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CREaTION - Workshop

Cost/Revenue Performance of LTE Employing Spectrum Aggregation with Multi-Band User Allocation over Two Frequency Bands

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Outline

- Introduction;
- Throughput improvement through SA and;
  - Propagation model
  - Cell topology;
  - Average SINR calculation;
  - Normalized transmitter power;
- Video traffic throughput;
- Cost/revenue optimization;
- Conclusions and future work.

Introduction

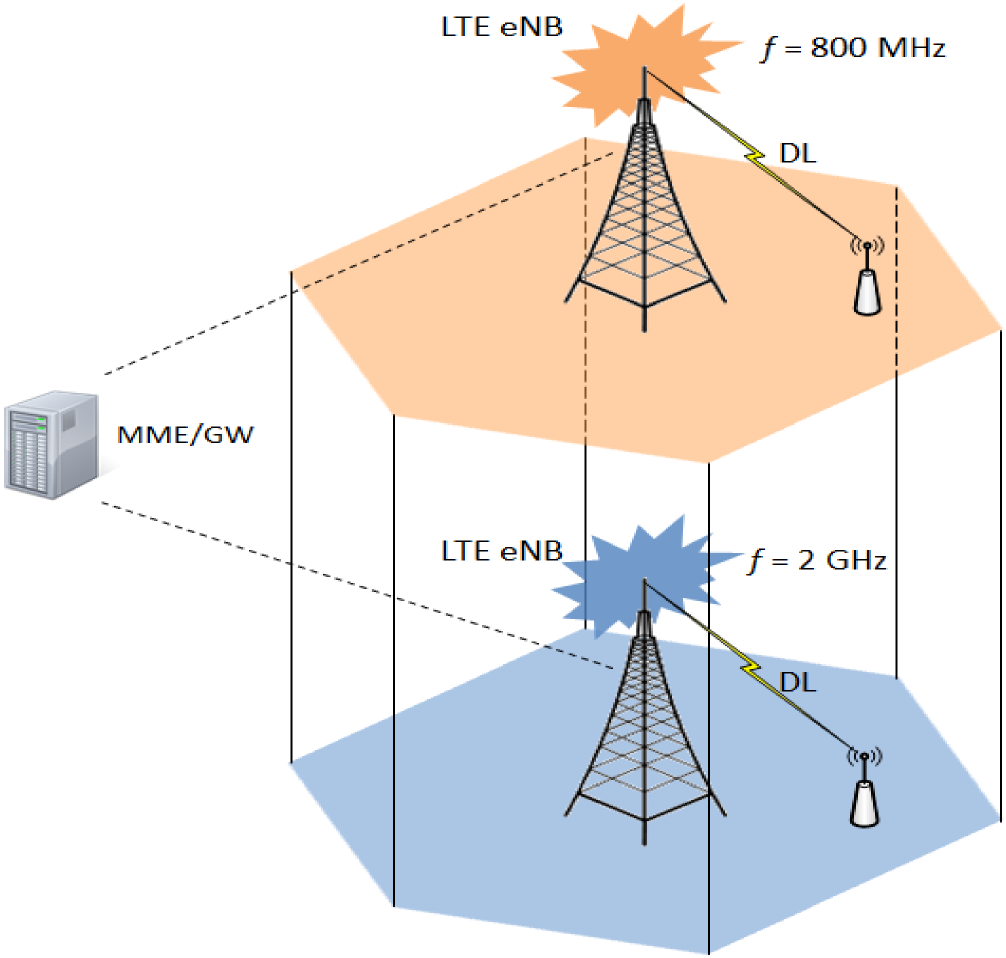
- Dynamic Spectrum Access (DSA) techniques are promising to enable Spectrum Aggregation (SA) with intra-operator Multiband (MB) scheduling, allowing to alleviate the spectrum scarcity problem;
- Radio Resource Management (RRM) is important to guarantee Quality of Service (QoS), since scheduling determines among packets that are ready for transmission;
- Common RRM (CRRM) is a set of functions that ensures an efficient and coordinated use of the available radio resources in heterogeneous networks scenarios;
- Cabral et al. [1] proposed an Integrated CRRM (iCRRM) entity where CRRM and SA functionalities are handled simultaneously. Their resource allocation assigns the user packets to the available radio resources to satisfy user requirements, and to ensure efficient packet transport to maximize spectral efficiency.

