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# Enhanced multi-band scheduling for carrier aggregation in LTE- Advanced scenarios

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Inovação



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*creating and sharing knowledge for telecommunications*

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# Outline

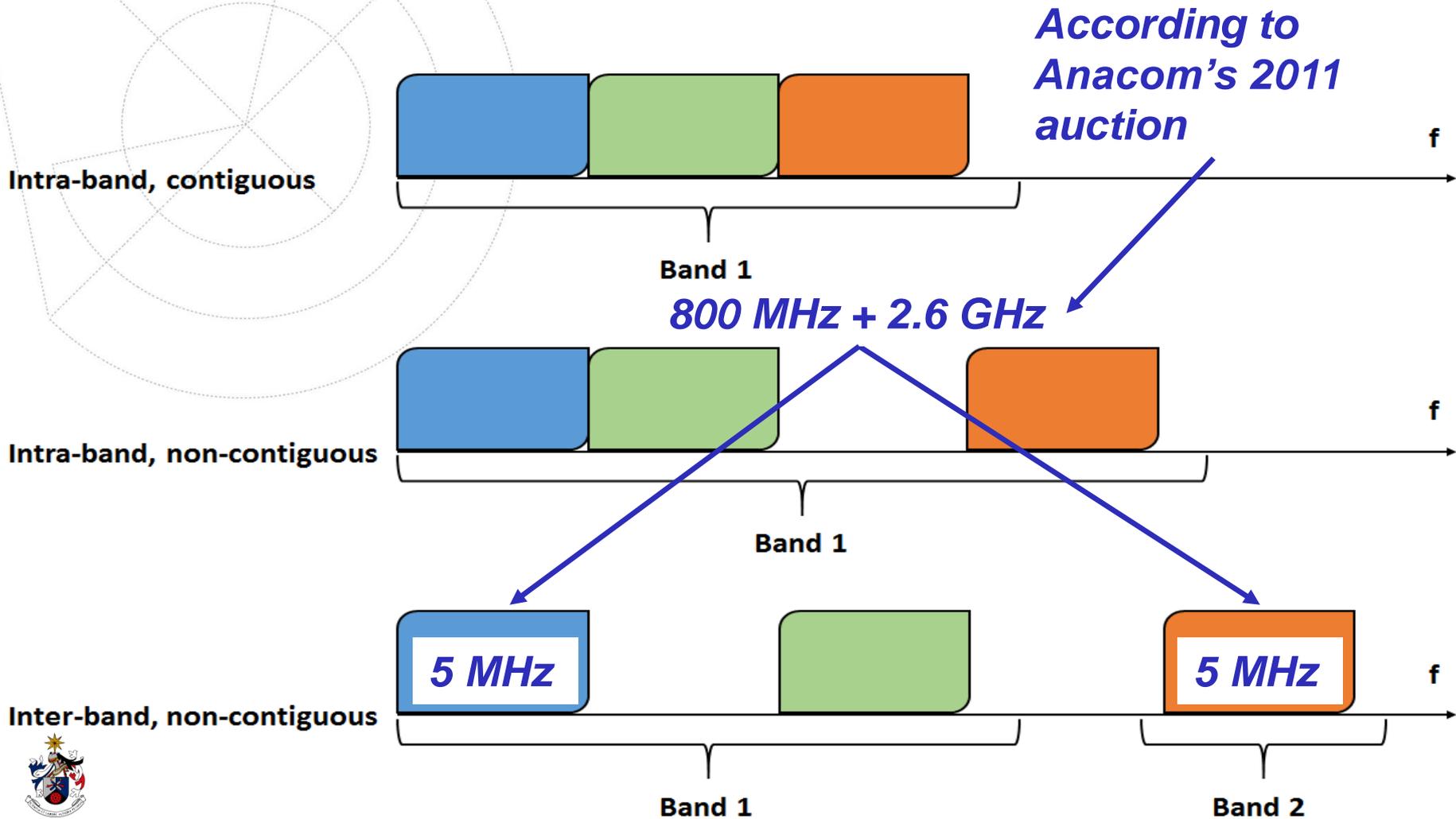
- ✂ CA alternatives;
- ✂ Approach and Scenario;
- ✂ Multi-Band Scheduling;
- ✂ Simulations and Results:
  - ✂ Packet Loss Ratio (PLR);
  - ✂ Delay;
  - ✂ Quality of Experience (QoE);
  - ✂ Goodput.
- ✂ Cost/Revenue Analysis;
- ✂ Conclusions.



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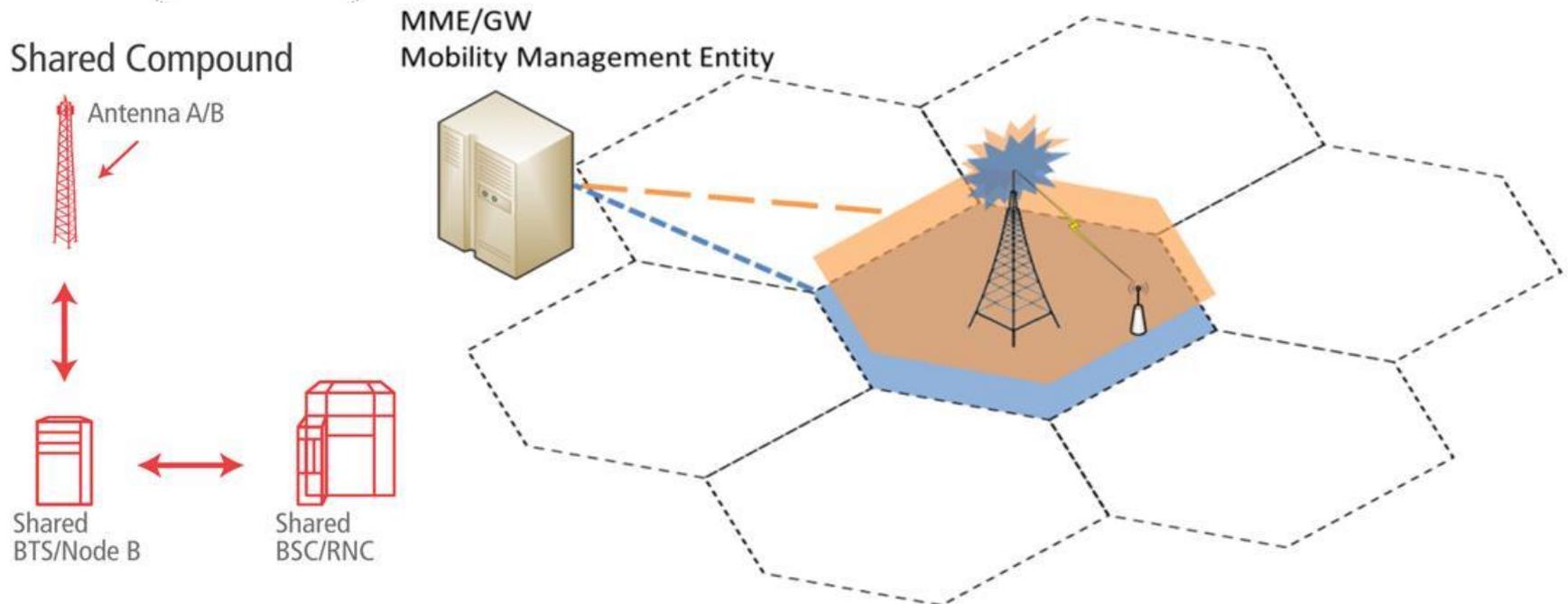
# Intra-band and inter-band CA alternatives



