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Service characterization for cost/benefit optimization of enhanced UMTS

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Abstract In this paper an all-IP Enhanced-Universal Mobile Telecommunications System (E-UMTS) is considered, where enhancements include link level behavior, high-speed downlink packet access (HSDPA) channel, resource management, Diffserv architecture, and Radio Resource Management schemes. An overview of E-UMTS deployment scenarios and service needs is presented based on the views of relevant players. Deployment and mobility scenarios are considered, including expected population density and usage of service mix for three environments, namely offices, urban/vehicular, and business city center. In addition, based on population and service penetration values, E-UMTS traffic generation and activity models are described and characterized. Based on these scenarios and characterizations, system level simulations are carried out and the enhanced service quality performance is demonstrated, including blocking probability, handover failure probability and end-to-end delay in each deployment scenario. By using system level simulations, services and environmental conditions can be mapped into deployment strategies (and supported system capacity) whose evaluation is essential prior to field trials and real implementation. On the one hand, costs depend on the prices of the spectrum, equipment, operation and maintenance, as well as on the number of cells which, in turn, depends on the cell radius. On the other, revenues depend on the price per MB and on the supported throughput. As the goal of operators and service providers is to maximize the profit, the profit in percentage was obtained for the three considered scenarios. Its optimum values are found for cell radii around 31, 257, and 310 m for offices, vehicular and business city center scenarios, respectively.

Keywords Enhanced UMTS · Service characterization · Deployment scenarios · Performance evaluation · Cost benefit analysis · Economic impact

1 Introduction

Enhanced-Universal Mobile Telecommunications System UMTS (E-UMTS) is a UMTS evolution step which provides bit rates higher than 2 Mbps in the uplink and downlink directions, over a 5 MHz frequency carrier. It enables the provision of new wideband services and a significant reduction of the price per bit, running over flexible Quality of Service (QoS) enabled IP based access and core networks, and making possible an effective end-to-end packet based transmission. European projects, (e.g. IST-SEACORN,[1] IST-

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[1] http://www.it.pt/project_detail_p.asp?ID=239.

BBONE,[2] IST-CMOBILE,[3] IST-UNITE[4]) have proposed a set of enhancements to UMTS, which include, among others, advanced modulation and radio transmission techniques, improved strategies for IP routing, and QoS assurance.

E-UMTS allows for expansion both in the downlink and uplink directions. High Speed Downlink Packet Access (HSDPA) for instance, a major part of the E-UMTS concept, mostly extends UMTS maximum achieved data rates for the downlink direction. Hence, E-UMTS supports wideband real-time/time-based mobile ubiquitous and seamless applications [1], scaling system capacity for mass-market services.

While in the Wireless LAN (WLAN) domain high capacity is possible with the different versions of IEEE 802.11 (54 Mbps with a/g standard, and 108 Mbps with the n standard), in the mobile communications domain the data-rates are not so high and E-UMTS is an important step to achieve this goal. Furthermore, with the use of a wider range of devices with various radio interfaces, E-UMTS is a 3.5G system able to support values of capacity comparable to the ones needed for broadband mobile applications, and will allow for the introduction of the Always Best Connected (ABC) concept [2]. In this context, instead of being a competing technology, E-UMTS is complementary to the various types of WLANs (and other radio and access technologies).

When a hardware demonstrator is not available and since the E-UMTS enhancements proposed in http://www.it.pt/project_detail_p.asp?ID=239, http://b-bone.ptinovacao.pt/, http://c-mobile.ptinovacao.pt/, http://www.ist-unite.org/ have not yet been totally implemented, the only practical way to evaluate the effect of the proposed enhancements in a multi-service context is by means of simulation. For that purpose a set of services needs to be considered in order to create a complete and realistic simulation framework, impacting directly on traffic generation models. These services are assessed from a variety of operation environments, each with its distinctive set of service preferences, usage patterns, and associated mobility profiles. Therefore, as an answer to these services and environmental conditions, a matching set of deployment strategies need to be studied, adapted and simulated.

The usage of each application, i.e., the percentage of an application's connections relative to the total number of active applications, is one of the most important aspects to be determined. This data is essential for multi-service traffic analysis and engineering purposes, as well as for simulations. The computation of the system capacity is, therefore, one of the main motivations for the realization of this study. At the same time, a further step is taken in traffic modelling by introducing long range dependence models [3], better adapted to wireless IP communications. These are based on recent research that uses field data and has concluded that traditional traffic models produce too optimistic results when used to model some types of data traffic. This may result in networks that are under dimensioned and therefore under-performing with respect to theoretical expectations.

A range of twenty-eight applications and eight deployment environments was first considered in [4] for complete deployment scenarios. In this work, a subset of five services and three operation environments are selected to meet the technical demands of the simulation tools. Without this summarization effort the framework proposed would be very difficult to evaluate due to the amount of computing resources it would require.

The system level simulations performed in this work consider the identification of E-UMTS new services, new wireless techniques for capacity increase, as well as QoS support. Each simulation environment incorporates the suggested traffic mix and the link layer enhancements. From these simulations, results can be extracted that focus on the assessment of QoS support in E-UMTS. The system level simulator was developed building on the publicly available simulation framework Network Simulator—version 2 (ns-2). New modules or additions to existing modules were developed to support the simulation of 3 G (and beyond) UMTS and Enhanced UMTS networks. Representative performance evaluation results are presented to demonstrate how the system level simulator can be used for system capacity determination and network planning.

The paper is organized as follows. Section 2 first presents a set of simulation scenarios derived for E-UMTS deployment environments. The environments include information on the expected population density and the expected usage of service mix. The set of applications cover voice, interactive data (e.g., Instant Messaging for Multimedia) and streaming-based services (Video-telephony, HD Video-telephony). Section 3 describes session and activity parameters. A choice of source traffic models to be used in E-UMTS simulations is also presented. Section 4 addresses details on the organization and development of the simulations and the main characterization parameters of the scenarios, including mobility aspects, while Sect. 5 presents the simulation results for each environment, including blocking probability, handover failure probability and end-to-end delay. In Sect. 6, a cost/revenue model is proposed and its usefulness for the optimization of the planning is shown for each of the scenarios. Finally, conclusions are drawn in Sect. 7.

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[2] http://b-bone.ptinovacao.pt/.

[3] http://c-mobile.ptinovacao.pt/.

[4] http://www.ist-unite.org/.

2 Deployment scenarios and traffic behavior

2.1 Application mix

Although tens of applications can be considered in the E-UMTS deployment scenarios [4, 5], a reduced set of representative services and environments is required in order to meet the technical demands of the simulation tools. Without this summarization effort the framework proposed would pose considerable difficulties to implement, due to the amount of computing resources it would require from simulators.

Three deployment scenarios are considered with a mixture of four or five services each, depending on the environment: (i) offices, OFF (buildings); (ii) urban/vehicular, URB/VEH; and (iii) business city center, BCC. Proposed applications and their relative usage for each environment are shown in Table 1. This table is adapted from previous work [4] by assuming, as a simplification, that the most significant application in a service group accounts for all the traffic usage in that group.

The envisaged approximated data rates are introduced for all applications in accordance with the service class associated with the application. The population density factors for each of the scenarios are also the ones from [4, 5]. Data rates are aligned as far as possible to existing standard values in UMTS and HSDPA.

