2º Workshop CREaTION
Porto, 15 October, 2014

Capacity enhancement of LTE-Advanced networks with Carrier Aggregation

Daniel Robalo
Fernando J. Velez

INSTITUIÇÕES ASSOCIADAS:

instituto de telecomunicações

creating and sharing knowledge for telecommunications

Outline

- Motivation;
- Approach and Scenario;
- Multi-Band Scheduling;
- Simulation Environment;
- Simulation Results:
  - Packet Loss Ratio (PLR);
  - Delay;
  - Quality of Experience (QoE);
  - Goodput.
- Cost/Revenue Analysis;
- Conclusion.

UBI Covilhã Portugal

instituto de telecomunicações

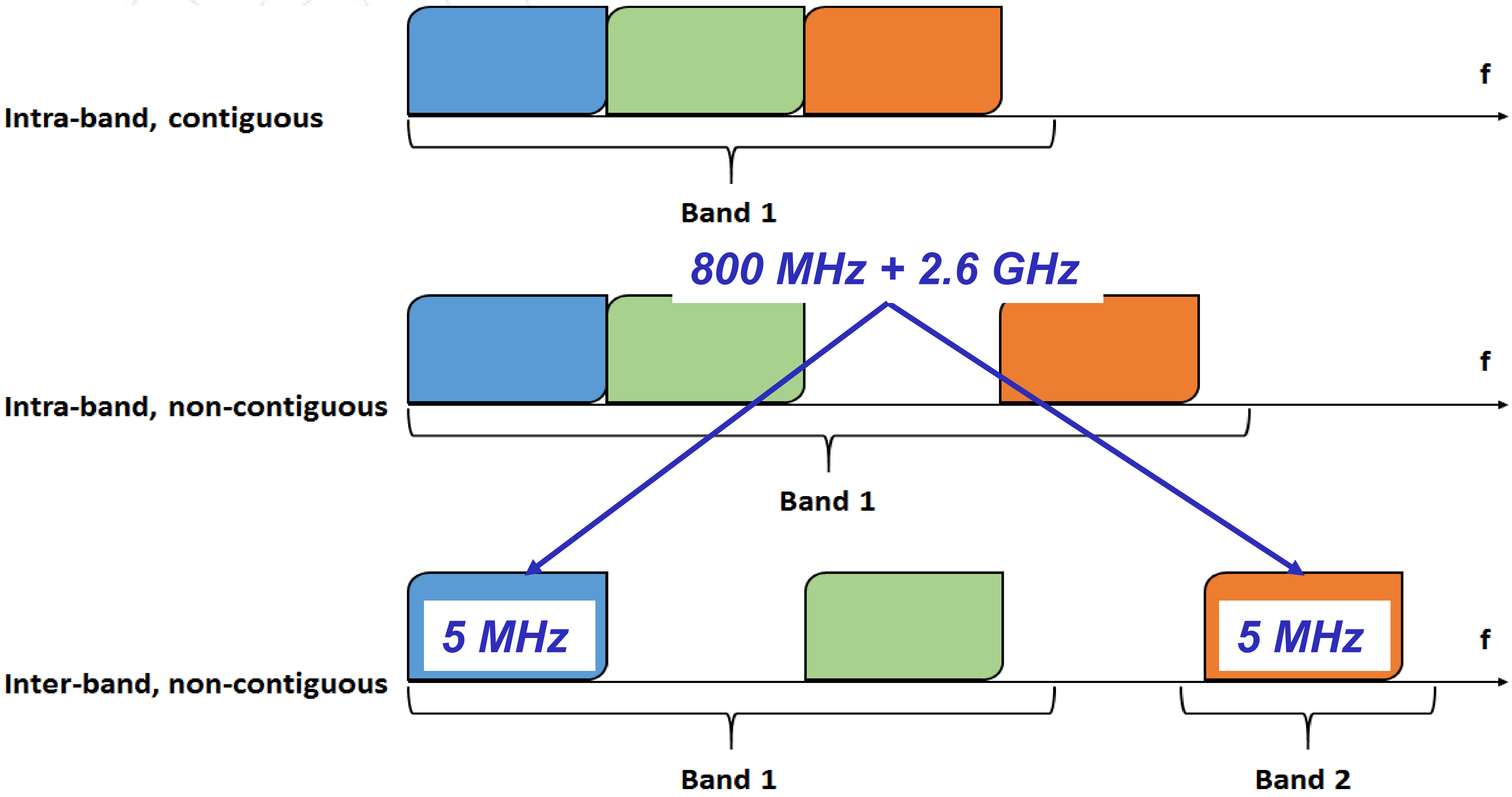
Motivation

- To meet the increasing demand for wireless broadband services from fast-growing mobile users, Carrier Aggregation (CA) was introduced by 3GPP in its Long Term Evolution-Advanced (LTE-A);
- CA consists of exploiting multiple, small spectrum fragments simultaneously (aggregation) to yield to a (virtual) single larger band and ultimately deliver a wider band service;
- By aggregating non-contiguous carriers, fragmented spectrum can be more efficiently utilized;

UBI Covilhã Portugal

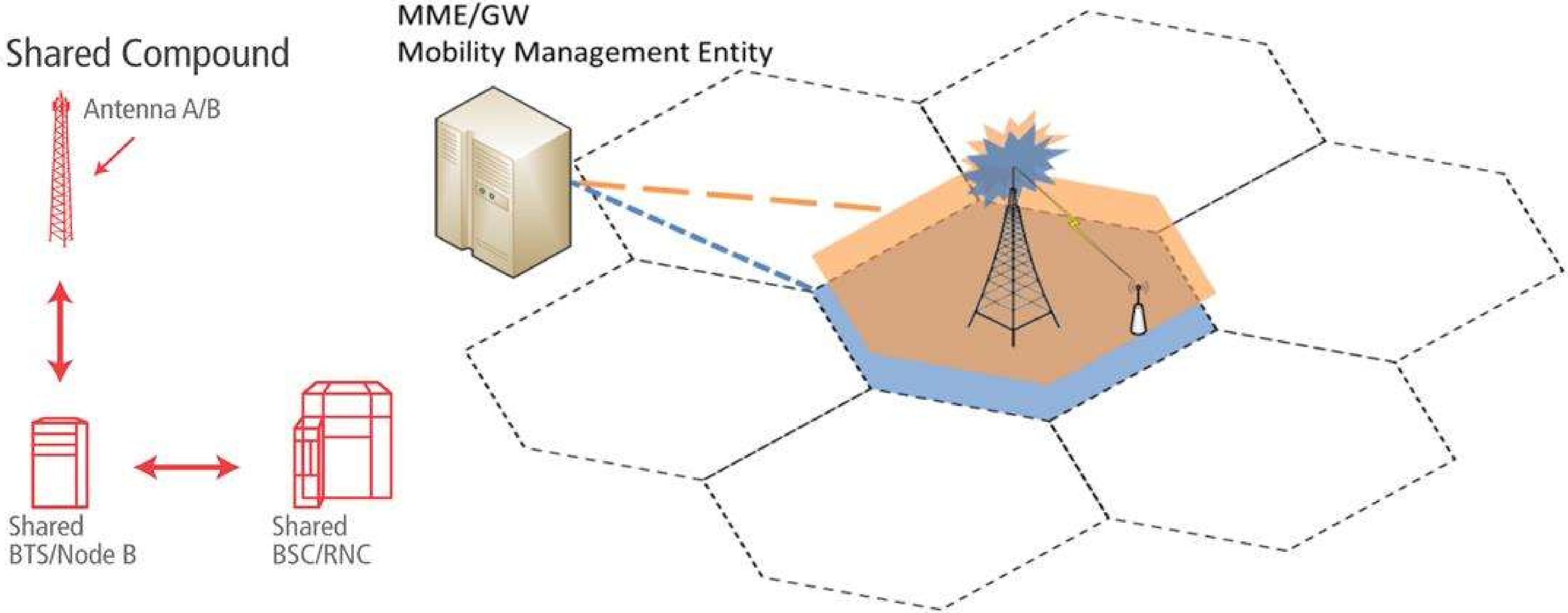
instituto de telecomunicações

Intra-band and inter-band CA alternatives



Approach and scenario

- This work proposes integrated Common Radio Resource Management (iCRRM) for CA between the 800 MHz and 2.6 GHz bands (5 MHz bandwidths), in the context of LTE-A scenarios. The iCRRM entity performs Component Carrier (CC) scheduling and increases user's QoS and QoE.



