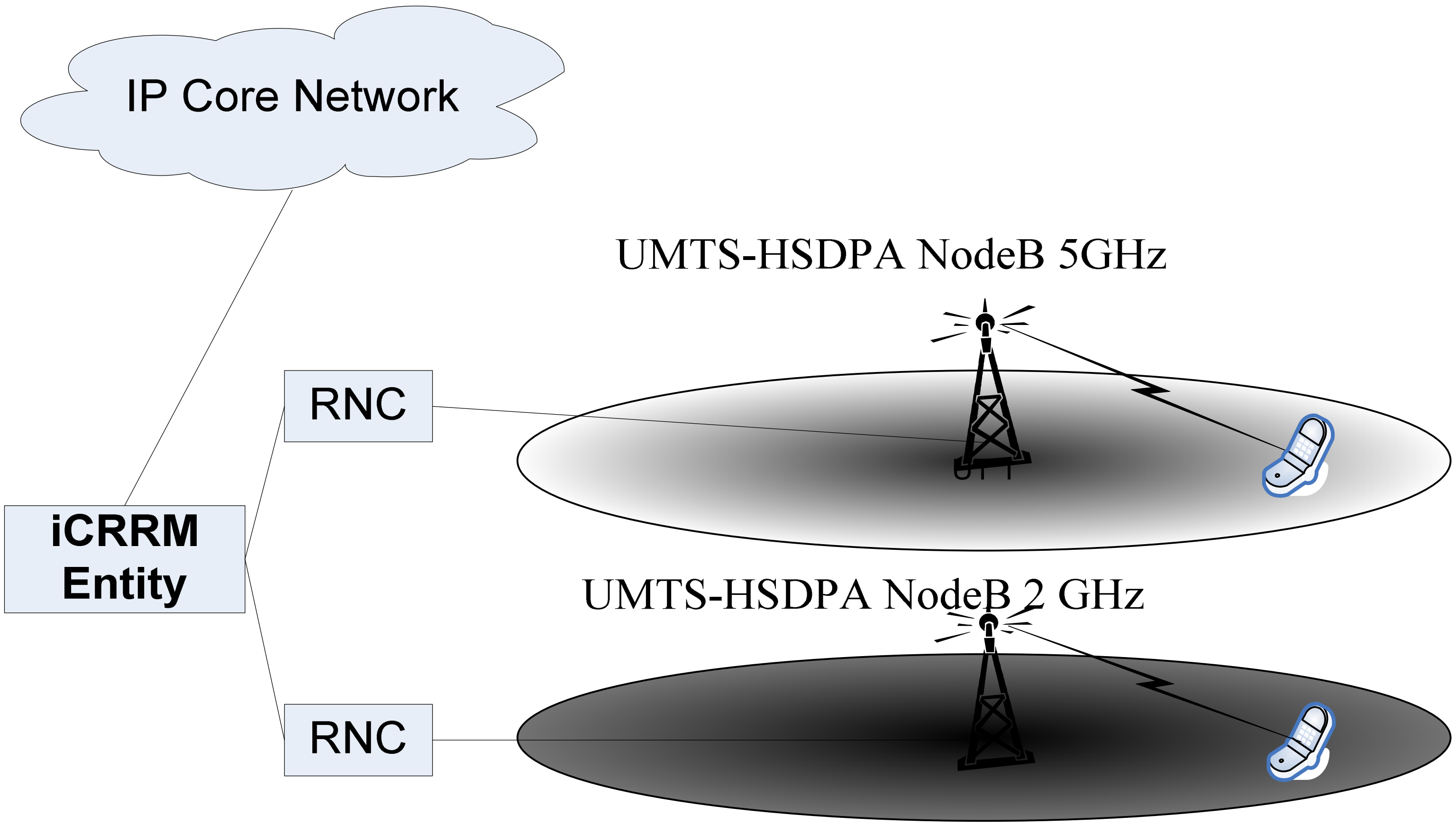
Structure of a multi-component carrier LTE-A system



SA/CA research within COST TERRA

- The research on SA/CA work proposes an integrated Common Radio Resource Management (iCRRM) that performs CC scheduling to satisfy user's QoS requirements and to maximize spectral efficiency
- Moreover, CA is analysed at constant average SINR to have comparable results, as such a detailed eNBs transmitted power formulation has also been proposed

Integrated CRRM scenario



Dynamic spectrum management as a function of the traffic loads

- The amount of required spectrum bandwidth for a network operator depends on
  - traffic / capacity requirements,
  - MCS scheme used,
  - cell sizes and the frequency reuse pattern
- General MBS: aims to determine the user allocation over two frequency bands in order to increase the total throughput
- **Two steps:**
  1. Determine the number of users to be allocated based on the load thresholds
  2. Apply multi-band scheduling (MBS) where the number of users to be allocated is upper bounded

iCRRM MBS Algorithm

(Profit Function) $\max \sum_{b=1}^{m} \sum_{u=1}^{n} W_{bu} x_{bu}$ $\quad W_{bu} = \frac{[1 - PER(CQI_{bu})] \cdot R(CQI_{bu})}{S_{rate}}$

(Allocation Constraint) $\sum_{b=1}^{m} x_{bu} \le 1, x_{bu} \in \{0,1\}, \forall u \in \{0,...,n\}$

