# Tele-traffic Engineering for Enhanced UMTS Multi-rate Applications

**Eva Reguera San José**[1,2], **Fernando J. Velez**[1,3]
[1] Department of Electromechanical Engineering
University of Beira Interior
Calçada Fonte do Lameiro, 6201-001 Covilhã, Portugal
[2] School of Technical Telecommunications Engineering
Polytechnic School of Valladolid, Valladolid, Spain
[3] Instituto de Telecomunicações, Pólo de Lisboa
Instituto Superior Técnico
Av. Rovisco Pais, 1049-001 Lisboa, Portugal

## ABSTRACT

*The tele-traffic behaviour of Enhanced UMTS (E-UMTS) is addressed in three different scenarios (business city centre, BCC, urban and roads). E-UMTS will allow achieve data rates up to 8-10 Mb/s, far beyond the values for UMTS. In the absence of mobility, the difference between the supported users in each of the scenarios is not relevant. However, when mobility is considered, from BCC to the other two scenarios, the difference in the number of users is higher than 50% with 75 channels per link (per cell), and decreases around 40% with 100 channels.. Within each of the scenarios, while in BCC the difference is small (17% reduction), in the other scenarios the reduction is higher than 50 %. When the number of channels increases 33%, from 75 to 100 channels, the number of supported users increases ~100%, from 15.6 to 32.5 in the urban scenario and from 15 to 30 in the roads one, i.e., there is a statistical multiplexing gain.*

## I. INTRODUCTION

One of the possibilities for the evolution of third generation WCDMA systems is high-speed downlink packet access, HSDPA [1]. It will try to satisfy the future demands for packet-data, video, and multimedia services, increasing substantially data rates, especially in downlink. The main goal of HDSPA is to allow WCDMA to support downlink peak data rates in the range of approximately 8-10 Mb/s for best effort packet-data services (within the current 5 MHz WCDMA bandwidth), far beyond the UMTS 2Mb/s requirements, via the use of higher order modulation (16-QAM and 64-QAM). Enhanced UMTS (E-UMTS) research within IST-SEACORN (Simulation of Enhanced UMTS Access and Core Networks) will take these ideas of HDSPA as a starting point. However, the objective of this research is to extend maximum data rates in both directions (up- and downlink). As it will be introduced before 4G, it will be called a 3.5G system, and will support high capacity wide- and broadband communications.

In this paper, 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, 50 channels of 128 kb/s. Hence, it is necessary to assume future allocation of new bands to support 75-100 channels, the values assumed in this work. Three scenarios have been considered: Business City Centre, BCC, Urban, URB, and Roads, ROA, each of them with a given mixture of 16 applications. Scenarios and applications have been analysed in [2], with a typical mixture of mostly real-time applications. In WCDMA systems, distinct data rates are supported on the 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 applications are expected to be supported in the future. Non-real-time 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.

This paper is organised as follows. Section II gives a brief overview of the model used to get traffic measures of interest, and of the way applications and service components behave. Section III presents service components and their correspondence with applications via different parameters. In Section IV, terminal mobility is addressed, and the impact of the handover rate on the maximum handover probability is analysed. Results for the three scenarios are analysed in Section V, both considering 75 and 100 channels per cell. Conclusions are extracted in Section VI.

## II. THEORETICAL MODEL

### A. Blocking

The Markov-Modulated Poisson Process, MMPP, is considered, whilst assuming that Interrupted Poisson Processes model the various types of traffic sources. The considered model is a loss system, where a customer arrival at the resources follows a specific random process. In E-UMTS one can consider that resources/channels serve applications via different service components, i.e., the system itself serves service components, which, in turn, serve applications. Different applications have different duration, and different associated data rates. Each application data rate is obtained by weighted sums of the data rates of the supporting service components, where the weights are the proportion of time they are active during the application, on average.

As the considered applications are mostly real-time ones, the performance measures that one is interested in are the time blocking probability, $P_{tb}$, 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, can be derived from the latter.