[1] O. Cabral, F. Meucci, A. Mihovska, F.J. Velez and N.R. Prasad. Integrated Common Radio Resource Management with Spectrum Aggregation over Non-Contiguous Frequency Bands. Wireless Personal Communications, Vol. 59, No. 3, Aug. 2011, pp. 499-523.

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 [2].

[2] 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, *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)

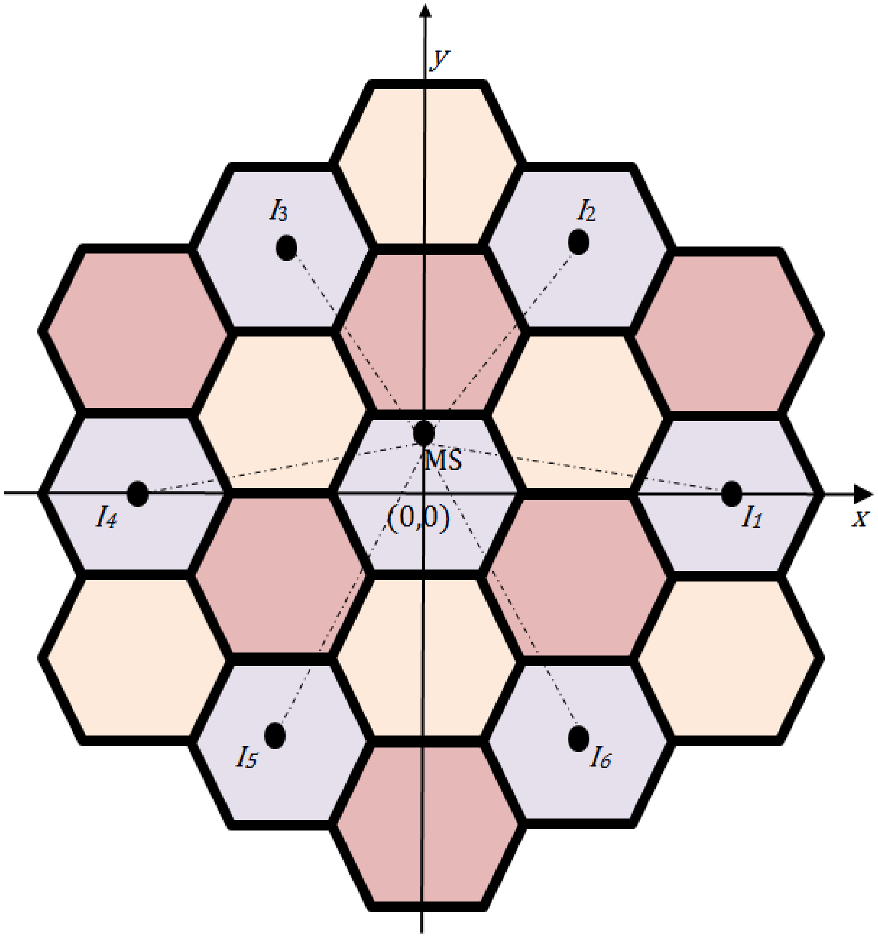
Parameters for LTE DL budget for a data rate of 1 Mbps and a commercial omnidirectional antenna.

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 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 SINR calculation

$$\overline{\mathrm{SINR}}(\mathrm{P}_{\mathrm{Tx}}, x, y) = \frac{\bar{P}_{ow}(P_{Tx},x,y)}{(1-\alpha)\bar{P}_{ow}(P_{Tx},x,y)+\bar{P}_{nh}(P_{Tx},x,y)+P_{noise}}$$

