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ENHANCED UMTS CELLULAR PLANNING FOR MULTIPLE TRAFFIC CLASSES IN OFFICES SCENARIOS

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ABSTRACT

It is shown that Enhanced UMTS will be an affordable solution for providing the required network quality and to reduce infrastructure investments in offices scenarios. System capacity results are obtained by using a system level simulator which considers traffic characterisation parameters and services usage in detail, among other. Results for the most profitable cell radius are obtained via an optimisation procedure based in economic aspects. 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, allowing for supporting higher system capacity, and reducing prices. Our approach is based in a detailed services analysis, which represents a worst case situation relatively to the total services approach, because the later does not discriminate results for the different traffic classes. The impact of call blocking, handover failure, end-to-end delay, and delay variation are taken into account.

I. 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, including the indoor business ones, such as offices, airports, commercial zones, etc, where it presents some advantages relatively to IEEE 802.11, e.g., seamless connection to outdoor 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 all-IP evolution step that provides bit rates higher than 2 Mbit/s in the uplink and downlink directions over a 5 MHz frequency carrier [1]. In indoor hotspots, there are limitations coming from high interference and the inter-dependence between capacity and coverage. A solution to overcome this problem can be to deploy a large number of pico cell, which will guarantee better coverage and higher system capacity.

In order to optimise E-UMTS networks and make simulation-based cellular planning tools available for network design, economic aspects, in the form of cost/revenue functions, are an essential issue. They will also allow for the quantification of the viability of E-UMTS in comparison with IEEE 802.11. By using the SLS (System Level Simulator) developed within the SEACORN project [1], worst case studies were considered in simulations that represent 200s of actual time, which last from several hours to several days to run.

In this work, we optimise cellular planning of E-UMTS based in a cost/revenue analysis considering in detail multiple classes of service. Differently from [2], where only total services as a whole are considered, we consider QoS (Quality of Service) for each application in detail. Besides we ran several simulations, improving the level of accuracy.

Section II presents the scenarios and the parameters to be used in simulations. Section III presents the main characteristics of the SLS, some QoS measures at call level and at packet level, the supported fraction of active users, and the throughput. In Section IV, a cost/revenue model is presented, and optimisation of E-UMTS coverage distances is achieved in offices scenario. Finally, conclusions are drawn in Section V.

II. SCENARIOS AND PARAMETERS

From the IST-SEACORN scenarios [3], in this work only the offices scenario and classes of service up to wideband are taken into consideration, Table 1, with slightly different assumptions. The data rate, R_b, and average duration, τ, are also defined in Table 1. Session activity parameters describe the detailed aspects of traffic within a call. Furthermore, 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. Table 2 presents the service characteristics of the corresponding applications: intrinsic time dependency, delivery requirements, directionality, symmetry/asymmetry [4]. Examples of sound, HIM (high interactive multimedia), NB (narrowband), and WB (wideband) applications are VOI (Voice), VTE (Video-telephony), MWB (Multimedia Web Browsing) and IMM (Instant Messaging for Multimedia), respectively.

Table 1: Proposal for application usage in offices.

Services and applications	R_b [kb/s]	Usage [%]	τ [min]	Distri-bution	Activity	
					ON[s]	OFF[s]
Sound-VOI	12.2	58.0	3	Expon.	1.4	1.7
HIM-VTE	144	22.3	3	-	τ	0
NB-MWB	384	8.0	15	Pareto	5	13
WD-IMM	768	11.7	15	Weibull	5	90

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Table 2: Enhanced UMTS service characteristics.

Applica-tions	Intrinsic time dependency	Delivery requirements	Directio-nality	Symmetry / Asymmetry
VOI	TB	RT	Bid	Sym
VTE	TB	RT	Bid	Sym
MWB	TB	RT	Bid	Asy
IMM	TB	NRT	Bid	Asy

TB-time-based; NTB-non-TB; RT- real-time; NRT-Non-RT, Bid-bidirectional.

E-UMTS optimisation can be achieved by seeking optimum values of a merit function taking into account both costs and revenues. The optimisation of costs and revenues provides a mean of joining together several contributions from cellular planning. From the IST-SEACORN scenarios [3], an offices scenario with omni directional pico-BS, a maximum power of 3 dBW was chosen. Additional parameters used in this scenario are described in Table 3. A floor with 140 m x 60 m, is considered as shown in Fig. 1, and 1260 users (corresponding to a density factor of 0.15 user/m^2 [4]). The mobility model used for the office environment scenario is the Random-Waypoint mobility model. The model defines a pattern of movement for each user individually. This pattern is confined within the predefined grid area and consists of a sequence of movements in the x or y direction due to the environment, Fig.1.

