HIGH CAPACITY WIDEBAND TRAFFIC IN ENHANCED UMTS: A STEP TOWARDS 4G

Fernando J Velez[1,2], **Rui R Paulo**[1,2]

[1] Department of Electromechanical Engineering, University of Beira Interior
Calçada Fonte do Lameiro, 6201-001 Covilhã, Portugal
[2] Instituto de Telecomunicações (Lisboa), Instituto Superior Técnico
Av. Rovisco Pais, 1049-001 Lisboa, Portugal
fjv@ubi.pt, r_8690@demnet.ubi.pt

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Abstract

In this paper new ways of facing the problem of mobile multimedia source traffic modelling are first discussed. Then, based in some hypothesis for mobility, and for the number of available resources, tele-traffic system capacity results are achieved using a 'macroscopic' model, very useful for cellular planning purposes. This allow for the comparison of capacities among different systems (GSM, UMTS, Enhanced UMTS and Mobile Broadband System), measured in terms of supported data rate per kilometre, and a kind of generalisation of Moore's and/or Gilder's law to mobile communications.

1 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, Fig.1. 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. European projects (e.g., IST-SEACORN [1]) will propose a set of enhancements to UMTS, which include, among others, advanced modulation and radio transmission techniques, improved strategies for IP routing and QoS assurance.

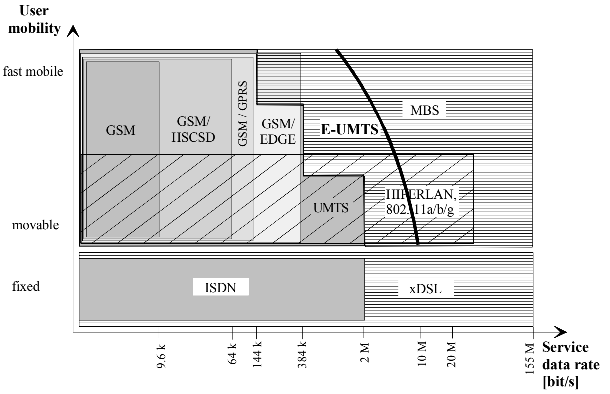

Fig. 1. Enhanced UMTS concept.

Unlike HSDPA, which will mostly extend UMTS maximum achieved data rates for the downlink, E-UMTS will allow for expansion in both down- and uplink directions. 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.

In the mobile communications domain, E-UMTS will be a first step to achieve the goal of ubiquitous and seamless communications [7], scaling system capacity for mass-market services, which implies that a capacity of the order of Gbps/km^2 will be available. While in the WLAN domain it 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. Besides, it will allow for the introduction of the ABC (Always Best Connected) concept [4], even before the introduction of OFDM/WCDMA and 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 interfaces and access technologies).

In IST-SEACORN, the effect of the proposed enhancements will be evaluated by means of simulation techniques. In the attempt of having adequate models for source traffic in Wireless IP, contemporary traffic models, adapted from the ones applied in fixed network tele-traffic engineering, have been explored, with emphasis on Long Range Dependence (LRD) models. Although many authors claim their usefulness, it is not evident that they will be very useful for low data rate applications because the modelling characteristics for emerging mobile multimedia applications are different (e.g., owing to smaller screen sizes or different packet network requirements); hence, a distinction between this type of applications (widely used in GPRS and UMTS [9]) and future wide- and broadband ones (e.g., E-UMTS) has to be made.

Although some of these new models have been incorporated in IST-SEACORN E-UMTS simulation work, the set of applications is mostly formed by real-time/time-based applications, and an analysis that considers Bernoulli-Poisson-Pascal (BPP) processes, in the context of Markov-modulated Poisson Processes (MMPP) can be appropriate, at least for macroscopic cellular planning purposes, where the very detailed traffic behaviour does not need to be known (but only its average behaviour and maximum supported load).

In Section 2, the importance of source and aggregate traffic modelling in E-UMTS is discussed either including results from GRPS and UMTS, or extending LRD source traffic models to wide- and broadband mobile communications. In Section 3, the characteristics of the mixtures of E-UMTS applications are presented for a set of outdoors deployment scenarios, and hypothesis for average data rates, bursty behaviour, and mobility are established. Then, by using the BPP/MMPP model, tele-traffic results are presented in Section 4. Besides, system capacity is evaluated, and the effect of the average load, and the impact of mobility are discussed. In Section 5, a comparison between system capacity in E-UMTS and other today's and future systems is presented. Conclusions are drawn in Section 6.