# Approach and scenario

✂ This work proposes integrated Common Radio Resource Management (iCRRM) for CA that performs Component Carrier (CC) scheduling to increase user's QoS and QoE for video traffic. ←

**Cisco's Forecast:**  
**53 % in 2013 -> 69% in 2018**  
**of worldwide mobile data traffic**



# General Multi-Band Scheduling (GMBS)

Maximize profit function (PF):

$$\sum_{b=1}^m \sum_{u=1}^n W_{b,u} \times x_{b,u}$$

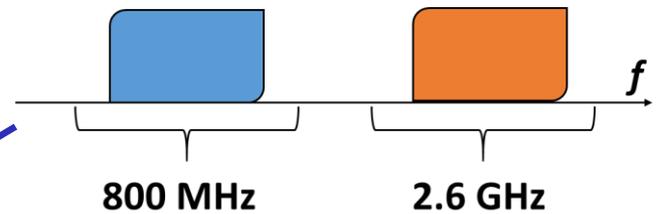
$x_{b,u}$  is the Boolean allocation variable  $\in \{0, 1\}$ , of user  $u$  on band  $b$ ,  
The normalised metric  $W_{b,u}$  is given by;

$$W_{b,u} = \frac{[1 - BER(CQI_{bu})] \cdot R(CQI_{bu})}{S_{rate}}$$

Bandwidth Constraint:

$$\sum_{b=1}^m \frac{S_{rate}(BER(CQI_{bu}))}{R(CQI_{bu})} \cdot x_{bu} \leq L_b^{max}$$

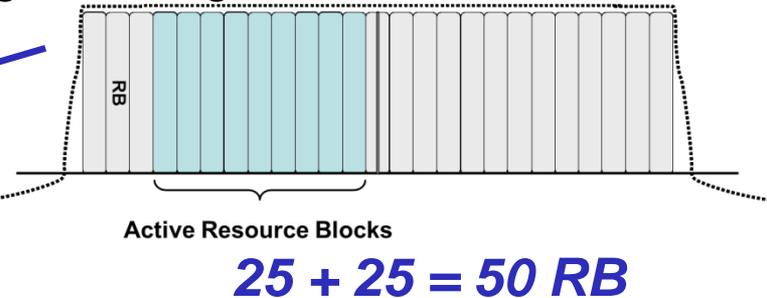
$S_{rate}$  is the video service rate,  $BER(CQI_{bu})$  is the average Bit Error Rate (BER) and  $R(CQI_{bu})$  is the DL channel throughput for user  $u$  on band  $b$



# Enhanced Multi-Band Scheduling (EMBS)

- Allows allocating UEs in either or both bands simultaneously;
- RBs allocation is performed according to the highest metric value computed as follows:

$$w_{i,j,b} = D_{HOL,i} \times \frac{R(CQI_{i,j,b})^2}{\bar{R}_i \times S_{rate}}$$



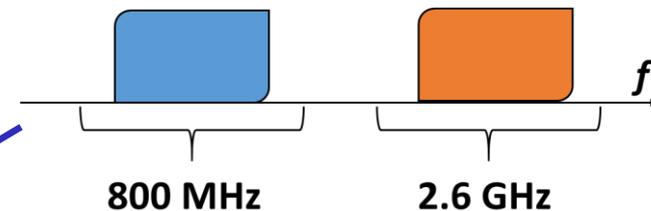
- where  $D_{HOL,i}$  is the  $i$ -th flow head of line (HOL) packet delay;
- $R(CQI_{i,j,b})$  is the DL throughput of band  $b$  for the  $i$ -th flow in the  $j$ -th sub-channel;
- $\bar{R}_i$  is  $i$ -th flow average transmission rate;
- $S_{rate}$  is the video service rate.

# Common Radio Resource Management (CRRM)

- For comparison purposes, a simple CRRM multi-band scheduler was implemented and considered for CA evaluation;
- Allocates UEs to one frequency band until its capacity ( $L_b$ ) is reached ( $L_b = L_{bmax}$ ), the remaining UEs are allocated to the second available frequency band;

- Allocation constraint is given by:

$$x_{b,u} = \begin{cases} 1 & \text{if } L_b \leq L_{bmax} \\ 0 & \text{if } L_b > L_{bmax} \end{cases}$$