Each node in the model is randomly assigned a pause time between 0 and the maximum pause time (200 s). Every node waits for the pause time, some not having a pause time in the 200 s of simulation. Then, a random location is chosen on the map, and the mobile moves toward that location with a fixed speed of 3 km/h (0.83 m/s), a typical pedestrian speed. The average ratio of room to corridor mobile terminals is 85%. Extra details on the mobility model are presented in [5].

Table 3: Parameters used in the offices scenario [2].

Handover Threshold	3 dB
Active set number	3
Downlink orthogonality	0.9
PC range	65 dB
Power control step size	1 dB
BS Noise figure	8 dB
MS noise figure	5 dB
Noise rise over thermal noise	3 dB
Log-normal shadowing ”slow fading”	10 dB
Fast fading margin (means PC headroom)	4 dB
Max BS Tx power (W)	33 dBm
UE transmit power class	+33, 27, 24, 21(default) dBm
Average tx. power per traffic channel, downlink	10 dBm Pico
Average tx. power per traffic channel (uplink)	4 dBm
Duration of Simulations	200s
Number of runs	5

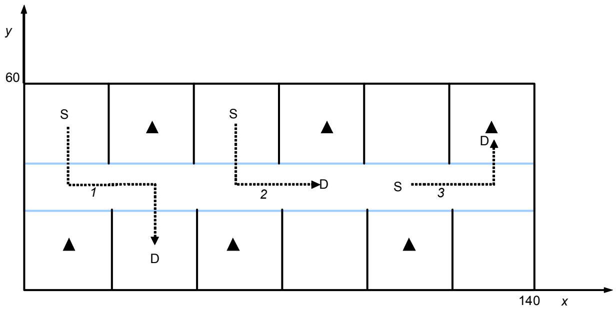

Figure 1: Offices topology (triangles represent BSs).

III. CAPACITY ESTIMATION

A. *System Level Simulations*

The SEACORN simulator is a SLS (System Level Simulator) [5], [6], [7] that captures the dynamic end-to-end behaviour of the all network, including the dynamic user behaviour (e.g., mobility and variable traffic demands), radio interface, radio access network, and core network, at an appropriate level of abstraction. The SLS is separated into three parts: mobile environment, control mechanisms, and performance evaluation [6]. 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 code, and if there is enough power, PC. Hard handover is the only one supported by the simulator. Details on load control and packet scheduling are given in [8]. Enhancements to UMTS are mainly applied to the radio link and the IP infrastructure. These enhancements include Multi-path Interference Canceller, MPIC, Space Time Transmit Diversity, STTD, and MIMO systems.

When the cell radius decreases more BSs are needed to cover the same area, Table 4.

Table 4: Cell radius 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

In order to find the maximum capacity of the network, a certain QoS needs to be guaranteed, and one considers call level and packet level groups of parameters.

B. *Call level*

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. The admission control is necessary to maintain desired QoS, specially to the real time services. At call level, the parameters considered to analyse system capacity are blocking and handover failure probabilities. Call blocking probability, P_b, is defined as the ratio between the number of blocked calls and the total number of call attempts, while the handover failure probability, P_{hf}, is the ratio between the number of handover failures and the number of handover attempts.

In the SLS, call blocking and handover failure occur in the context of the implementation of two mechanisms: CAC (Call Admission Control) and PC (Power Control). This two mechanisms test if there are OVSF codes available to support the required data rate and thresholds of power.

The offices scenario involves several classes of services. As only one carrier is considered, the bandwidth is shared among classes. In such situation, due to different characteristics of each class of service, the QoS performance needs to be analysed separately for each one, Table 2. Blocking probability is only being considered for real time/time based applications.

The first set of results include the blocking probability as a function of the cell radius, R, for the fraction of active users, f=12.4%, for several applications, Table 1, and also for the blocking probability, P_b, when all the services are not discriminated, P_{b_total}, Fig. 2, example for f=12.4%.