2 Traffic Modelling

2.1 Importance

In recent years, as a consequence of the increase of popularity of data and multimedia services, there has been a marked evolutionary shift in the underlying technology from circuit- to packet-switched communications. In some way, the bursty nature of this type of traffic is characterised by ON and OFF periods. In some cases, e.g., World Wide Web applications, the ON period represents data transfer (e.g., file downloading) while OFF periods represent the user reading time. Thus, for the nature of emerging mobile networks traffic, the current circuit-switched technique and simple Erlang formulas are no longer appropriate to use in detailed traffic modelling [12].

However, because of its simplicity and flexibility, MMPP (Markov-modulated Poisson Processes) are being tested for multi-rate voice, data, video, and multimedia communications. By considering service components, it will be possible to recover the telecommunication operator's traditional approaches of modelling traffic, via the evaluation of average service durations, generation rates, and dwelling times.

Although they enable to capture some degree of correlation of traffic, they present an inadequate autocorrelation, and are unsuitable for LRD modelling. Hence, MMPP are only adequate to represent the average behaviour of the aggregate traffic, e.g., for cellular planning purposes [11], but not for dimensioning traffic management functions or assessing detailed QoS parameters. Since the traditional traffic models are becoming inadequate to capture today's network characteristics, traffic models for packet-switched data have been developed on the basis of measurements from actual data networks. However, their suitability to be used beyond simulation, e.g., in wireless network modelling and analysis, is still being tested and will require demonstration.

2.2 Source Traffic

Different views have been presented in literature for UMTS applications source traffic modelling [6], which present Pareto or Weibull (heavy-tailed) models, and even Poisson distributions, as the most suitable to represent ON/OFF durations, and taking LRD into account. It was identified that the next-generation mobile networks will offer many different applications and each application will have different QoS requirements. In packet-switched networks, because the nature of service is discontinuous, there is no strict restriction on delay requirements. Instead, packet error rates and loss rates are more important to consider, and the network performance criteria have to be changed as well.

In the cases of GPRS and UMTS, however, these views [6] are based in somehow unadjusted visions. In [9], models are presented for the following types of low data-rate applications: i) packet voice, ii) e-mail and MMS, iii) WAP, WWW and FTP, and iv) video streaming.

LRD models are essentially useful for fixed broadband applications. Hence, for E-UMTS, as higher data rates will be supported, and large screens will be possible (e.g., with the introduction of larger PDAs or even Tablet PCs), LRD models are still a possibility. In this context, these types of models were still useful in the IST-SEACORN project. In SEACORN, details on session and activity parameters were produced for several E-UMTS applications, including: i) speech source model, ii) multimedia (MM) web browsing, iii) instant messaging for MM, iv) assistance in travel, v) WLAN interconnection, and vi) MPEG4 for video.

2.3 Unified Model

Although a detailed description of applications source traffic is already possible, without real data available it is not clear when a unified model will be available, that accounts for LRD, and does aggregate the individual behaviour of source traffics into a multi-service model.

Simulation outputs from IST-SEACORN will provide results for the aggregate traffic whose comparison with results obtained analytically will lead to important conclusions. Although packet error rates, detailed loss rates, and other parameters will be obtained from the simulator, for comparison purposes, it is still important to obtain analytical results for the supported traffic load. As the considered applications are mostly real-time ones, the performance measures that one is interested in are the customer or connection blocking probability, P_b, and, due to terminal mobility, the handover failure probability, P_{hf}, the probability of an user not succeed in transferring its connection from a cell to another. The probability of forced termination of a connection during its duration, i.e., the connection dropping probability, P_d, can be associated to the latter [5]. Given QoS constraints for blocking and connection dropping probabilities ($P_b = 2\%$, and $P_d = 0.5\%$), the BPP model is used to obtain the supported load; details on the model itself, the service components, and the user model can be found in [11].

In E-UMTS one can consider that resources/channels serve applications via different service components, Table 1, i.e., the system itself serves service components, which, in turn, serve applications. In this work, service components are sound, SND, streaming, STR, basic, BAS, low-rate data, LOD, medium-rate data, MD1, MD2 and MD3, and interactive video, IV4. Although service components with grey background are still considered in Table 1 for clarity, they are not used in our set of applications.

Service component	j	a_j	B_{sj} [kb/s]
SND	1	1	16
STR	2	4	64
BAS=IV1	3	8	128
LOD=IV2	4	24	384
MD1	5	48	768
MD2	6	64	1024
MD3=IV3	7	96	1536
IV4	8	120	1920

Table 1: Service components.