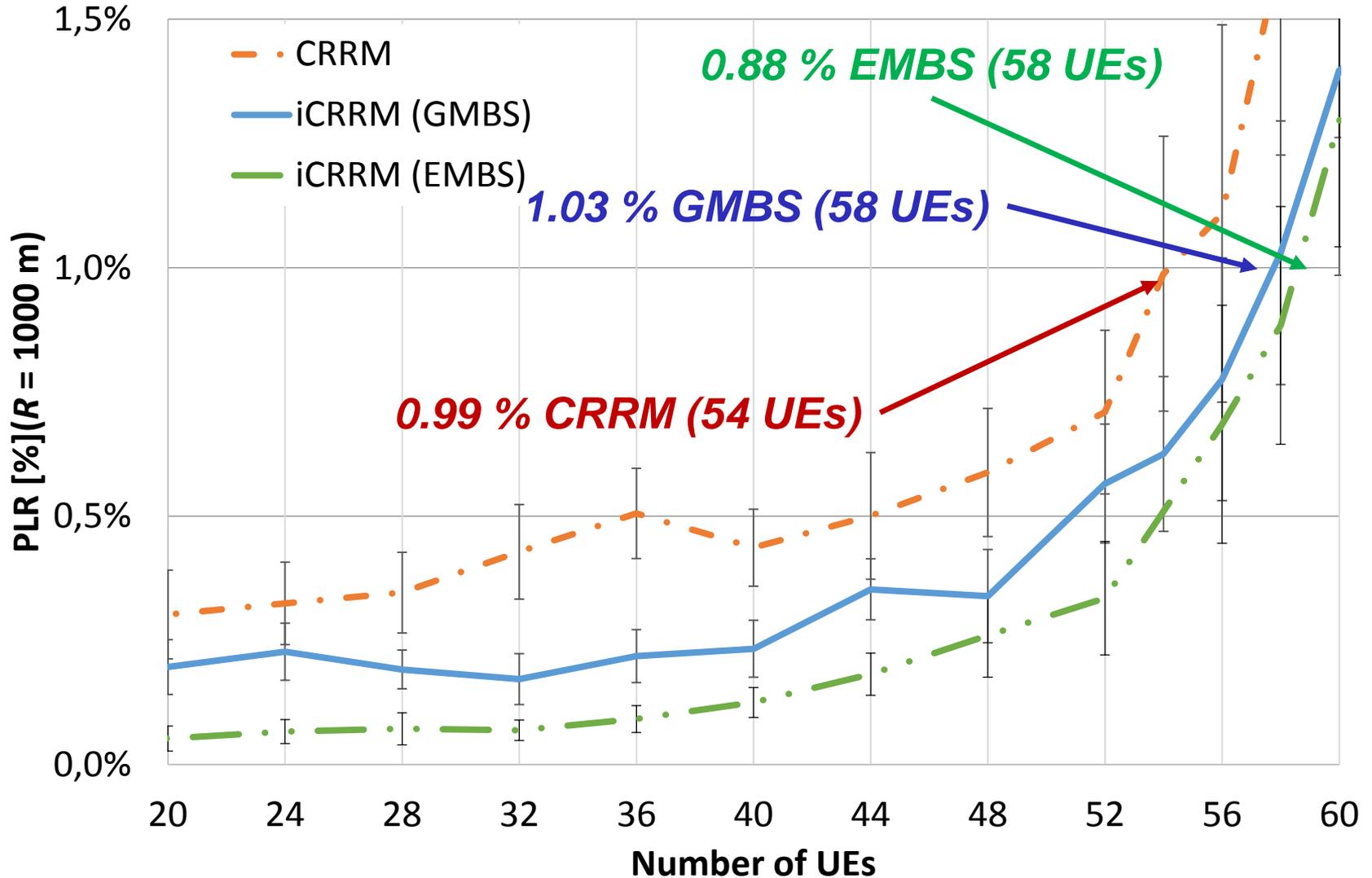
- $x_{b,u}$  is the Boolean allocation variable,  $x_{b,u} \in \{0, 1\}$ .

# Simulation Environment

- ✎ Three simulation sets were performed with **128 kbps video** traffic:
  1. Two LTE systems operating separately at 800 MHz and 2.6 GHz (no CA);
  2. One LTE-A scenario with both bands managed with basic CRRM;
  3. One LTE-A scenario with both bands managed by iCRRM:
    - a) One set performed with GMBS;
    - b) One set performed with EMBS.
- ✎ The **PLR** and **delay** from each LTE systems from 1) are average, whereas the system cell supported **goodput** are summed and compared with the results from 2) and 3).

