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

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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.

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/km² 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.
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.

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

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

$$b_k = \sum_{k=1}^{n} U_k \cdot b_k$$

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 $\Delta [8, 11]$. Values for $V_{av}$, $A_{f}$, and $\Delta = 0, 1, 10, 15 \text{ m/s}^2$ are considered for the ST, PD, UB, and MR scenarios, respectively, while $V_{av} = 22.5$ and $\Delta = 12.5 \text{ m/s}^2$ 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.

Table 3: Applications data rate.
Table 4: Asymmetry factor between DL and UL.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Link</th>
<th>fₐ [%]</th>
<th>(Pₑₐ)ₘₐₓ</th>
<th>Users per km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCC</td>
<td>U 602</td>
<td>2.11</td>
<td>1.64</td>
<td>77.02 x 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>D 598</td>
<td>2.16</td>
<td>1.64</td>
<td>77.02 x 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>U 671</td>
<td>8.86</td>
<td>2.50</td>
<td>11.6 x 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>D 529</td>
<td>10.79</td>
<td>2.50</td>
<td>11.6 x 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>U 843</td>
<td>6.04</td>
<td>2.63</td>
<td>77 x 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>D 557</td>
<td>6.13</td>
<td>2.63</td>
<td>77 x 10⁻⁴</td>
</tr>
</tbody>
</table>

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

Table 6: Supported fₐ 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.
Table 7: Hypothesis for system capacity comparison, BCC.

<table>
<thead>
<tr>
<th>System</th>
<th>Supported users per km</th>
<th>Average data rate [kb/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM</td>
<td>32</td>
<td>9.6</td>
</tr>
<tr>
<td>UMTS</td>
<td>148</td>
<td>23.5</td>
</tr>
<tr>
<td>E-UMTS</td>
<td>37</td>
<td>451</td>
</tr>
<tr>
<td>MBS</td>
<td>137</td>
<td>657</td>
</tr>
</tbody>
</table>

Table 8: System capacity comparison.

<table>
<thead>
<tr>
<th>System</th>
<th>Supported data rate per km [kb/s/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL</td>
<td>DL</td>
</tr>
<tr>
<td>GSM</td>
<td>307.2</td>
</tr>
<tr>
<td>UMTS</td>
<td>3480</td>
</tr>
<tr>
<td>E-UMTS</td>
<td>16709</td>
</tr>
<tr>
<td>MBS</td>
<td>90009</td>
</tr>
</tbody>
</table>

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 km² will be approximately ten times the values presented in Table 8. Hence, with MBS, system capacities of the order of Gbps/km² 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/km² 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/km² will be achieved, it will be a step towards 4G.

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