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:

  - $$w_{i,j,b} = D_{HOL,i} \times \frac{R\left(CQI_{i,j,b}\right)^2}{\overline{R_i} \times S_{rate}}$$

- 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;
- $\overline{R_i}$ is *i*-th flow average transmission rate;
- S_{rate} is the video service rate;

UBI
Covilhã
Portugal

dem

instituto de
telecomunicações

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:

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

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

UBI
Covilhã
Portugal

instituto de
telecomunicações

Simulation Environment

- Three simulation sets have been performed:
  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).

UBI Covilhã Portugal

instituto de telecomunicações

Simulation Parameters

According to Anacom's 2011 auction

Cisco's Forecast:

53 % in 2013 -> 69% in 2018 of all worldwide mobile data traffic

tion parameters	
	3
Simulation duration	46 s
Flow duration	40 s
Frame structure	FDD
Bandwidth	5 MHz per CC
Slot duration	0.5 ms
Scheduling time (TTI)	1 ms
Number of RBs	25 per CC
Max delay	0.1 s
Video bitrate	128 kbps
UE mobility	random direction, 3 kmph

UBI Covilhã Portugal

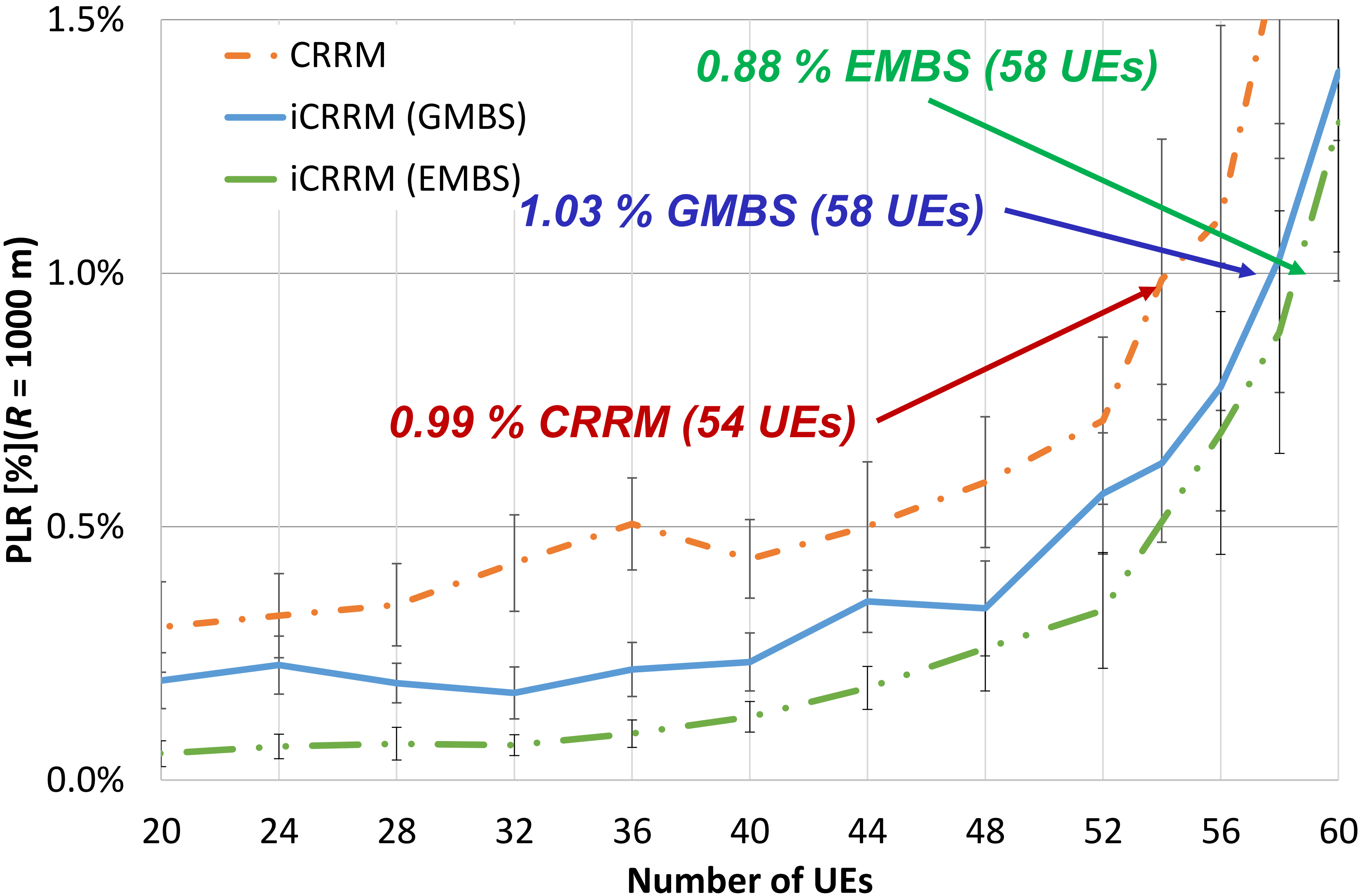
instituto de telecomunicações

Simulation Results and Analysis

- Parameters:
  - Average cell Packet loss Ratio (PLR);
  - Average cell delay;
  - Average cell QoE;
  - Average cell goodput (application level throughput).