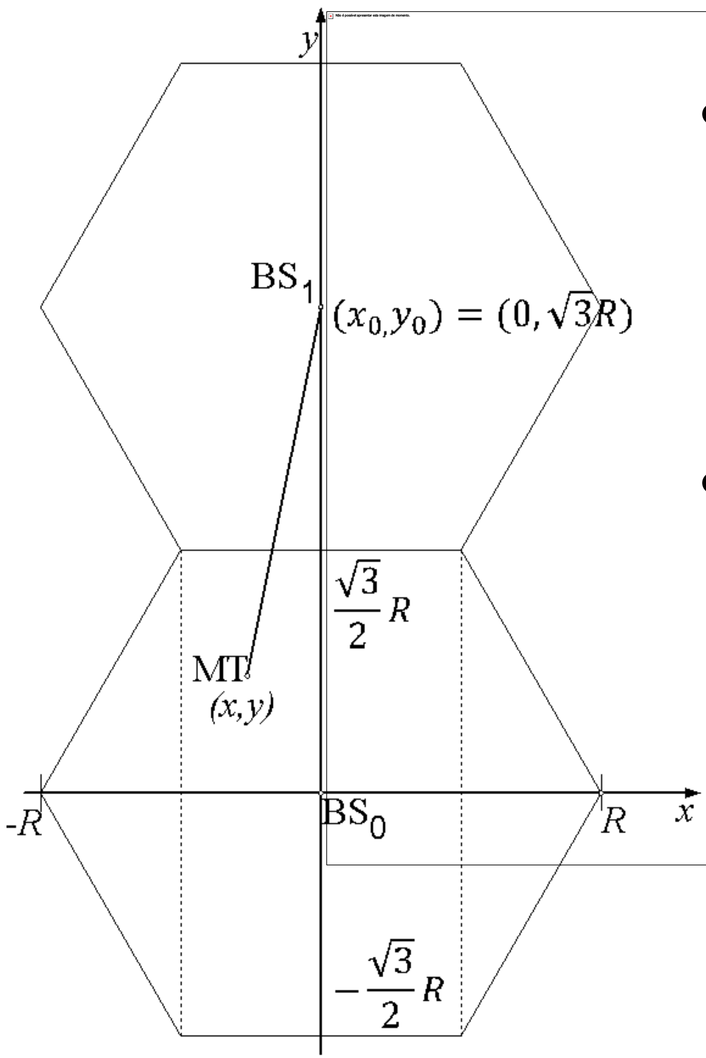
(Bandwidth Constraint) $\sum_{u=1}^{n} \frac{S_{rate} \cdot (1 + R_{Tx} \cdot PER(CQI_{bu}))}{R(CQI_{bu}) \cdot N_{codes}} x_{bu} \le L_b^{\max}, \forall b \in \{1,...,m\}$

$$R(CQI_{bu}) = \begin{cases} 188.5 \; if \;\; CQI_{bu} = 5 \\ 198.0 \; if \;\; CQI_{bu} = 8 \\ 331.9 \; if \;\; CQI_{bu} = 15 \\ 716.8 \; if \;\; CQI_{bu} = 22 \end{cases}$$

$$L^{\max} = \begin{bmatrix} L_1^{\max} \\ L_2^{\max} \end{bmatrix}$$

x_{bu} is the allocation variable

Normalization procedures (HSDPA)



- SINR

$$SINR(P_{Tx}, x, y) = \frac{P_{ow}(P_{Tx}, x, y)}{(1-\alpha)\cdot P_{ow}(P_{Tx}, x, y) + P_{nh}(P_{Tx}, x, y) + P_{noise}}$$

- Average signal power

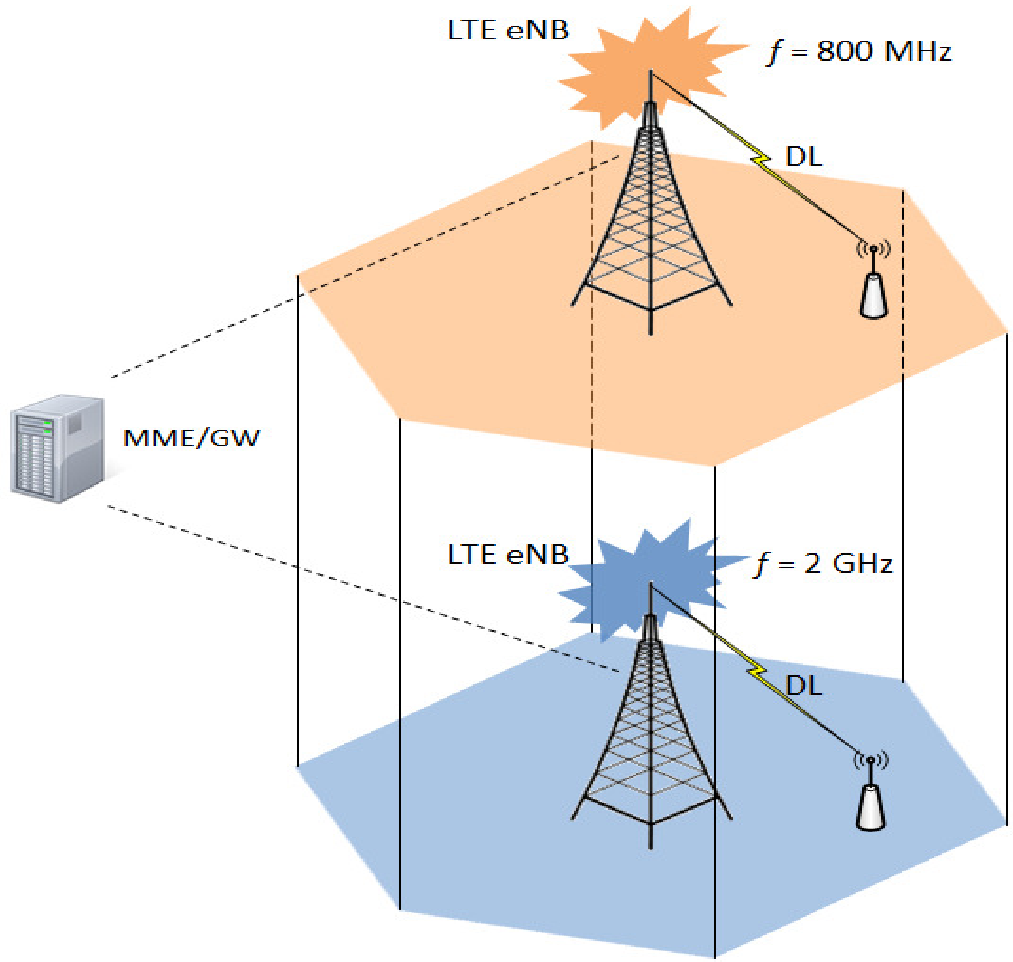
$$\overline{P}(R, P_{Tx}) = \int_y \int_x f_P(P_{Tx}, x, y)\,dxdy = \int_y \int_x \frac{P_{Tx} G_{Tx} G_{Rx}}{A_{Cell}} PL(x, y)\,dxdy$$