Different applications have different duration, and different associated data rates, b_k. These data rates are obtained by weighted sums of the data rates of their supporting service components, where the weights are the proportion of average time they are active during the application.

When a single service is considered, if guard channels for handover are not used, the handover failure probability is equal to the blocking probability [5]. Here, this approach is generalised, as an approximation, for multi-service traffic, too. Besides, it was shown in [10] that, for long duration connections, there is no practical advantage in using guard channels for handover; hence, we did not use them because the majority of our applications have long average duration.

3 Services and Applications

3.1 Deployment Scenarios

The high number of multi-service E-UMTS applications may pose some difficulties to the performance of simulations, due to the complexity involved. To overcome this problem, it is necessary to consider a reduced set of applications in order to decrease processing load. Still, although it is important to establish simpler scenarios for simulation purposes, with few relevant applications, these mixtures needs to be fairly representative of the whole E-UMTS operating applications. Table 2 presents the case of Outdoor Scenarios: business city centre, BCC, urban, URB and roads, ROA, and includes sound applications plus narrow- and wideband ones.

Applications Usage [%]	**Abbreviation**	**Max Data Rate** [kb/s]	**BCC**	**URB**	**ROA**
Sound					
Voice	VOI	12	19.9	40.2	29.0
Voice over IP	VIP	12	14.3	29.1	20.9
Audio Streaming	AUD	64		9.7	6.6
Total			**34.2**	**79.0**	**56.5**
Narrowband					
Videoconference, Tele-advertising	VCO	384	4.6		
Data File Transfer, FTP	FTP	384	7.8		5.3
Desktop MM, Web browsing	DMM	384	16.8	6.8	11.3
Broadband Videotex, E-commerce	ECO	384	7.8		5.3
Total			**37.0**	**6.8**	**21.9**
Wideband					
Mobile Tele-working	MTW	1536	7.7		
Assistance in Travel	ATR	1536		4.9	13.5
E-newspaper	ENP	1536	5.3	4.4	
HD Videotelephony	HVT	1920	15.8	4.9	8.1
Total			**28.8**	**14.1**	**21.6**

Table 2: Deployment scenarios for outdoors.

As far as the characteristics of the service components (sound, data and video) that support these applications are defined in terms of their traffic generation characteristics, duration, and bursty behaviour (active/inactive periods), it is possible to perform computations, taking these values for the usage into account. The set of parameters that describe these services from the traffic perspective are defined in [2], where their range of variation is also presented. Values, agreeing with the service characteristics, are presented in [8].

3.2 Average Load and Data Rates

The average load of the mixture of applications is given by

$$b_1 = \sum_{k=VOI}^{HVT} U_k \cdot b_k \qquad (1)$$

where U_k is application k usage, Table 2, and b_k can be extracted from Table 3 for up-and downlinks (UL and DL). Values of b_k are computed considered the bursty behaviour of applications; therefore, in some cases they can be much lower than the maximum data rates presented in Table 2. The computation of the average load for both links allows for the computation of the asymmetry factor, A_f, the ratio of the average loads between the down- and uplinks, Table 4.

In the considered deployment scenarios, the characteristics for terminal mobility are the following: static, ST, pedestrian, PD, urban, UB, main roads, MR, or highways HW.

Different types of mobility are assumed for each application in each of the scenarios. A triangular distribution is considered for the velocity, with average V_{av} and deviation Δ [8, 11]. Values for $V_{av} = \Delta = 0, 1, 10, 15$ m·s^{-1} are considered for the ST, PD, UB, and MR scenarios, respectively, while $V_{av} = 22.5$ and $\Delta = 12.5$ m·s^{-1} for the HW scenario.

4 System Capacity

In this work, hypothesis is equivalent to consider a 64-QAM type of modulation. Thus, all data rates are four times higher than in UMTS, leading to a higher capacity for the new services and applications. The nowadays UMTS capacity of two carriers multiplied by four corresponds to support, approximately, 400 channels of 16 kb/s. Hence, it is necessary to assume future allocation of new bands to support 600-800 channels, the values assumed in this work.

Application	**b_k [kb/s]**	
	UL	**DL**
VOI	16.0	16.0
VIP	16.0	16.0
AUD	64.0	64.0
VCO	384.0	384.0
FTP	19.3	384.0
DMM	21.1	16.2
ECO	15.9	48.6
MTW	1542.4	1542.4
ATR	1545.6	1545.6
ENP	0.8	194.3
HVT	1920.0	1920.0

Table 3: Applications data rate.