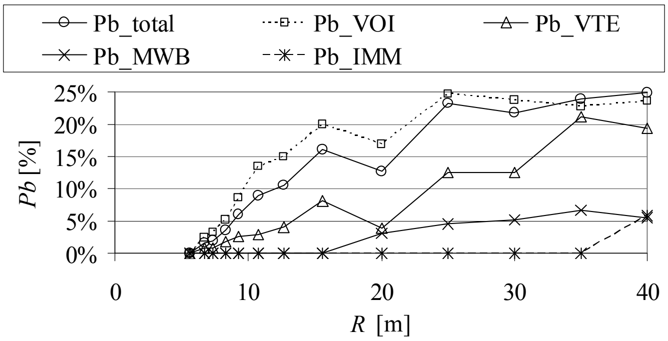

Figure 2: P_b as a function of the coverage distance for f=12.4%.

By considering a GoS of P_b=2%, for f=12.4%, the acceptable cell radiuses, R_a, are 6.5, 8.6, 18.4 and 36.7m for VOI, VTE, MWB and IMM, respectively. While R_a is obtained according to blocking probability constraints, R_{ap} agrees with handover failure probability constraints.

HO (Handover) is one of the major characteristics of mobile systems. Its influence on QoS is proportional to its intensity/ rate. The smaller is the cell radius and higher is the mobility of users, the highest is the handover intensity/rate, Fig. 3, example for VOI and VTE. The SLS only considers hard handover.

A user is dropped only after six unsuccessful attempts to make handover. In order to find the maximum acceptable P_{hf}, P_{hfmax}, the model described in [9] was considered, and a maximum call dropping probability of 1% was assumed.

P_{hfmax} is computed by using

$$P_{hfmax}=\frac{P_{d\max}}{Nb\_HO_j}, \tag{1}$$

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%.

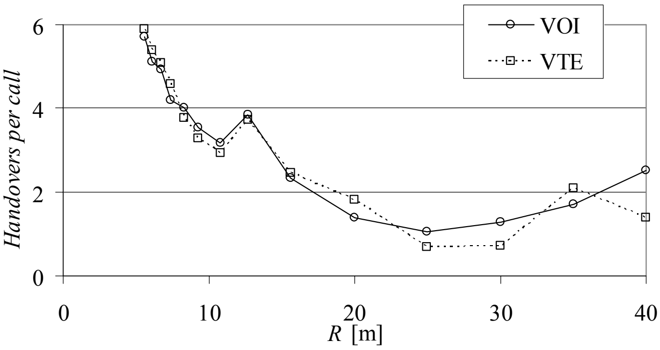

Figure 3: Number of Handovers per call for VOI and VTE.

Fig. 4 presents results for P_{hf} as a function of the cell radius, example for VOI application, and for f=4.1, 8.2, 12.4 and 16.5%. The variation of P_{hfmax} with the coverage distance is also presented for each application.

By adding BSs to the topology, although the network capacity increases, the number of handovers per call also increases, Fig. 3. 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. A call being dropped causes extreme dissatisfaction to the users. Hence, when analysing Fig. 4, for VOI, the most appropriate cell radiuses, R_{ap}, are 39.3, 10.0, 6.5 and 5.6 m for f=4.1, 8.2, 12.4 and 16.5%, respectively. The most appropriate cell radiuses, R_{ap}, for other applications are presented in Table 5.

Table 5 presents a summary of the results of R_a and R_{ap} for the various applications. Voice is the most limitative one.

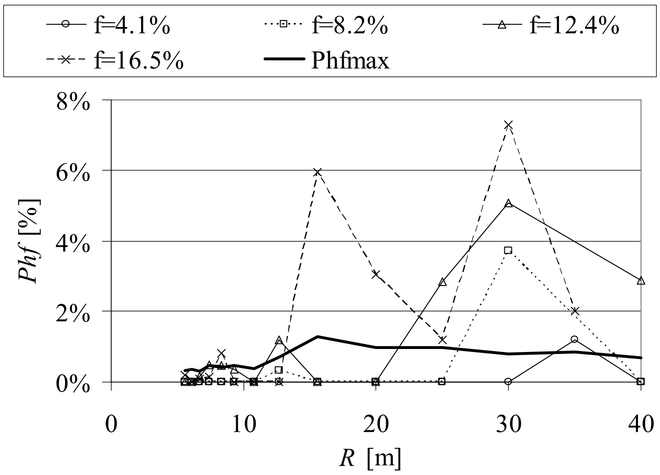

Figure 4: P_{hf} for VOI.

Table 5: Cell radiuses 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	**33.4**	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	

C. *Packet level*

The communications between different entities of an all-IP network result from sending/receiving IP packets. In E-UMTS, PDP contexts are defined to make this packet exchange possible. Each PDP context exists either during the packet transmission/reception states or in standby state [10]. The packet level parameters that are being considered to evaluate system capacity are packet delay, and delay variation.