When a single service is considered, if guard channels for handover are not used, the handover failure probability is equal to the blocking probability [3]. Here, this approach is generalised, as an approximation, for multi-service traffic, too. Besides, it was shown in [4] that, for long duration connections, there is no practical advantage in using guard channels for handover. Because more than an half of our applications have long average duration, we did not consider guard channels for handover.

Service components users (i.e., customers) request a fixed number of channels, which are granted if available. If not, the request is cleared and the customer is blocked. The classification of customers is done on the basis of their arrival process, capacity requirement and mean holding time.

Service components are generated according to the Bernoulli case of a Bernoulli-Poisson-Pascal (BPP) process [5]. The capacity vector **A** gives the number of code channels that each application demands and it is of the type

$$\mathbf{A} = \{a_j\},\ j = 1,\ldots,J\,, \tag{1}$$

where $a_j$ is the service component $j$ capacity demand. Blocking situations occur when the request of a new user cannot be granted, i.e., they take place when the system is within the set

$$\mathrm{B}_j = \{n \in \mathrm{N} : n \cdot \mathbf{A} + a_j > c\}, \tag{2}$$

where N is the set of possible channels [6], upper-bounded by the finite channel capacity ($c$ resources available). If there are no resources available the request will be cleared and the user blocked, and the system will remain in the same state. The blocking probability of the service component $j$ is given by the ratio between the expectation of the number of blocked requests, per time unit, and the total number of service component requests, per time unit. The algorithm for its computation is given in [5].

### *B. User model*

There are $c$ resources (or channels) available in each cell, which are being used by $M_T$ equivalent users. Considering the traffic mixtures defined in [2], formed by a total of 16 applications, the model for applications activation is the one presented in Figs. 1-2, where resources are used via the access to audio, data and video service components (see Section III for details, and acronyms).

Each user can be either in an idle state or using one of the 16 applications, with generation rate, $\Lambda_k$, and total service rate, $\mathrm{H}_k$, respectively. Once application $k$ is active, the six service components can be activated with rate $\Lambda_{j|k}$ and extinguished with total service rate $\mathrm{H}_{j|k}$, $j = 1, \ldots, J$. They can be simultaneously active, or not, and some can even not be activated for a given application.

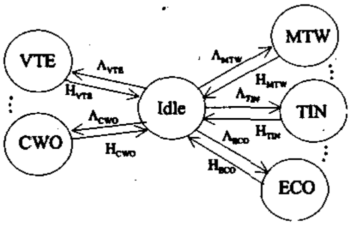

Fig. 1 - Model for applications activation.

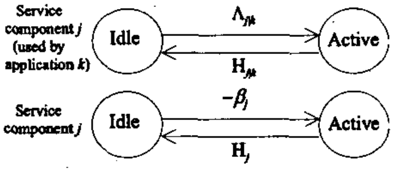

Fig. 2 - Model for service component activation.

The service rate of service component $j$ is .

$$\mathrm{H}_j = \sum_{k=\mathrm{VTE}}^{ENP} \Lambda_{j|k} \cdot \frac{\Lambda_k}{\mathrm{H}_k} \Bigg/ \left( \sum_{k=\mathrm{VTE}}^{ENP} \frac{\Lambda_{j|k}}{\mathrm{H}_{j|k}} \cdot \frac{\Lambda_k}{\mathrm{H}_k} \right) \tag{3}$$

If terminal mobility is considered [7], $\Lambda_{j|k}$ has to be replaced by $\Lambda_{j|k}$ times a factor $(\mu_k+\eta_k)/\mu_k$, where $\mu_k$ and $\eta_k$ are the service and the cross-over rates associated with application $k$, respectively [6].

This is a loss system, whose performance can be measured by the blocking probability of each service component, which simplifies the analysis (because one only needs to consider the most limiting service components, and not each application).

