Urban Cellular Planning Optimisation of Multi-service Enhanced UMTS Based in Economic Issues

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Abstract. Results for Enhanced UMTS (E-UMTS) cost/revenue optimisation are obtained, as a function of the coverage distance, R. E-UMTS traffic generation and activity models are described and characterised in an urban scenario based on population and service penetration values. By using a System Level Simulator results were obtained for blocking and handover failure probabilities. Models for the supported fraction of active users and for the supported throughput, as a function of active users, were obtained. When one amplifier is used, the maximum throughput per BS is around 600kb/s. However, it achieves values up to 2000kb/s when three amplifiers per BS are considered. Generally, the profit in percentage is a decreasing function with R. The use of three amplifiers per BS is strongly advised in order to get cheaper communications, with prices that vary from 0.016 to 0.07 €/min, for R=250 and 1075m, respectively.

1 Introduction

UMTS (Universal Mobile Telecommunications System) has an enormous potential in answering to the challenge of supporting heterogeneous traffic like data, video, audio, and multimedia communications together with voice in all kind of environments. However, because of limitations of the first releases of UMTS, innovations have to be sought, e.g., for making higher data rates available in both links. HSDPA/HSUPA (High speed downlink/uplink packet access) seek for these solutions, and IST-SEACORN (Simulation of Enhanced UMTS Access and Core Networks) proposed a so-called, E-UMTS (Enhanced UMTS), which is a UMTS evolution step that provides bit rates higher than 2 Mbit/s in the uplink and downlink directions over a 5 MHz frequency carrier [1]. 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. E-UMTS will allow for expansion in both down- and uplink directions, e.g., by using higher order modulations or advanced coding schemes. Hence, it will support wideband real-time (RT)/time-based (TB) mobile applications with a very high system capacity, and will set the ground for an initial introduction of actual broadband mobile applications, an important step towards 4G. Since the proposed enhancements have not yet been implemented, the only practical way to evaluate their effect is by means of simulation.

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From the SEACORN scenarios [2], in this work only the urban scenario, with two BSs (Base Stations) configuration is explored, with slightly different assumptions for service usage, Table 1. The data rate, R_b, and average duration, τ, are also defined in Table 1. The traffic model is based on population and service penetration values, in order to determine call generation rates for the constituent services within the scenario. Service characteristics of the corresponding applications, i.e., intrinsic time dependency, delivery requirements, directionality, and symmetry/asymmetry were extracted from [3], [4]. Examples of sound, high interactive multimedia (HIMM), narrowband (NB), and wideband (WB) applications are VOI (Voice), VTE (Video-telephony), MWB (Multimedia, MM, Web Browsing), and ATR (Assistance in Travel), respectively.

Table 1. Applications Usage in the Urban Scenario

Services	R_b [kb/s]	*Usage* [%]	τ [min]	Distribution of activity/inactivity	Activity duration	
					ON [s]	OFF [s]
Sound Voice (VOI)	12.2	82.5	3	Exponential	1.4	1.7
High Inter. Multimedia Video-telephony(VTE)	144	11.0	3	-	10	10
Narrowband MM Web browsing (MWB)	384	2.0	15	Pareto	10	13
Wideband Assistance in travel (ATR)	768	4.5	15	Weibull/Pareto	10	10

Session activity parameters describe the detailed aspects of traffic within a call. This is accomplished by means of an alternating ON/OFF state model. The activity within a call can be modelled by defining an average duration of each period, together with an adequate statistical distribution (e.g., reflecting long-range dependence).

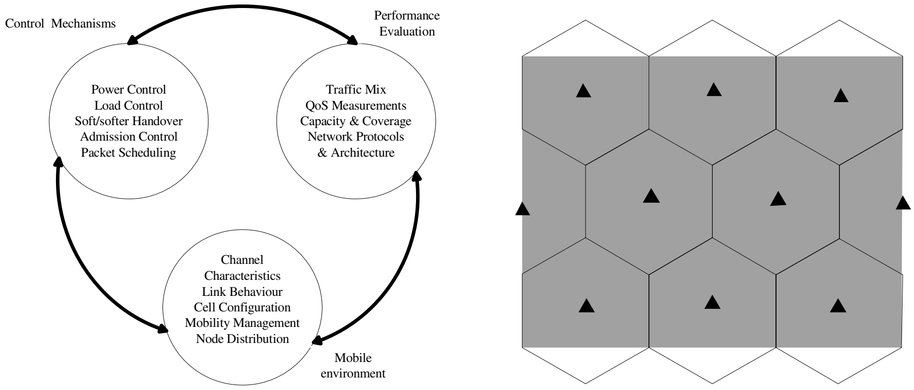
The purpose of this work is to optimise the cellular planning process for multi-service E-UMTS in urban scenarios by using results for system capacity as an input for a cost/revenue function, e.g., to choose the best coverage distance of cells. Similar results are presented in [5] for the offices scenario.