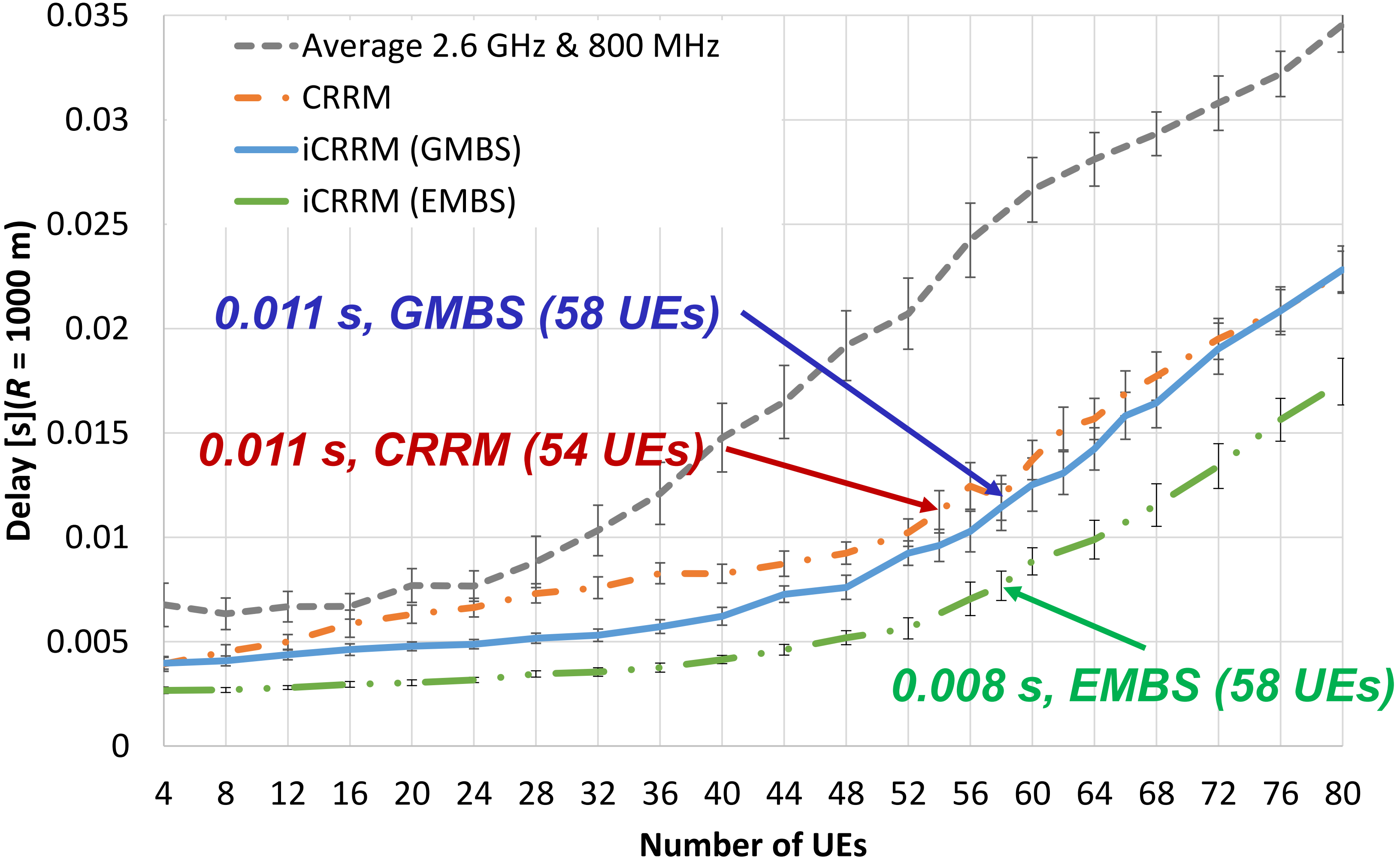
Simulation Results – PLR

ITU-T G.1010 and 3GPP TS 22.105 performance target: PLR ≤ 1%



Simulation Results - Delay

ITU-T and 3GPP performance target: delay ≤ 0.15 s



telecomunicações

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.

UBI
Covilhã
Portugal

dem

instituto de telecomunicações

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
...	...	...	...

UBI Covilhã Portugal

instituto de telecomunicações

Video

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

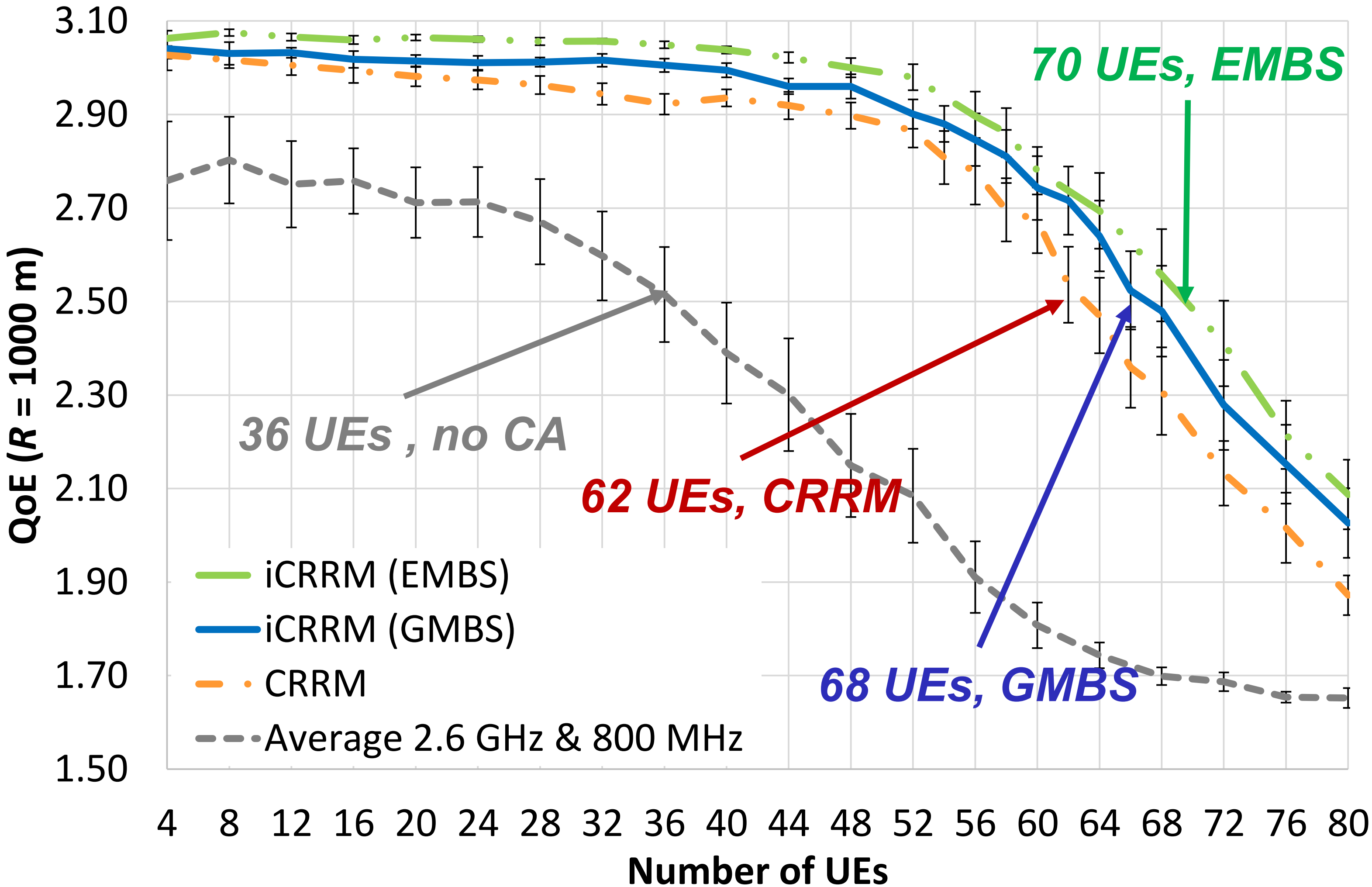
$$
\begin{aligned}
\mathrm{MOS} = {} & 3.2147 - 0.00266916 \times \boldsymbol{b_{rate}} - 10.4811 \times \boldsymbol{d} - 20.9894 \times \boldsymbol{\rho} \\
& - 5.8875 \times 10^{-6} \times \boldsymbol{b_{rate}}^2 + 40.3305 \times \boldsymbol{d}^2 + 166.121 \times \boldsymbol{\rho}^2 \\
& + 1.449 \times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

