Cost/Revenue Optimisation of Multi-service Cellular Planning for City Centre E-UMTS

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Abstract— An overview of All-IP Enhanced Universal Mobile Telecommunication System, E-UMTS, service needs in the business city centre, BCC, scenario is first presented. Then, E-UMTS traffic generation and activity models are described and characterised. System level simulations are carried out and the enhanced performance is demonstrated based in a single quality parameter, which simultaneously accounts for call blocking and handover failure probabilities. End-to-end delays do not present a limitation. By considering a grade of service of 1% for the quality parameter, and different hypothesis for costs and prices, an optimum coverage distance is obtained around ~200-425 m, which maximises the supported throughput per km^2. However, results for the profit in percentage indicates that coverage distances in the range 395-425 m should be used in BCC.

Keywords — Cost/revenue optimisation, business city centre, cellular planning, Enhanced UMTS, system capacity.

I. INTRODUCTION

Enhanced UMTS, E-UMTS, is a UMTS evolution step which provides bit rates higher than 2 Mbit/s 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], 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 in both 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 ubiquitous and seamless mobile applications [2] with a very high system capacity, and will set the ground for an initial introduction of actual broadband mobile applications.

While, in the Wireless Local Area Network, WLAN, domain, high capacity is becoming possible with IEEE 802.11a, b, g, etc., in the mobile communications domain, E-UMTS will be a first step to achieve this goal. Furthermore, with the use of a wider range of devices with various radio interfaces, E-UMTS will be the first 3.5G system to support values of capacity comparable to the ones needed for broadband mobile applications, which implies that a capacity of the order of Gbit/s/km^2 will be available, and will allow for the introduction of the Always Best Connected, ABC, concept [3] even before the introduction of Orthogonal Frequency Division Multiplexing/Wideband Code Division Multiple Access, OFDM/WCDMA, and Ultra Wideband, UWB, systems for 4G. In this context, instead of being a competing technology, E-UMTS will be complementary to the various types of WLANs (and other radio and access technologies).

Since the enhancements proposed in E-UMTS have not yet been totally implemented, the only practical way to evaluate the effect of the proposed enhancements is by means of simulation. For that purpose a set of services needs to be used, in order to create a complete and realistic simulation framework, impacting directly on traffic generation models. These services will be accessed from a variety of operation environments each with its distinctive set of service preferences, usage patterns, and associated mobility profiles. As an answer to these services and environmental conditions a matching set of deployment strategies was studied, adapted, and simulated.

The usage of each application, i.e., the percentage of applications connections relative to the total number of active applications, is one of the most important aspects to be determined. These data, together with source traffic characterisation models, is essential for multi-service traffic analysis and engineering purposes, and simulations as well. A range of twenty-eight applications and eight deployment environments was first considered in [4] for a complete scenario. This number was later integrated and condensed into a smaller but representative set of services and service environments to meet the technical demands of the simulation tools. Without this summarisation effort the framework proposed would pose considerable difficulties to implement due to the amount of computing resources it would require from simulators. A subset of services and environments are therefore selected in the business city centre, BCC, scenario, and four services were finally used. Although it is possible to define several types of applications/services classifications for UMTS, this paper focuses the third generation, 3G, QoS in the perspective of the UMTS Forum and Third Generation Partnership Project, 3GPP, which considers the following classes: conversational, streaming, interactive and background [5], distinguished by their delivery requirements, and intrinsic time dependency.

From the suggested BCC traffic mix, and the link layer enhancements, results can be extracted that focus on the

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assessment of QoS support in E-UMTS. A system level simulator was developed building on the publicly available simulation framework ns-2 (network simulator, version 2). New modules or additions to existing modules are developed to support the simulation of 3G and beyond UMTS and Enhanced UMTS networks. Representative performance evaluation results are presented to demonstrate how the system level simulator can be used for Enhanced UMTS performance evaluation and optimisation of network planning. A cost/revenue function was developed taking into account the cost of building and maintaining the infrastructure, and the way the available resources in each cell affects operators' revenues. Fixed costs for licensing and bandwidth auctions (or 'beauty contests') should also be taken into account. The economic analysis is referred as a cost/revenue performance analysis because optimising costs do not necessarily mean optimising net revenues.