In Section 2, the urban scenario is characterised and the main features of the system level simulator are described. Section 3 presents results for the blocking and handover failure probabilities when one amplifier per tri-sectorial BS is used. In Section 4, the process of determination of system capacity is addressed for both BS configuration, one and three amplifiers per BS. In Section 5, a cost/revenue model is proposed and described, and its particular application to the urban scenario is presented. Section 6 discusses results regarding costs/revenues, and the optimisation of the coverage distance (that maximises the profit in percentage). Finally, conclusions are presented in Section 7.

2 Traffic Modelling and Simulations

The activity within a call is modelled by defining an average duration of each active/inactive period, together with an adequate statistical distribution. For example, the basic model for data applications normally uses a Web session as a paradigm, although the model may be used for all types of data. A session is composed of a set of active periods made of packet sequences (packet calls) separated by inactivity periods. A packet call is a sequence or burst of packets, corresponding, e.g., to a Web page or other data item. Inactivity periods between packet call arrivals are often called reading or inactivity time.

A simulation approach is being considered, and the SEACORN SLS (System Level Simulator [6], [7], [8]) is used. It captures the dynamic end-to-end behaviour of the whole network, including the dynamic user behaviour (e.g., mobility and variable traffic demands), radio interface, radio access network, and core network. The SLS is separated into three modules: mobile environment, control mechanisms, and performance evaluation, Figure 1.a). This separation is made according to their functionality. Control mechanisms involve PC (power control), CAC (call admission control), handover control, load control, and packet scheduling. PC consists of open-loop PC and inner-loop PC, outer-loop PC in both UL (uplink) and DL (downlink) directions, and slow PC applied to the DL common channels. When a new call is required, the CAC checks if there is an OVSF (Orthogonal Variable Spreading Factor) code, and PC checks if there is enough power. Hard handover is the only one supported by the simulator. The scheduling algorithm is the Drop Tail (FIFO) queuing one. Details on load control and packet scheduling are given in [8].



a) SLS modules

b) Urban environment

Fig. 1. Modular View of the System Level Simulator and cellular topology

The mobile environment category contains the methods of generating a topology for a scenario as well as the initialization or redefinition of node properties. Node Bs and user equipments (UEs) are distributed in a predefined grid that represents the simulation area. For the basic simulator the cells are initially assumed to be circular with equal radius but it can be extended to hexagonal (or other) patterns.

Performance evaluation will consider the network traffic model, the network protocols and architecture from the network and transport level simulations, and scenarios for traffic services and applications. Network performance must enable the evaluation of coverage, capacity, Radio Resource Management (RRM) mechanisms, protocols, architectures, and QoS (using metrics such as call blocking, call/packet dropping, and end-to-end packet delay).

Several factors influence the performance including the coverage and capacity, i.e., mobility, QoS demands, radio environment, plus radio and core network control mechanisms. For example, the distance between the User Equipment (UE) and the Node-B, the path loss, and the power control mechanisms affect the coverage. Capacity is affected by traffic and handover mechanisms. Interference affects both coverage and capacity. QoS is affected by the different network architectures, protocols, and Radio Resource Management (RRM) mechanisms. These factors are addressed by simulations at network and transport levels. The basic algorithm for system level simulations is presented in [9]. Enhancements are mainly applied to the radio link, and to the IP infrastructure. These enhancements include Multi-path Interference Canceller, MPIC, Space Time Transmit Diversity, STTD, and MIMO systems [8].

The topology of the urban scenarios consists of several BSs, using tri-sectored antennas, and two different hypothesis are considered: one and three wideband amplifiers. Several values were tested for cell radius so that a 4km^2 area is covered in an efficient way, Figure 1.b).