	BCC		URB		ROA	
	UL	DL	UL	DL	UL	DL
b_1	451.58	492.00	250.02	196.76	380.70	401.20
A_f	1.0895		0.7870		1.0539	
$b_{1\text{-UL}}+b_{1\text{-DL}}$	943.59		446.78		781.90	

Table 4: Asymmetry factor between DL and UL.

It is, however, important to note that considering a given number of channels for each service component with a given data rate is only an equivalent way to represent the problem for the purpose of applying the BPP algorithm. In practice, in WCDMA systems, distinct data rates are supported by traffic channels through the use of different spreading factors. Dedicated channels are usually allocated for real-time applications such as conversational and streaming classes, although full IP solutions for real-time (RT) applications are expected to be supported in the future. Non-RT applications are handled as scheduled packet data over either common, shared, or dedicated channels; for the purpose of our computations, only the minimum data rate is considered for best-effort/ ABR applications.

The influence of mobility was studied by comparing results in absence and presence of mobility. In both cases, resources were re-distributed between the links in order to get symmetry on the supported fraction of active users, i.e., to compensate asymmetry, the total number of channels, e.g., 600+600, have to be differently distributed between up- and downlinks. Blocking probability was calculated, for both links, as a function of f_a, the fraction of active users. However, only results and graphs for the most limiting service component, i.e., IV4, are presented. Assumptions were made for the number of potential users, M_T, and the coverage distance, R in each scenario: $M_T = 250$, 100 and 100 users, while R =100, 100 and 150 m in BCC, URB and ROA scenarios, respectively.

Table 5 present results for 600+600 channels. In Fig. 2, an example of $P_b(f_a)$ is presented for the URB scenario, downlink (where there are 529 channels, while the remaining 671 are for the uplink). From this, it is straightforward to obtain f_a (by an inversion procedure, extracting values of f_a for a fixed P_b = 2% or $P_{hf}= (P_{hf})_{max}$, in absence and presence of mobility, respectively), Table 5. The difference between the number of channels between the up- and downlinks leads, in presence of mobility, to similar values for the supported f_a in both links. In BCC, as terminal mobility is low, the reduction between the number of supported users in absence and presence of mobility is low (23% only). However, in URB and ROA scenarios the reduction becomes relevant (> 60 %).

Sce-nario	Link/ Chan	f_a [%]		$(P_{hf})_{max}$	Users per km	
		$P_b = 2\%$	$P_{hf} = (P_{hf})_{max}$		absence	Presence
BCC	U 602	2.11	1.64	77.02×10^{-4}	26	20
	D 598	2.16	1.64	77.02×10^{-4}		
URB	U 671	8.86	2.50	11.6×10^{-5}	44	12
	D 529	10.79	2.50	11.6×10^{-5}		
ROA	U 643	6.04	2.63	77×10^{-5}	20	8
	D 557	6.18	2.63	77×10^{-5}		

Table 5: Supported f_a and the number of users per km with 600+600 channels in the absence and presence of mobility.

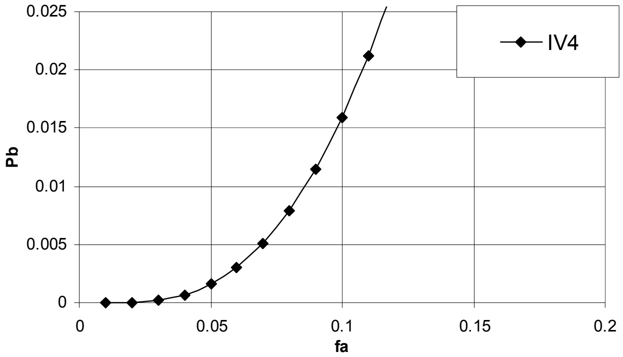

Fig. 2: Blocking probability as a function of f_a for 529 channels (URB scenario, downlink).

While in absence of mobility the large differences of the number of supported users between scenarios can be explained by differences in the average load, b_1, in the presence of mobility a difference arises: the most important factor becomes high mobility, and the supported number of users decreases from 20 to 12, from BCC to URB, and from 12 to 8 user/km, from URB to ROA.