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

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

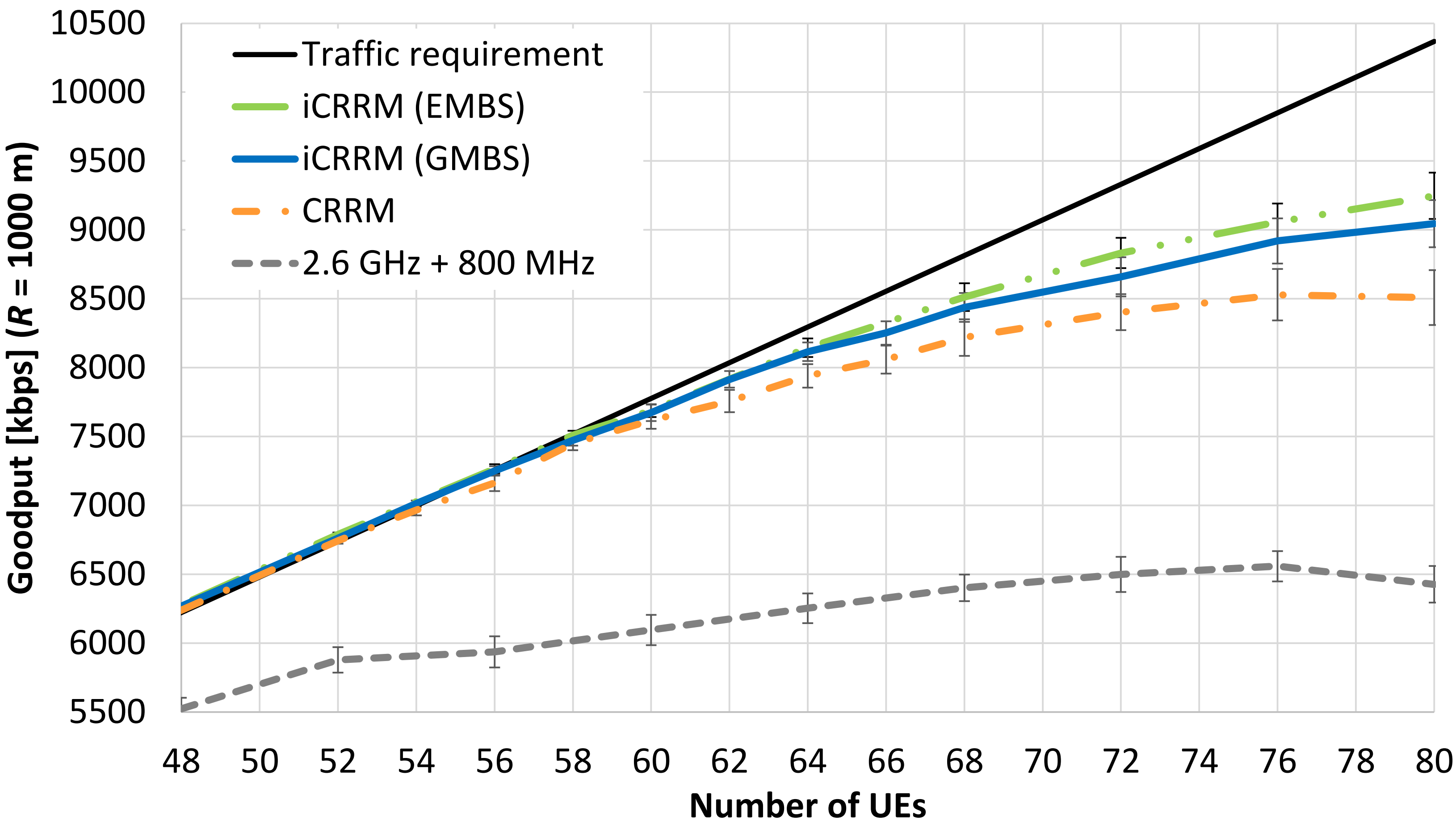
Simulation Results – Quality of Experience (QoE)