$$\overline{SINR}(R, P_{Tx}) = \overline{SINR}(R_0, P_{Tx,R_0})$$

Throughput improvement through SA and MB-scheduler

- The system architecture considers a MB-CRRM entity [1], the 2 GHz and 800 MHz bands and a single operator scenario under a constant average SINR. LTE Simulator is considered [Piro11].

[Piro11] G. Piro, L. A. Grieco, G. Boggia, F. Capozzi and P. Camarda, "Simulating LTE Cellular Systems: an Open Source Framework," IEEE Transaction on Vehicular Technologies, Vol. 60, No. 2, Feb 2011, pp. 498-513.



Propagation Model

- Path Loss Model

  The radio channel follows the ITU radio propagation COST-231 Hata model for urban and suburban scenarios ;

$$L_{[dB]} = 40 \cdot (1 - 4 \cdot 10^{-3} \cdot D_{hb[Km]}) \log_{10}(R_{[Km]}) - 18 \cdot \log_{10}(D_{hb[Km]}) + 21 \cdot \log_{10}(f_{[MHz]}) + 80$$

  R is the base station (BS)/user equipment (UE) maximum separation (cell coverage distance), *f* is the carrier frequency, and D_{hb} is the BS antenna height (from the average rooftop level).

- Considering two carrier frequencies, 800 MHz and 2 GHz, D_{hb} = 15 m and a UE antenna of 1.5 m, we obtain the following path loss model:

Carrier frequency	800 MHz	2 GHz
Bandwidth, *BW*	5 MHz	5 MHz
Path loss model	$L_{800\ \mathrm{MHz}} = 119.6 + 37.2 \cdot \log_{10}(R)$	$L_{2\ \mathrm{GHz}} = 128.1 + 37.6 \cdot \log_{10}(R)$

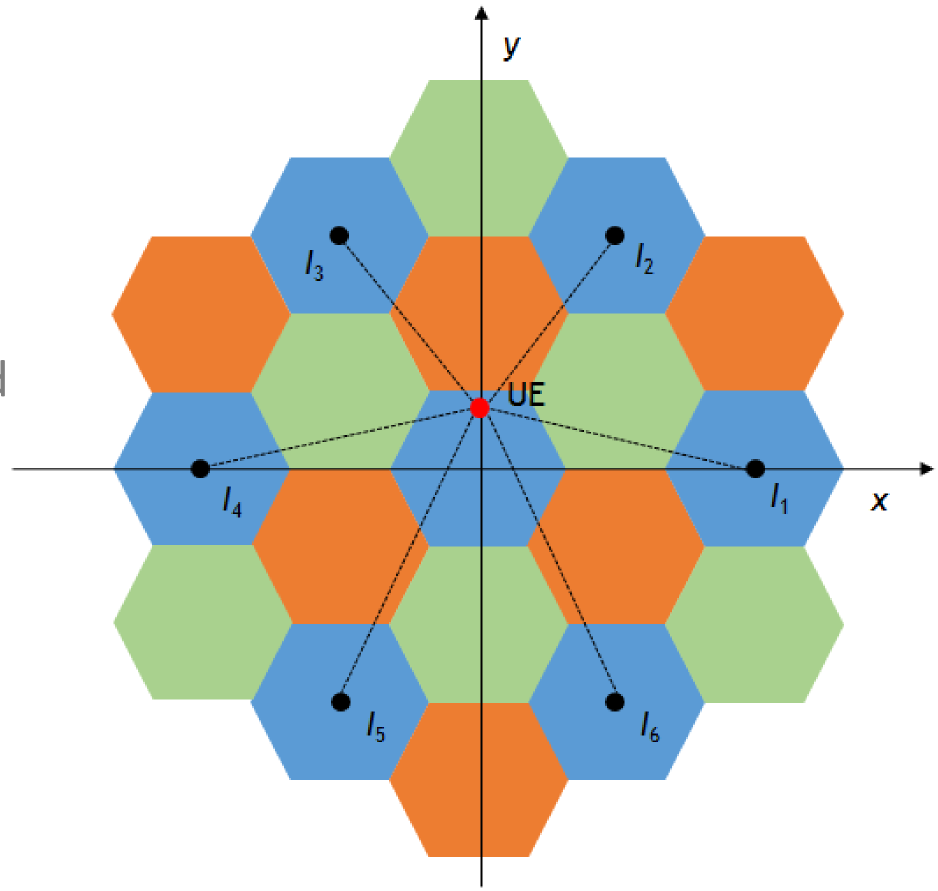
Propagation Model (II)

