

Enhanced UMTS Simulation-based Cellular Planning in Urban Scenarios

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Abstract – Aspects of cellular planning for E-UMTS (Enhanced UMTS) are addressed, and results for system capacity are obtained, as a function of the coverage distance. E-UMTS traffic generation and activity models are described and characterised, based on population and service penetration values. An urban scenario was defined with a selection of relevant multi-rate bursty applications. By using a System Level Simulator results were obtained for the end-to-end delay, and for blocking and handover failure probabilities. By using these results, models for the supported fraction of active users and throughput were obtained, as a function of the cell coverage distance. When the coverage distance decreases from 600 to ~200 m, the supported throughput per km² increases from ~1Mb/s to ~5 Mb/s. By using trisectorial antennas with one amplifier a maximum throughput per BS of 600kb/s was obtained.

Keywords - Enhanced UMTS, supported traffic, deployment scenarios, simulation, system capacity

I. INTRODUCTION

E-UMTS (Enhanced 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 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/time-based 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. IST-SEACORN [1] proposed scenarios that include expected population density, deployment and mobility characteristics, and usage of service mix for each environment [2]. To meet the technical demands of the simulation tools a reduced set of services and environments were selected, distributed among different service classes (Sound, High Interactive Multimedia, Narrow-, Wide-, and Broadband, depending on data rates). As a result, in SEACORN, three operation environments (offices, business city centre, and urban vehicular) were defined [2], with four or five services each. In this work only the urban scenario is explored, Table I, with slightly different assumptions for service usage. The data

rate, R_b , and average duration, τ , are also defined in Table I. 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 II presents the service characteristics of the corresponding applications, i.e., intrinsic time dependency, delivery requirements, directionality, symmetry/asymmetry [3]. Examples of sound, HIMM (high interactive multimedia), NB (narrowband), and WB (wideband) applications are VOI (Voice), VTE (Video-telephony), MWB (Multimedia Web Browsing) and ATR (Assistance in Travel), respectively.

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). 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.

TABLE I. APPLICATIONS USAGE IN THE URBAN SCENARIO.

Services	R_b [kb/s]	Usage[%]	τ [min]
Sound - VOI	12.2	82.5	3
High Inter. Mult. - VTE	144	11.0	3
Narrowband - MWB	384	2.0	15
Wideband - ATR	768	4.5	15

TABLE II. ENHANCED UMTS SERVICE CHARACTERISTICS [4].

Applications	Intrinsic time dependency	Delivery requirements	Directionality	Symmetry / Asymmetry
VOI	TB	RT	Bid	Sym
VTE	TB	RT	Bid	Sym
MWB	TB	RT	Bid	Asy
ATR	TB	RT/NRT	Bid	Asy

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

In Section II details on traffic modelling, on the system level simulator, and the simulation scenarios are presented, including aspects of the mobility model and the traffic mixtures. Section III presents results for the blocking and handover failure probabilities, and end-to-end delay. In Section IV, results are obtained for the supported fraction of active users, supported throughput, and for the throughput per BS, given GoS (Grade of Service) constraints. Conclusions are presented in Section V.

II. 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. 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 statistical distributions of the active and inactive durations. Extra details on the parameters of the distributions used can be found in [5].

TABLE III. APPLICATION ACTIVITY PARAMETERS.

Applications	Active state, ON			Inactive state, OFF	
	Avg.[s]	Filesize[kB]	Distrib	Avg.[s]	Distrib.
VOI	1.4s	2.14	Expon.	1.7 s	Expon.
VTE	10	-	-	0	-
MWB	10	240	Pareto	13	Pareto
ATR	60	11520	Weibul	14	Pareto

The objective of this paper is to analyse the system capacity supported by E-UMTS while maintaining a given GoS. The analysis is performed by using QoS (Quality of Service) measures like blocking probability, handover failure probability, and end-to-end delay. Providing a given GoS in an All-IP mobile network requires end-to-end delay analysis. On the one hand, at the packet level, there are several entities that may cause delay, errors and losses of IP packets. On the other hand, at the call level, this end-to-end analysis is also needed since real time services, like voice, cannot be queued; hence it is imperative to know if there are available resources.