Considering QoE ≥ 2.5 performance target

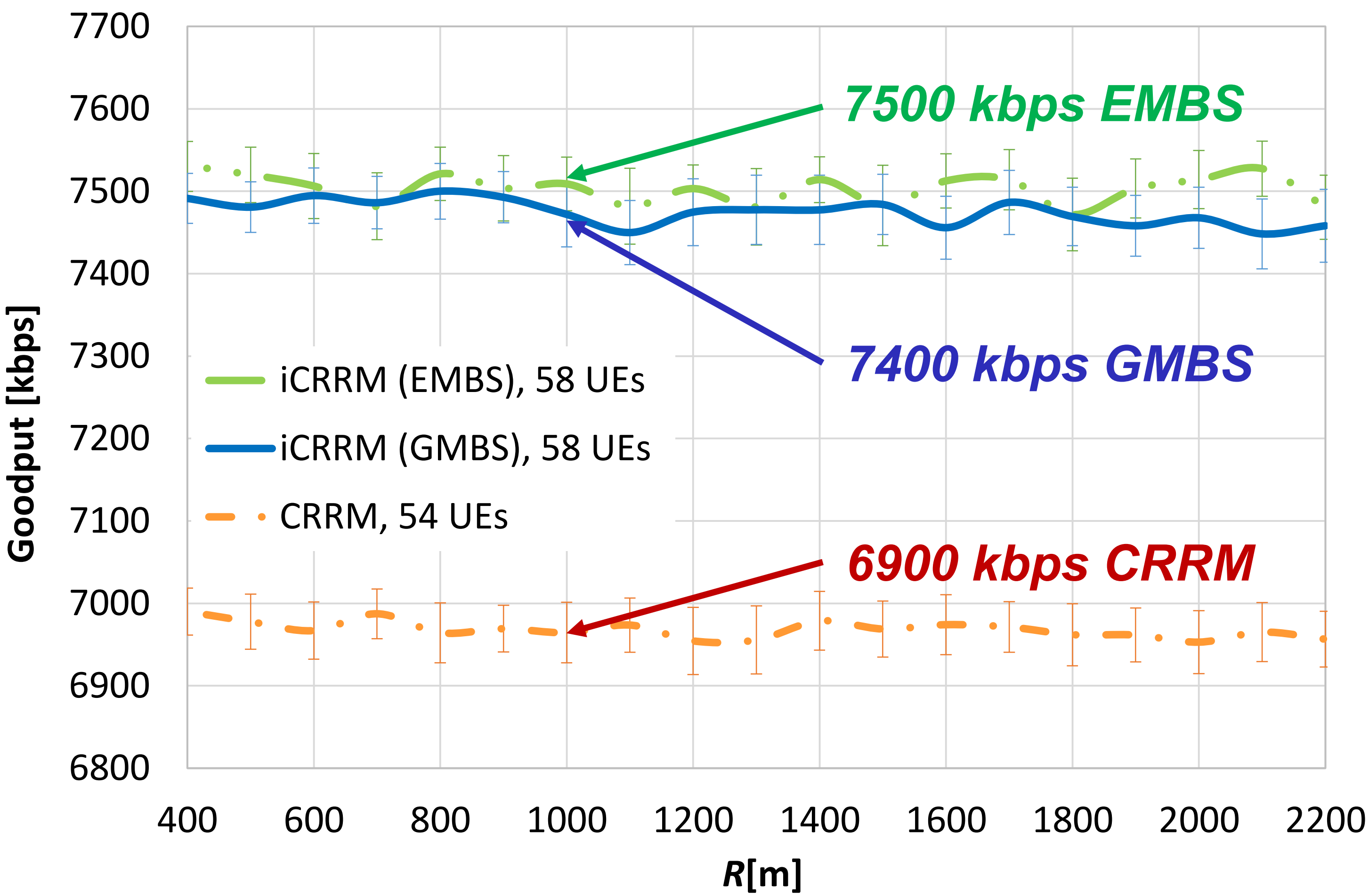


Simulation Results - Goodput

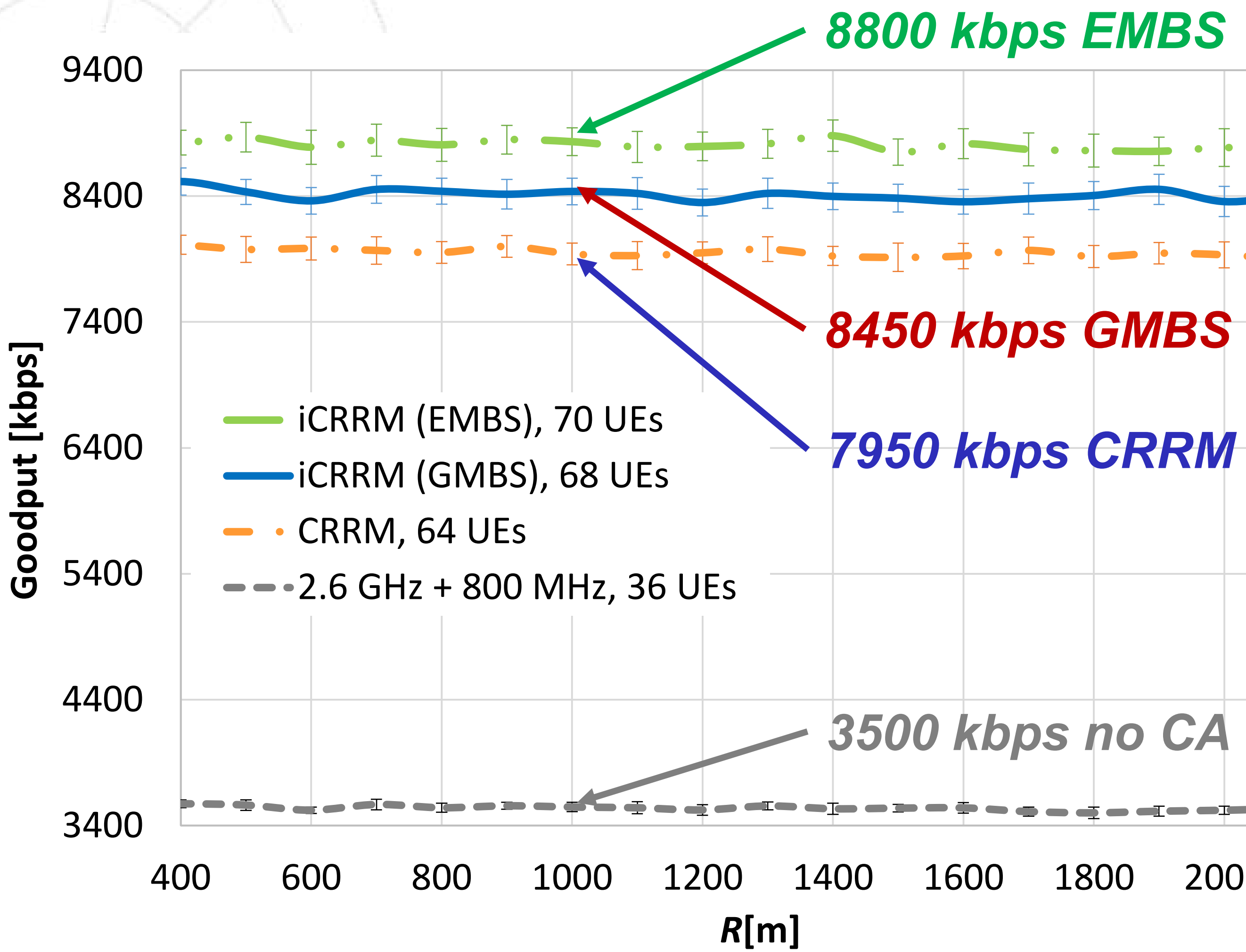
- Video bitrate of 128 kbps:



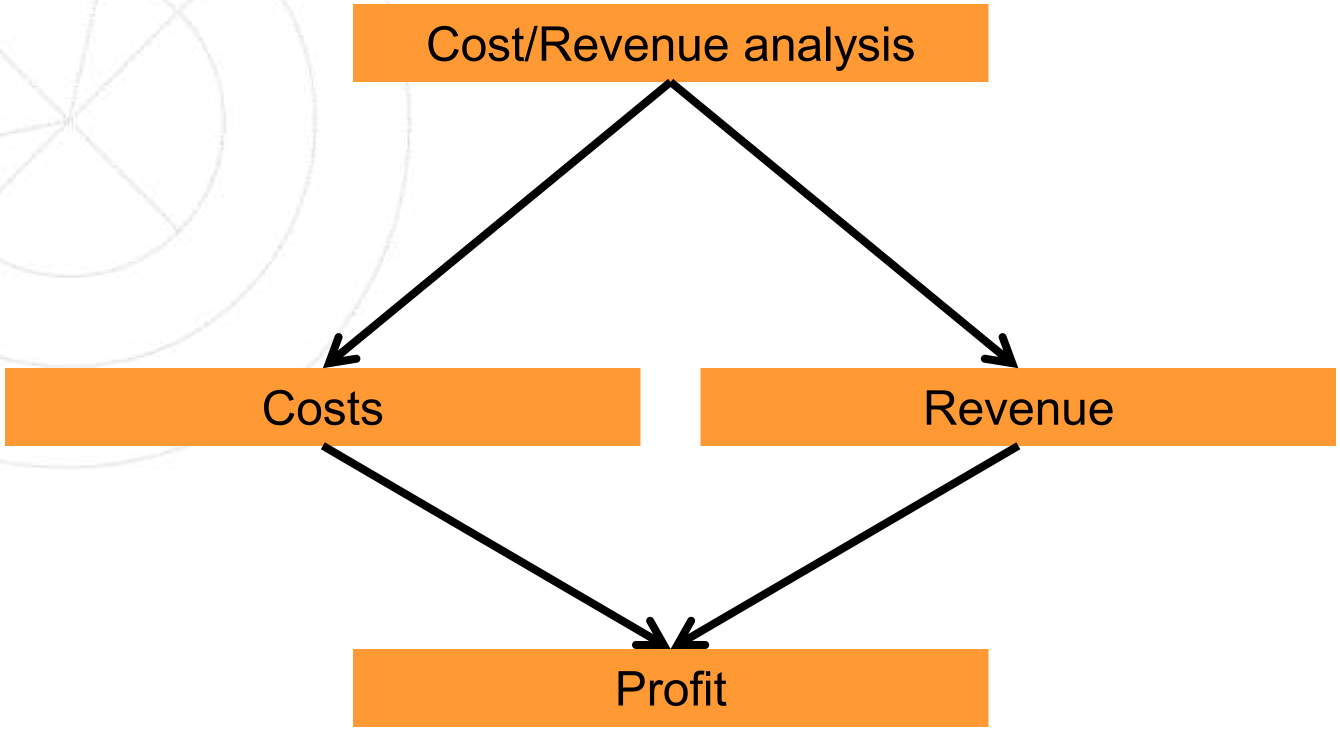
Simulation Results – Goodput for PLR ≤ 1%