This paper is organized as follows. Section II first presents the business city centre, BCC, scenario, including expected population density, and expected usage of service mix. The activity behaviour of each application is described, and a quality parameter is introduced. Section III introduces the parameters for system level simulations, and presents results for the quality of service, and throughput. By considering a threshold of 1% for the quality parameter, the supported throughput per km^2 and per Base Station, BS, is obtained as a function of coverage distance. In Section IV, after presenting the cost/revenue model and its parameters, optimisation results are obtained by having the net revenue and the profit in percentage into account. Finally, conclusions are drawn in Section V.

II. E-UMTS SCENARIOS ANDTRAFFIC BEHAVIOUR

A. Application Mix

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

As a result, in SEACORN, three operation environments were considered with a mixture of four or five services each, depending on the environment: i) offices, OFF, an indoor scenario; ii) business city centre, BCC, the microcellular outdoor scenario which is addressed in this work, and iii) vehicular, VEH. In BCC the mobile units move along the streets, Fig. 1, and can change direction in crossroads following a certain probability. The position actualisation needs to be performed with some frequency, since pedestrian velocities are considered in this environment, an actualisation at each 5 m is reasonable. At each position actualisation, a velocity variation may occur according to a certain probability. A Manhattan topology with base stations, BSs, placed on crossings is often used to represent BCC scenarios, Fig 1. This model consists of a rectangular grid composed of intersecting streets, characterised by homogeneous square buildings with, e.g., 200 meters length, and streets with 30 meters width. It is also characterised by small areas with skyscrapers and a large density of users with pedestrian mobility [6]. The radio propagation model is the Walfisch propagation one [7], and omnidirectional antennas are used.

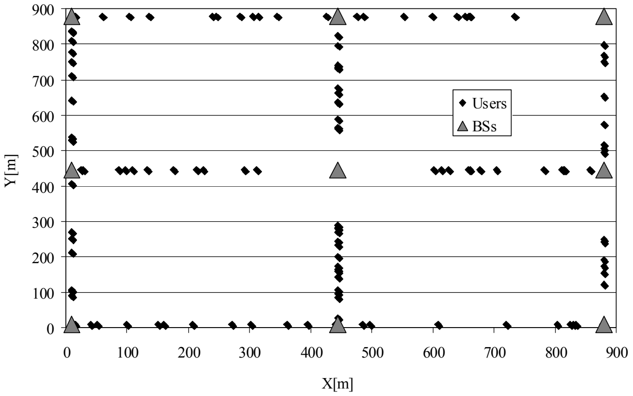

Fig. 1. Manhattan topology model.

Proposed applications and their relative usage are shown in Table I. This simple scenario is obtained from scenarios previously defined with tens of applications [8], by assuming, as a simplification, that the most significant application in a service group accounts for all the traffic usage in that group. Applications in each class are VOI, voice, VTE, Video-telephony, MWB, Multimedia Web Browsing, and HDT, High Definition Video-telephony. Table II presents the service characteristics of these applications (TB, time based, NTB, non TB, RT, real time, NRT, non real time, Bi-directional). In Table I, R_b represents the data rate for each of the considered applications while the usage is the percentage of E-UMTS applications users in BCC scenarios [8].

The model for traffic mix defined for these environments generates traffic according to the predefined usage percentages, and assigns an application to each user accordingly. Each user has a probability to be active which is determined by the Busy Hour Call Attempts, BHCA.

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

TABLE I
E-UMTS APPLICATIONS DATA RATE AND USAGE IN BCC.