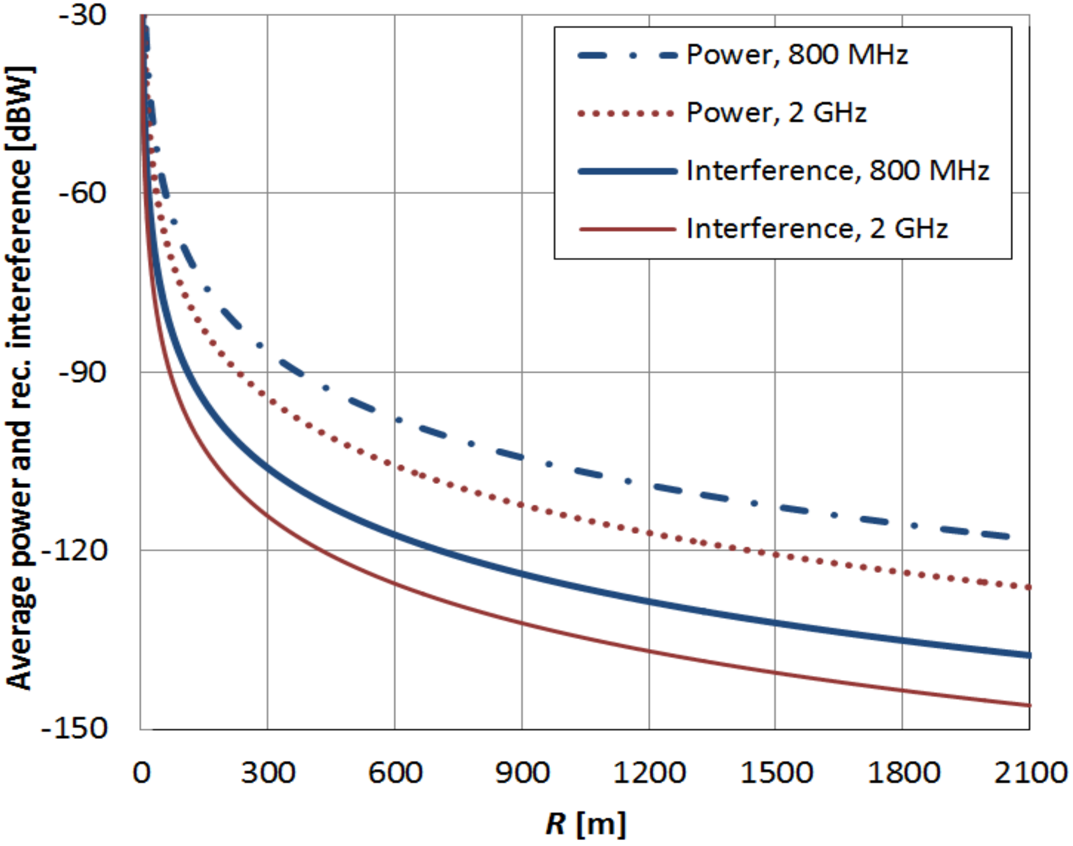
where:

- P_{Tx} is BS transmitter power;
- P_{ow} is the power received from the own cell;
- α is the orthogonality factor;
- P_{nh} is the total amount of interfering power coming from the neighbour cells;
- P_{noise} is the thermal noise power, given by:

  $P_{noise} = -174 + 10 \cdot \log_{10}(BW) + NF$ being *NF* = 8 dB for LTE and *BW* = 5 MHz.