The system average load is [6]

$$L = f_a \cdot b_1 \cdot M_T\,, \tag{4}$$

where $f_a$ is the fraction of active users and $b_1$ is the maximum load per user, given by

$$b_1 = \sum_{k=1}^{K_{ss}} prop_k \cdot b_k\,. \tag{5}$$

$b_k$ is the application $k$ data rate, and the values for the usage, $prop_k$, are a characteristic of each specific deployment scenario [2]. The product $prop_k \cdot b_k$ gives the maximum load per application.

## III. SERVICE COMPONENTS

The fundamental service components are audio, data and video, which can be sub-divided into eight different kinds, distinguished in terms of types and data rates, $B_{sj}$. Besides, there is a correspondence between types of information supporting applications (such as sound, text, moving pictures, multimedia) and the service components themselves, Table 1:

- Interactive video: IV1 at 128 kb/s, IV2 at 384 kb/s, IV3 at 1536 kb/s, and IV4 at 1920 kb/s.
- Medium bit rate data: MD1 at 768 kb/s, MD2 at 1024 kb/s and MD3 at 1536 kb/s.
- Low bit rate data: LOD at 384 kb/s.

Table 1. Service Components: types and data rates.

| Service component | $j$ | $a_j$ | $B_{sj}$ [kb/s] |
|---|---|---|---|
| BAS | 1 | 1 | 128 |
| LOD = IV2 | 2 | 3 | 384 |
| MD1 | 3 | 6 | 768 |
| MD2 | 4 | 8 | 1024 |
| MD3 = IV3 | 5 | 12 | 1536 |
| IV4 | 6 | 15 | 1920 |

In the context of this work, IV1 is the basic channel, BAS; hence, the basic data rate is 128 kb/s, and, in Table 1, LOD replaces IV2, while MD3 stands both for IV3 and MD3 itself. This replacement is possible by assuming that both service components in each pair, LOD-IV2 and MD3-IV3, have the same characteristics, and that applications do not use components of these pairs simultaneously. $a_j$ is the number of channels requested by each service component.

The set of considered applications is defined by the deployment scenarios of [2], where MM and HIMM mean multimedia and high interactive MM, respectively :

| | | | |
|---|---|---|---|
| VTE | Video-telephony | MTW | Mobile Tele-working |
| HVT | HD Video-telephony | EMB | Electronic Mailbox for MM |
| HVC | HIMM Video-conference | ECO | E-commerce |
| VCO | Videoconference | TIN | Tourist Information |
| MVS | Mobile Video Surveillance | RPC | Remote Procedure Call |
| FTP | Data File Transfer (FTP) | UGD | Urban Guidance |
| DMM | Desktop Multimedia | ATR | Assistance in Travel |
| CWO | Collaborative working | ENP | E-newspaper |

Their service characterisation parameters are the following [2], [8], Table 2:

- intrinsic time dependency (time-based, TB, or non time-based, NTB, information),
- delivery requirements (real-time, RT, or non real-time, NRT),
- directionality (the flow of information can be bi - or unidirectional),
- symmetry of the connections,
- interactivity,
- number of parties.

All these applications are bi-directional and interactive, while almost everyone is one-to-one (except video-conference and e-newspaper, which are one-to-many).

Table 2. Service characteristics and average duration.

| Service Hierarchies | Type of Information | Appli-cations | $\overline{\tau}$ [min] | Service Characteristics | | |
|---|---|---|---|---|---|---|
| | | | | Time de-pendency | delivery re-quirements | Symmetry |
| Interactive, Conversa-tional | Moving Pictures And Sound | VTE | 3 | TB | RT | Sym/ Asy |
| | | HVT | 3 | | | |
| | | HVC | 20 | | | |
| | | VCO | 30 | | | |
| | | MVS | 10 | | | Asy |
| | Data | FTP | 0.33 | NTB | RT | |
| | Document (multimedia) | DMM | 15 | TB | RT | |
| | | CWO | 30 | | | Sym |
| | | MTW | 20 | | | |
| Interactive, Messaging | Mixed Document | EMB | 1 | TB | NRT | Asy |
| Interactive, Retrieval | Text, data, graphics, sound, still images, moving pictures. | ECO | 5 | TB | RT | Asy |
| | | TIN | 15 | NTB | | |
| | | RPC | 5 | | NRT/RT | |
| | | UGD | 5 | TB | | |
| | | ATR | 20 | | | |
| Distribution Cyclical | Text, graphics, sound, still images | ENP | 20 | TB | NRT | Asy |