The mobility model used for the urban vehicular environment is the Gauss-Markov mobility one. This is an entity mobility model as it defines individual but not group movement patterns. The pattern is confined within the predefined grid area. As in all mobility models, the users are confined within this area and return to a point inside the topology when they reach the boundaries. The Gauss-Markov model is defined to be between the random walk (slow speeds) and the fluid flow (very high speeds) models. The two models, random walk and fluid flow, are labelled as extremes. Most of the nodes move somewhere in-between those speeds. Parameters for the Gauss-Markov model include the mobile speed at 50km/h (13.89m/s), and a random seed, a number that is fed into a random number generator, which allows that this model can assign pseudorandom paths to the mobile users. The Radio Propagation model is the Hata propagation one [7].

The traffic mix model defined for this environment generates traffic according to predefined usage percentages, Table 1 and assigns an application to each user accordingly. Each user in the urban scenarios has a probability to be active. This is determined by the Busy Hour Call Attempts (BHCA) provided as a set of bounds for the percentage of active users in a simulation run. Busy hour call attempt represents in this case the total number of call attempts by all users considered in one simulation

$$BHCA_j = \frac{Usage_j}{\tau_j} \cdot M_T \cdot \rho \ , \tag{1}$$

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 can vary from 0 to 1. In simulations, one considers one fourth of the user density given in [2], i.e., 0.012/4; this reduction is owing to limitations of the simulator, which did not support higher user densities. Hence, in an area of 4000000m^2, M_T =4000000m^2×0.012/4=12000. The fraction of active users, f, is obtained from the average traffic per user as $f = \rho/(\rho+1)$. In the urban scenario, one considers the following values: f=0.7, 0.8, 1.7, 2.3, 3.4, 4.3, and 5.2%.

3 Results for Quality of Service

Quality of service results were obtained by using the SEACORN SLS for a maximum transmitted power of 16dBW. The aim is to get the best cell radius in order to guarantee a certain grade of service (GoS). The considered QoS measures are blocking probability, P_b, and handover failure probability, P_{hf}. The first set of results include the blocking probability, where an analysis of all classes of services together, a so-called "total services" approach, is considered. While in this analysis the results for the various applications are not distinguished, a "detailed services" one can be defined, which discriminates the classes of services. Figure 2 presents results for the "total services" approach.

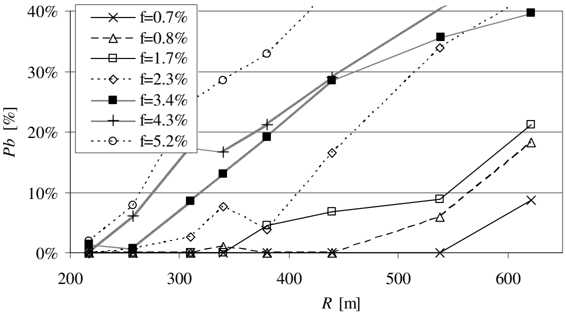


Fig. 2. Blocking probability for *f*=0.7, 0.8, 1.7, 2.3, 3.4, 4.3 and 5.2%, "total services"

It is a worth noting that the mechanisms involved in new calls blocking are CAC (Call Admission Control) and PC (Power Control), which test the power thresholds, and the existence of OVSF codes. In the context of an all IP network, the most common way to treat users is to queue them instead of blocking. However, for services with real time QoS requirements, an admission control algorithm has to be implemented. It is necessary to maintain desired QoS, especially for RT/TB services. Regarding GoS, the blocking probability has to be lower than 2% [2]. By analysing Figure 2, the acceptable radius, R_a, is obtained by using a linear intersection with P_b=2%. Figure 3 presents results for each individual class of service in the "detailed services" approach. By using the same procedure as for the "total services" approach, one obtains the correspondence between f and R_a, the acceptable cell radius for a given P_b. Table 2, presents results for both approaches. Although the results for ATR are presented in Figure 3, these results are not considered in Table 2, as ATR is a Non-RT application, and the simulation algorithm obtains it in an almost straightforward way. For NRT applications, blocking probability has low influence in QoS since establishing a connection will be transparent for users, and will not be delay sensitive.

HO (Handover) is one of the major characteristics of mobile systems. Its influence in QoS is proportional to its intensity/ rate. The smaller is the cell radius and the higher is the user mobility, the higher is the handover intensity/rate. The SEACORN SLS only considers hard handover. Besides, it considers three base stations in the active set; a user is dropped only after six unsuccessful attempts to make handover. Figure 4 presents results for P_{hf} as a function of the cell radius, and also for P_{hfmax}, the handover failure probability threshold, for the "total services" approach. Figure 5 presents results for P_{hf} as a function of the cell radius for the "detailed services" approach.