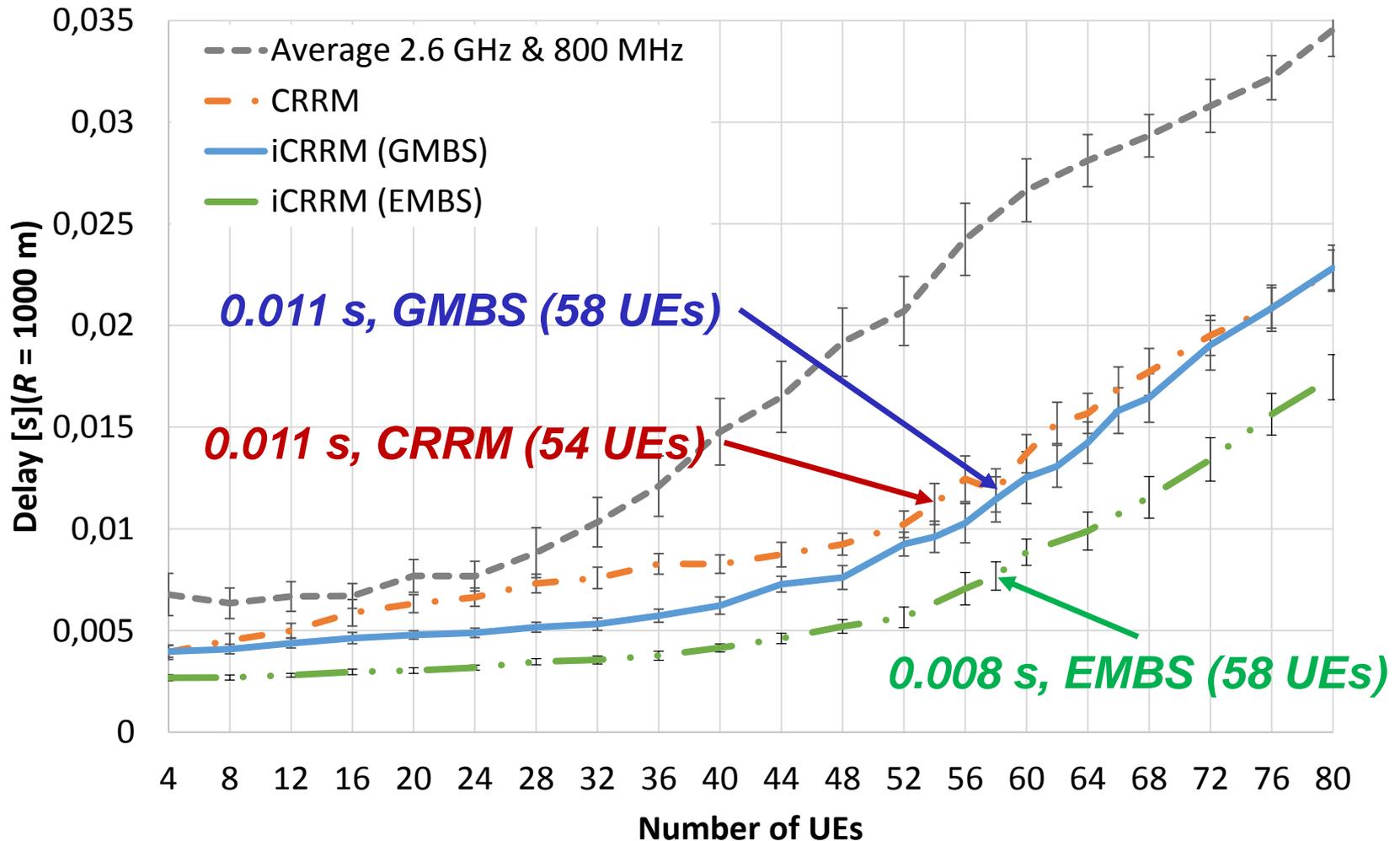
# Simulation Results – PLR

**ITU-T G.1010 and 3GPP TS 22.105 performance target:  $PLR \leq 1\%$**



# Simulation Results - Delay

*ITU-T and 3GPP performance target: delay  $\leq 0.15$  s*

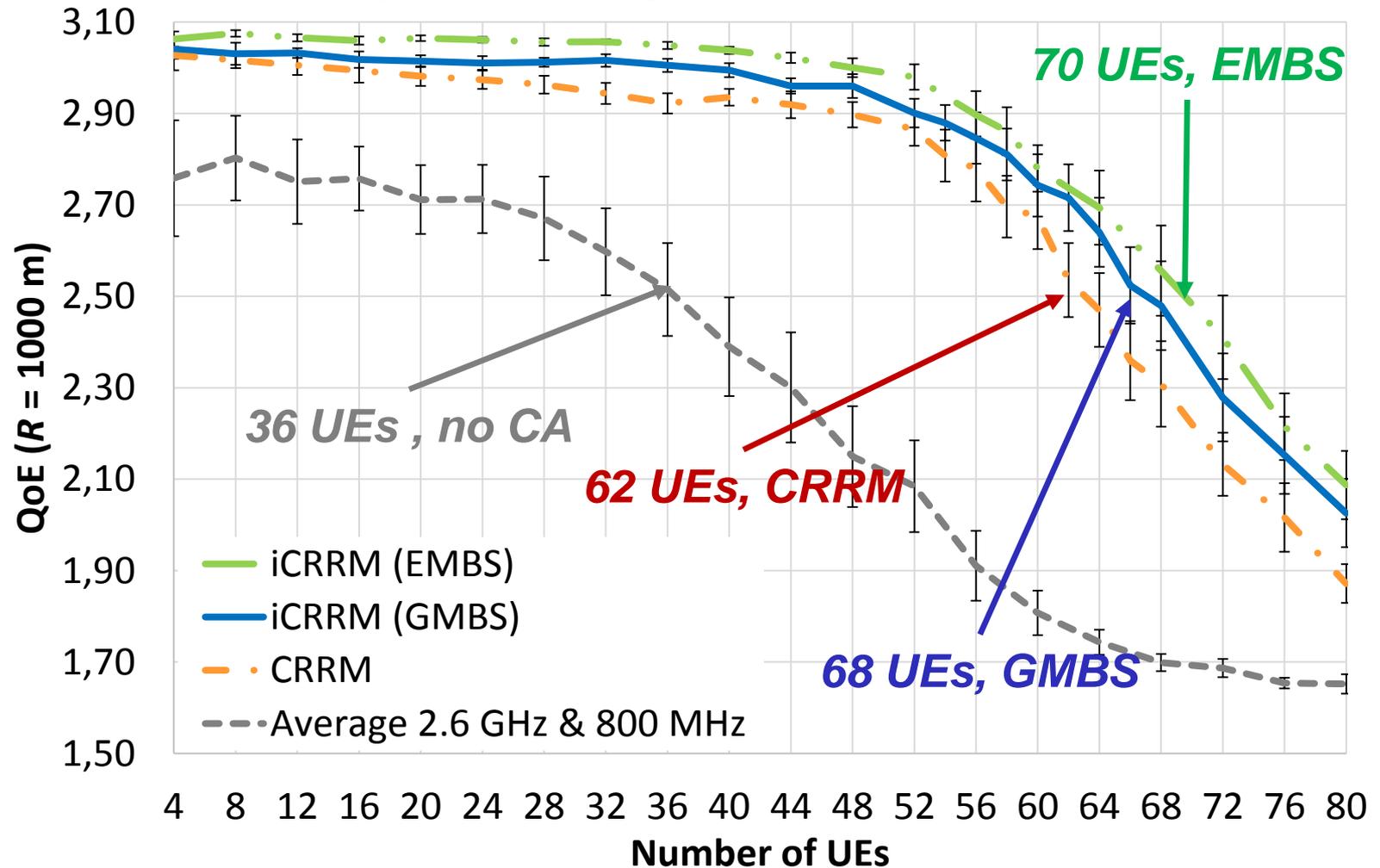


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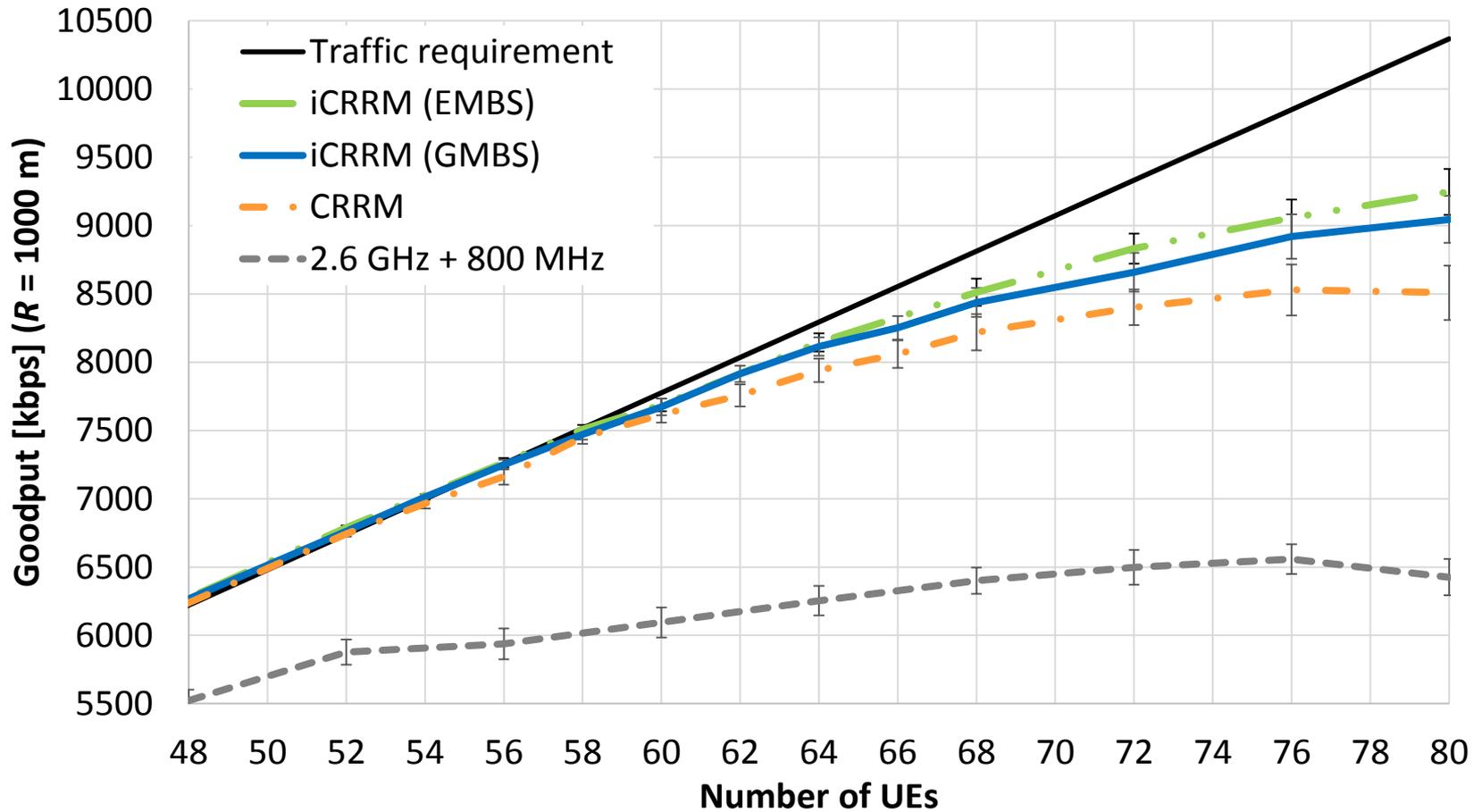
# Simulation Results – Quality of Experience (QoE)