Services and Applications	R_b [kb/s]	τ [min]	Usage [%]
Sound (e.g., VOI)	12	3	27
Multimedia (e.g., VTE)	144	3	16
Narrowband (e.g., MWB)	384	15	26
Wideband (e.g., HDT)	768	30	31

TABLE II
ENHANCED UMTS SERVICE CHARACTERISTICS [9].

Applications	Intrinsic time dependency	Delivery requirements	Directio-nality	Symmetry / Asymmetry
VOI	TB	RT	Bid	Sym
VTE	TB	RT	Bid	Sym
MWB	TB/NTB	RT	Bid	Asy
HDT	TB	RT/NRT	Bid	Asy

The model is based on population and service penetration values in order to determine call generation rates for the constituent services within each of the selected scenarios.

The activity within a call is modelled by defining an average duration of each active/inactive period, together with an adequate statistical distribution. The basic model for application data 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. Table III describes average active versus inactive durations, and presents the statistical distributions of the active and inactive durations. VTE is a permanent application with average duration τ=3 min.

TABLE III
APPLICATION ACTIVITY PARAMETERS.

Applications	Active state (ON)		Inactive state (OFF)	
	Avg.[s]	Distrib.	Avg.[s]	Distrib.
VOI	1.4	Expon.	1.7	Expon.
VTE	τ	Expon.	0	Expon.
MWB	5	Pareto	13	Pareto
HDT	60	Weibul	14	Pareto

B. Busy Hour Call Attempt

From the SEACORN values of usage for the BCC scenario, it is important to obtain, for each considered service, the values of the busy hour call attempts to be used in simulations. Busy hour call attempt represents in this case the total number of call attempts by all users considered in one simulation. They will correspond to the call attempts per unit time for the users covered by a radio cell or part of a cell

$$BHCA_j = \frac{Usage_j}{\bar{\tau}_j} \cdot M_T \cdot \rho, \tag{1}$$

where M_T is the number of users in the cell, $\bar{\tau}_j$ is the average call duration, and ρ is the average traffic per user, which can vary from 0 to 1 Erl. From the values for usage from Table I and applications average duration, taking a given user population, e.g., $M_T = 100$, it is straightforward to obtain results for BHCA as a function of ρ, as it has a linear dependence.

C. Grade of Service for Quality

Quality of service parameters include upper limits for latency or end-to-end delay, bit error rate, BER, and frame erasure rate, FER. The maximum allowed latency varies between 150 and 200 ms for voice and video-telephony applications, and 2-10 s for Multimedia Web Browsing. While the maximum allowed BER is 10^{-4} for voice and video-telephony applications it decreases down to 10^{-6} for the remaining applications. Regarding FER, a limit of 1-3% was defined for VOI, VTE and HDT.

Grade of service, GoS, aspects include blocking and handover failure probabilities. Specific recommendations exist from the International Telecommunications Union – Telecommunications, ITU-T. Recommendation E.771 [10] proposes a limit of one percent 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 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., one half of one percent (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 [11], where an upper limit of two percent was considered for call blocking. In this work, however, we consider a quality parameter, QP, that joins together the number of blocked setup attempts and handover failures in a unique QoS parameter [12]

$$QP = \frac{nb\_blocked\_call + 10 \cdot nb\_interrupted\_call}{total\_nb\_call}, \tag{2}$$

where *nb_blocked_call* is the number of blocked calls, *nb_interrupted_call* is the number of interrupted calls, and *total_nb_call* is the total number of calls. The threshold assumed for QP is a GoS of 1%, i.e., $QP \leq 1$. A lower grade of service corresponds to a higher quality of service.

The maximum setup delay varies between 15-20 s for voice, video-telephony and assistance in travel applications, and 60 s for the remaining ones. It corresponds to the worst case of an international call setup. Local calls require a setup delay under 10 s [10].