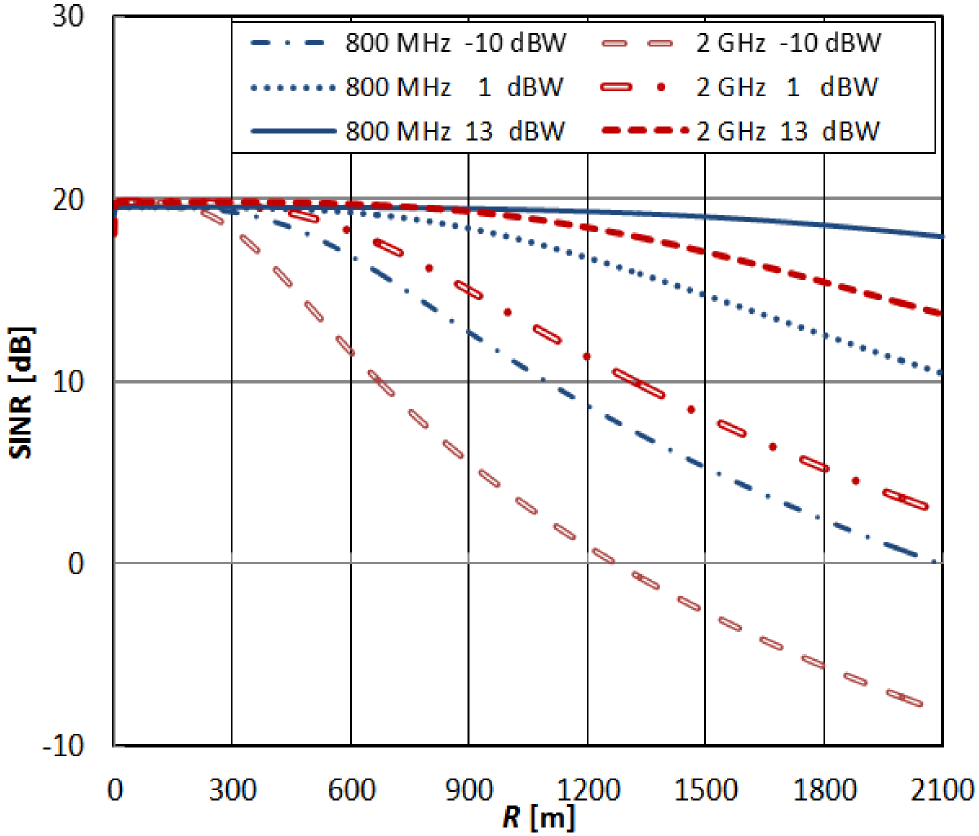
Average power and interference

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



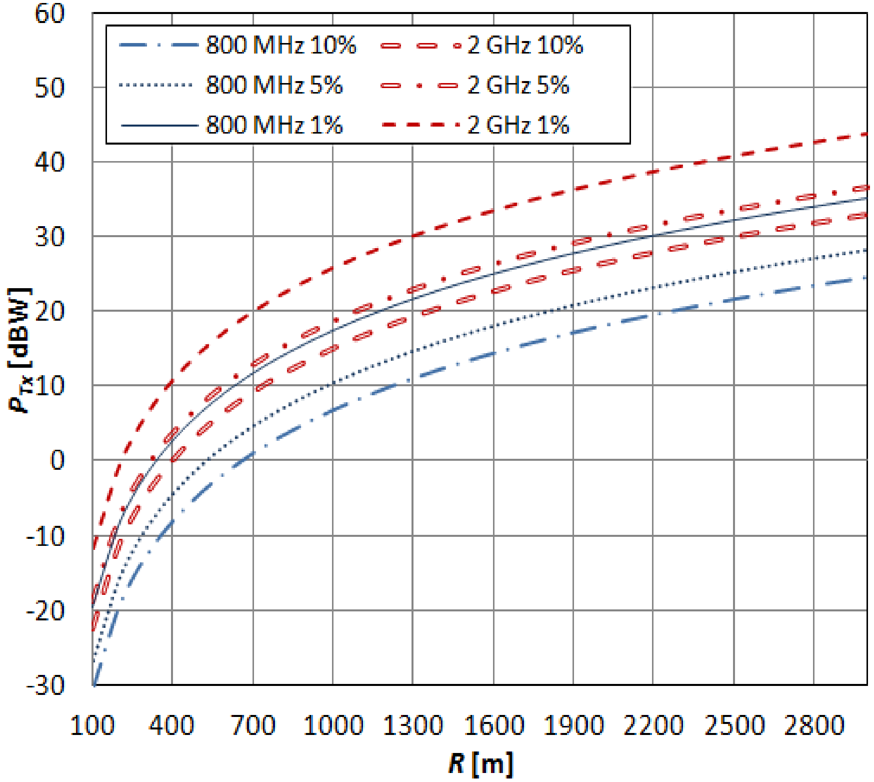
Average SINR

- Average SINR as a function of the cell radius (m) with three values of P_{Tx}(-10, 1 and 13 dBW [2]) for 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