Considering  $QoE \geq 2.5$  performance target



# Simulation Results - Goodput

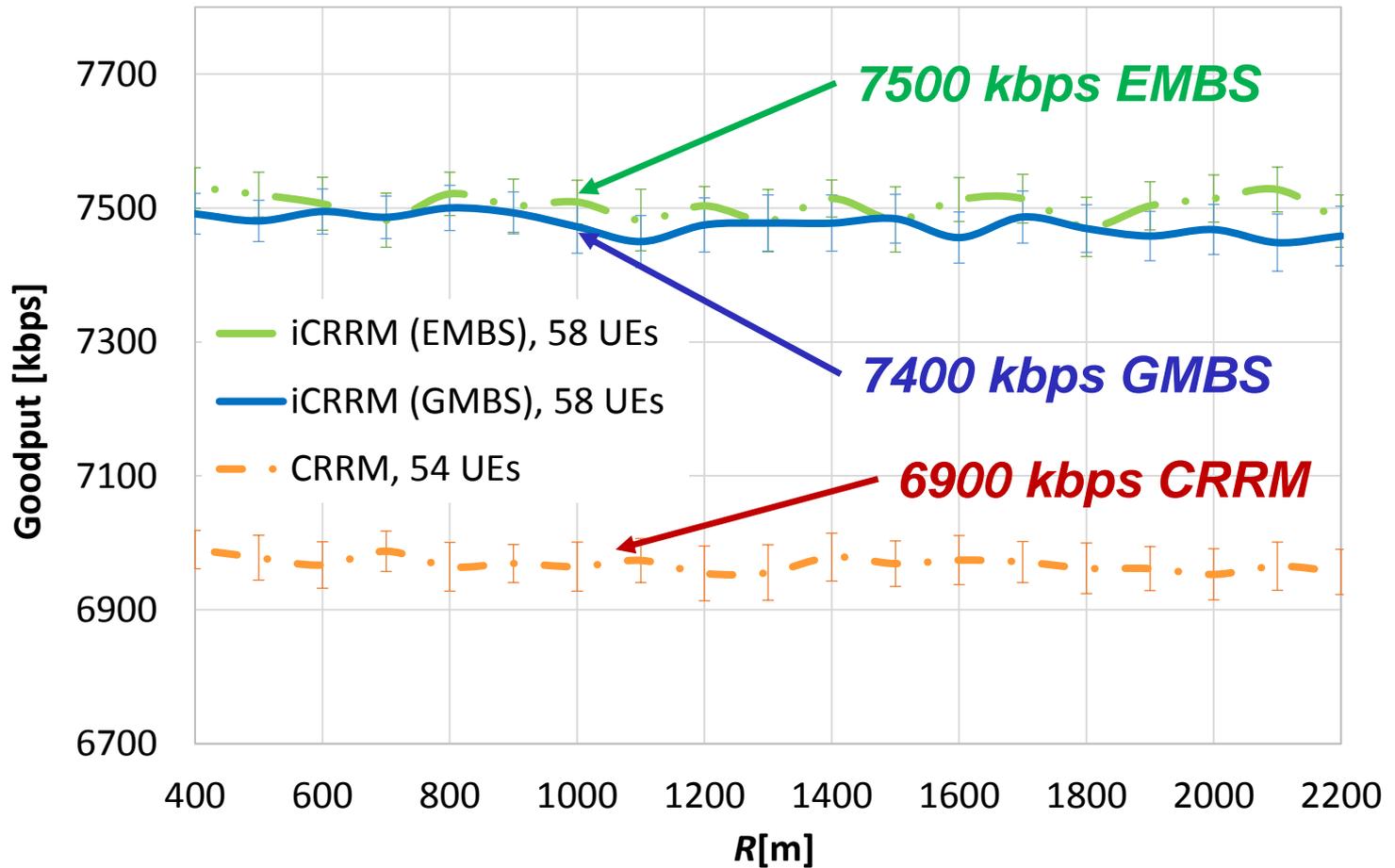
Video bitrate of 128 kbps:



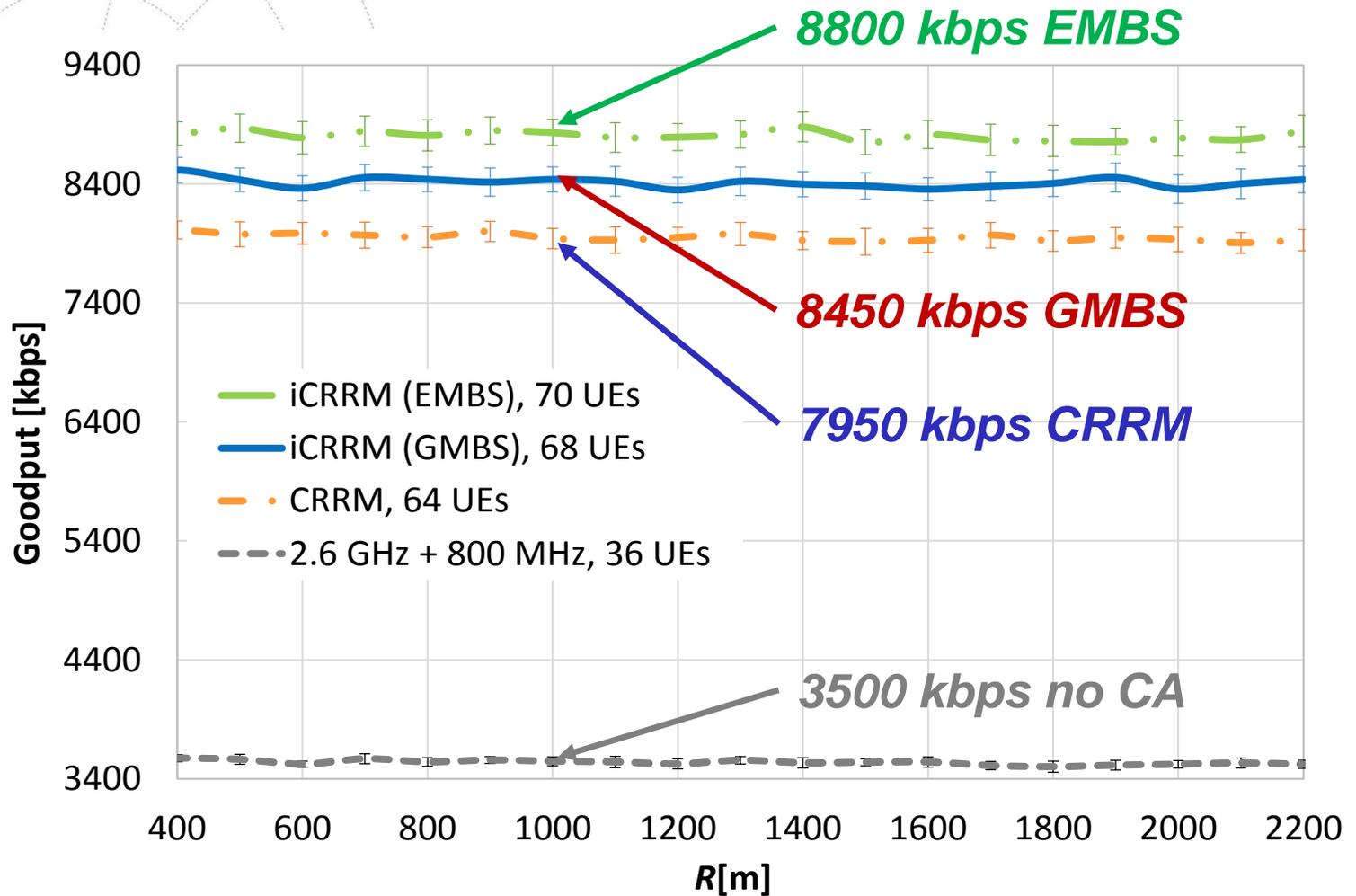
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# Simulation Results – Goodput for $PLR \leq 1\%$



# Simulation Results– Goodput for QoE $\geq 2.5$



# Cost/Revenue analysis

## Cost/Revenue analysis

Costs

Revenue

Profit

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

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

- +

*Mbyte price of 0.005 and 0.01 € for a channel with a data rate  $R_b[\text{kbps}]$*