The use of service component $j$ serving application $k$, is characterised by parameters $n_{fjk}$, the number of times it is accessed during application $k$, and $\mu_{fjk}$, its service rate given application $k$. Values, agreeing with the service characteristics, are presented in Tables 3-4. Application $k$ data rate is given by [6]

$$b_k = \sum_{j=VTE}^{ENP} \frac{n_{fjk} \cdot \mu_{fjk}^{-1}}{\mu_k^{-1}} \cdot a_j \cdot \qquad (6)$$

Table 3. Service component $j$ given application $k$, uplink.

| Appli-cation | $n_{fjk}$ | | | | | | $\overline{\tau_{fjk}}$ [min] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BAS | LOD | MD1 | MD2 | MD3 | IV4 | BAS | LOD | MD1 | MD2 | MD3 | IV4 |
| VTE | 1 | - | - | - | - | - | 3 | - | - | - | - | - |
| HVT | - | - | - | - | - | 1 | - | - | - | - | - | 3 |
| HVC | 1 | - | - | - | - | - | 20 | - | - | - | - | - |
| VCO | - | 1 | - | - | - | - | - | 30 | - | - | - | - |
| MVS | - | - | - | - | 1 | - | - | - | - | - | 10 | - |
| FTP | - | 2 | - | - | - | - | - | 0.0083 | - | - | - | - |
| DMM | - | 15 | - | - | - | - | - | 0.0550 | - | - | - | - |
| CWO | 1 | 20 | - | - | - | - | 30 | 0.0083 | - | - | - | - |
| MTW | - | - | 20 | - | 1 | - | - | - | 0.0083 | - | 20 | - |
| EMB | - | 3 | - | - | - | - | - | 0.0550 | - | - | - | - |
| ECO | - | 25 | - | - | - | - | - | 0.0083 | - | - | - | - |
| TIN | - | - | 20 | - | - | - | - | - | 0.0083 | - | - | - |
| RPC | - | - | 5 | - | - | - | - | - | 0.0083 | - | - | - |
| UGD | - | - | 8 | - | 1 | - | - | - | 0.0083 | - | 5 | - |
| ATR | - | - | 30 | - | 1 | - | - | - | 0.0083 | - | 20 | - |
| ENP | - | 5 | - | - | - | - | - | 0.0083 | - | - | - | - |

Table 4. Service compon. $j$ given application $k$, downlink.

| Appli-cation | $n_{fjk}$ | | | | | | $\overrightarrow{\tau_{fjk}}$ [min] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BAS | LOD | MD1 | MD2 | MD3 | IV4 | BAS | LOD | MD1 | MD2 | MD3 | IV4 |
| VTE | 1 | - | - | - | - | - | 3 | - | - | - | - | - |
| HVT | - | - | - | - | - | 1 | - | - | - | - | - | 3 |
| HVC | 1 | - | - | - | - | - | 20 | - | - | - | - | - |
| VCO | - | 1 | - | - | - | - | - | 30 | - | - | - | - |
| MVS | - | 30 | - | - | - | - | - | 0.0083 | - | - | - | - |
| FTP | - | 1 | - | - | - | - | - | 0.33 | - | - | - | - |
| DMM | - | 11.5 | - | - | - | - | - | 0.0550 | - | - | - | - |
| CWO | 1 | 20 | - | - | - | - | 30 | 0.0083 | - | - | - | - |
| MTW | - | - | 20 | - | 1 | - | - | - | 0.0083 | - | 20 | - |
| EMB | - | - | - | 1 | - | - | - | - | - | 1 | - | - |
| ECO | - | 11.5 | - | - | - | - | - | 0.0550 | - | - | - | - |
| TIN | - | - | - | - | 34.5 | - | - | - | - | - | 0.0550 | - |
| RPC | - | - | - | 11.5 | - | - | - | - | - | 0.0550 | - | - |
| UGD | - | - | 8 | - | 1 | - | - | - | 0.0083 | - | 5 | - |
| ATR | - | - | 30 | - | 1 | - | - | - | 0.0083 | - | 20 | - |
| ENP | - | - | - | - | 46 | - | - | - | - | - | 0.0550 | - |