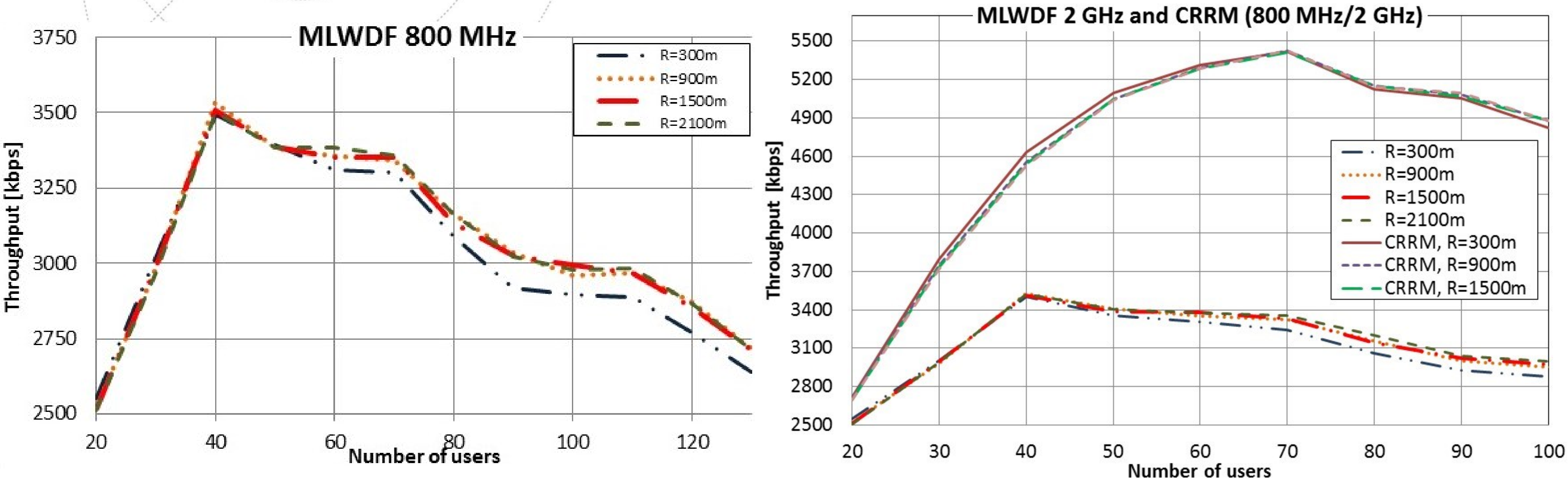


Video traffic throughput

- 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.