2.2 Application traffic

At the application level, the amount of generated calls/sessions is dependent on the number of potential users and the session arrival rate per user that characterizes each service and environment. Together with call/session duration and activity pattern, they determine the traffic behavior at up- and downlink. It is a worth noting that the term call usually refers to conversational services while session refers to data connections.

2.3 Busy hour call attempt

Busy hour call attempts represent in our work the total number of call attempts by all users considered in one simulation. They correspond to the call attempts per unit time for the users covered by a radio cell or part of a cell [4]

$$BHCA_j = \frac{Usage_j}{\tau_j} \cdot M_T \cdot \rho \qquad (1)$$

where M_T is the number of users in the cell, τ_j is the average call/session duration, and ρ is the average traffic per user (which depends on the fraction of active users f, which can vary from 0 to 1 [6]). From the values for the usage from Table 1 and for given application's average duration, taking a given user population (e.g., $M_T = 100$) into account, it is straightforward to obtain results for *BHCA* as a function of ρ, as it has a linear dependence [4].

2.4 Quality and grade of service

Quality of service parameters include upper limits for latency (end-to-end delay), bit error rate (BER), and frame error rate (FER). In terms of grade of service, the maximum allowed latency varies between 150 and 200 ms for voice and video-telephony applications (or even up to 500 ms for assistance in travel), and 2–10 s for Instant Messaging for Multimedia or Multimedia Web Browsing [5]. While the maximum allowed BER is 10^{-4} for voice and video-telephony applications it decreases down to 10^{-6} for the remaining ones. Regarding FER, a limit of 1–3% was defined for VOI, VTE and HDT.[5]

Values for the grade of service were identified for the blocking, handover failure and call/session dropping prob-

Table 1 Proposal for E-UMTS applications usage in each of the SEACORN simulation scenarios

Applications usage	Data rate [kbps]	Usage [%] OFF	URB	BCC
Sound				
Voice (VOI)	12.2	58.0	82.5	27.0
High Interactive Multimedia				
Video-telephony (VTE)	128	22.3	11.0	16.0
Narrowband				
Multimedia Web Browsing (MWB)	384	8.0	2.0	26.0
Wideband				
Instant Messaging for Multimedia (IMM)	1024	11.7	–	–
Assistance in Travel (ATR)	1660	–	4.5	–
HD Video telephony (HDT)	2048	–	–	31.0
Density Factor (users/m^2)		0.150	0.012	0.031

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[5] The acronyms VOI, VTE, MWB, IMM, ATR, and HDT refer to the applications considered in our scenarios, and are defined in Table 1.

abilities. The handover failure probability is the probability of a user not succeeding in transferring its connection from a cell to another. By call/session dropping probability we refer to the probability of forced connection termination. Thus, in our approach, call dropping is caused by handover failure during the whole connection, and can then be related with the handover failure probability. According to [7], the threshold for handover failure probability can be related to the maximum connection dropping probability by

$$(P_{hf})_{\max} = \frac{\mu}{\eta} \cdot (P_d)_{\max} \tag{2}$$

where μ is the service rate, meaning that the average duration is given by $\tau = 1/\mu$, η is the cross-over rate, and $\gamma = \eta/\mu$ is the handover rate. Hence,

$$(P_{hf})_{\max} = \frac{1}{\gamma} \cdot (P_d)_{\max}, \tag{3}$$

and $\gamma = \eta\tau$. Recommendation E.771 [8] proposes a limit of 1% blocking probability for future mobile systems, including the radio channel blocking probability. Concerning handover failure, a fixed value, independent of the cell size, can only be defined for the call dropping probability, P_d, which can nevertheless be easily related with handover failure probability. Half of the limit of blocking probability is proposed for P_d, i.e., 0.5% (in order to provide ongoing calls with a higher degree of service quality). Some more tolerant figures concerning maximum blocking probability were used in 3G preliminary estimations [9], where an upper limit of 2% is used for the call blocking probability.

The maximum setup delay varies between 15–20 s for Voice, Video-telephony and Multimedia Web Browsing, and 60 s for the remaining applications. It corresponds to the worst-case of an international call setup. Local calls require a setup delay under 10 s [8].

Concerning services like Instant Messaging for Multimedia (IMM), Assistance in Travel (AIT), and HD Video Telephony (HDVT) an important issue is the definition of a blocked call since these ones can be non-time-based services and can therefore tolerate a longer delay, instead of blocking (whenever resources are unavailable); hence, a longer maximum setup delay was defined for these services. A call attempt is considered blocked whenever its maximum setup delay values is exceeded.

3 Session and activity characteristics

3.1 Call generation and traffic parameters

Call generation and traffic parameters describe service behavior in terms of traffic generation. They include the average data-rate, session arrival rate per user during the busy hour, average call duration, burstiness and symmetry factor [5]. Because model parameters for each type of connection may be different it is useful to have different designations. Nevertheless, in E-UMTS the concept is basically the same, since both entities are similarly supported on packet data protocol context establishment. Since uplink and downlink data-rates are not necessarily the same it must be referred that in simulations, the data-rate parameter value refers to the highest value between the two links, which is the downlink in all exemplified cases.

The set of traffic parameters is defined in Table 2. Two levels of behavior may be distinguished: call/session representing traffic generation process, and activity models that describe how a session behaves in terms of idle and active periods.

Call and session related parameters are used to model the birth and death of calls and sessions. Session arrival rate represents the average number of calls generated per service subscriber during the busy hour. The Poisson process is used to model session arrivals. Values for call/session arrival rate are derived from service penetration [5], P_j, and session average duration values, τ_j, for application j considering $\rho = 0.03$ Erl. These parameters are tightly associated for each application, and deployment scenario, as formulated below. Usage, U_j, is expressed as a ratio between the traffic for service j, (derived from session arrival rate,

Table 2 Call generation and traffic parameters

Applications	Data rate [kbps]	Session arrival rate [min^{-1}]			τ_j [min]	Burstiness	Symmetry UL/DL
		OFF	BCC	URB			
Voice	12	0.50	0.54	0.84	3	1	1
Video-telephony	128	0.45	0.48	0.48	3	1–5	1
Multimedia web browsing	384	0.16	0.21	0.19	15	1–20	0.25
Instant Messaging for MM	1024	0.15	–	–	15	1–50	0.05
Assistance in Travel	1536	–	–	0.11	20	1–5	0.07
HD Video-telephony	2048	–	0.09	–	30	1–5	1
WLAN Interconnection	12,780	0.03	–	–	60	1–20	0.25

Table 3 Application activity parameters

Applications	Active state (ON)			Inactive state (OFF)	
	Average [s]	File size [kB]	Distribution	Average [s]	Distribution
Voice	1,4	2.14	Exponential	1.7	Exponential
Video-telephony	τ	–	–	0	–
Multimedia web browsing	5	240	Pareto	13	Pareto
Instant Messaging for MM	5	640	Weibull	90	Pareto
Assistance in Travel	60	11,520	Weibull	14	Pareto
HD Video-telephony	τ	–	–	0	–
WLAN Interconnection	5	7988	Weibull	1	Pareto

duration and number of subscribers), and the total produced traffic, during the busy hour, by all services. The conversion to *BHCA* can be done by using (4).

$$U_j = \frac{SessArrRate_j \cdot P_j \cdot \tau_j}{\sum_i SessArrRate_i \cdot P_i \cdot \tau_i} \tag{4}$$

3.2 Application activity parameters

Session activity parameters describe the detailed aspects of traffic within a call. This is accomplished by means of an alternating active/inactive state model, i.e., *on/off* states. The activity within a call can be modelled by defining an average duration for each on and off periods, together with an adequate statistical distribution. Video telephony is always active in both directions. Hence, it does not present a bursty behavior.