Parameters for LTE DL budget for a data rate of 1 Mbps and a commercial omnidirectional antenna.

Transmitter – NodeB		
a) Max. T_X power (dBm)	50	
b) T_X antenna gain (dBi)	3 - 3.5	For 800 MHz and 2 GHz respectively
c) Body loss (dB)	2	
d) EIRP (dBm)	**51- 51.5**	$= a + b - c$
Receiver UE		
e) Node B noise figure (dB)	8	LTE specifications
f) Receiver noise floor (dBm)	-99	=-174+10log (BW) + *e*
g) SINR (dB)	-10	From simulations
h) Receiver sensitivity (dBm)	-109	$= f + g$
i) Interference margin (dB)	3	
j) Cable loss (dB)	1	
k) R_X antenna gain (dBi)	0	
l) Fast fade margin (dB)	0	
m) Maximum path loss (dBm)	**156-156.5**	$= d - h - i - j + k - l$

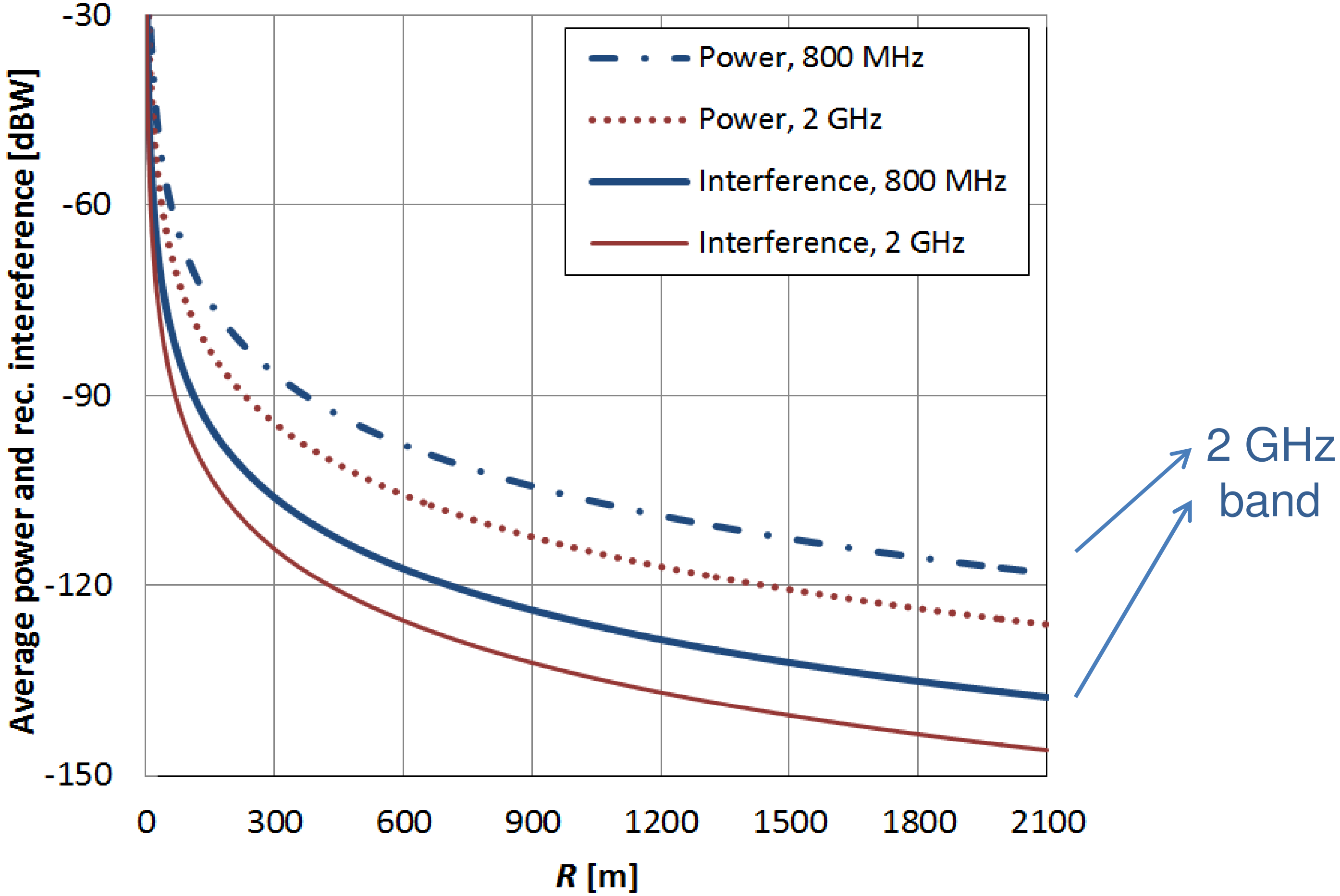
Cell topology

- The SA/CA gain has to be evaluated for several inter-cell distances with a frequency reuse pattern $K = 3$;
- In order to have comparable results, SA needs to be analysed at constant average SINR then by tuning the BSs transmitter power, the average SINR has been kept constant.