Permanent service components are only activated once, and have the same duration of the application they are serving, while the characteristics of non-permanent service components can be summarised as follows:

- the average duration of service component $j$ given application $k$ is $\overline{\tau_{fjk}} = (\mu_{fjk})^{-1}$ = 0.055 min, and refers to the IPP model for Web Browsing [9], i.e., on/off average duration of 3.3 and 22.8 s, respectively.
- other values refer to the characterisation given in [10]: average duration of 0.0083 min for data access.

## IV. INFLUENCE OF TERMINAL MOBILITY

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, Table 5.

Table 5. Terminal mobility.

| Scenario | $V_{av}$[m·s$^{-1}$] | Δ [m·s$^{-1}$] | $\eta^{*}$[m·s$^{-1}$] |
|---|---|---|---|
| Static | 0 | 0 | 0 |
| Pedestrian | 1 | 1 | 0.72 |
| Urban | 10 | 10 | 7.21 |
| Main roads | 15 | 15 | 10.82 |
| Highways | 22.5 | 12.5 | 21.21 |

In a homogeneous distribution of users, although mobility does not affect the computation of blocking probability (for given density of users and fraction of active users), it imposes the proportion of new/handover connections. Hence, for each service component, it has influence on the handover failure probability threshold, given by

$$(P_{hf})_{j\,max} = \left( \mu_j / \eta_j \right) \cdot (P_d)_{max}, \qquad (7)$$

where $(P_d)_{max}$ is the maximum allowed connection dropping probability. The handover rate of service component $j$ is the ratio between the respective cross-over and service rates, $\gamma_j = \eta_j/\mu_j$, and increases as the users move fast, depending also on the coverage distance, $R$, of the cells. Fig. 3 presents $\gamma_j$ as a function of $R$ for the BCC scenario, uplink. A pedestrian type of mobility was considered for the majority of moving pictures and sound applications, while most data and MM ones are static.

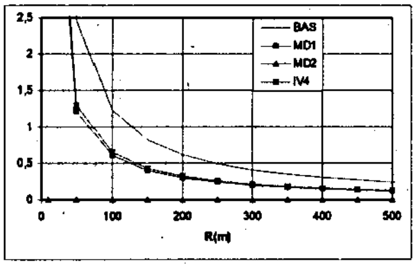

Fig. 3 - Handover rate as a function of $R$ (BCC scenario).

Comparing the graphs among different scenarios, $\gamma_j$ takes higher values for higher mobility scenarios, and is a decreasing function with $R$. From these curves, one can obtain the maximum handover failure probability, $(P_{hf})_{max}$, using (7). For a maximum connection dropping probability $(P_d)_{max}$ = 0.5 %, the value of the handover rate has important consequences on the handover failure probability threshold. An example is given in Fig. 4, URB scenario, uplink. In this scenario the majority of moving pictures, and sound applications have urban mobility, while data and multimedia ones are static.