Concerning such services as Multimedia (MM) Web Browsing, an important issue is the definition of a blocked call since they 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 will be considered blocked whenever its maximum setup delay values are exceeded.

III. SYSTEM LEVEL SIMULATION AND SYSTEM CAPACITY

Due to the involved complexity, it is only possible to analyse the 3G/3.5G networks behaviour case by case, e.g., by using a simulation approach. The proposed scenarios were simulated in the event-based ns-2 system level simulator developed within SEACORN. Each simulation scenario is defined by a variety of parameters, including traffic, propagation and mobility models as well as topologies and user population. In the case of BCC, the parameters are the ones from Table IV.

The BCC scenario represents the system behaviour in a Manhattan geometry outdoor environment with microcells and omni directional antennas. Nine base stations were assumed, corresponding however to an equivalent area of five cells, Fig. 1. In simulations, some parameters varied in order to study its influence on the system performance. These parameters include the number of user, M_T, and the distance between base stations (n.b., the dimensions of the covered area depends on the coverage distance being therefore variable).

TABLE IV
SIMULATION PARAMETERS FOR THE BCC SCENARIO.

Parameters	Values
Average user velocity	3km/h
Minimum velocity	0km/h
Direction update	5m
Probability to change velocity in position update	0.2
Probability to turn in a crossroad	0.5
Number of base stations	9
Distance between base stations	[135, 885]m
Cell coverage distance	[67.5, 442.5]m
BS Antenna	Omnidirectional
Maximum BS Tx power	13dBW
Antenna gain	0 dBi
Number of users	[556, 20000]
Interval between successive calls	0.005s
Simulation time	3600s

Based on the scenarios and traffic characterisation described in previous sections, system level simulations were carried out for different ρs and cell radius, *R*s, by using different randomization to achieve more accurate results, and the enhanced performance was demonstrated in the downlink direction. The results were extracted by using our own scripts, developed in Java, and include call blocking and handover failure probabilities for the different classes of services, in a so-called “detailed services” approach. However, throughput, and end-to-end delays were extracted for the whole system.

The average over six simulation runs was computed for each metric presented below. Simulation lasted for a maximum of 3600 s of actual time but, in some cases, simulations crashed before it (mainly in cases with a heavy load). A reference geometry of 900x900 m was considered, and a population density of 6173 user/km^2 was assumed. As the coverage distance of cells varies, the simulated area also varied, and the number of users varied accordingly but keeping this fixed value for the density factor.

The computation of the most appropriate cell radius for each value of ρ, i.e., coverage distances corresponding to *QP*=1%, is very important for the determination of system capacity. As an example, Fig. 2 presents the curves for blocking probability, P_b, handover failer probability, P_{hf} and *QP* for the voice application, and the most appropriate cell radius is obtained for the coverage distance where *QP* achieves the value of 1%. Then, the minimum coverage distance among all applications is chosen and taken as the optimum coverage distance, R_{opt}, for a given ρ.

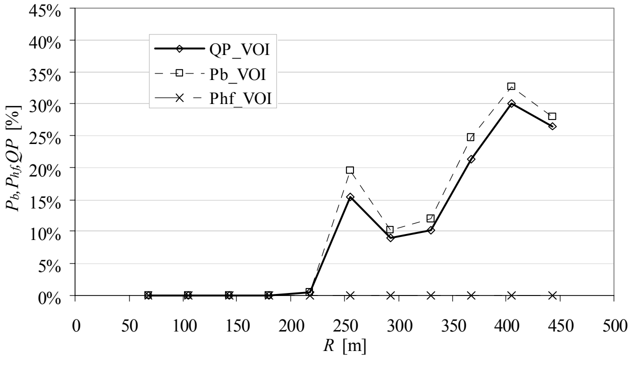

Fig. 2. Quality of service for voice, ρ = 0.005Erl.