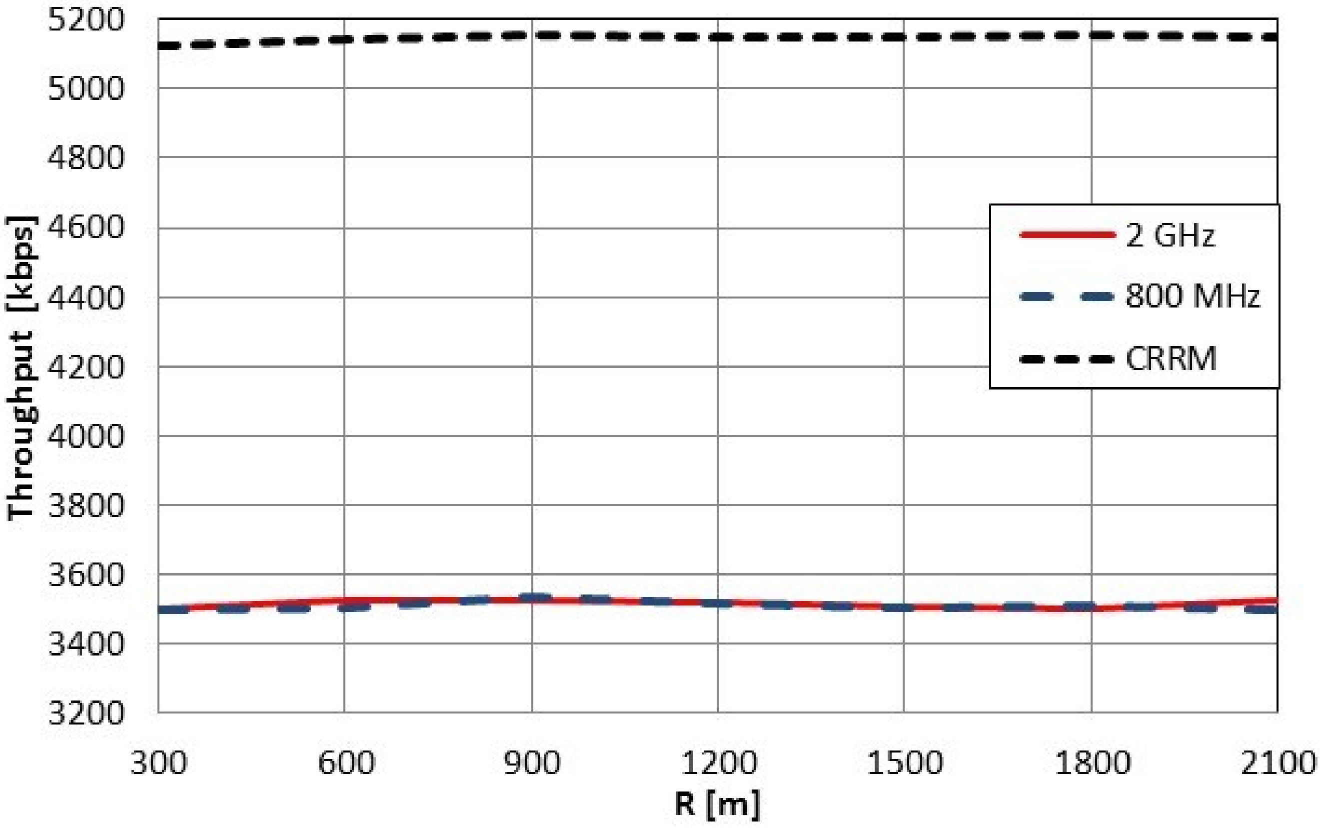
Results for video traffic throughput

Average throughput vs. number of users for different cell radii



Results for video traffic throughput (II)

Average throughput as a function of cell radius, *R*, for 40 users (2 GHz and 800 MHz bands) and 2X40 users with CRRM



Formulation for the costs

- The **cost per unit area** is given by:

$$C_{[/km^2]} = C_{fi[\text{€}/km^2]} + C_b N_{[cell/km^2]}$$

where C_{fi} is the fixed term of the costs (e.g. licensing and spectrum auctions or fees), and C_b is the cost per BS.

- The **number of cells per unit area** is given by:

$$N_{[cell/km^2]} = \frac{2}{3\sqrt{3}R^2}$$

and the **cost per BS** is given by:

$$C_b = \frac{C_{BS} + C_{bh} + C_{Inst}}{N_{year}} + C_{M\&O}$$

where N_{year} is the project's lifetime (5 in our case), C_{BS} is the BS cost, C_{bh} is the backhaul cost, C_{Inst} is the BS installation cost, and $C_{M\&O}$ is the operation and maintenance cost.

Assumptions for the costs:

- C_{fi} for BW of 5 MHz and *K* = 3;
- Assuming that the annual cost of a license, for 3x5MHz, is 82.500.000 € at 800 MHz, and 45.000.000 € at 2 GHz;
- Considering the total Portugal area of 91391.5 km^2:

$$C_{fi800MHz[€/km^2]} = \frac{82500000}{91391.5 \text{ x } 5} = 180.542 \approx 180 \text{ €/km}^2$$

$$C_{fi2GHz[€/km^2]} = \frac{45000000}{91391.5 \text{ x } 5} = 98.477 \approx 100 \text{ €/km}^2$$

Costs	Omnidirectional *K* = 3
$C_{fi800MHz[€/km^2]}$ $C_{fi2GHz[€/km^2]}$	$180.542 \approx 180$ $98.477 \approx 100$
C_{BS} [€]	33000
C_{Inst}[€]	22500
C_{bh}[€]	5000
$C_{M\&O}[€/year]$	1500

Formulation for the revenue

- The **revenue per cell per year**, $(R_v)_{cell}$, can be obtained as a function of the supported throughput per BS, $R_{b-\sup[kbps]}$, and the revenue of a channel with a data rate $R_{b[kbps]}$, $R_{R_b[€/min]}$, by:

$$(R_v)_{cell[€]} = \frac{N_{sec} * R_{b-\sup[kbps]} * T_{bh\ [min]} * R_{R_b[€/min]}}{R_{b-ch[kbps]}}$$

where N_{sec} is the number of sectors, T_{bh} is the equivalent duration of busy hours per day (6 busy hours per day, 240 busy days per year) and $R_{b-ch[kbps]}$ is the bit rate of the basic "channel";

- We consider a revenue/price of a 144 kbps "channel" per minute (approximately corresponding to the price of 1 MB, as 144 × 60 = 8640 kb ≈ 1 MByte), $R_{144[€/min]}$. The revenue per cell can be obtained as:

$$(R_v)_{cell[€]} = \frac{1 * R_{b-\sup[kbps]} * 60 * 6 * 240 * \ R_{144\ [€/min]}}{144_{[kbps]}}$$

Profit and profit in percentage

- The (absolute) profit is given by:

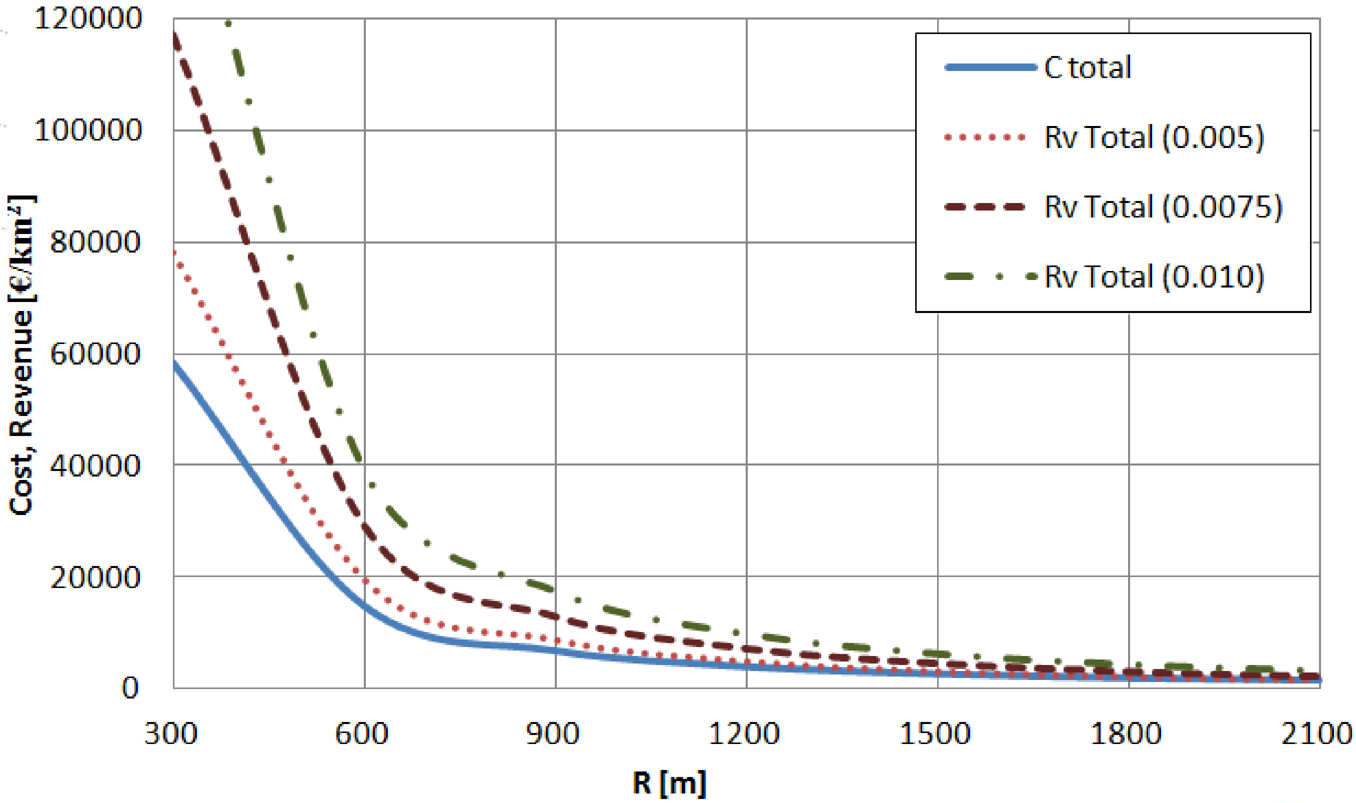
$$P_{[€/km^2]} = R_v + C$$

- from which, the profit in percentage terms is given by:

$$P_{[\%]} = \frac{R_{v-C}}{C} \times 100$$

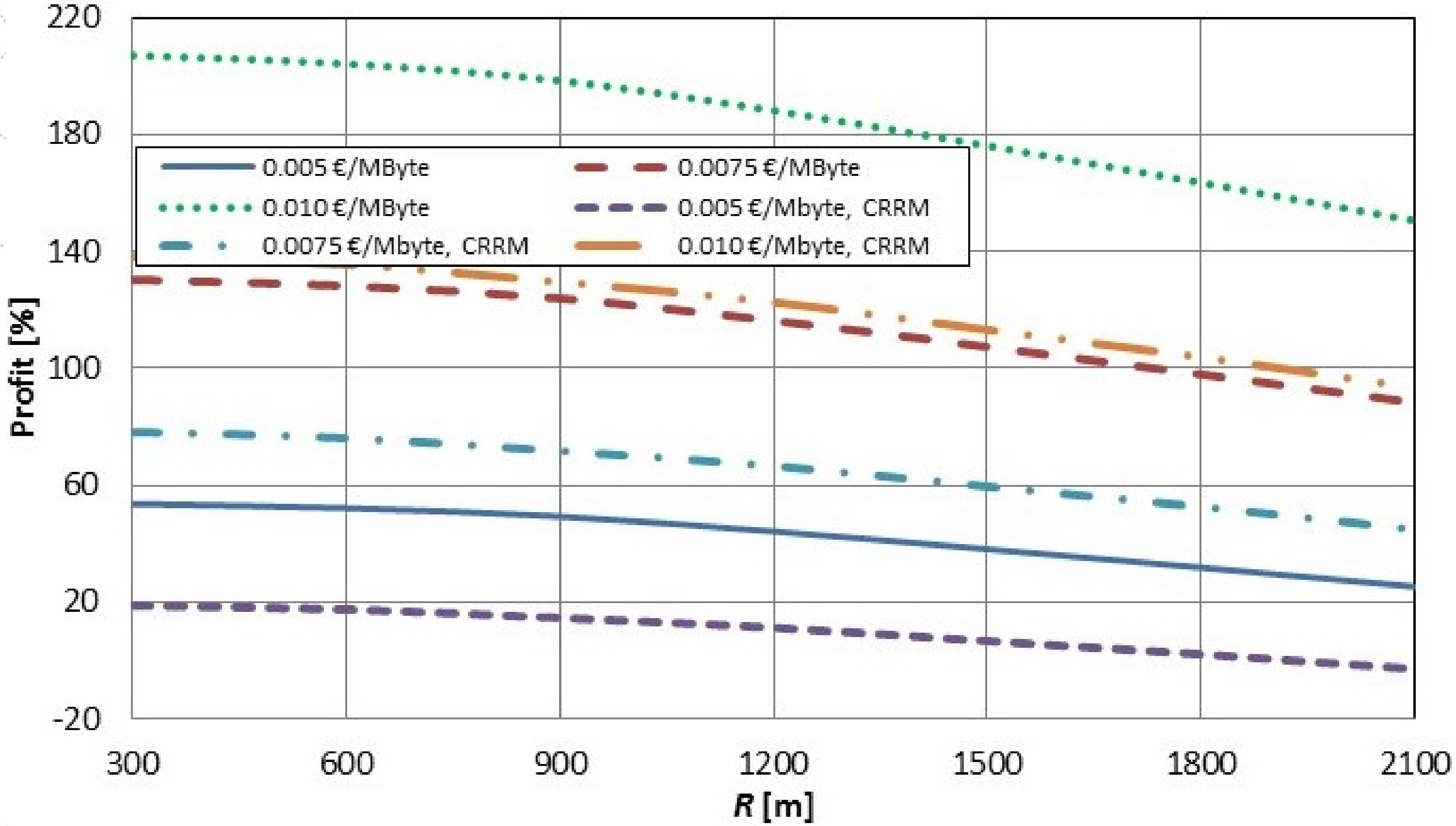
Results for the cost/revenue optimization

- In order to obtain profit optimization, revenues should be maximized with respect to cost. The revenue curves were obtained for different $R_{(144[€/min])}$, i.e. 0.005, 0.0075 and 0.010 €/Mbyte:



Results for the cost/revenue optimization (II)

- Results for the profit, in percentage, as a function of cell radius for different values of cost:



Conclusions and future work

- We propose an innovative formulation in the context of SA for computing the transmission power required in LTE systems which comprise an CRRM entity and schedules the users between the two LTE systems operating at 800 MHz and 2 GHz;

- We considered a topology with $K = 3$ and the COST-231 Hata model for the path loss, and obtained the average SINR in the cell;

- We have evaluated the impact of the normalized P_{Tx} required to achieve a selected high average SINR (dB), near the maximum for different cell radii.

Conclusions and future work (II)

- As expected, increasing the price per MByte, increases the revenue. The total cost is fixed and lower than the revenues;
- When $R_{144[€/min]} = 0.010\,€/\text{Mbyte}$, a maximum profit of about 167% is achieved; whilst maximum profits of 33% and 100% were obtained for $R_{144[€/min]}$ =0.005 and 0.0075 €/Mbyte, respectively;
- Future work includes improving the CRRM entity and include the iCRRM with integer programming for throughput optimization.

Thank You!

Q & S

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