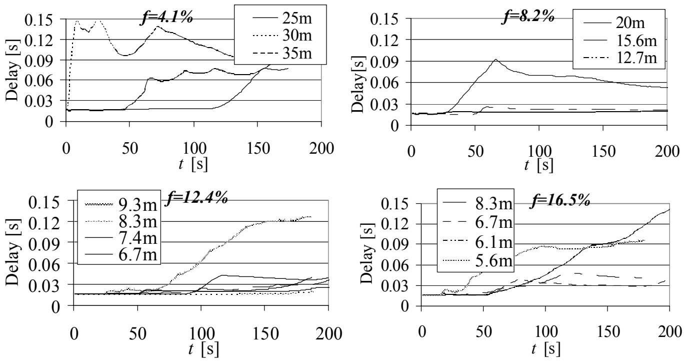

Figure 5: Delay for f=4.1, 8.2, 12.4 and 16.5 % for several values of R.

Regarding GoS, the maximum acceptable values for latency (end-to-end delay) is 150 ms. From the simulation results, one can observe that the maximum values for latency do not overcome the threshold. Regarding delay variation, values never overcome 1ms, being also bellow the acceptable limits.

D. *System Capacity*

Taking a worst case situation between the GoS constraints for P_b, P_{hf}, delay, and delay variation into account (which correspond to the worst case between P_b and P_{hf}, in practice, Table 5), by using an inversion procedure, the most suitable f for each value of R was found, Fig. 6.

By using a curve fit approach, a curve for the supported f can be found, $f_{[\%]}=0.4995R^{-0.6992}$. From analysis made in [2] the supported f, was $f_{[\%]}=0.4614R^{-0.6669}$, identified by *total services* in Fig. 6, corresponds to an analysis taking all the services simultaneously into account, and only considers P_b constraints. The lower values obtained in the detailed services approach correspond to a more accurate approach, since the blocking probability of wideband class of service is not considered as it is a NRT application. The lower values for the supported fraction of active users, in comparison with the ones of the total services (P_b_only) approach from [2], are due to the use of additional QoS measures. As a consequence, the acceptable radius slightly decreases. Note that, in this work, the curve for the supported f for the total services differs from the one presented in [2] by a factor of 4.12 because here one presents the actual f, while in [2], the curve refers to an auxiliary f, used as an input to the SLS. However, they correspond to the same set of results. Another aspect resulting from the detailed analysis regards VOI, which seems to be the application with more problems, and limits cell radius. This occurs since bad results for the blocking probability are shared by other applications, which have lower blocking probability; in Fig 2, P_{b_VOI} is always above P_{b_total}. The same occurs for the corresponding handover failure probability.

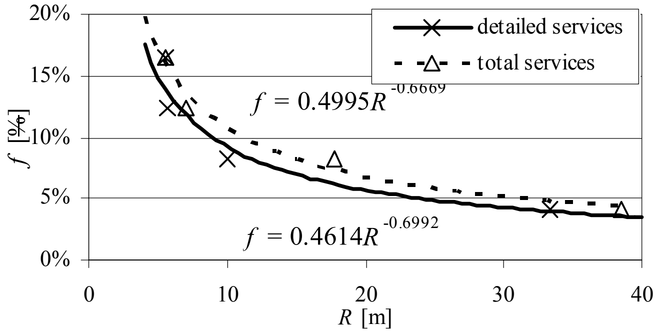

Figure 6: Fraction of active users as function of cell radius.

By using these curves for $f(R)$, the total throughput, $thr_{[\mathrm{Mb/s}]}$, can be extracted from the simulation results, Fig. 7. By using a curve fit approach, the curve for the supported throughput in the downlink can be found, $thr_{[\mathrm{Mbit/s}]}=32.368R^{-0.759}$, which also presents a decreasing behaviour.

The results between the detailed services (from this work) and the total services, P_b_only, approaches (from [2], where the curve is $thr_{[\mathrm{Mbit/s}]}=37.145R^{-0.7225}$) can be compared. As the supported f is lower, the supported throughput is also lower.