Fig. 3 presents the curve for throughput for these values of R_{opt}, and presents its intersection with the curves of system throughput (for each value of ρ, varying from 0.00025 to 0.02 Erl) as well. This throughput corresponds to the geometry of nine cells presented in Fig. 1. Values for delay were below 25 ms, much lower than the 150 ms threshold.

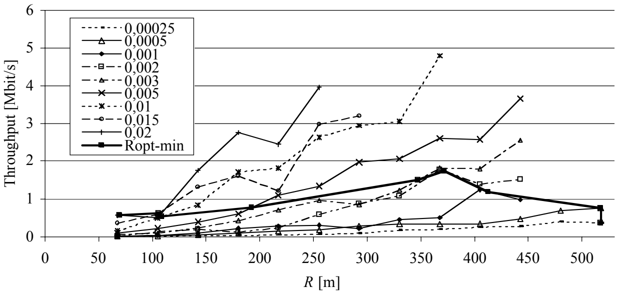

Fig. 3. Values of the throughout as a function of the optimum cell radius, with ρ as a parameter.

The throughput per cell is a measure of system capacity, and is obtained by dividing the system throughput by 5. The throughput per km^2 is obtained by multiplying the throughput per BS by the number of cell per km^2. A formula was obtained for its variation with *R* via a curve fit approach, Fig. 4. It is a decreasing function with *R*, and varies from ~6.0 Mbit/s down to ~200 kbit/s. However, this increasing behaviour while *R* decreases may not be advantageous if the cost of installing and maintaining extra BSs does not compensate. Fig. 5 presents the throughput per BS as a function of *R* (for *QP*=1%).

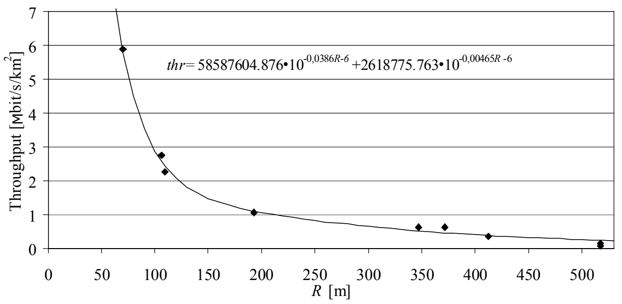

Fig. 4. Throughout per km^2 as a function of the cell radius.

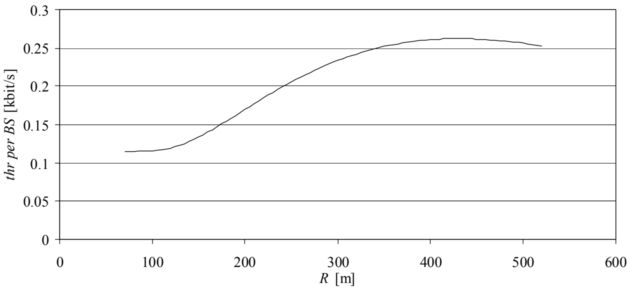

Fig. 5. Throughput per BS as a function of the cell radius.

Each BS achieves a maximum throughput of ~0.26 Mbit/s for $R \approx 440$ m. In the initial part of the curve, as the coverage distance increases the interference decreases. Then, for coverage distances higher than the one corresponding to the maximum throughput per BS, coverage problems arise.

IV. COST/REVENUE ANALISIS

In this work, we consider the operator/service provider's point of view [13]. A cost/revenue function was developed for the BCC scenario, 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 [14]. By no means is it intended to perform a complete economic study but only to present initial contributions. 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, only one carrier is considered, and this is incorporated in C_b). The hypothesis for costs are presented in Table V.

TABLE V
HYPOTHESES FOR THE COST OF MICROCELLS.