The basic model for data application normally uses a web session as a paradigm, although the model may be used for all types of data. A session is composed by of a set of active periods made of packet sequences (packet calls) separated by inactivity periods. A packet call is a sequence or bursts of packets, corresponding, e.g., to a web page or other data item. Inactivity periods between packet call arrivals are often called reading time (or inactivity time). This model is described in [10].

Table 3 presents the average active versus inactive durations, the corresponding file sizes of activity packet session periods and the statistical distributions of the active and inactive durations as well.

Further details on traffic source models and their parameters are given in [5]. Regarding streaming services, a model for streaming video is also outlined in [11], based on MPEG-4 trace statistics. Multicast and broadcast traffic in an Enhanced-UMTS environment is studied in [11].

4 Simulation topologies and mobility

Each simulation scenario is defined by a variety of parameters, including traffic, propagation and mobility models, as well as topologies and user population. Furthermore, each scenario corresponds to a specific operating environment. The three simulated environments are the Office (OFF) environment, the Urban/Vehicular (URB/VEH) environment, and the Business City Centre (BCC) one. For the URB and OFF scenarios, a threshold for the maximum handover failure probability was defined. For the BCC scenario, in turn, a combined threshold was used that simultaneously accounts for the influence of blocked and dropped calls/sessions.

4.1 Office

In an office environment users are stationary most of the time. When they move they have a specific destination, which is randomly chosen. The source and destination positions are either in an office room or a corridor. Therefore, the chosen path is either along the x or the y axis. To characterize this environment, several parameters may be specified such as the ratio of room-situated mobile terminals to the corridor-situated mobile terminals at any time, the average time in an office room (and the corresponding average time in the corridor), the mobile speed, and the average distance between source and destination. The considered mobility model is the Random-Waypoint one [5, 12]. The model defines a pattern of movements for each user individually. In this pattern, each mobile node is assigned a pause time. Every node waits for the time specified as the pause time. Then it chooses a random location on the map and heads toward that location with a fixed speed of 3 km/h (0.83 m/s), a typical pedestrian speed.

The topology for the OFF scenario [5, 12] consists of several pico cells distributed in a floor of 140 × 60 m, according to Fig. 1. Offices are separated by a corridor 5 m wide and have a height of 3 m. As the cell radius increases or decreases, the number of cells, N_c, decreases or increases accordingly. This relation is presented in Table 4. Figure 1 illustrates a topology with a cell radius of 20 m.

Fig. 1 Offices topology (triangles represent base stations)

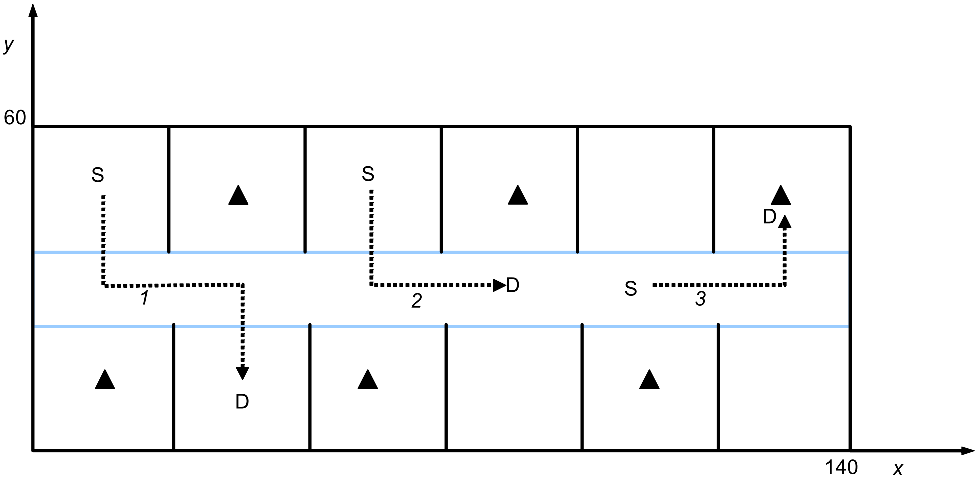


Table 4 Cell radius R versus number of cells, N_c

R [m]	35.0	20.0	15.6	12.7	10.8	9.3	8.3	7.4	6.7	6.1	5.6
N_c	3	6	8	10	12	14	16	18	20	22	24

4.2 Urban

In an urban environment the high speed mobile terminals move according to a pseudorandom mobility model. Position updates are often due to the high speeds. As an example, the positions may be updated every twenty meters. Parameters that could be specified are the following: average speed, probability to change direction at a position update and maximum angle for this change of direction.

The mobility model used for the urban environment is the Gauss-Markov one [5, 12]. The pattern is confined within the predefined grid area. The Gauss-Markov model is defined to be between the random walk (slow mobiles) and the fluid flow (very high speed mobiles) models, which are labeled as extremes. Most of the nodes move somewhere in-between those speeds. Parameters for the Gauss-Markov model include the mobile speed at 50 km/h (13.89 m/s), and a seed, a random number that is fed into a random number generator, as this model aims to assign pseudorandom paths to the mobile users.

The topology consists of several base stations, using tri-sectored antennas. A tri-sectored antenna consists of three 120° sectors in each Node B, allowing for 360° coverage and up to three times the capacity of an omni-antenna node B. Several cell radii were tested so that an area of 4 km^2 can be covered, Table 5. A topology with cell radius equal to 439 m is presented in Fig. 2.

Table 5 Cell radius, R versus number of cells, N_c

R [m]	217	257	310	340	380	439	538	621
N_c	37	27	19	16	13	10	7	5

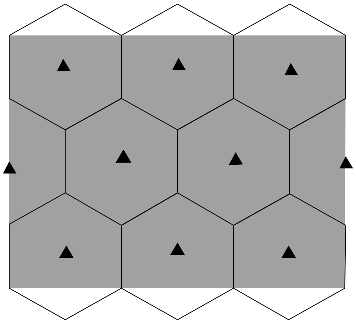


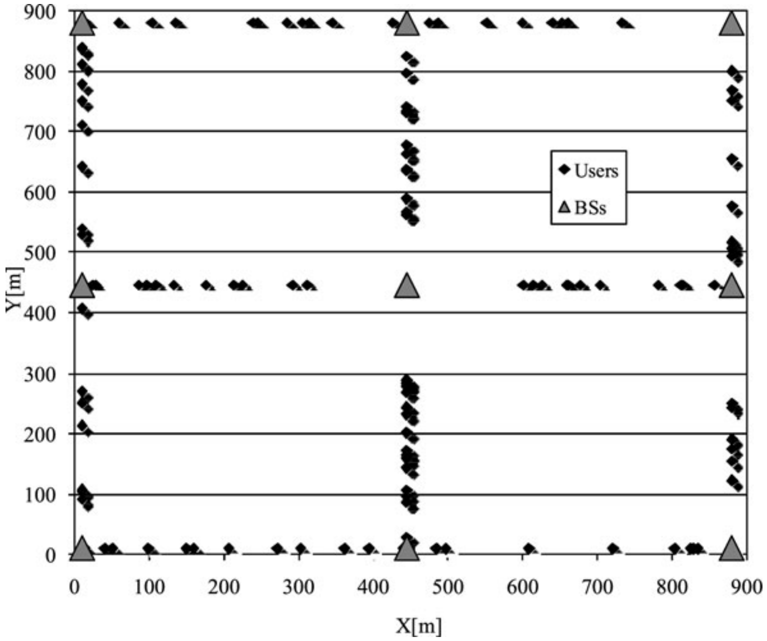
Fig. 2 Urban topology scheme for a cell radius of 439 m