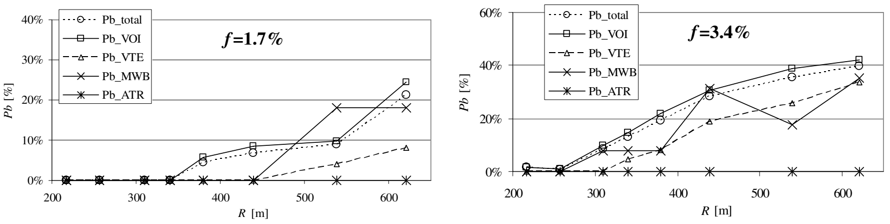


Fig. 3. Blocking probability, example for f=1.7 and 3.4%, "detailed services"

Table 2. Acceptable cell radiuses considering P_b constraints

$f_{[\%]}$	*Pb_total*	*Pb_VOI*	*Pb_VTE*	*Pb_MWB*
0.7	557	552	621	621
0.8	472	473	550	447
1.7	358	354	488	458
2.3	293	285	317	385
3.4	266	264	323	271
4.3	230	228	280	274
5.2	218	217	269	267

The variation of the maximum allowed P_{hf}, P_{hfmax}, with the coverage distance, is also presented in each case, it being different for each application. P_{hfmax} is computed from the simulation results by using $P_{hfmax}=P_{dmax}/Nb\_HO_j$, where Nb_HO_j is the number of handovers per application j call/session, and the value of the maximum call dropping probability is $P_{dmax}=1\%$ [10]. By adding BSs to the topology, although the network capacity increases, the number of handovers per call also increases. Then, small cell radius may not be the solution which better satisfy handover failure probability requirements. This is true in particular for RT/TB calls/sessions, like VOI, VTE and MWB, as a call being dropped causes extreme dissatisfaction to the users.

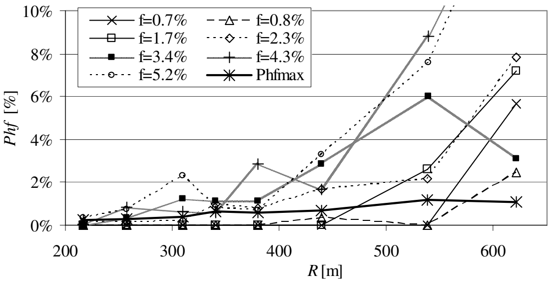


Fig. 4. Handover failure probability for f=0.7, 0.8, 1.7, 2.3, 3.4, 4.3 e 5.2%, "total services"

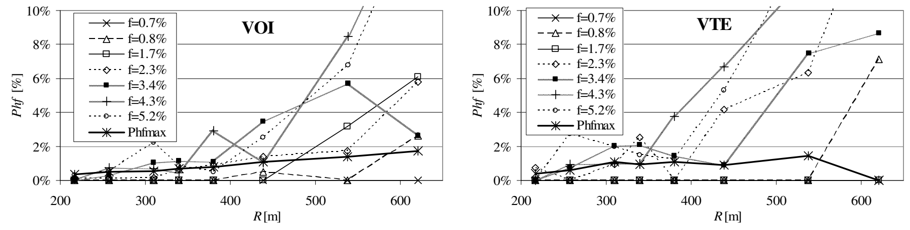


Fig. 5. P_{hf} for VOI and VTE, f=0.7, 0.8, 1.7, 2.3, 3.4, 4.3 e 5.2%, "detailed services"

Hence, when analysing Figures 4 -5 for several values of f, the most appropriate cell radiuses, R_{ap}, agreeing with handover failure constraints, have to be chosen, Table 3.

Table 3. The most appropriate cell radius agreeing considering P_{hf} constraints

$f_{[\%]}$	*Phf_total*	*Phf_VOI*	*Phf_VTE*	*Phf_MWB*
0.7	555	621	621	621
0.8	577	588	552	621
1.7	471	476	621	538
2.3	322	350	395	341
3.4	256	271	247	258
4.3	227	239	239	311
5.2	217	238	224	256

4 System Capacity

Although results for QoS were only presented when one amplifier is considered, the same analysis was performed for three amplifiers, and the respective results for system capacity will be presented in this Section. Only the "detailed services" approach is being addressed since it seems to be the most accurate one. Taking a worst case situation between P_b and P_{hf} GoS constraints into account, by using an inversion procedure, the most suitable f was found for each value of R, Figure 6. By using a curve fit approach, curves for the supported f were found:

- one amplifier $f=1/(-0.38192+0.00072\cdot R^{1.24156})$,
- three amplifiers $f=1/(-0.15486+1.27916\cdot 10^{-04}\cdot R^{1.34116})$.