One adopted the SEACORN system level simulator. It is a SLS (System Level Simulator) 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. In order to fulfil a system level simulation three different simulators were joined together, i.e., link level (radio link), network and transport level, and the system level simulator ones. Details about the SLS are given in [6].

Since UMTS provides a variety of services with variable data rate, a wide range of QoS mechanisms are necessary in order to support the variety of the services characteristics efficiently. Radio resource management mechanisms handle the QoS provisioning over the wireless interface and control cell capacity and interference as well, in order to optimise the utilization of the wireless interface resources. The Radio Resource Management mechanisms implemented for the E-UMTS system level simulator include functions such as power control, handover, call admission control, load control, and packet scheduling [7]. The basic algorithm for system level simulations is presented in [8].

Enhancements to UMTS 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.

The topology of the Urban scenario consists of several BS (base stations), using tri-sector antennas, thus having sectors. The area to cover is of 4km². Several cell radiuses were tested so that the 4km² area can be covered. One of the topologies, where radius is equal to 439m is presented in Figure 1. Table IV presents the radiuses that correspond to a coverage of 4km².

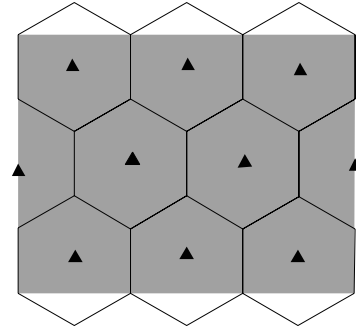


Figure 1: Urban topology scheme for a cell radius of 439m.

TABLE IV. CELL RADIUS 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

Three 120° sectorial antennas are used in each BS, in order to have a 360° coverage. One could think that it could allow up to three times the capacity of an omnidirectional antenna. However, by using one amplifier, this increase only occurs for the uplink. At the downlink the 16 dBW of power assigned to the BS is shared among the three sectors, and there is no meaningful increase in the BS downlink capacity.

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 scenarios, 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 50 km/h (13.89 m/s), and a random seed, a number that is fed into a random number generator, as this model aims to assign pseudorandom paths to the mobile users. The Radio Propagation model is the Hata propagation model. More details regarding mobility models, radio propagation model, BS and MS configuration can be found in [9].

The traffic mix model defined for this environment generates traffic according to predefined usage percentages, Table I, and assigns an application to each user accordingly. Each user in

the Urban scenario has a probability to be active, to be generating traffic. 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

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

where M_T is the number of users in the cell, τ 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]; hence, in an area of 4000000m^2 , $M_T = 4000000\text{m}^2 \times 0.012/4 = 12000$. This reduction is owing to limitations of the simulator, which did not support higher user densities. The percentage of active users is random. In the urban scenario this percentage depends on the fraction of active users, f , whose values are 0.7, 0.8, 1.7, 2.3, 3.4, 4.3, and 5.2%.

III. RESULTS FOR QUALITY OF SERVICE

Results were obtained by using the SLS previously mentioned for a maximum transmitted power of 16 dBW. The aim is to get the best cell radius that guarantees a certain grade of service (GoS). The considered QoS measures are blocking probability, P_b , handover failure probability, P_{hf} , end-to-end delay, and delay variation.

Figure 2, presents results for the blocking probability, where a detailed analysis of each service is performed for $f=1.7$ and 3.4%. For comparison purposes, results for the “total services” approach, i.e., not distinguishing different applications but considering the overall impact of their mixture, are also considered. 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 linear intersection with $P_b=2\%$. The values of R_a , obtained with P_b constraints, are presented in Table V. Although the results for ATR are presented in Figure 2, these results are not considered in Table V, as ATR is a NRT application.