4.3 Business city center

In a BCC environment, the mobiles move along streets and may turn at crossroads with a given probability, Fig. 3. Positions are updated relatively often because the speeds considered for this environment are pedestrian. A good value for a position update is every five meters. At each position update, there may be a speed change according to a given probability. Several parameters may be specified such as the average speed and the minimum speed, and the probabilities to turn or to change speed.

The mobility model used for the BCC environment is the Manhattan grid one [5, 12]. The Manhattan grid model specifies that mobile nodes move only on predefined paths along a Manhattan grid (only parallel to either the xx or the yy direction). In the model we assume a Manhattan grid, i.e., blocks along the x and y axis separated by paths where mo-

Fig. 3 Manhattan topology model



bile users move. Since only pedestrian users are considered the user speed is set here again as in the office environment equal to 3 km/h or (as ns-2 specifications require), 0.83 m/s. The users move on the roads and, at each crossroad, they have a 0.5 probability to turn (0.25 to turn left and 0.25 to turn right) and a 0.5 probability to keep walking straight away.

The BCC topology consists of 9 micro cells, which are arranged as a square grid tessellated with building blocks, and with node Bs at crossroads. The grid size (total simulation area) for this 9-cell topology varies between 0.0968 and 3.3205 km^2, making the distance between node Bs to vary between 70 and 410 m. The antennas used in this scenario are omni-directional ones, i.e., antennas with a 360° coverage radiation pattern. The Node Bs are located outside the buildings in one of the corners, as shown in Fig. 3.

5 Simulation results

Based on the scenarios and traffic characterization described in Sects. 3 and 4, system level simulations were carried out and the E-UMTS performance was demonstrated. The results include the analysis of call blocking and handover failure probabilities for each application along with the results for throughput and end-to-end delay for each environment/topology.

A set of simulations was run using different randomization seeds to achieve more accurate results while achieving statistical relevance. The curves for each metric presented below are obtained by computing the average over all simulation runs.

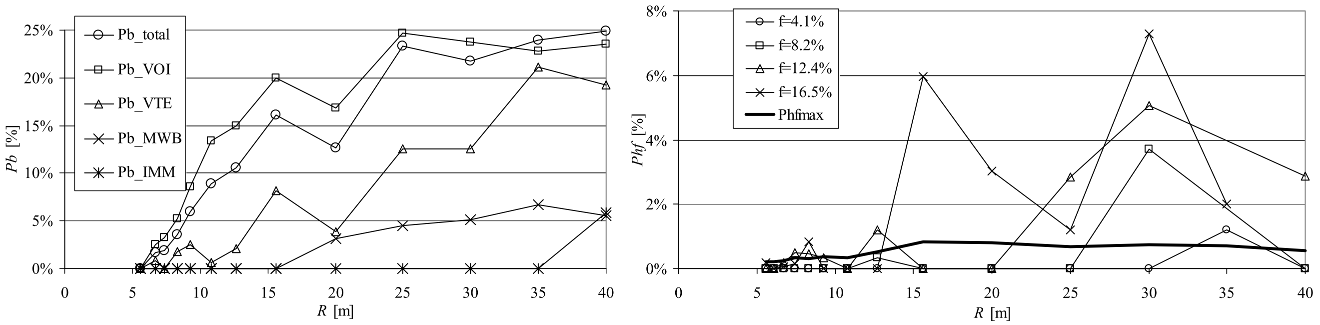
5.1 Office

In the office environment, a population of 1260 users is considered. The values for the fraction of active users generating traffic at any given time are presented in Table 6. The acceptable number of blocked calls over a whole simulation run is less than or equal to 2% of the total number of calls. Besides, the acceptable maximum for handover failures is dependent on the call dropping probability threshold and on the average number of handovers per call. The curves for these two metrics, blocking and soft-handover failure probabilities are depicted in Fig. 4. While Fig. 4(a) shows the blocking probability, P_b, as a function of the coverage distance for $f = 12.4\%$, Fig. 4(b) presents the variation of the handover failure probability with the coverage distance, for VOI [13], the most problematic application.

The acceptable upper bound for the delay is 150 ms [5]. Although the curves not presented here, delay is always less than 150 ms for every fraction of active users and cell radius.

In Fig. 4(a), as a trend, the call blocking probability increases with the increase of the cell radius, R. This behavior occurs for all fractions of active users. Hence, considering that the maximum acceptable percentage is 2%, the maximum acceptable cell radius, R_a, for the different applications corresponds to the intersection of P_b with $P_b = 2\%$ as shown in Table 6. In Fig. 4(b), although the curves for the handover failure probability are unstable, some trend exists for P_{hf} to overcome the $(P_{hf})_{\max}$ threshold while the cell radius increases. The appropriate cell radius, R_{ap}, is determined by computing the intersection points with the curve for $(P_{hf})_{\max}$, also included in Table 6.

Taking a worst-case situation between the GoS constraints for P_b, P_{hf}, and delay into account, Table 6, and by



(a) (b)

Fig. 4 Simulation results for the office scenario: (**a**) blocking and (**b**) handover failure probabilities as a function of the cell radius

Table 6 Cell radii versus supported fraction of active users for VOI, VTE, MWB and IMM

f [%]	VOI		VTE		MWB		IMM	
	R_a [m]	R_{ap} [m]	R_a [m]	R_{ap} [m]	R_a [m]	R_{ap} [m]	R_a [m]	R_{ap} [m]
4.1	39.3	**33.2**	40.0	40.0	40.0	40.0	40.0	40.0
8.2	**10.0**	26.2	31.7	40.0	18.7	30.2	36.8	
12.4	**6.5**	21.3	8.6	20.4	18.4	25.1	36.7	
16.5	**5.6**	12.8	5.9	16.0	18.4	25.1	36.7	

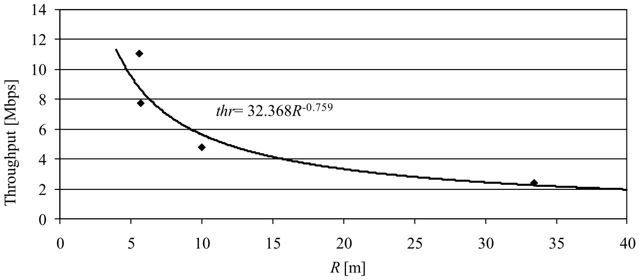


Fig. 5 Total system throughput for the OFF scenario as function of R

using an inversion procedure, the most suitable supported throughput for each value of R was found (see Fig. 5). In practice, this corresponds to the worst-case between P_b and P_{hf}. The curve for the supported throughput was found by using a curve fit approach, $thr_{[\mathrm{Mbps}]} = 32.368 \cdot R^{-0.759}$.