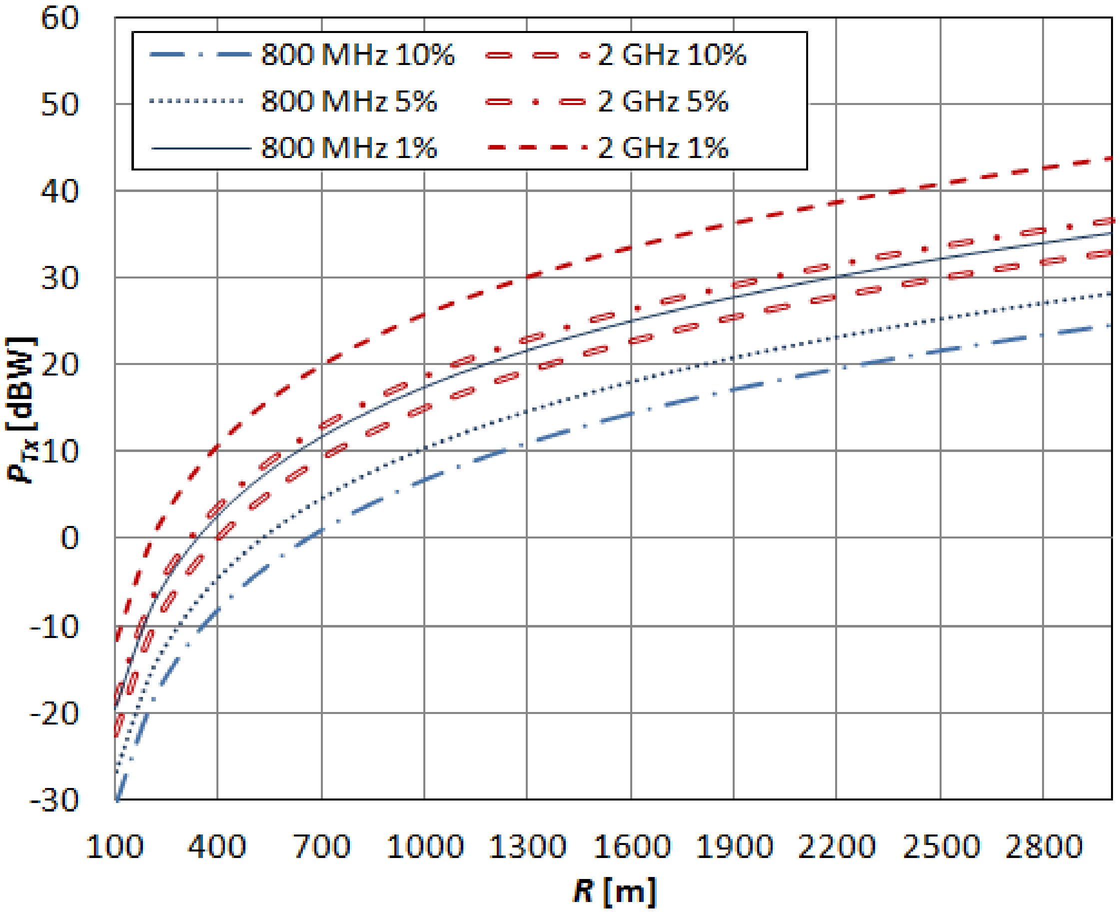
Average power and interference

- Average power and interference within a cell as a function of the inter-cell distance with P_{Tx} = 1 dBW and α = 1



Normalized transmitter power

- Normalized P_{Tx} required to achieve a selected high average SINR (dB), near the maximum, as a function of the cell radius at 800 MHz and 2 GHz for α =1