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

Licence	2x5MHz
800 MHz	45,000,000 €
2.6 GHz	3,000,000 €

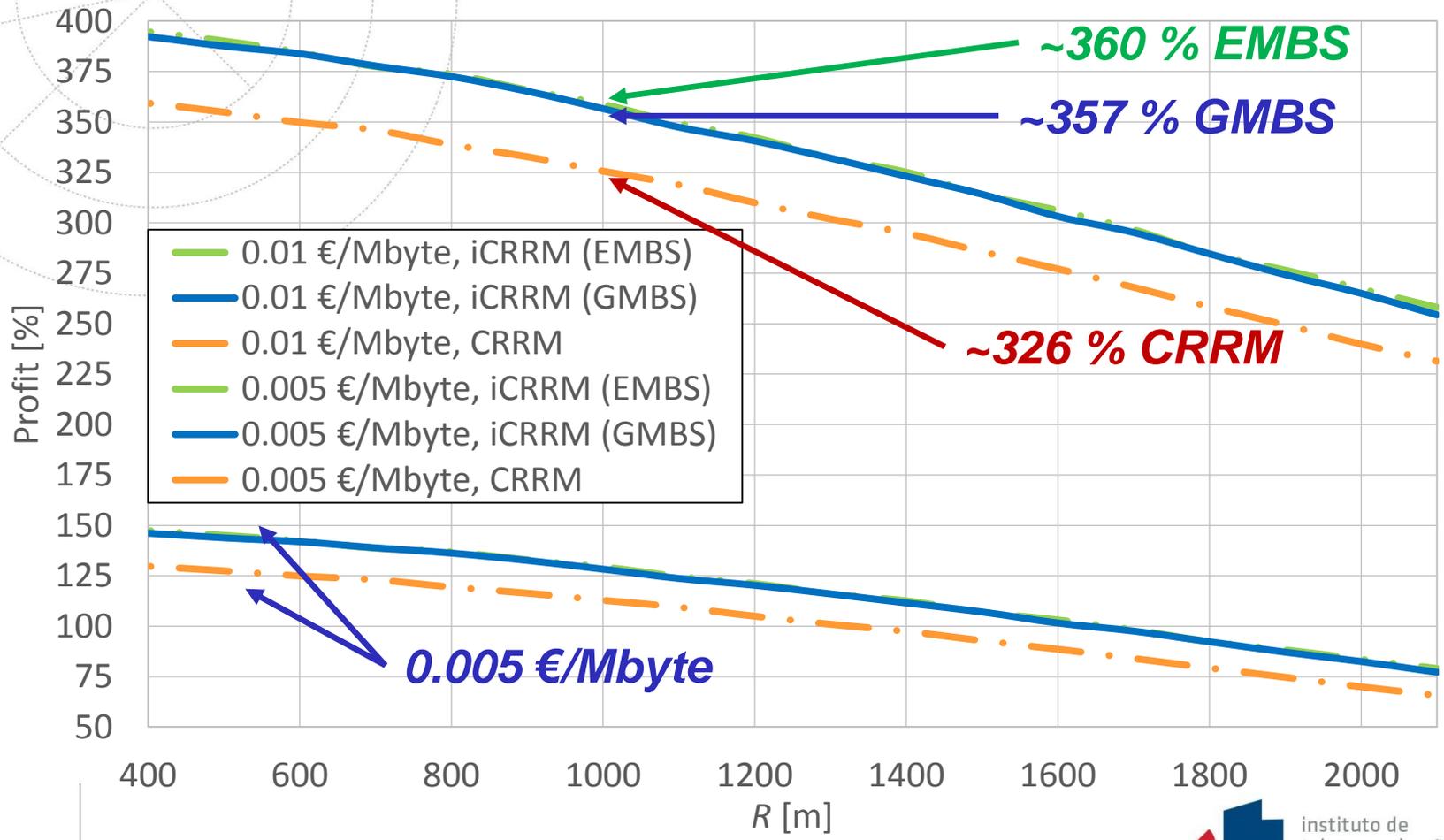


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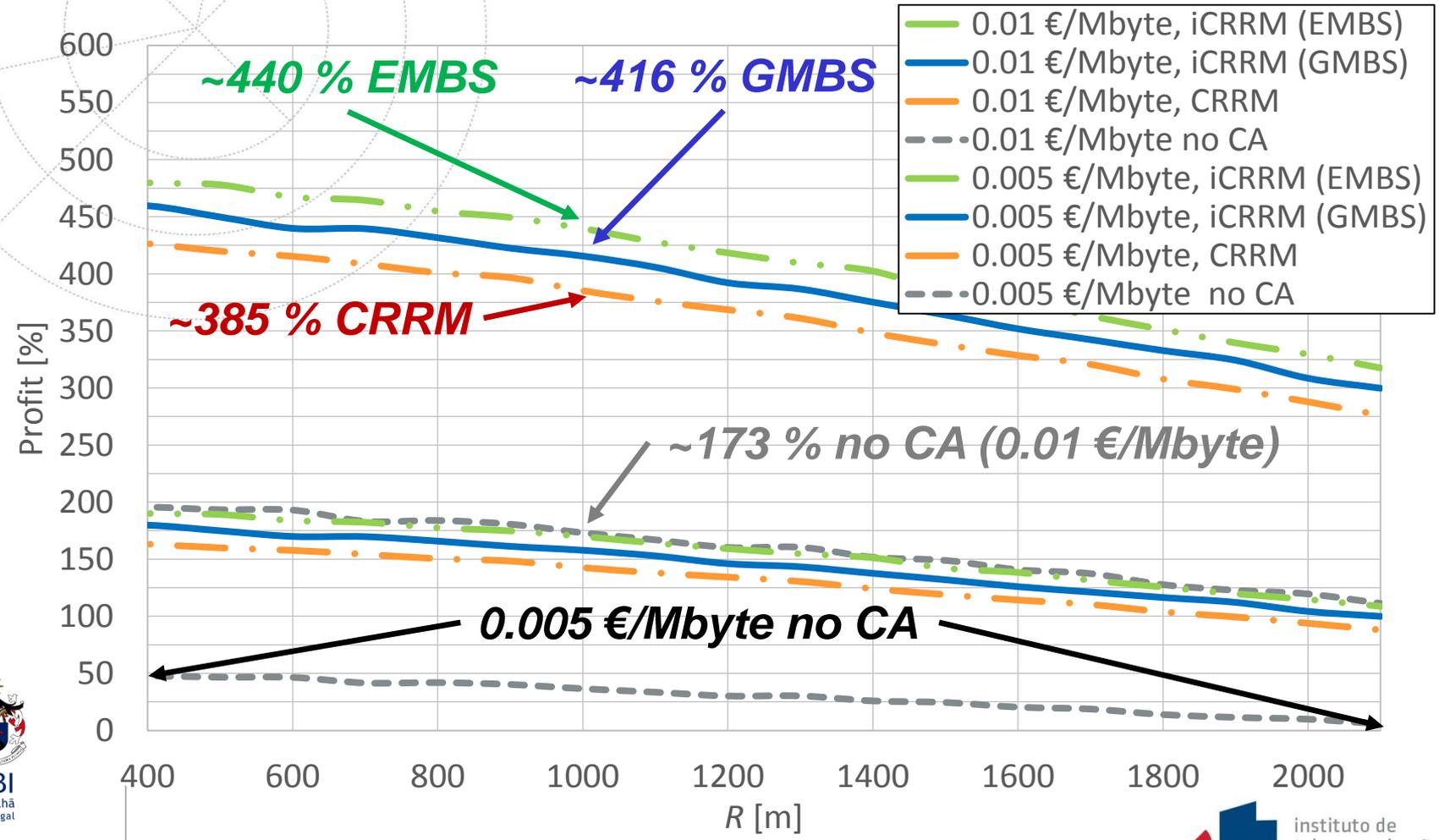
# Results for the cost/revenue optimization, $PLR \leq 1\%$

Percentage of profit for a Mbyte sale price of 0.005 and 0.01 €



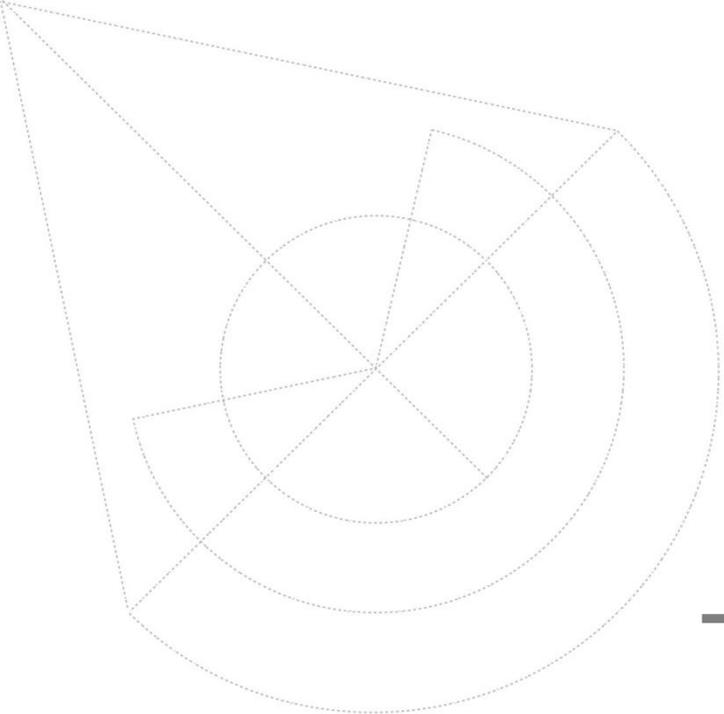
# Results for the cost/revenue optimization, QoE $\geq 2.5$

Percentage of profit for a Mbyte sale price of 0.005 and 0.01 €



# Conclusions

- ✎ This work proposes an iCRRM entity that implements inter-band CA by performing scheduling between the 800 MHz and 2.6 GHz bands;
- ✎ Three multi-band scheduling strategies have been addressed and evaluated against the performance of two LTE systems operating without CA;
- ✎ Simulation results shown capacity improvements provided by CA, specially using the EMBS.
- ✎ Cost/revenues analysis showed a profit increase with CA.



Thank you,  
Questions are Welcome

# Unified model for the mapping between the Quality of Service and Experience in multimedia applications

- ✎ We propose a unified model that characterizes the relation between QoS parameters and the corresponding QoE, providing network and service providers a framework to evaluate user's satisfaction;
- ✎ Four types of applications are considered:
  - ✎ Gaming;
  - ✎ Video;
  - ✎ Web-browsing;
  - ✎ Audio.