The throughput increases as the cell radius decreases. This is the expected behavior since the system does not demonstrate excessive losses. When the cell radius decreases the number of cells increases in order to cover the same area. If there are more cells in the covered area, then more resources are going to be available.

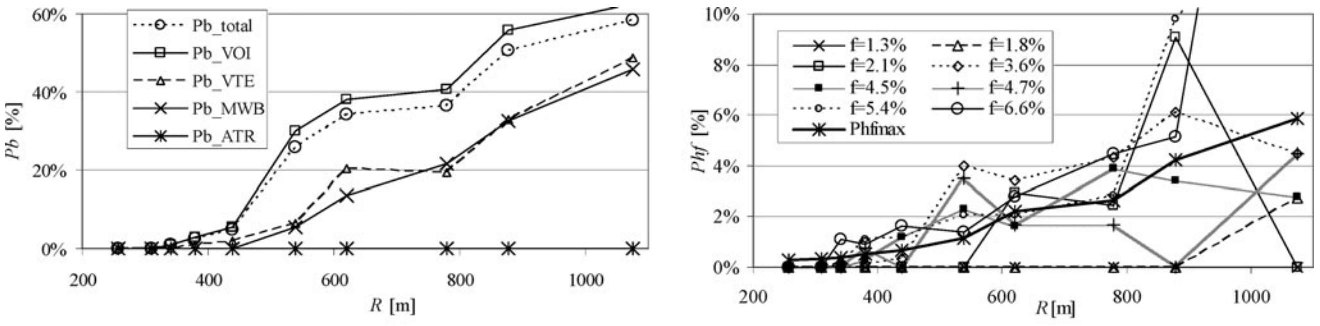
To show that the obtained throughput is comparable to the theoretical achievable one it is necessary to pick a scenario from each environment with given dimension and to compute the two values (theoretical and obtained throughput). For the office environment we selected a scenario with a given fraction of active users $f = 16.5\%$ (145 users), which generates a throughput around 11 Mbps. By calculating the theoretical throughput based on the predefined traffic mix (58% of 12 kbps, 22% of 144 kbps, 8% of 384 kbps and 12% of 768 kbps), one obtains a value close to 12 Mbps. The difference between the two values, 11 and 12 Mbps, is within the expectation. The obtained value was expected to be lower than the theoretical one due to factors such as call blocks and drops as well as the average duration. Many calls do not finish by the end of a simulation run because their average duration is longer for higher data rate applications.

5.2 Urban

The simulations for the urban environment considers an area of 4 km^2 with 12000 users, for which several values of the fraction of active users are used, as presented in Table 7. One considers the same bounds for the grade of service as in the office scenario. Figure 6(a) shows the blocking probability for $f = 4.7\%$ while Fig. 6(b) shows the handover failure probability for VOI.

By using the same inversion procedure as in the office environment one obtains the correspondence between f, R_a, and R_{ap} presented in Table 7.

Taking a worst-case situation between the GoS constraints for P_b, P_{hf}, and delay from Table 7 into account and by using the inversion procedure, the most suitable supported throughput was found for each value of R as shown in Fig. 7. In practice, this corresponds to the worst-case between P_b and P_{hf}. The curve for the supported throughput can be found by using a curve fit approach, $thr_{[\mathrm{Mbps}]} = 1/(-6.425 \cdot 10^{-02} + 1.617 \cdot 10^{-04} \cdot R^{1.104})$.



(a) (b)

Fig. 6 Simulation results for the Urban scenario. (**a**) Blocking probability as a function of cell radius for $f = 4.7\%$ and (**b**) handover failure probability as a function of cell radius for VOI

Table 7 Cell radii versus supported fraction of active users for VOI, VTE and MWB

f [%]	VOI		VTE		MWB	
	R_a [m]	R_{ap} [m]	R_a [m]	R_{ap} [m]	R_a [m]	R_{ap} [m]
1.3	**903**	1075	1075	1075	1075	1075
1.5	**580**	1075	1075	883	1075	1075
1.8	**579**	1016	743	1075	808	1075
2.1	**511**	562	568	1075	792	1075
3.6	474	**410**	793	550	550	532
4.5	415	382	548	385	492	**381**
4.7	360	**352**	443	343	476	1075
5.4	352	341	332	**314**	415	780
6.6	**338**	1075	389	1075	370	1075

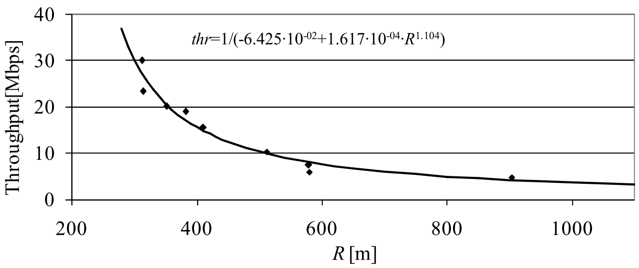


Fig. 7 Total system throughput as function of R for the URB scenario

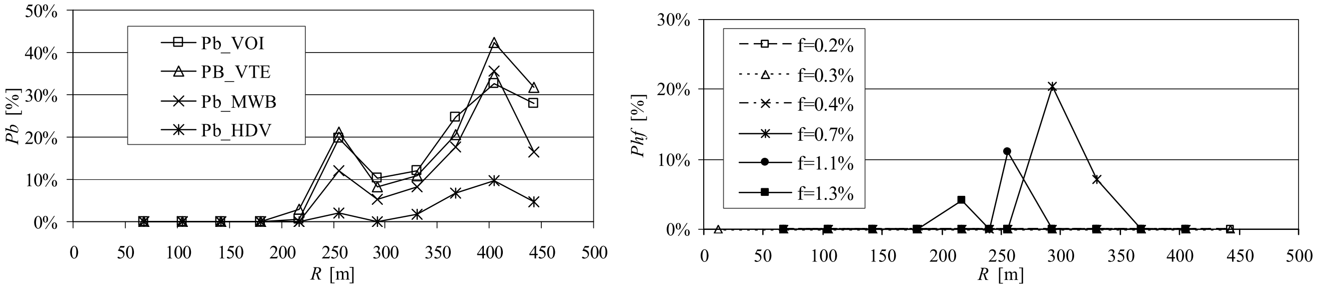
As expected, as the cell radius increases system capacity decreases. Nevertheless, it is worthwhile to note that although there is a high decreasing trend up to 400–500 m, after this value for the coverage distance there is a trend for the throughput to be constant. For short cell radius users can be easily served as they are closer to the Base Station (BS); they transmit with low power (by using Power Control algorithms) causing low interference to each other. As a consequence, high values are obtained for the throughput. However, for cell radius higher than 400 m, if the same power was used more blocks would occur owing to the higher distance from users to BSs; hence, users need to have a higher transmission power causing higher interference. As a consequence, BSs have to make more power available for each user, and resources scarce more rapidly [14] (http://b-bone.ptinovacao.pt/).