It is worthwhile to note that the mechanisms that can cause blocking of new calls are the CAC (Call Admission Control) and PC (Power Control). These two mechanisms 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. The admission control is necessary to maintain desired QoS, specially to RT/TB services. The new calls in the scenario simulated are blocked only due to power control issues and not due to lack of OVSF codes.

HO (Handover) is one of the major characteristics of mobile systems. Its influence in QoS is proportional to its intensity/rate. The smaller the cell radius is and the higher the user mobility is, the highest is the handover intensity/rate. The SLS only considers hard handover.

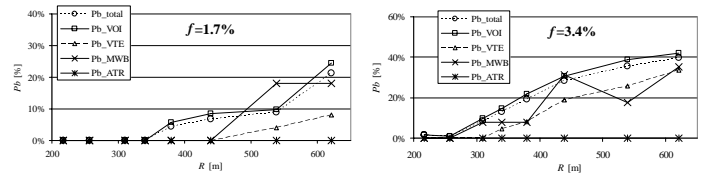


Figure 2: Blocking probability for $f=1.7$ and 3.4%.

TABLE V. ACCEPTABLE CELL RADIISES WITH 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

Besides, it considers three base stations in the active set; a user is dropped only after six unsuccessful handover attempts.

In order to find the maximum acceptable P_{hf} , P_{hfmax} , the model described in [10] was considered. P_{hfmax} is computed by using

$$P_{hfmax} = \frac{P_{dmax}}{Nb_HO_j}, \quad (2)$$

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 presents results for P_{hf} for VOI for the several fraction of active users as a function of the cell radius. The variation of P_{hfmax} with the coverage distance is also presented. By adding BSs to the topology, although the network capacity increases the number of handovers per call also increases. Then, from this point of view, small cell radiuses 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 users. Hence, when analysing Figure 3 and the results obtained for the other applications the most appropriate cell radius with handover failure constraints, R_{ap} , has to be chosen, Table VI. Regarding ATR, latency is a more appropriate QoS measure. Furthermore, one observes that for ATR there are no handover failures, since the algorithm of the simulator accepts NRT in an almost straightforward way.

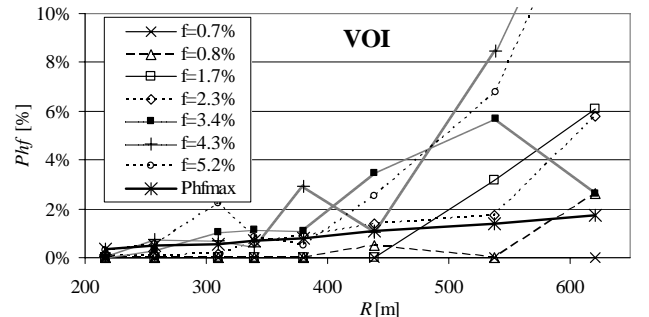


Figure 3. P_{hf} for VOI, $f=0.7, 0.8, 1.7, 2.3, 3.4, 4.3$ e 5.2%, “detailed services”.

TABLE VI. THE MOST APPROPRIATE CELL RADIUS WITH 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

For NRT applications (e.g., ATR), instead of the handover failure probability a more appropriate QoS measure is latency, i.e., end-to-end delay. In All-IP networks like E-UMTS, PDP contexts are defined to make IP packet exchange possible. Each PDP context exists either during the packet transmission/reception states or in standby state [11].

From the simulation results, one concludes that the maximum value for latency (i.e., 150 ms) is overcome. It can also be concluded that the high delay does not depend on high values for the load since in environments with the lowest value for f , i.e., $f=0.8\%$, it takes high values. Besides a trend of the variation of delay with the cell radius could not be found. Therefore, by having these results into consideration, one identifies that improvements are needed in the scheduling algorithm. However, by now we will not consider delay in the determination of system capacity results.