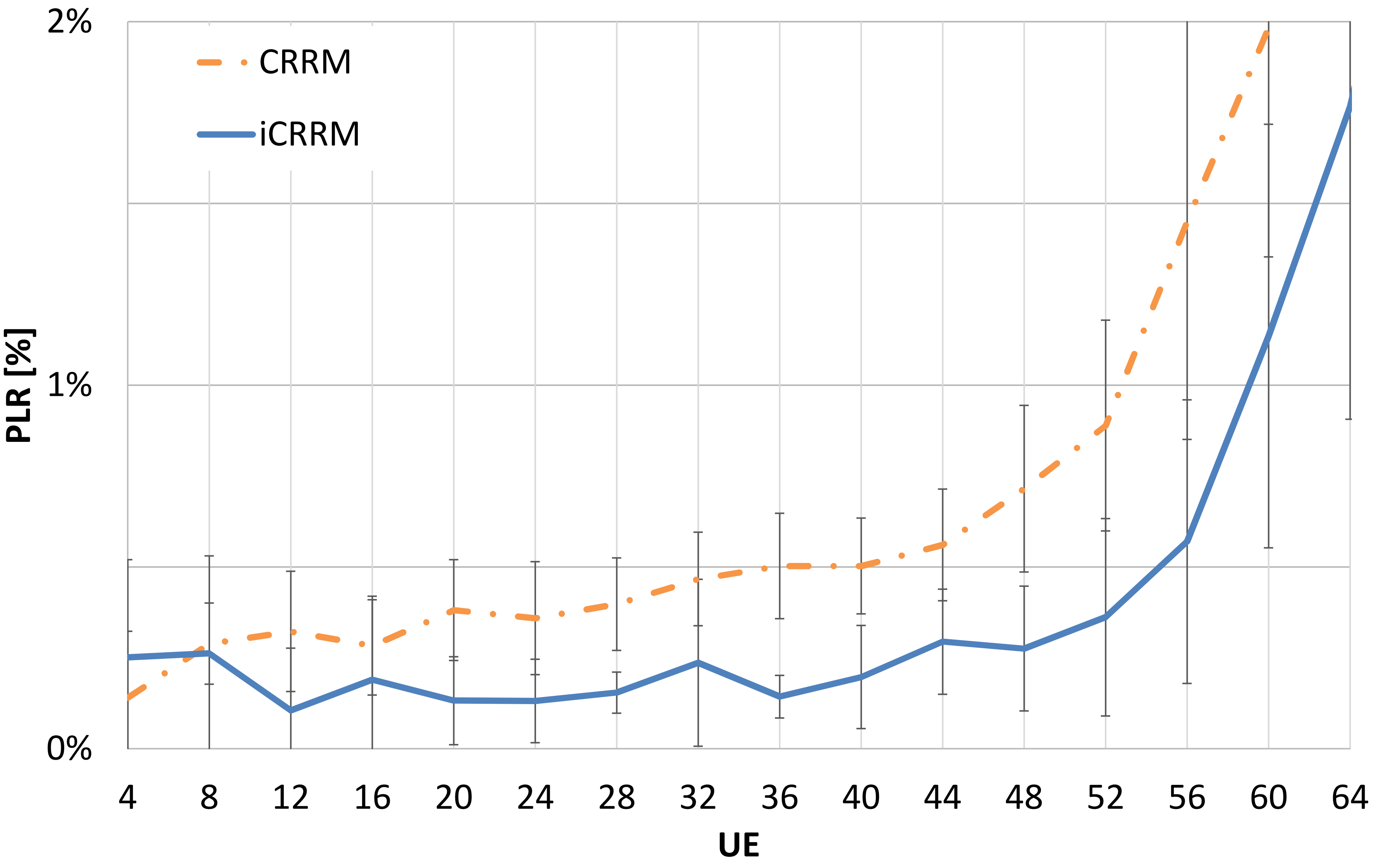
Video traffic throughput

- Video traffic simulation setup:
  - Traced-based video sessions have been addressed for simulations, these applications send packets based on realistic video trace files
  - We have considered a video bit rate of 128 kbps
  - Modified Largest Weighted Delay First (MLWDF) scheduler

LTE-A aggregation results: PLR

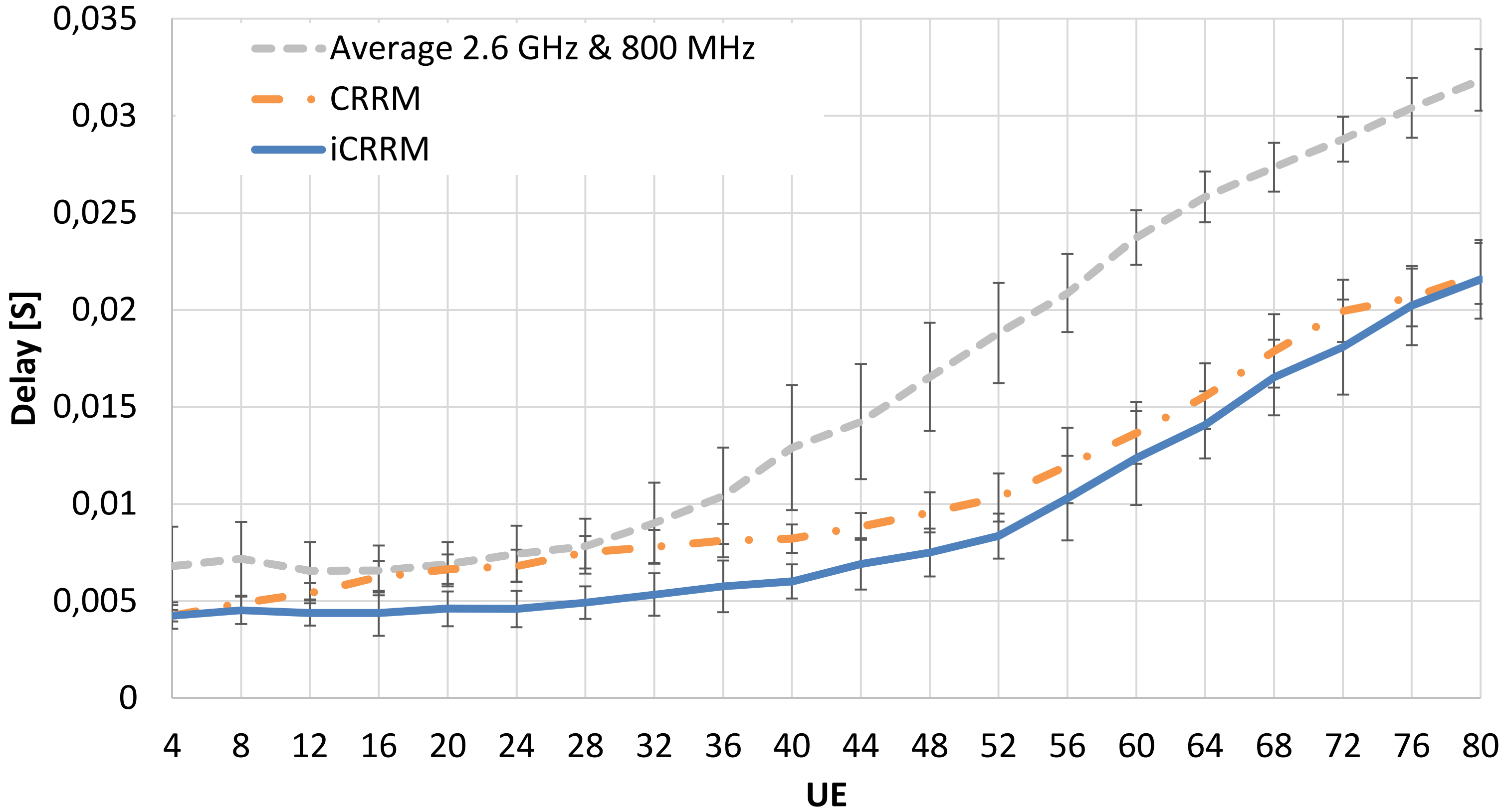
- Packet Loss Ratio (PLR), focused on 3GPP TS 22.105 and ITU-T G.1010   **1 %** performance target (not achieved without SA)
- The 1% PLR threshold is only reached above 60 UEs with iCRRM whereas CRRM only supports up to 52 UEs