Simulation Results– Goodput for QoE ≥ 2.5



Cost/Revenue analysis



Cost/Revenue analysis

Cost/Revenue analysis

Costs

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

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

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

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

K = 3

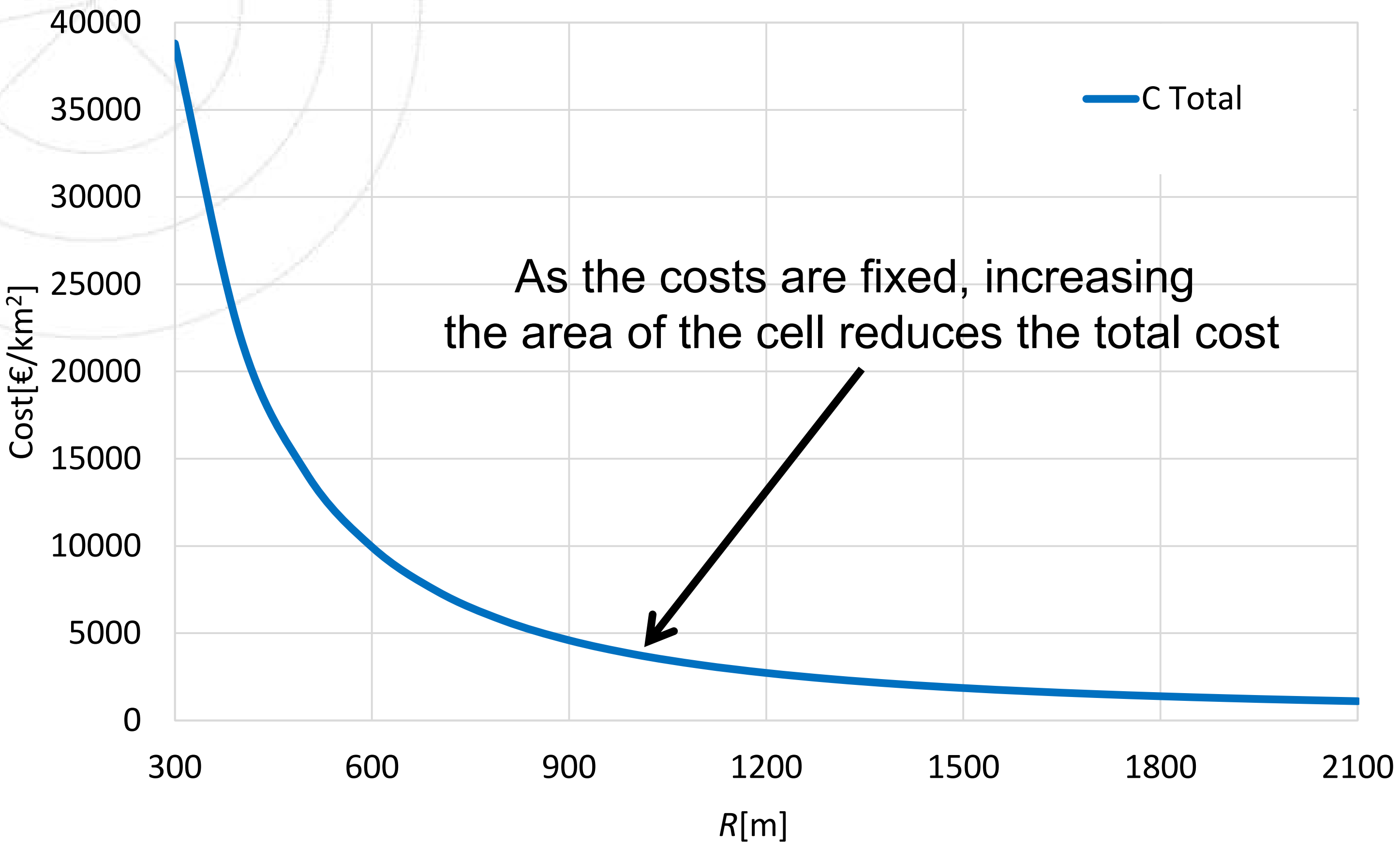
$$C_{fi\ 800\ \mathrm{MHz}[€/km^2]} = \frac{45{,}000{,}000 \times 3}{91{,}391.5 \times 5} \approx 295\ €/\mathrm{km}^2$$

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

Area of Portugal

5 year project

Costs



40000
35000
30000
25000
20000
15000
10000
5000
0
Cost[€/km²]
300
600
900
1200
1500
1800
2100
R[m]
C Total
As the costs are fixed, increasing the area of the cell reduces the total cost

Cost/Revenue analysis

Cost/Revenue analysis

→ Revenue

Number of sectors

Supported throughput

Duration of busy hours per day

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

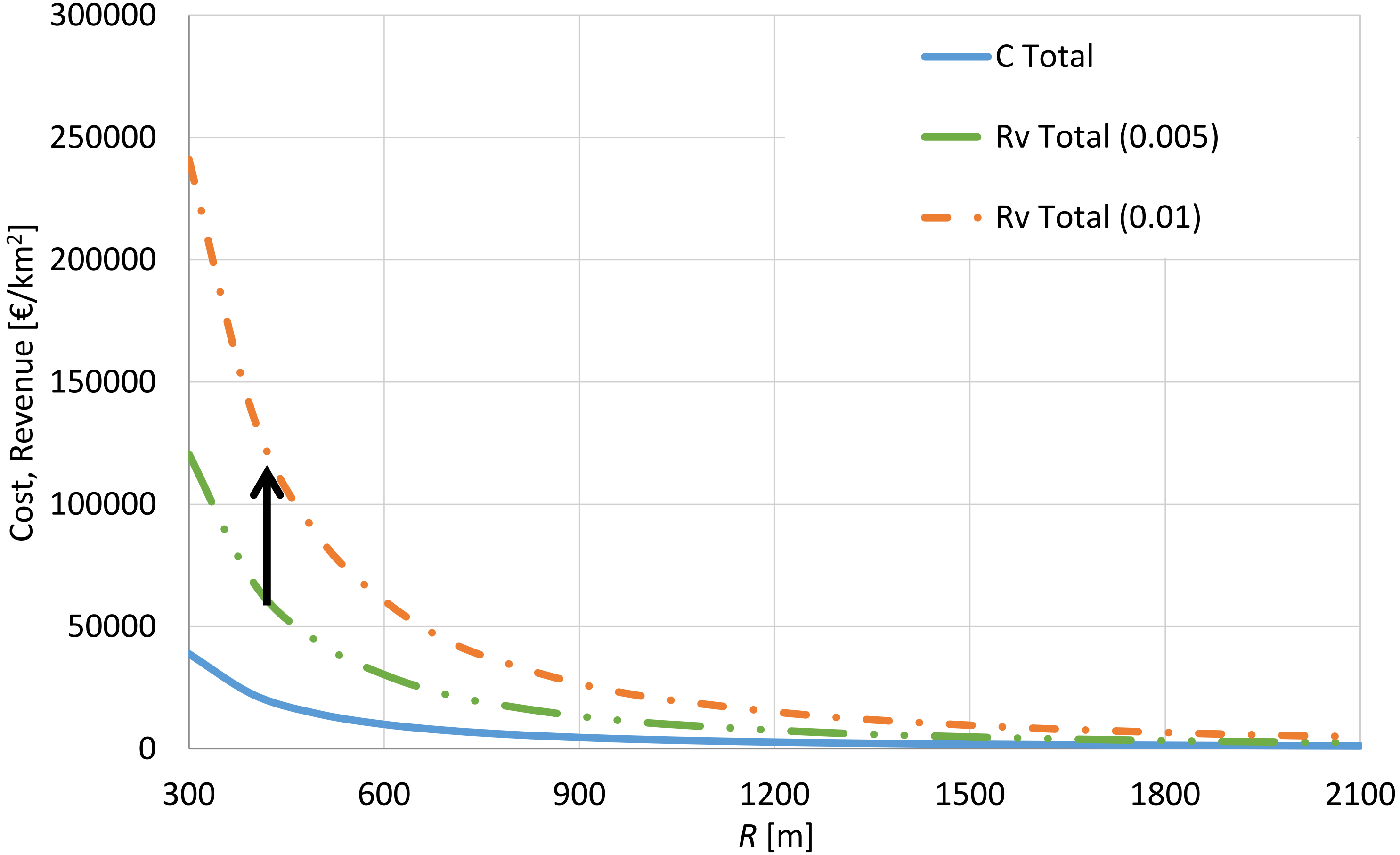
bit rate of the basic 144 “channel”
(144 × 60 = 8640 kb ≈ 1 MByte)