For the component simulated and theoretical throughput we picked a scenario with a given fraction of active users again and we showed that the obtained throughput is comparable to the expected theoretical one. For $f = 1.5\%$, by calculating the theoretical throughput based on the predefined traffic mix (82.5% of 12 kbps, 11% of 144 kbps, 2% of 384 kbps and 4.5% of 768 kbps), one obtains a value close to 6 Mbps, which is similar to the value obtained by simulation. The two values are again within expectation, as discussed in the simulations for the office environment.

5.3 Business city center

The simulations for the BCC scenario were run for several values for the size of the geometries but a reference geometry of 900×900 m was considered for all users, with $R = 150$ m, while assuming a population density of 6173 user/km^2. As the coverage distance of cells varies, the simulated area also varied, and the number of users varied accordingly for all the cases (but keeping the fixed value for the density factor). A normalization/transposition from simulation results (obtained with geometries of different dimensions, corresponding to different cell coverage distance, R) to the reference geometry was performed. This is justified because, as cells are tessellated in between blocks of buildings; hence, for each R, in the usual approach for BCC scenarios, there are different dimensions for the block of buildings because the length of the blocks of buildings is $2R - w$, where w is the street width.

By analyzing the results, the mean end-to-end delay does not appear as an issue since it was always less than the 150 ms threshold. Regarding call blocking and handover failure probabilities a different approach was considered to assess the grade of service. Instead of using the lowest value



(a) (b)

Fig. 8 Simulation results for the Business City Centre scenario: (**a**) blocking probability as a function of cell radius for $f = 0.4\%$, and (**b**) handover failure probability as a function of cell radius for VOI

between R_a and R_{ap} for each cell radius, a quality parameter, QP, was introduced that joins together, in a unique QoS parameter the number of blocked calls (*nb_blocked_calls*), the number of handover failures (*nb_interrupted_calls*) and the total number of calls (*total_nb_call*) as follows

$$QP = \frac{nb\_blocked\_call + 10 \cdot nb\_interrupted\_call}{total\_nb\_call} \tag{5}$$

The threshold assumed for QP is 1%, i.e., $QP \leq 1\%$. A lower grade of service corresponds to a higher quality of service.

Figure 8 shows results for the blocking probability in the Business City Centre environment for $f = 0.4\%$ and different applications, while Fig. 8(b) presents results for the handover failure probability for the VOI application.

In this scenario, the trend for the percentage of call blocks, Fig. 8(a), is to increase as the cell radius increases. There is, however, some strange behavior for $R = 255$ m and for $R = 405$ m. Although the curves from Fig. 8(b), are very irregular the handover failures occur for high number of active users. The minimum coverage distance is chosen among all applications, and taken as the optimum coverage distance, R_{opt}, for a given f. It is determined when the QP overcomes the 1% bound, as presented in Table 8.

Table 8 Cell radii versus supported fraction of active users for VOI, VTE and MWB

f [%]	VOI	VTE	MWB
0.1	442.5	**412.5**	442.5
0.2	**371.5**	376.1	373.9
0.3	**347.3**	371.4	371.0
0.5	219.9	**192.6**	222.8
1.0	109.0	**108.9**	114.5
1.5	106.0	**105.9**	106.8
2.0	**69.6**	69.6	73.5

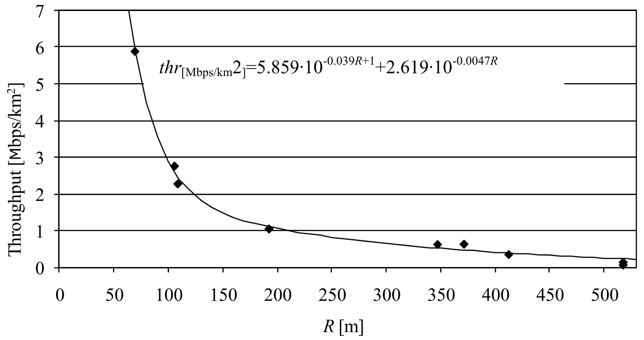


Fig. 9 Total system throughput as a function of R in the BCC scenario

As delay is not a limitation, the curve for the supported throughput considers only R_{opt}. As the area is variable, the supported throughput is premeasured in Mbps/km^2. By using a curve fit approach a curve for the supported throughput was found, Fig. 9. It is a decreasing function with R, and varies from ~6.0 Mbps down to ~400 kbps.

As the users are getting further from the BS, the BS has to increase the power in order to serve the same user, causing more interference while BS resources (power) become scarce. The throughput generated for this scenario is around 2.3 Mbps for $f = 1\%$, and the theoretical value for the traffic mix considered (27% for 12 kbps, 16% for 144 kbps, 26% for 384 kbps and 31% for 768 kbps) comes to 27.7 Mbps. The high expected throughput is a result of the high percentage of wideband traffic in the BCC scenario mix, which, is higher than in any other environment. However, the blocks, drops and the high call duration time (i.e. in a simulation run many high bit-rate connection, which are the longer, are not completely finished), which favors the lowest bit-rate users whose are the main reasons for this difference between the two values.

6 Cost/revenue analysis

6.1 Introduction

In order to optimize the network from the cost/revenue point of view, one obtains results for network optimization by using the model described in [15] of which is made a brief introduction. The system cost contains a fixed term, C_{fi}, that represents licensing and spectrum auction fees, and a term proportional to the number of BSs, $C_{fb\ [€]} \cdot N_{c/ula}$. Hence, the overall cost of the network per unit length or area, *ula*, per year is,

$$C_{0[€/ula]} = C_{fi\ [€/ula]} + C_{fb\ [€]} \cdot N_{c/ula}, \tag{6}$$

where C_{fb} includes the installation costs of the BSs including the cost of obtaining cell sites, the normal backhaul, and the cost of hardware and core equipment common to all (see (10)); and $N_{c/ula}$ is the number of cells per unit length or area. C_0 and C_{fi} are also given per *ula*. The estimation of the variation of system capacity, obtained for a given grade of service, is an input for the revenues. The revenue per cell per year, $(R_v)_{cell}$ can be obtained as a function of the throughput per BS, $thr_{BS[\mathrm{kbps}]}$, and the revenue of a channel with a data rate $R_{b\ [\mathrm{kbps}]}$, $R_{Rb\ [€/\mathrm{min}]}$, by

$$(R_v)_{cell\ [€]} = \frac{thr_{BS\ [\mathrm{kbps}]} \cdot T_{bh} \cdot R_{R_b\ [€/\mathrm{min}]}}{R_{b\ [\mathrm{kbps}]}}, \tag{7}$$

where T_{bh} is the equivalent duration of busy hours per day, as defined in [15, 16].

The revenue per unit length or area per year, $R_{v\ [€/ula]}$, is obtained by multiplying the revenue per cell by the number of cells per unit length or area

$$R_{v\ [€/ula]} = N_{c/ula} \cdot (R_v)_{cell\ [€]}. \tag{8}$$

6.2 Hypothesis

It is now important to present the main parameters that serve as an input to the model. The project duration is of 5 years, and we assumed a null discount rate. Costs and revenues are taken on an annual basis. It were considered six busy hours per day, 240 busy days per year,[6] and the revenue/price of a 144 kbps "channel" per minute (corresponding to the price of one MB, approximately), $R_{144\ [€/\mathrm{min}]}$. The revenue per cell can be obtained as

$$(R_v)_{cell\ [€]} = \frac{thr_{BS\ [\mathrm{kbps}]} \cdot 60 \cdot 6 \cdot 240 \cdot R_{144\ [€/\mathrm{min}]}}{144_{[\mathrm{kbps}]}}. \tag{9}$$

In the future, with equipment normalization and mass production, the equipment prices will get lower, and the channel prices will also get lower, making this kind of communication system more accessible. Table 9 considers several hypothesis for the price of the 144 kbps channel for the different scenarios.