Parameters	Hypothesis	
	2	3
Initial Costs:		
BS price, C_{BS} [€]	8000	3200
Installation, C_{Inst} [€]	2490	208
License fees, C_f[€/km^2]	1590	1590
Annual Cost:		
Operation and maintenance, $C_{M\&O}$ [€]	750	188

As the project lifetime is N_{year}= 5, the cost per BS is computed according to the following equation

$$C_{b[\text{€}]} = \frac{C_{BS} + C_{Inst}}{N_{year}} + C_{M\&O} \cdot \tag{3}$$

The BCC scenario has a regular geometry (Manhattan) which allows for an analysis similar to the linear geometry. Hence, by using a 'linearised' approach which only considers one of the perpendicular streets [14], the total cost per unit of length is given by

$$C_{[\text{€}/\,km]} = C_{f[\text{€}/\,km]} + \frac{C_{b[\text{€}]}}{2R_{[km]} - \frac{l_{[km]}}{2}}, \tag{4}$$

where l is the street width of the Manhattan geometry. The annual revenue per unit of length is given by

$$R_{v[\text{€}/km]} = \frac{p_{[\text{€}/kb]} \cdot Q_{cell[kb]}}{2R_{[km]} - \frac{l_{[km]}}{2}}, \tag{5}$$

where p represents the price per kb of data, and Q_{cell} the load supported by a cell during a year, which is obtained by

$$Q_{cell[kb]} = \frac{Thr_{[kb/s]} \cdot t_{BHCA[s]}}{N_{cells}}. \tag{6}$$

Note that $Q_{[\text{kb}]}=Ncells \cdot Q_{cell[\text{kb}]}$, where N_{cells} is the number of cells for the 'linearised' geometry.

The annual period corresponding to this busy hour call attempts, t_{BHCA}, is obtained by considering 6 equivalent busy hours per day during 240 days per year, i.e., 5184000 seconds per year.

The net revenue, R_n, is given by the difference between the revenues and the costs, in €/km, while the profit in percentage is given by the net revenue normalised by the cost, i.e.,

$$P_{f[\%]_t} = \frac{R_{v[\text{€}/km]} - C_{0[\text{€}/km]}}{C_{0[\text{€}/km]}} \cdot 100 \cdot \tag{7}$$

By considering the hypothesis for prices per MB from Table VI, one obtained results for R_n and for the profit, in percentage for hypothesis 2 and 3 for costs, and for hypothesis A, B, and C for revenues. In hypothesis 2, while the revenues decreases the optimum (maximum) for R_n moves from ~410 m to ~425 m.

TABLE VI
HYPOTHESES FOR THE PRICE PER MB.

Hypotheses	p [€/MB]
A	0.10
B	0.05
C	0.025

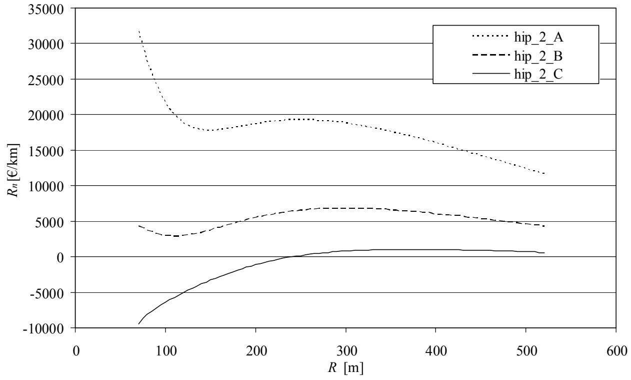

Fig. 6. Net revenue as a function of the cell radius, hypothesis 2.

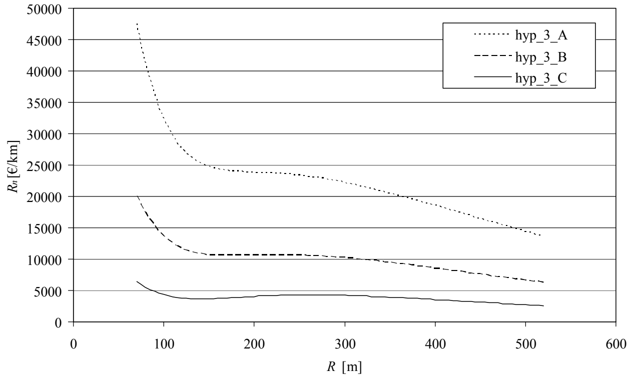

Fig. 7. Net revenue as a function of the cell radius, hypothesis 3.