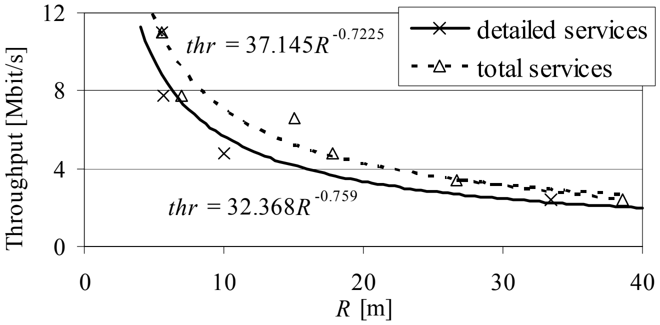

Figure 7: Total throughput of the system as function of R.

IV. NETWORK OPTIMISATION BASED IN COST/REVENUE

In order to optimise the network from the cost/revenue point of view, one obtains results for network optimisation by using the model described in [2]. Although the project duration is five years [11], [12], the costs and revenues will be taken in an annual basis. In the offices topology, Fig. 1, the number of cells per hectometre is given by

$$N_{c/\mathrm{hm}}=\frac{1}{R_{[\mathrm{hm}]}}-1 . \qquad (2)$$

The system cost contains a fixed term, C_{fi}, and a term proportional to the number of BSs, C_{fb}. So, the overall cost of the network per unit length per year is [8], [13]

$$C_{0\,[€/\mathrm{hm}]}= C_{fi[€/\mathrm{hm}]} + C_{fb\,[€]} \cdot N_{c/hm} . \qquad (3)$$

Regarding revenues, one considers the price per minute of a connection at a given data rate, e.g., 144 kb/s; hence, the price per minute that corresponds to a given throughput is obtained by multiplying the revenue per minute for a 144 kb/s transfer by the ratio between the total throughput, in kb/s, and 144kb/s. 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.

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, $thr_{\text{BS [kb/s]}}$, and the revenue of a channel with a data rate $R_{b\text{[kb/s]}}$, $R_{Rb\text{[€/min]}}$, by

$$(R_{\text{v}})_{cell\,\text{[€]}}=\frac{thr_{\text{BS[kb/s]}}\cdot T_{bh}\cdot R_{R_b\text{[€/min]}}}{R_{b[kb/s]}}, \tag{4}$$

where T_{bh} is the equivalent duration of busy hours per day.

The revenue per hectometre per year, R_v, is obtained by multiplying the revenue per cell by the number of cells per hectometre

$$R_{\text{v[€/hm]}}= N_{c/hm}\cdot(R_{\text{v}})_{cell\,\text{[€]}}. \tag{5}$$

The net revenue, R_n, in €/hm/year, is obtained by the difference between the revenues and costs per year, and results from (3) and (5). If R_n is positive there is profit.

Taking costs and revenues on an annual basis, and considering six busy hours per day, 240 busy days per year [8], and the revenue/price of a 144 kb/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 hectometre can be obtained as

$$R_{\text{v[€/hm]}}=\left(\frac{1}{R_{\text{[hm]}}}-1\right)\cdot\left(\frac{thr_{BS\text{[kb/s]}}\cdot 60\cdot 6\cdot 240\cdot R_{144\text{[€/min]}}}{144_{\text{[kb/s]}}}\right). \tag{6}$$

The prices of information transfer at different data rates can be computed proportionally, and two hypothesis have been assumed: $R_{144\text{[€/min]}}$=0.02 and $R_{144\text{[€/min]}}$=0.005. Two different assumptions (hypothesis A [9], and B) were also considered for the cost of pico cell BSs, Table 6. One also assumes that the maximum life-time of equipment, e.g., BSs is N_{year}=5 years.

$C_{fb\,\text{[€]}}$ is calculated by

$$C_{fb\text{[€]}} = \frac{C_{BS}+C_{Inst}}{N_{year}} + C_{M\&O}. \tag{7}$$

Fig. 8 presents results for the overall cost per unit length per year, $C_{0\text{[€/hm]}}$, and the revenue per unit length per year, $R_{\text{v[€/hm]}}$, for the cases $R_{144\text{[€/min]}}$=0.02 and 0.005, for both approaches. Comparing revenues in hypothesis *A* (for costs), one can conclude that for the lowest values of revenues, $R_{144\text{[€/min]}}$=0.005, the costs are higher than revenues, while for $R_{144\text{[€/min]}}$=0.02 revenues clearly overcome costs.

Table 6: Assumptions for base station costs.