Two hypotheses were made for costs (A [17] and B), Table 10. Costs are different for several scenarios, since the office scenario uses pico-cells, the urban one uses macro-cells and the BCC one uses micro-cells. $C_{fb\ [€]}$ can be determined by

Table 9 Hypothesis for $R_{144\ [€/\mathrm{min}]}$ for offices, urban and BCC scenario

	OFF	URB	BCC
$R_{144\ [€/\mathrm{min}]}$	0.02	0.01	0.10
	0.005	0.05	0.05
	–	0.10	0.025

$$C_{fb\ [€]} = \frac{C_{BS} + C_{Inst}}{N_{year}} + C_{M\&O}. \tag{10}$$

The profit, P_{ft}, an important result to optimize the network, is given by the difference between the revenues and the costs, in €/*ula*, while the profit in percentage is given by the net revenue normalized by the cost, i.e.,

$$P_{ft\ [\%]} = \frac{R_{v\ [€/\mathrm{km}]} - C_{0\ [€/\mathrm{km}]}}{C_{0\ [€/km]}} \cdot 100_{[\%]}. \tag{11}$$

We consider the profit in percentage instead of the absolute profit because this is a more relevant metric for operators and service providers.

6.3 Optimization and profit

6.3.1 Offices

The offices scenario has a linear geometry with two levels, i.e., two rows of offices (located side by side) along a central corridor, see Fig. 1. In this geometry, with an area $w \times l$, where w is the width and l is the length, and BSs are alternately located inside offices at each side of the corridor, Fig. 1. The number of cells per hectometer is given by

$$N_{c/\mathrm{hm}} = \frac{l_{[\mathrm{hm}]}}{R_{[\mathrm{hm}]}} - 1, \tag{12}$$

where $l_{[\mathrm{hm}]} = 1$. Fig. 10(a) presents results for the overall cost per unit length per year, $C_{0\ [€/\mathrm{hm}]}$, and the revenue per unit length per year, $R_{v\ [€/\mathrm{hm}]}$, for the cases $R_{144\ [€/\mathrm{min}]} = 0.02$ and 0.005. By comparing revenues in hypothesis A (for costs), one concludes that, for the lowest values of revenues, i.e., $R_{144\ [€/\mathrm{min}]} = 0.005$, the costs are higher than revenues, while for $R_{144\ [€/\mathrm{min}]} = 0.02$ revenues clearly overcome costs.

Figure 10(b) presents the profit in percentage per unit length. By analyzing these curves, optimum/maximum values, around 30–32 m, are only found for hypothesis B, the case of lower costs. By varying $R_{144\ [€/\mathrm{min}]}$ from 0.005 to

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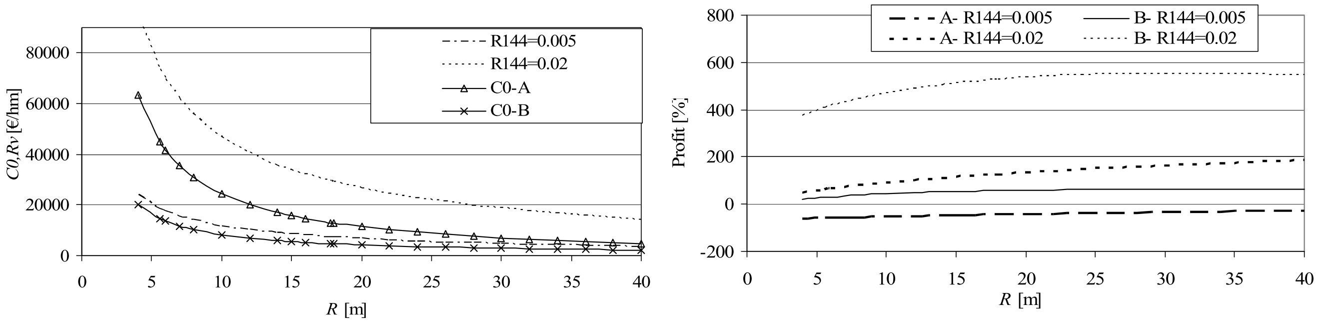
[6] http://b-bone.ptinovacao.pt/.

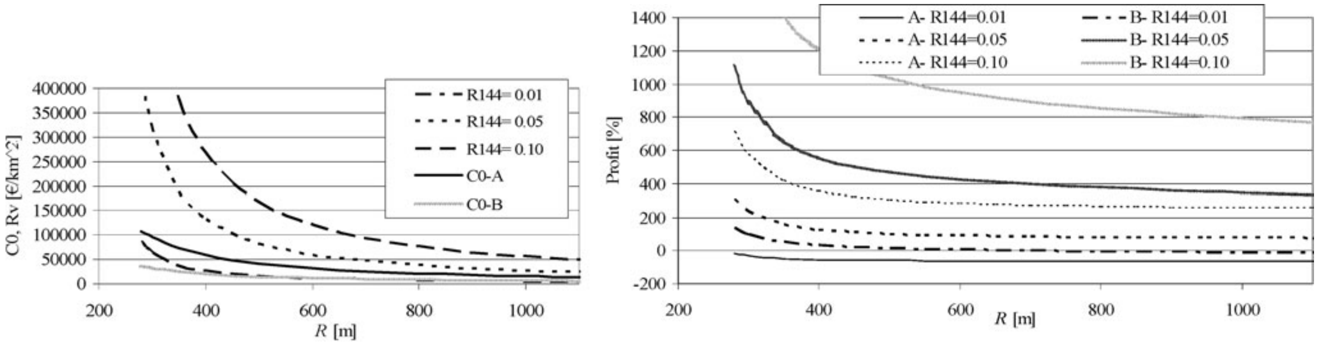
Table 10 Hypothesis for costs

Parameters	Pico-cell		Macro-cell		Micro-cell	
	A	B	A	B	A	B
Initial Costs:						
BS price, C_{BS} [€]	5000	2500	50,000	25,000	8000	3200
Installation, C_{Inst} [€]	3000	250	30,000	2500	2490	208
License fees, C_{fi} [€/*ula*]	1000	1000	1590	1590	1590	1590
Annual Cost:						
Operation and maintenance, $C_{\mathrm{M\&O}}$ [€]	1000	250	3000	750	750	188



(a) (b)

Fig. 10 Office scenario: (**a**) costs and revenues per unit length as a function of *R*, and (**b**) profit per unit length as a function of *R*



(a) (b)

Fig. 11 Urban scenario: (**a**) costs and revenues per km^2 as a function of *R*, and (**b**) profit per km^2 as a function of *R*

0.02 there is no significant variation on the optimum coverage distance but the profit increases about eight times, from 63% to 552%. If hypothesis A is considered, i.e., higher costs, no optimum coverage distance was found in the range of the simulations. Furthermore, profit is negative when $R_{144\ [€/\mathrm{min}]} = 0.005$.