With 800 channels per link comparing the results between the absence and presence of mobility one concludes that there is a strong degradation in high mobility scenarios, Table 6. While the reduction is only 20% in the BCC scenario, in the URB and ROA ones the reduction is higher than 48 %. By comparing the cases of 800 and 600 channels, with high mobility, an increase of 33 % in the number of channels corresponds to more than 125 % increase in the number of supported user/km, i.e., a statistical multiplexing gain occurs.

Sce-nario	Link/ chan	f_a [%]		$(P_{hf})_{max}$	Users per km	
		$P_b = 2\%$	$P_{hf} = (P_{hf})_{max}$		absence	presence
BCC	U 828	3.75	3.01	77.02×10^{-4}	46	37
	D 772	3.76	3.01	77.02×10^{-4}		
URB	U 917	16.10	6.11	11.6×10^{-5}	80	30
	D 683	18.57	6.11	11.6×10^{-5}		
ROA	U 851	10.65	5.51	77×10^{-5}	35	18
	D 749	10.96	5.52	77×10^{-5}		

Table 6: Supported f_a and the number of users per km with 800+800 channels (absence and presence of mobility).

5 Generalisation of Moore's and Gilder's Laws

It is often discussed in literature how Moore's and Gilder's laws can be generalised to cellular communication systems. However, it is not enough to say that typical data rates will increase, e.g., from 9.6 to 64 kb/s in GPRS, to 384 kb/s within UMTS, or to 2 Mb/s within E-UMTS, or even 10 Mb/s within MBS (Mobile Broadband Systems) [11]. It is also necessary to compare system capacity, e.g., in kbps/km, and to verify what its actual evolution will be. By doing so, it is possible to understand how E-UMTS will be a step towards 4G.

Results for capacity are extracted from [3] for GSM and UMTS (one and two cells per km, respectively), while, in the case of MBS (5 cells per km) one uses results from [11], respectively, Table 7. Results for the supported data rate per km are presented in Table 8 and Fig. 3.

System	Supported users per km	Average data rate [kb/s]	
		UL	DL
GSM	32	9.6	9.6
UMTS	148	23.5	23.5
E-UMTS	37	451	492
MBS	137	657	1868

Table 7:Hypothesis for system capacity comparison, BCC.

System	Supported data rate per km [kb/s/km]	
	UL	DL
GSM	307.2	307.2
UMTS	3480	3480
E-UMTS	16709	18204
MBS	90009	255916

Table 8: System capacity comparison.

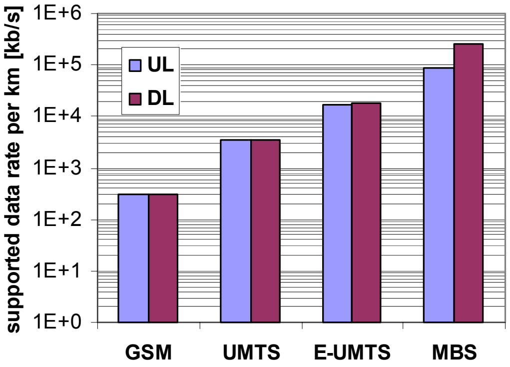

Fig.: 3 Generalisation of Moore's and Gilder's laws.

Using a simple example, if one considers a total of 10 streets of 1 km each (e.g., in a Manhattan grid BCC geometry) the supported data rate per km^2 will be approximately ten times the values presented in Table 8. Hence, with MBS, system capacities of the order of Gbps/km^2 can be achieved in both directions (up- and downlink). Besides, from our results, one can conclude that, because system capacities of the order of 170-180 Mbps/km^2 are achieved, E-UMTS will be a step towards 4G, if additional bands will be made available.

6 Conclusions

In this paper new ways of facing the problem of mobile multimedia source traffic modelling are first discussed. Based in the IST-SEACORN project deployment scenarios definition, in some hypothesis for mobility, and the number of available resources, tele-traffic system capacity results are achieved using a BPP/MMPP model, very useful for cellular planning purposes. Comparing scenarios with increasing mobility (BCC, URB, and ROA), while, in the absence of mobility, system capacity, measured in terms of the number of supported users per km, depends on the average load of application in each scenario, in the presence of mobility the behaviour changes, and the critical factor is the increase of average velocities, which results in reduction of system capacity. By comparing values of system capacity among GSM, UMTS, E-UMTS, and MBS, a kind of generalisation of Moore's and Gilder's laws to mobile multimedia communications arises; besides, we verify that, with E-UMTS, as system capacities of the order of 170-180 Mbps/km^2 will be achieved, it will be a step towards 4G.

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