# Unified model for the mapping between the Quality of Service and Experience in multimedia applications

 MOS results:

Video bitrate [kbps]	Delay [s]	loss	MOS
1600	0.016	0	4.16
1600	0.08	0.05	2.71
1600	0.094	0.85	1.32
1100	2.85	0	3.37
1100	3.981	0.53	1.96
1100	0.092	0.24	1.67
600	0.016	0	1.12
600	3.677	0.43	2.63
600	3.205	0.11	3.33
100	0.018	0	2.66
100	0.084	0.66	1.09
100	2.819	0	1.97
2886	2.76	0.71	1.25
2866	1.09	0	4.87
2886	2	0.18	1.75
...	...	...	...

# Video

🔗 For video applications we considered MOS results available in the literature;

MOS

$$\begin{aligned} &= 3.2147 - 0.00266916 \times b_{rate} - 10.4811 \times d - 20.9894 \times \rho - 5.8875 \\ &\times 10^{-6} \times b_{rate}^2 + 40.3305 \times d^2 + 166.121 \times \rho^2 + 1.449 \times 10^{-8} \\ &\times b_{rate}^3 - 42.493 \times d^3 - 730.016 \times \rho^3 - 4.2939 \times 10^{-12} \times b_{rate}^4 \\ &+ 18.3884 \times d^4 + 1764.47 \times \rho^4 - 2.29851 \times 10^{-15} \times b_{rate}^5 - 3.48213 \\ &\times d^5 - 2069.09 \times \rho^5 + 8.08679 \times 10^{-19} \times b_{rate}^6 + 0.237418 \times d^6 \\ &+ 903.102 \times \rho^6 \end{aligned}$$

where  $b_{rate}$  is the video encoding bitrate, in kbps,  $d$  is de delay in ms, and  $\rho$  is the percentage of loss;

🔗  $R=0.915$ ,  $R^2=0.838$  and the  $MSE=0.197$ .

# Cost/Revenue analysis

## Cost/Revenue analysis

### Costs

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

$$C_{[€/km^2]} = C_{fi}[€/km^2] + C_b \times N_{[cell/km^2]} \quad \longleftrightarrow \quad N_{[cell/km^2]} = \frac{2}{3\sqrt{3}R^2}$$

Licence	2x5MHz
800 MHz	45,000,000 €
2.6 GHz	3,000,000 €

Costs	Omni. $K = 3$
$C_{BS}$ [€]	33,000
$C_{bh}$ [€]	5,000
$C_{Inst}$ [€]	22,500
$C_{M\&O}$ [€/year]	1,500
$N_{year}$	5

$$C_{fi \text{ 800 MHz}} [€/km^2] = \frac{45,000,000 \times 3}{91,391.5 \times 5} \approx 295 \text{ €/km}^2$$

$$C_{fi \text{ 2.6 GHz}} [€/km^2] = \frac{3,000,000 \times 3}{91,391.5 \times 5} \approx 19.7 \text{ €/km}^2$$

5 year project

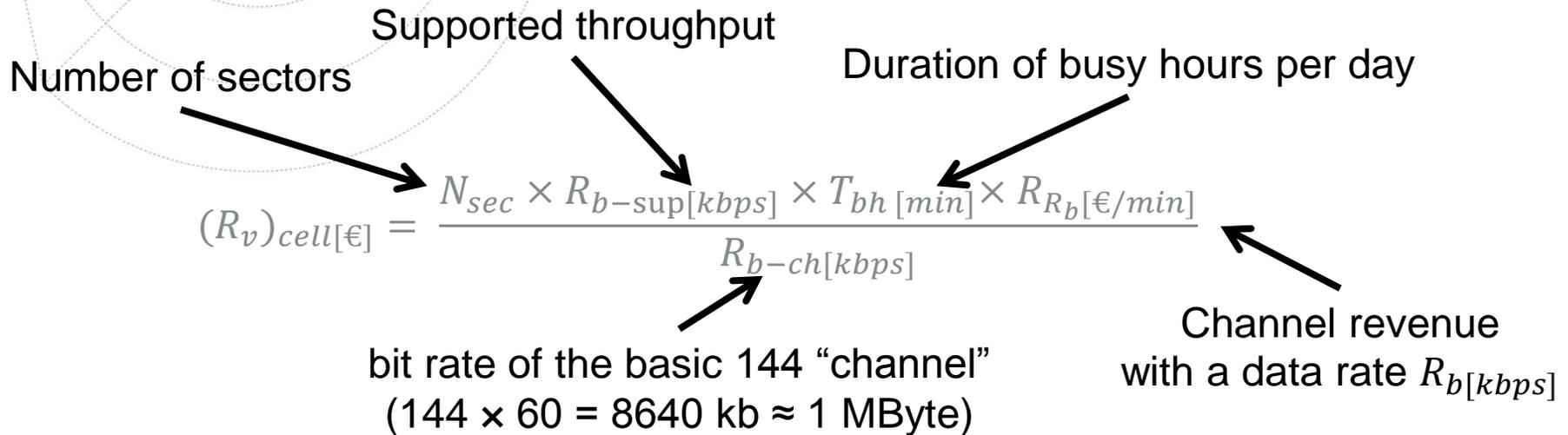
Area of Portugal

$K = 3$

# Cost/Revenue analysis

Cost/Revenue analysis

Revenue



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

## Conclusion (QoS and QoE for $R = 1000$ m)

- ✘ The **1 %** PLR performance target is only exceeded above:
  - ✘ 58 UEs, iCRRM → 7500 with EMBS, 7400 kbps with GMBS;
  - ✘ 54 UEs, CRRM → 6900 kbps with CRRM.
- ✘ The **150 ms** delay performance target has not been reach in the context of the performed simulations;
- ✘ The **2.5** QoE performance target can be supported up to:
  - ✘ 70 UEs with EMBS → 8800 kbps;
  - ✘ 68 UEs with GMBS → 8450 kbps;
  - ✘ 64 UES with CRRM → 7950 kbps;
  - ✘ 36 UEs without CA → 3500 kbps.

## Conclusion (cost/revenue analysis for $R = 1000$ m)

✂ For  $PLR \leq 1\%$  and prices per Mbyte of 0.005 and 0.01 €/Mbyte:

✂ 130 and 360 % profits with EMBS;

✂ 129 and 357 % profits with GMBS;

✂ 113 and 326 % profits with CRRM.

✂ For  $QoE \geq 2.5$  and prices per Mbyte of 0.005 and 0.01 €/Mbyte:

✂ 170 and 440 % profits with EMBS;

✂ 158 and 416 % profits with GMBS;

✂ 143 and 385 % profits with CRRM;

✂ 37 and 173 % profits without CA.