By considering these results for $f(R)$, the system throughput, $thr_{[\mathrm{Mb/s}]}$, can be extracted from simulation results, for the same values of R, Figure 6.

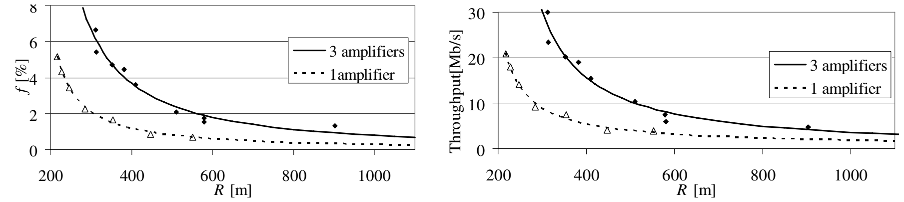


Fig. 6. Supported fraction of active users and total throughput as function of cell radius, R.

Once more, by using a curve fit approach, the curve for the supported throughput can be found (downlink), which presents a decreasing behaviour:

- one amplifier $thr=1/(-0.22620+0.00790\cdot R^{0.65905})$,
- three amplifiers $thr=1/(-6.42541\cdot 10^{-02}+1.61696\cdot 10^{-04}\cdot R^{1.10393})$.

Hence, as the cell radius increases system capacity decreases. This decreasing behaviour of system capacity is the normal trend, although it can be noticed that there is a high decreasing tendency up to 400-500m, after this coverage distances there is a tendency for the throughput to be constant. By doing an analysis of the throughput per BS, Figure 7, each base station reaches maxima of 600kb/s and 2000kb/s, for $R\approx 217$ and 250m, for one and three amplifiers, respectively. When the cell radius is low the high value of the throughput per BS can be explained due to the fact of users being closer to the BS can easily be served; they transmit with low power (by using Power Control algorithms) causing low interference to each other. However, for cell radius higher than 400m, if the same power were used, owing to the higher distance from users to BSs, more blocks would occur; hence, users have to transmit with a high power level, causing higher interference. As a consequence, BSs have to make more power available for each user, and resources vanish more rapidly [11].

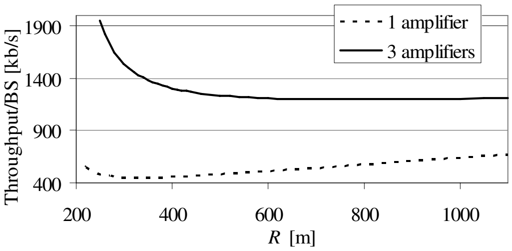


Fig. 7. Throughput per BS as function of R

5 Cost/Revenue Model

In this work, we consider the operator/service provider's point of view [12]. In urban scenarios, a cost/revenue function was developed taking into account the cost of building and maintaining the infrastructure, and the way the number of channels available in each cell affects operators' revenues. Fixed costs for licensing and bandwidth auctions should also be taken into account. Although one considers a project duration of five years as a working hypothesis, one will analyse costs and revenues on an annual basis. Furthermore, the analysis is made under the assumption of null discount rate [13]. Note however that appropriate changes would be needed to perform a complete economic analysis based on discounted cash flows (e.g., to compute the net present value).

The system costs includes a fixed term that represents the fixed costs, C_f, and one term proportional to the number of base stations, C_b (although there is a term proportional to the number of carrier of a base station, in this work approach, only one carrier is considered, and this is incorporated in C_b).