LTE-A aggregation results: PLR



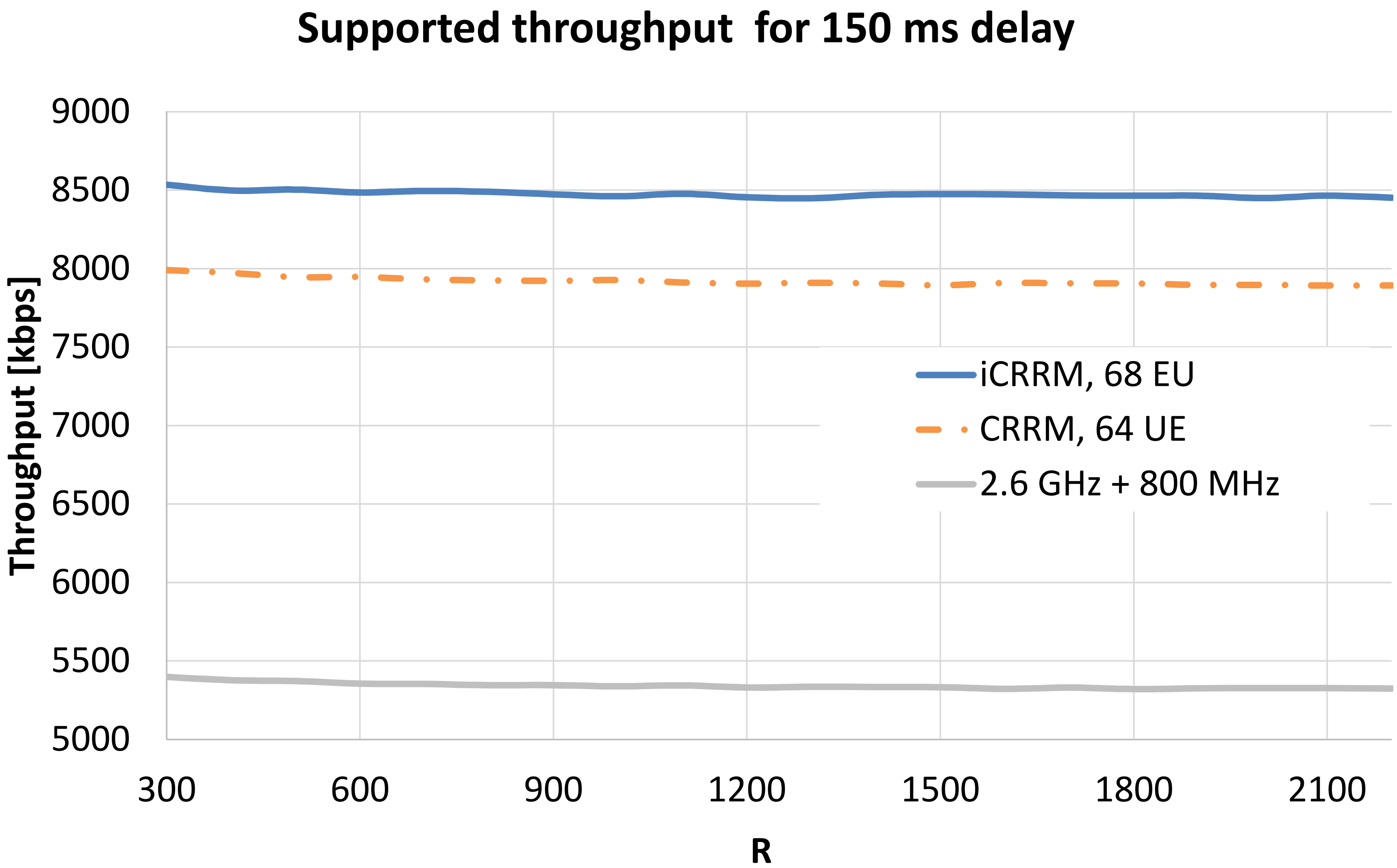
LTE-A aggregation results: Delay

- Delay: 3GPP TS 22.105 and ITU-T G.1010 preferred delay performance target is **150 ms**