Parameters	*Values* [€]	
	A	*B*
Initial Costs:		
BS price, C_{BS}	5000	2500
Installation, C_{Inst}	3000	250
License fees	1000	1000
Annual Cost:		
Operation and maintenance, $C_{M\&O}$	1000	250

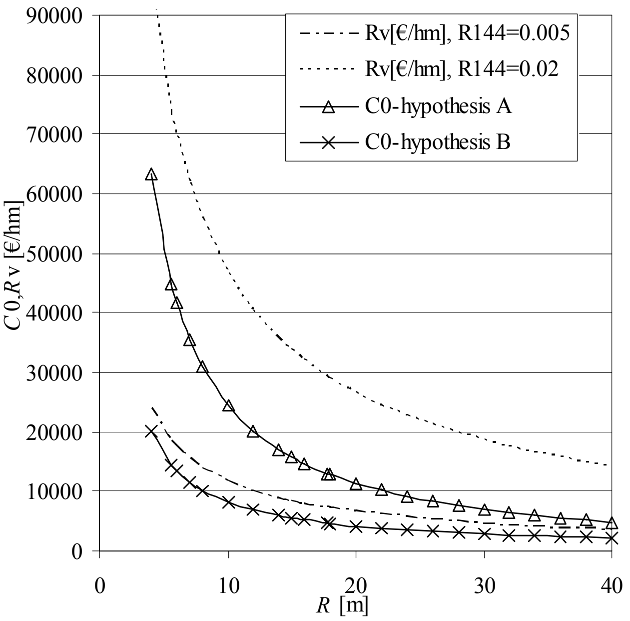

Figure 8: Network revenue/cost per unit length per year as, a function of *R*.

Using hypothesis *B*, the revenues are always higher than the costs. Another important result that can be obtained is the profit, P_{ft}, in percentage.

$$P_{ft\text{[€/hm]}}=((R_{\text{v}})_{\text{cell[€]}}-C_{0\,\text{[€/hm]}})/(C_{0\,\text{[€/hm]}}). \tag{8}$$

Fig. 9 presents the curves for profit. Optimum/maximum values for the profit (in percentage) are only found for hypothesis B, the case of lower costs, for both approaches.

By analysing Fig. 9, the optimum value for the cell radius is around 30-32m. By varying $R_{144\text{[€/min]}}$ from 0.005 to 0.02 there is no significant variation on the optimum coverage distance but the profit increases about eight times, from 63% to 552%. Although in [2] the supported fraction of active users is higher, the difference of optimal cell radius is minimal, 34-35m.

Using hypothesis A, i.e., higher costs, no optimum coverage distance was found in the range of the simulations. Furthermore, profit is negative when $R_{144\text{[€/min]}}$= 0.005.

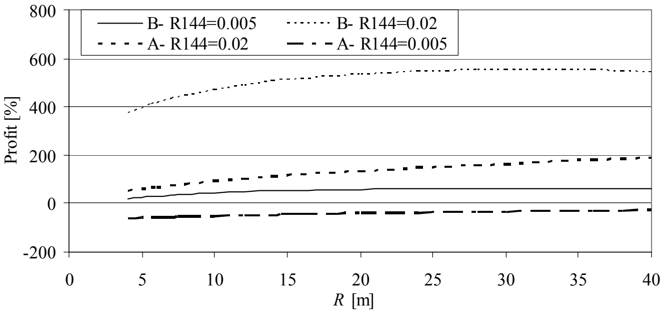

Figure 9: Profit per unit length per year, in percentage, for hypothesis A and B, and different $R_{144\text{[€/min]}}$.

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 optimum cell radius pico cell can be installed in the future, when costs of deploying and maintaining the network will decrease, allowing for supporting higher capacity. In this case (hypothesis B) because revenues will increase considerably prices will not need to be so high.

V. CONCLUSIONS

Based in E-UMTS traffic characterisation, values for services usage, and by using a SLS, in this paper, we start by obtaining system capacity results for the offices scenario in the presence of multiple traffic classes. Then, we address the optimisation of cellular planning by using a model for costs/revenues, which allows for the determination of revenues and costs per hectometre, per year. Revenues are proportional to the supported throughput. The detailed services approach represents a worst case situation; hence it is more adequate than the total services one (presented in [2]).

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 in the case of higher costs the reduction of cells size is not profitable (even if there is a need of extra system capacity), results for lower costs shows 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, allowing for supporting higher system capacity, and reducing prices. Although slightly lower profits are achieved in comparison with the approach from [2], the optimum coverage distances are similar.

One future challenge to improve our approach consists in joining together all QoS measures for all services, and one possibility will be to propose a weighted function that joins together the several QoS measures for all services.

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