Although in hypothesis A the reduction of cells size is not profitable (even if there is a need to support a given system capacity), results from case B shows that a higher number of pico-cell can be installed in the future, when costs of deploying and maintaining the network will decrease, enabling the support of higher system capacity.

6.3.2 Urban

In the urban scenario, the 2D cellular geometry is arbitrary and it has to cover an area of 4 km^2. The number of BS per km^2 can be obtained by using

$$N_{c/\mathrm{km}^2} \cong \frac{1}{-0.0168 + 2.7729 \cdot 10^{-5} \cdot R^{1.3674}}. \tag{13}$$

Figure 11(a) presents costs/revenues per km^2, as a function of *R*, when three wideband amplifiers are used. The case $R_{144\ [€/\mathrm{min}]} = 0.01$ is the only one with negative profit. Figure 11(b) presents the dependence of the profit in percentage on the cell radius for three amplifiers per BS. In this case, it can be observed that the curves have a decreasing behavior. The most profitable cell radius is 257 m (the lowest simulated one). By varying the price from $R_{144\ [€/\text{min}]} = 0.01$ to $R_{144\ [€/\text{min}]} = 0.05$ and to $R_{144\ [€/\text{min}]} = 0.10$, a variation in the profit from -18% up to 308% and to 716% is obtained, respectively (in hypothesis A).

6.3.3 BCC

The BCC scenario represents the system behavior in a Manhattan geometry outdoor environment with microcells and omni-directional antennas. This kind of geometry allows a linearized analysis in which the number of cells per kilometer is

$$N_{c/\text{km}} = \frac{1}{2 \cdot R_{[\text{km}]}}, \tag{14}$$

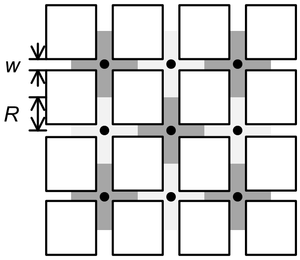
where R is the cell radius. However, in order to get a correspondence between the two geometry types, a cell composed by two street portions with length equal to $(2R - w/2)$ and with w must be considered, Fig. 12.

This linearization corresponds to considering the total length of the several orthogonal streets. Consequently, the number of cells per kilometer will be given by

$$N_{c/\text{km}} = \frac{1}{2 \cdot R_{[\text{km}]} - \frac{w_{[\text{km}]}}{2}}. \tag{15}$$

It is important to notice that the buildings block dimensions change with R, since the side length is $(2R - w)$, causing a variation in the streets area, what does not occur in reality. However, the linearized curves of costs and profits of the network, presented in Fig. 13 are not affected, since only the street length is considered, instead of the area [15].

Fig. 12 Manhattan geometry linearization

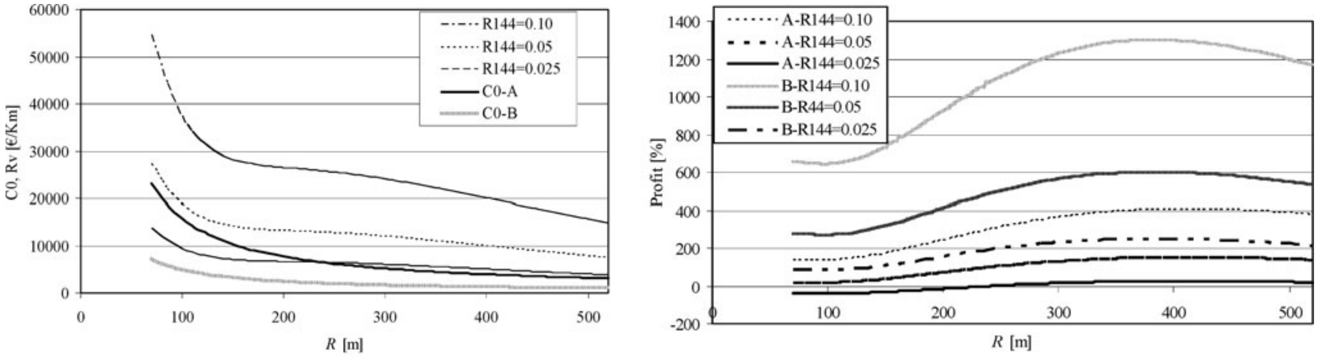


By considering the hypothesis for the price per minute of Table 8, the hypothesis for costs from Table 9 and $C_{fi\ [€/\text{km}]} = 1590/5 = 318$ €/km (5 years), the curves for revenues, costs and profit in percentage were obtained for the several hypotheses, Fig. 13.

The optimum values for the profit in percentage are obtained for $R \approx 425$ and $R \approx 395$ m, for hypothesis A and B, respectively. For $R_{144\ [€/\text{min}]} = 0.10$ the profit takes a value near 400%, for hypothesis A, and of 1300 €/min for hypothesis B. The results clearly indicate that coverage distances of 395–425 m should be used to optimize E-UMTS by having into consideration the maximization of the profit in percentage. However, if extra cells are needed to increase system capacity, lower coverage distances can be considered, maximizing the net revenue (i.e, the difference between the revenues and costs) for coverage distances lower than ~130 m.

7 Conclusions

Future 3.5G systems have to be able to support current communication applications as well as new ones, with different capacity and requirements. In this paper an all-IP Enhanced-UMTS is considered, where enhancements include link level behavior, HSDPA channel, resource management, Diffserv architecture, and Radio Resource Management schemes. In this paper, an overview of E-UMTS deployment scenarios and service needs was presented. Along with deployment and mobility scenarios, including expected population density and usage of service mix were considered for three environments, namely office, urban, and city center.



(a)

(b)

Fig. 13 BCC scenario: (**a**) costs and revenues per km has a function of R, and (**b**) profit per km as a function of R

E-UMTS traffic generation and activity models were described and characterized, based on population and service penetration values. By considering these scenarios and characterizations, system level simulations were carried out and the enhanced performance, including call blocks, handover failures, end-to-end delays, and throughputs is demonstrated in several deployment scenarios. The results have shown that the proposed models are quality-efficient as the block and failure percentages as well as the delay measurements are within acceptable limits for the given simulation scenarios (although some handover failure limitations occur in the office scenario because of the small cell size). Furthermore, the obtained throughput for each scenario is within expectation when compared to the theoretical ideal values. Therefore, by using system level simulation, identified services and environmental conditions can be mapped into deployment strategies and evaluated prior to field trials and real implementation.

In the offices scenario, the profit (in percentage) was obtained, and the optimum (most profitable) cell radius was found. We observe that the profit is highly dependent on costs. Although the reduction of cells size is not profitable in the case of high costs (even if there is a need of extra system capacity), numerical results for low values of the costs show that a higher number of pico cells (with a smaller radius, around 30–32 m) can be installed in the future when costs of deploying and maintaining the network decreases, enabling higher system capacity while reducing prices.

In the urban/vehicular scenario the profit is generally a decreasing function with R. As a consequence the most profitable cell radius is the lowest simulated one, i.e., 257 m.

In the BCC scenario a quality parameter was introduced that simultaneously accounts for blocking and handover failure probabilities. Different hypothesis for costs and prices were considered, and an optimum coverage distance is obtained around 410–440 m. Although this range of cell radius maximizes the supported throughput per BS. In BCC E-UMTS, the results for the profit in percentage indicates that coverage distances in the range 395–425 m should be used.

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