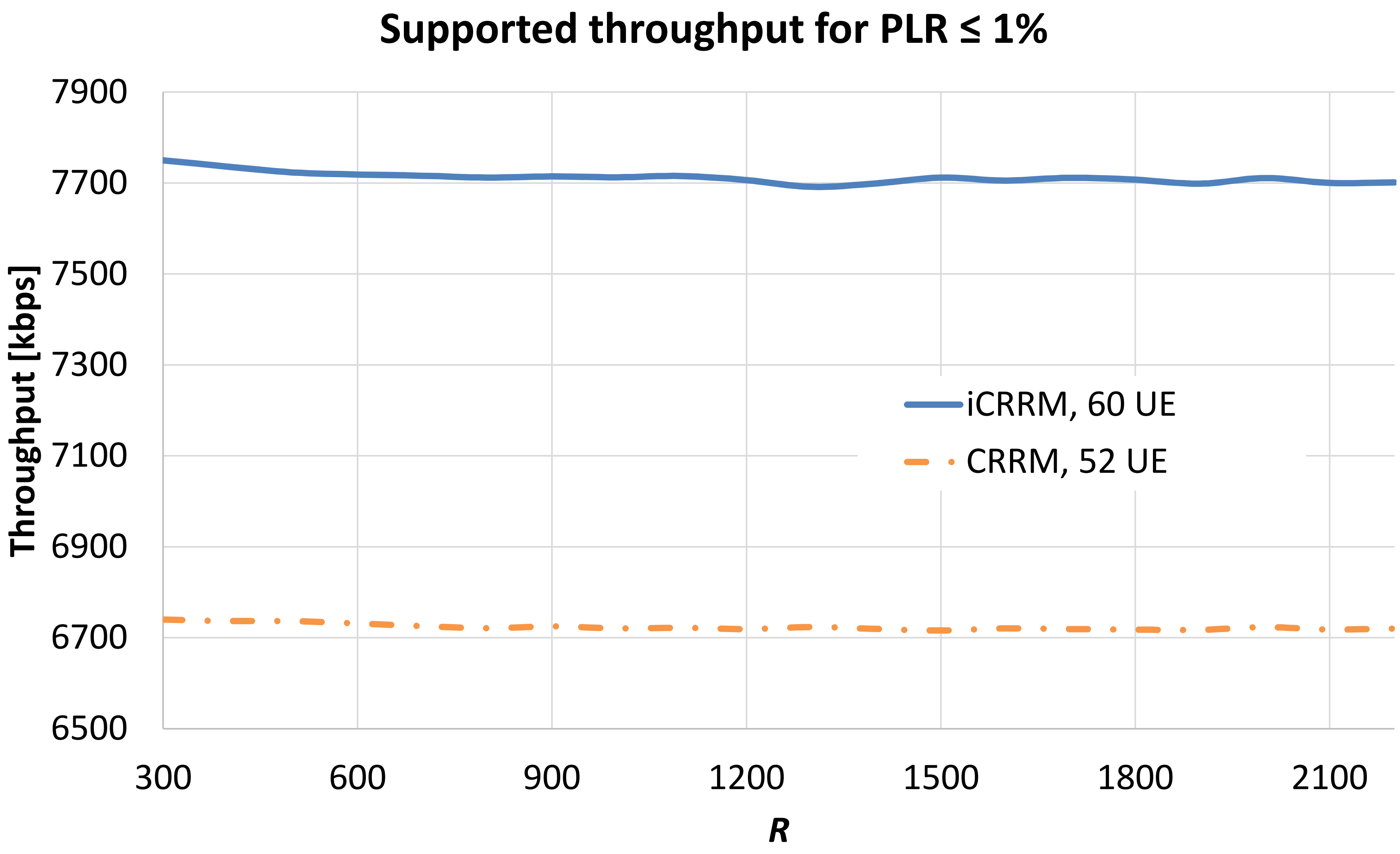


- The delay threshold is reached with 44, 64 and approximately 68 UEs. without SA, CRRM and iCRRM, respectively

LTE-A aggregation results: throughput



LTE-A aggregation results: throughput



Road ahead and conclusions

- The research work behind this talk analyses concepts, scenarios and definitions to enable Carrier Aggregation and Multi-band Scheduling
- Its application has an enormous potential, and of special interest is to explore these concepts in the near future for heterogeneous networks with small cells
- Then, it proposes an iCRRM entity that has control over a pool of frequency resources. It assigns these resources to the active MSs with the solution of an optimisation problem with the objective of total Service Throughput maximisation
- The proposal is in the scope the use of SA/CA proposed by ITU-R and 3GPP, towards IMT-A systems, and in particular the use of SA

Road ahead and conclusions

- To test the iCRRM with several cell radii with comparable conditions, a formulation was developed that gives the average SINR in the cell for LTE-A
- Achieved reduction in delay varies from 33% to 55 %
- At the load saturation point, the iCRRM system has shown a gain of up to ~34% in throughput
- With iCRRM, the intra-operator SA procedure is able to support a higher number of video users, due to the ability of scheduling their traffic according to the radio channel quality in different parts of the radio spectrum