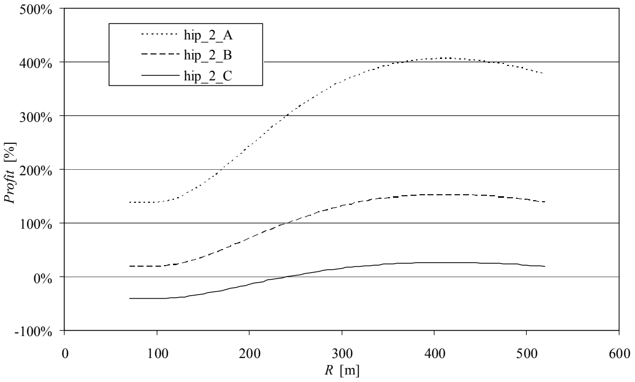

Fig. 8. Profit in percentage as a function of the cell radius, hypothesis 2.

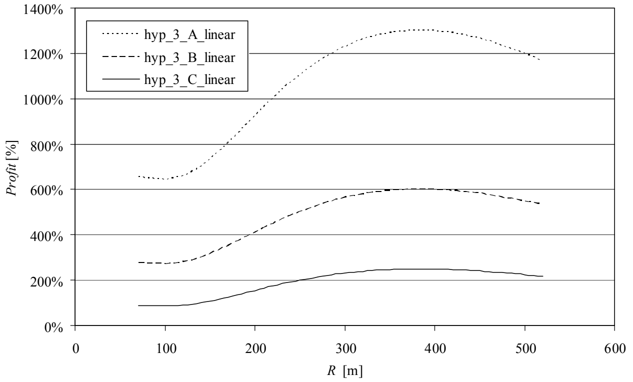

Fig. 9. Profit in percentage as a function of the cell radius, hypothesis 3.

In hypothesis 2, for a price of 0.10 €/MB the maximum of R_n is higher than 20 k€/km. In hypothesis 3, there is a similar behaviour, and maxima are obtained for ~200-265 m. For a price of 0.10 €/MB, the maximum of R_n is ~23 k€/km, and the increase relatively to hypothesis 2 is due to lower costs.

The maxima for the profit in percentage occur for values of R~425 and ~395 m, for hypothesis 2 and 3, respectively. For price of 0.10 €/MB, the profit takes values of ~400% in hypothesis 2, and 1300% in hypothesis 3. The results clearly indicate that coverage distances of 395-425 m should be used to optimise E-UMTS by having into consideration the maximisation of the profit in percentage. However, if extra cells are needed to increase system capacity, lower coverage distances can be considered, maximising the absolute profit, i.e., the net revenue, for coverage distances lower than 130 m.

V. CONCLUSIONS

Future 3.5G systems have to be able to support current applications as well as new ones, with different capacity and requirements. In this paper an All-IP Enhanced-UMTS BCC deployment and mobility scenario is considered, including expected population density, and usage of service mix. E-UMTS traffic generation and activity models, based on population and service penetration values are also described and characterised.

System level simulations were carried out, and the enhanced performance, including call blocking, handover failure probability, end-to-end delays, and throughputs are demonstrated in the BCC scenario. By considering a quality parameter that simultaneously accounts for blocking and handover failure probabilities, and different hypothesis for costs and prices, an optimum coverage distance is obtained around 200-425 m, which maximises the supported throughout per km^2. However, results for the profit in percentage indicate that coverage distances in the range 395-425 m should be used in BCC E-UMTS.

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