Channel revenue
with a data rate $R_{b[kbps]}$

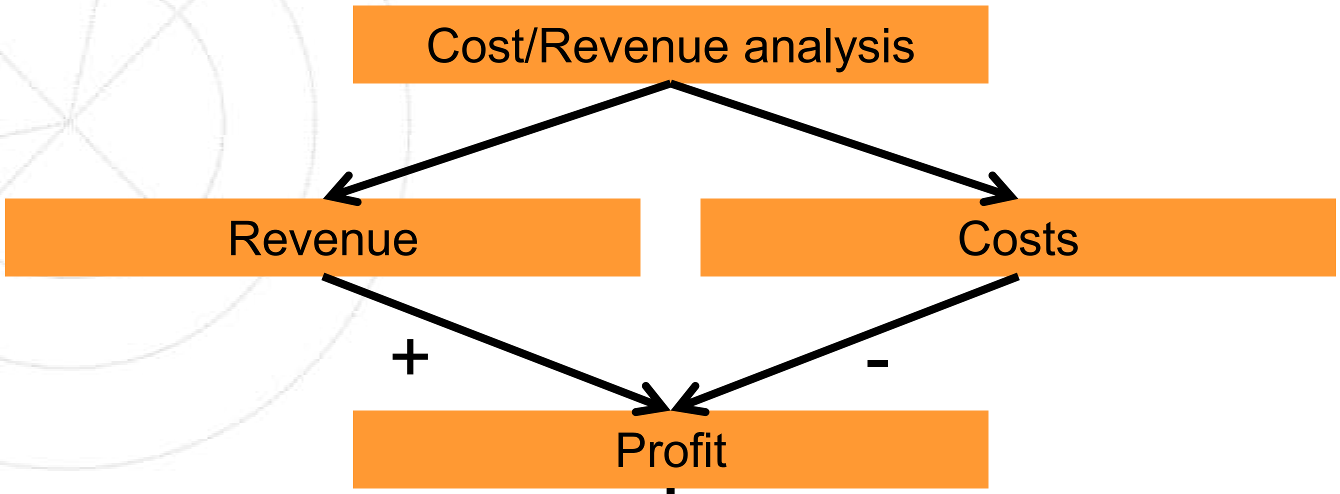
$$(R_v)_{cell[€]} = \frac{1 \times R_{b-\sup[kbps]} \times 60 \times 6 \times 240 \times R_{144\,[€/min]}}{144_{[kbps]}}$$

Revenues

- The revenue curves were obtained for different $R_{144[€/MByte]}$, i.e., values per Mbyte equal to 0.005 and 0.01 €/Mbyte:



Cost/Revenue analysis



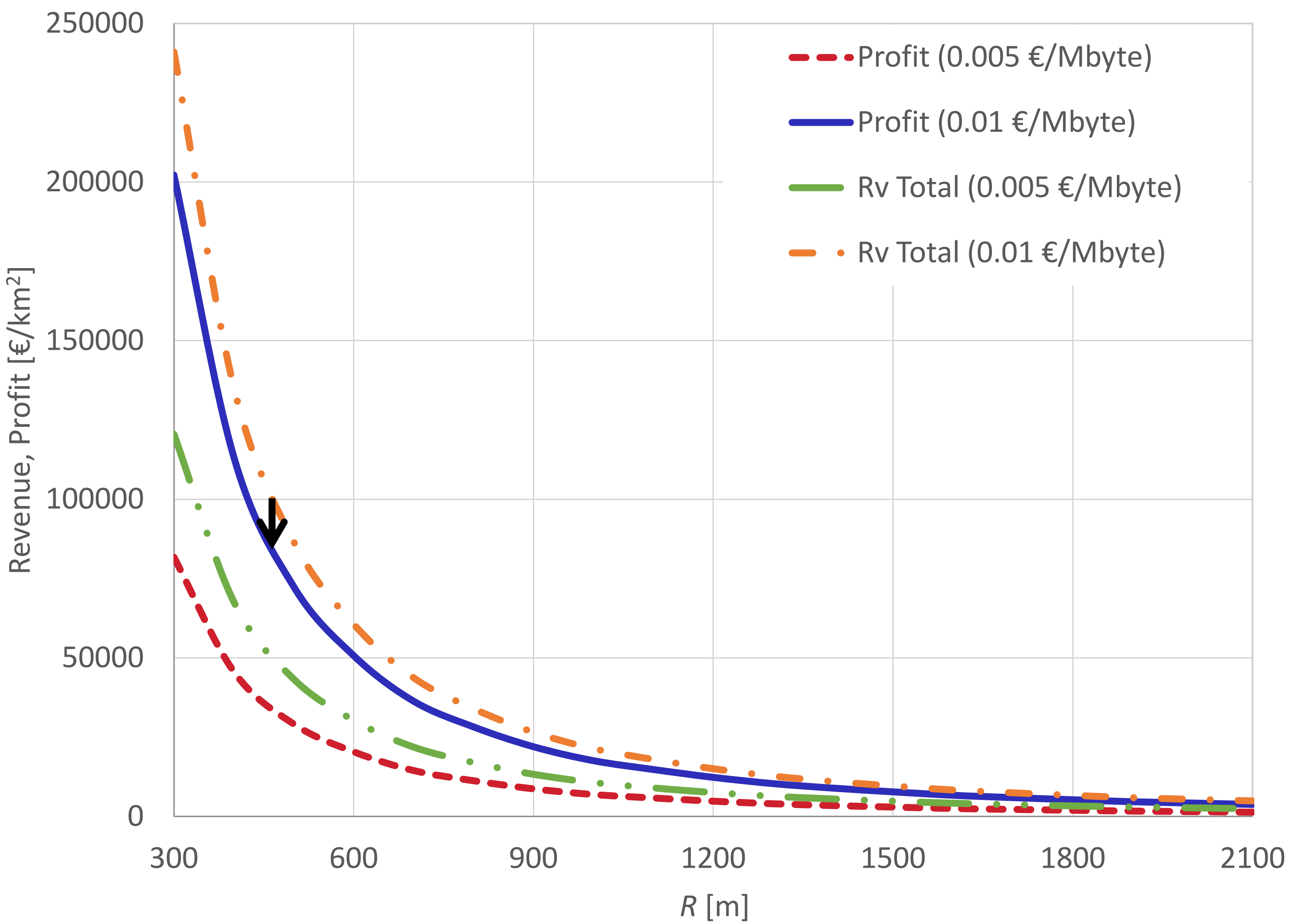
Absolute profit

$$P_{[€/km^2]} = R_v - C$$

Percentage of profit

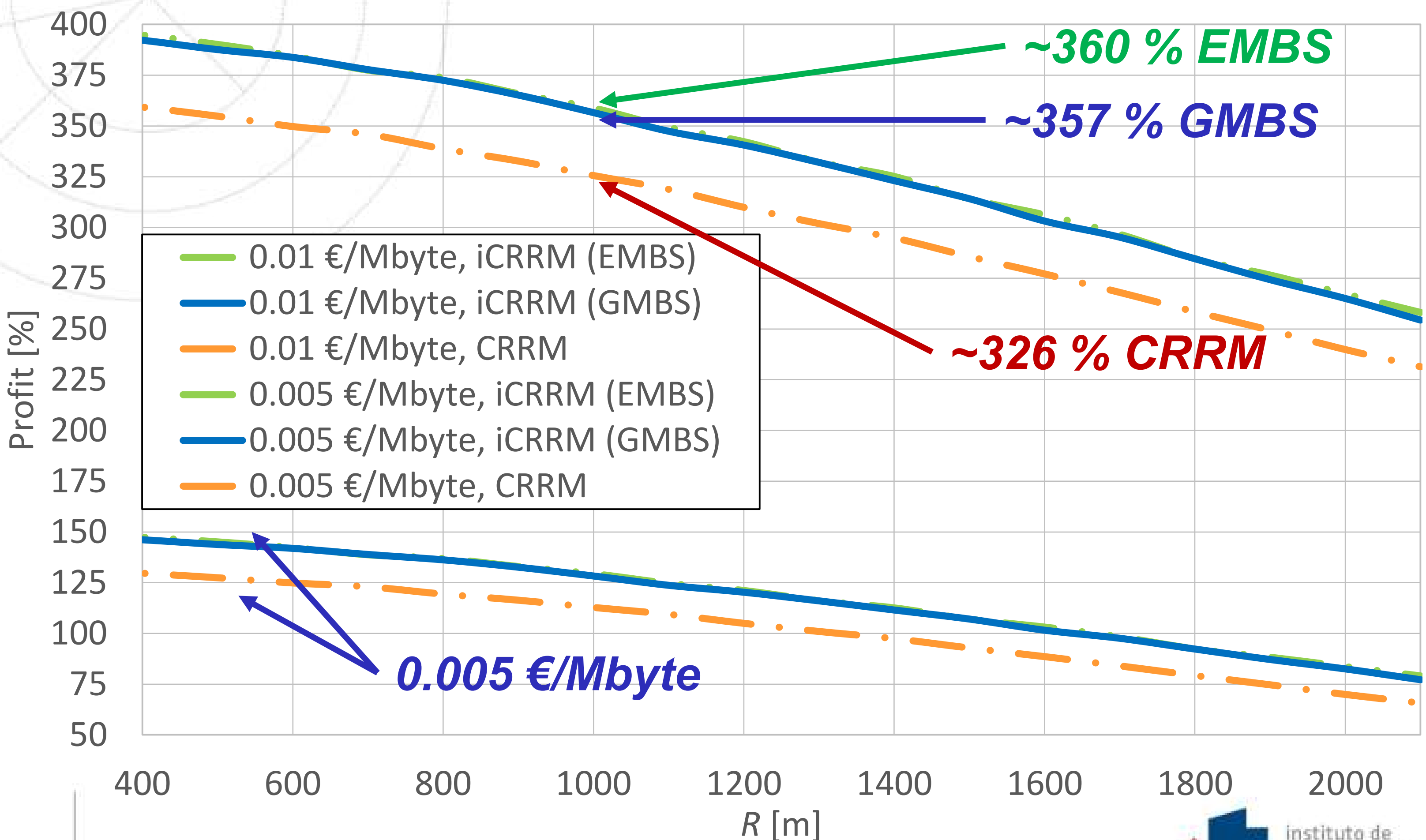
$$P_{[\%]} = \frac{R_v - C}{C} \times 100$$

Absolute profit



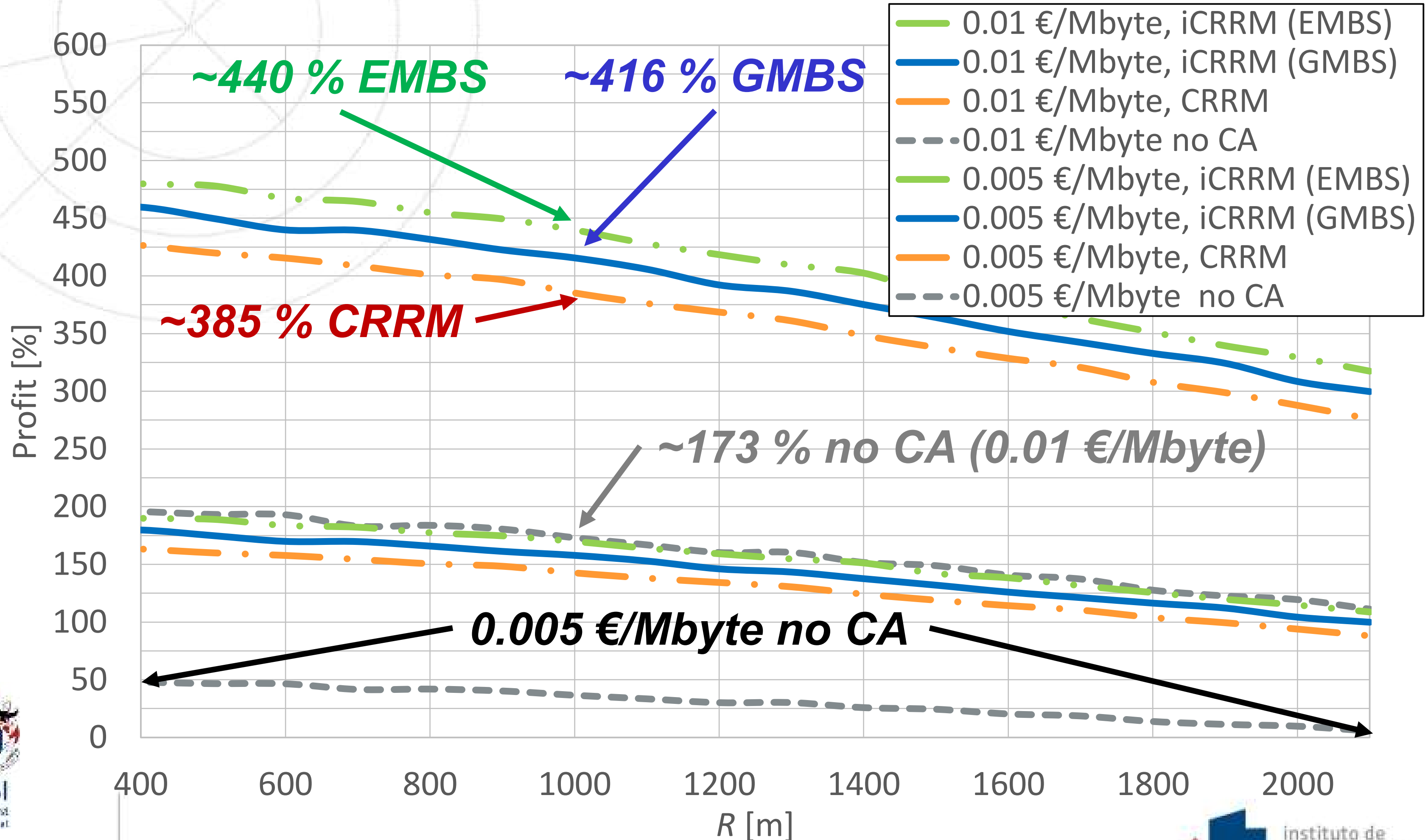
Results for the cost/revenue optimization, PLR ≤ 1 %

- Percentage of profit for 0.005 and 0.01 €/MByte



Results for the cost/revenue optimization, QoE ≥ 2.5

- Percentage of profit for 0.005 and 0.01 €/MByte



Conclusion

- This work proposes an iCRRM entity that implements inter-band CA by performing scheduling between the 800 MHz and 2.6 GHz bands, with the aim of increasing users' quality of service and experience;
- 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 and GMBS.

UBI Covilhã Portugal

dem

instituto de telecomunicações

Conclusion (QoS and QoE)

- The **1 %** PLR performance target is only exceeded above 58 and 54 UEs with iCRRM and simple CRRM. Which corresponds to a average cell goodput of 7500 and 7400 kbps with EMBS and GMBS, respectively, and 6900 kbps with CRRM;
- The **150 ms** delay performance target has not been reach in the context of the performed simulations;
- Considering a QoE performance target of **2.5**, 70, 68, 64 and 36 UEs can be supported, with a corresponding goodput of 8800, 8450, 7950 and 3500 kbps with EMBS, GMBS, CRRM and without CA, respectively.

Conclusion (cost/revenue analysis)

- For R = 1000 m and PLR ≤ 1% profits of 130 and 360 %, 129 and 357 %, and 113 and 326 % were obtained with EMBS, GMBS and CRRM, for $R_{144[€/MByte]}$ equal to 0.005 and 0.01, respectively;

- For R = 1000 m and QoE ≥ 2.5, profits equal to 170 and 440 %, 158 and 416 %, 143 and 385 %, and 37 and 173 % were obtained with EMBS, GMBS, CRRM and without CA, with $R_{144[€/MByte]}$ equal to 0.005 and 0.01, respectively.

UBI Covilhã Portugal

instituto de telecomunicações

Thank you,
Questions are Welcome

UBI
Covilhã
Portugal

instituto de telecomunicações