The total cost per unit area is given by

$$C_{[\text{€/km}^2]} = C_{f\,[\text{€/km}^2]} + C_{b[\text{€}]} \cdot N_{cell/km^2}\ , \tag{2}$$

where N_{cell/km^2} is the actual number of cells per square kilometre in the simulated geometries. The revenue per cell per year, $(R_v)_{cell}$ can be obtained as a function of the throughput per BS, $thr_{\text{BS [kb/s]}}$, and of the revenue of a channel with a data rate $R_{b[\text{kb/s}]}$, $R_{Rb[\text{€/min}]}$,

$$(R_v)_{\text{cell [€]}} = \frac{thr_{\text{BS [kb/s]}} \cdot T_{bh} \cdot R_{R_b}[\text{€/min}]}{R_{b[\text{kb/s}]}}\ , \tag{3}$$

where T_{bh} is the equivalent duration of busy hours per day. The revenue per square kilometre per year, R_v, is obtained by multiplying the revenue per cell by the number of cells per square kilometre

$$R_{v[\text{€/km}^2]} = N_{cell/km^2}(R_v)_{cell\ [\text{€}]} = N_{c/km^2} \cdot \frac{thr_{BS[\text{kb/s}]} \cdot T_{bh} \cdot R_{R_b[\text{€/min}]}}{R_{b[\text{kb/s}]}}\ . \tag{4}$$

By considering six busy hours per day, 240 busy days per year [13], T_{bh}=6·240·60min, and the revenue/price of a 144kb/s "channel" per minute (corresponding to information truly transferred, i.e., obtained by discounting the off periods of the traffic), $R_{144[\text{€/min}]}$, the revenue per square kilometre can be obtained as

$$R_{v[\text{€/km}^2]} = \frac{1}{-0.0168 + 2.7729 \cdot 10^{-5} \cdot R^{1.3674}} \cdot \left(\frac{thr_{BS[\text{kb/s}]} \cdot 60 \cdot 6 \cdot 240 \cdot R_{144[\text{€/min}]}}{144_{[\text{kb/s}]}} \right), \tag{5}$$

where

$$N_{c/km^2} = \frac{1}{-0.0168 + 2.7729 \cdot 10^{-5} \cdot R^{1.3674}}\ , \tag{6}$$

gives the number of cell in a 4km^2 area. Three hypothesis have been considered for the revenue/price of a 144kb/s channel: $R_{144[\text{€/min}]}$=0.01, $R_{144[\text{€/min}]}$=0.05 and $R_{144[\text{€/min}]}$=0.10. As the transfer of 1 MB of information lasts 56s at 144 kb/s, R_{144} corresponds approximately to the price of a 1 MB transfer. Two different assumptions (hypothesis A [14], and B) were also considered for the cost of tri-sectorial BSs with one and three wideband amplifiers, Table 4. One also assumes that the maximum lifetime of BS is five years.

Table 4. Assumptions for costs

Parameters	Macrocell (three amplifiers)		Macrocell (one amplifier)	
	A	*B*	*A*	*B*
Initial Costs:				
BS price, C_{BS} [€]	50 000	25 000	20 000	10 000
Installation, C_{Inst} [€]	30 000	2 500	30 000	2 500
License fees, C_{fi}[€/km^2]	1 590	1 590	1 590	1 590
Annual Cost:				
Operation and maintenance, $C_{M\&O}$	3 000	750	3 000	750

6 Optimisation

The left hand side of Figure 8 presents costs/revenues per km^2 as a function of R for the three hypotheses for prices and for the two hypothesis for costs, for the case of one wideband amplifier. For $R_{144[€/\mathrm{min}]}$=0.01, in case A costs are always higher than revenues, while in case B cost are equal to revenues; while in the first case the network profit is negative, in the second case it is null. For $R_{144[€/\mathrm{min}]}$=0.05, while in case B there is clearly profit, for case A the profit is approximately zero. For $R_{144[€/\mathrm{min}]}$=0.10, the network is always being profitable since revenues always overcome costs.

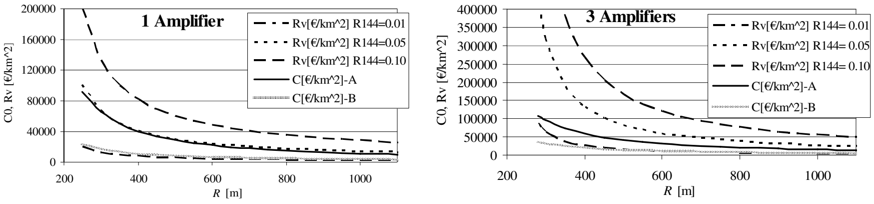


Fig. 8. Costs/revenues per km^2 as a function of R, one and three amplifiers per BS