IV. SYSTEM CAPACITY

Taking a worst case situation between P_b and P_{hf} GoS constraints into account, by using an inversion procedure, the most suitable f for each value of R was found, Figure 4. By using a curve fit approach, a curve for the supported f was found. By considering these results for $f(R)$, the system throughput, $thr_{[Mb/s]}$, can be extracted from simulation results, Figure 5. Once more, by using a curve fit approach, the curve for the supported throughput can be found for the downlink, which presents a clear decreasing behaviour. It means that, as the radius increases system capacity decreases.

Another important result is the throughput per BS, thr_{BS} , Figure 6, which can be obtained from the trendline of Figure 5. Each base station reaches maxima of 600kb/s, for $R \approx 217$ m. When the cell radius is low the high value of the throughput per BS can be explained due to the fact of users that are closer to the BS can easily be served; they transmit with low power, by using PC algorithms, causing low interference to each other.

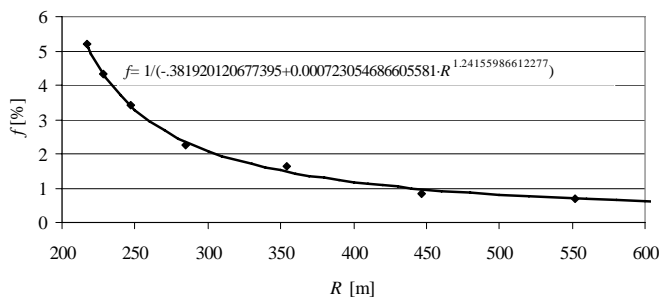


Figure 4. Supported fraction of active users as function of cell radius.

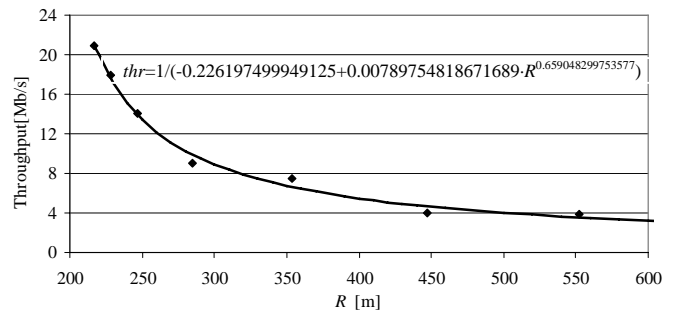


Figure 5. Total throughput of the system as function of R .

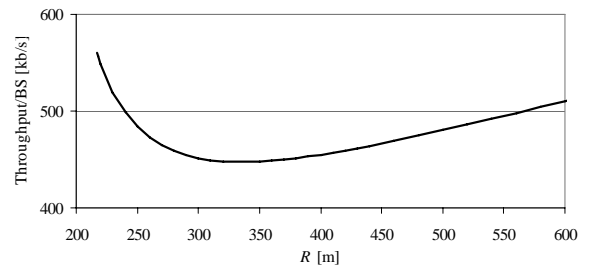


Figure 6. Throughput per BS as function of R .

However, for cell radius higher than 300m, 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.

V. CONCLUSIONS

A traffic generation model was used to allow quantification and description of traffic offered to the E-UMTS in an urban environment. The SEACORN System Level Simulator was used to obtain Quality of service results, such as packet delay, blocking probability and handover failure probability. By using these results, a model for the supported fraction of active users as a function of active users was found, for a given GoS. A model for the supported throughput was also found. As a fixed area of 4 km² is covered this function also represents the trend of the throughput per unit area (km²), which increases from ~1 Mb/s to ~5 Mb/s when the coverage distance decreases from 600 to ~200 m. One can also conclude that, in the range of the considered coverage distances, the maximum throughput per BS is about 600kb/s. This relatively low value is due to the use of only one amplifier for the three sectors.

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