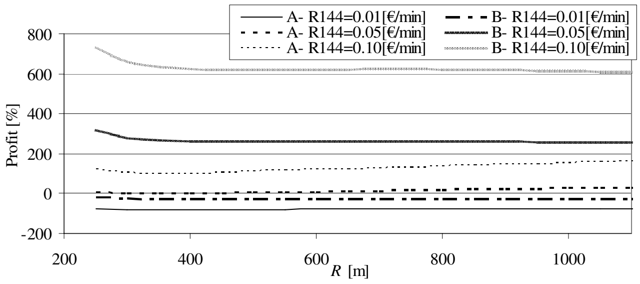


Fig. 9. Profit per km^2 as a function of R (one amplifier)

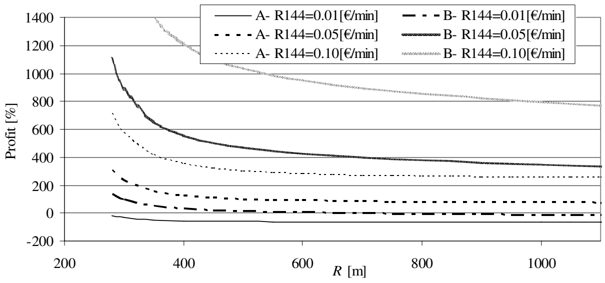


Fig. 10. Profit per km^2 as a function of R (three amplifiers)

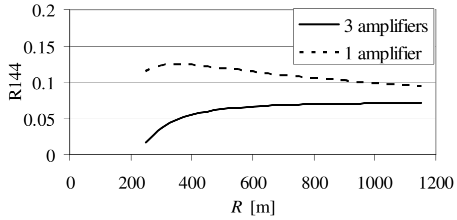


Fig. 11. Required $R_{144[€/min]}$ to obtain a profit of 250%

The right hand side of Figure 8 presents costs/revenues per km^2, as a function of *R*, when three wideband amplifiers are used. The same hypotheses are considered for prices and costs. The case $R_{144[€/min]}$=0.01 is the only one with negative profit.

Figure 9 presents the dependence of the profit in percentage on the cell radius for one amplifier per BS. It can be observed that the curves present a decreasing behaviour for case B and an increasing behaviour for case A. Hence, for one amplifier the most profitable cell radius will be 217m (the lowest simulated one) for hypothesis B, and 621m (the highest simulated one) for hypothesis A. By varying the price from $R_{144[€/min]}$=0.01 up to $R_{144[€/min]}$=0.05, or to $R_{144[€/min]}$=0.10, a variation in the profit from -78% up to 9%, or to 119% is obtained in hypothesis A (for *R*=621m) .

Figure 10 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 behaviour. The most profitable radius will be 257m (the lowest simulated one). By varying the price from $R_{144[€/min]}$=0.01 to $R_{144[€/min]}$=0.05, or to $R_{144[€/min]}$=0.10, a variation in the profit from -18% up to 308%, or to 716% is obtained (in hypothesis A).

If the objective is to obtain a profit of 250% for both configurations, the respective price, R_{144}, presents the variation from Figure 11. When the coverage distance varies from 217 to 1075m, the values of $R_{144[€/min]}$ converge to a limit between 0.07-0.09 €/min. However, for the smallest cell radius, $R_{144[€/min]}$ can be very low when three amplifiers are used, meaning that the amount of traffic required has to be high to provide low cost services.

7 Conclusions

The SEACORN System Level Simulator incorporates a E-UMTS traffic generation model, which was applied to an urban environment to obtain Quality of service results, such as blocking and handover failure probabilities. By using these results, models for the supported fraction of active users, and for the supported throughput, as a function of *R*, were found for a given GoS. These models were found for different BS configurations: with one and three amplifiers per tri-sectorial BS.

When the cell radius decreases, the supported traffic and the corresponding throughput increases. However, it occurs at the cost of a significant increase in the number of BSs. There is an optimum of 600kb/s for the throughput per BS around *R*=217m when one amplifier per BS is used, and of 2000kb/s around 250m when three amplifiers per BS are used.

By using a cost/revenue model, where revenues depend on the throughput, one concludes that the profit is generally a decreasing function with *R*. The use of three amplifiers per BS is strongly advised in order to get cheaper mobile network access with prices that vary from 0.016 €/min, for R = 250m, up to 0.07 €/min, for R=1075m.

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