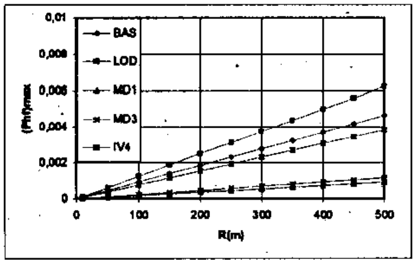

Fig. 4 - $(P_{hf})_{max}$ as a function of $R$ (URB scenario).

In the BCC scenario a handover failure threshold of, e.g., 0.02, is achieved for $R$ = 100 m. However, in URB and ROA scenarios, the corresponding $R$ has to be higher than 1000 m, while smaller cells would correspond to stringent conditions, i.e., very low values of $(P_{hf})_{max}$.
These results will be used to obtain the supported traffic. The most limiting service component will be considered, which is different from a scenario to another, and for each of the links, up-&down-.

## V. RESULTS

Results have been obtained for 75 and 100 channels per cell (both in up- and downlink). For each situation, the influence of mobility was studied by comparing results in presence and absence of mobility. In both cases, resources were distributed between the links in order to get symmetry on the supported fraction of active users.
Blocking probability was calculated as a function of $f_a$, the fraction of active users (for both links). However, only the most limiting service component is presented in the results and graphs, i.e., IV4 for BCC and URB scenarios, and MD3 for roads.
Assumptions were made for each scenario for the number of potential users, $M_T$, and the coverage distance, $R$: $M_T$ = 250, 100 and 100 users, while $R$ = 100, 100 and 150 m in BCC, URB and ROA scenarios, respectively.
Fig. 5 and Table 6 present results for 75 channels per link. In Fig. 5, an example of $P_b(f_a)$ is presented for the BCC scenario, uplink. From this, it is straightforward to obtain $f_a$ (by an inversion procedure, extracting values of $f_a$ for a fixed $P_b$ or $P_{hf}$, Table 6.

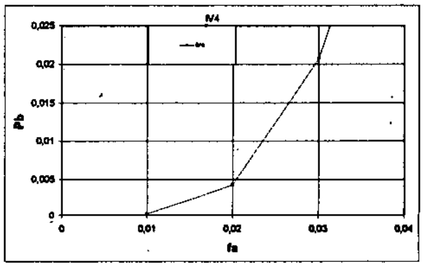

Fig. 5 - Blocking probability as a function of $f_a$ (BCC scenario, uplink).

Table 6 - Results for the supported $f_a$ and the number of users per km with 75 channels per link.

| Sce-nario | Link/ Chan | $f_a$ [%] | | $(P_{hf})_{max}$ | Users per km | |
|---|---|---|---|---|---|---|
| | | $P_b$ = 2% | $P_{hf}$ = $(P_{hf})_{max}$ | | absence | presence |
| BCC | U 75 | 3.3 | 3.0 | 77.02 x $10^{-4}$ | 41.25 | 37.5 |
| | D 75 | 3.2 | 3.0 | 77.02 x $10^{-4}$ | | |
| URB | U 75 | 8.4 | 4.7 | 77 x $10^{-5}$ | 42 | 15.6 |
| | D 75 | 8.7 | 4.9 | 77 x $10^{-5}$ | | |
| ROA | U 76 | 11.8 | 4.5 | 206 x $10^{-6}$ | 39.4 | 15 |

As in BCC the terminal mobility is low, the difference between the number of supported users in absence and presence of mobility (i.e., between the cases $P_b$ = 2% and $P_{hf}$ = $(P_{hf})_{max}$) is negligible (a 4% reduction only). However, in the URB and ROA scenarios the difference becomes relevant (the reduction is higher than 60%).

Analysing the results in absence of mobility, there is no important difference in the number of supported users among the three scenarios. In the presence of mobility, however, a difference arises. Results are 37.5, 15.6 and 15 user/km in BCC, URB and ROA scenarios, respectively. In this case, the difference in the number of supported users per kilometre between BCC and the other two scenarios is higher than 50%. Fig. 6 shows results for 100 channels per link, in the case of ROA scenario, uplink.

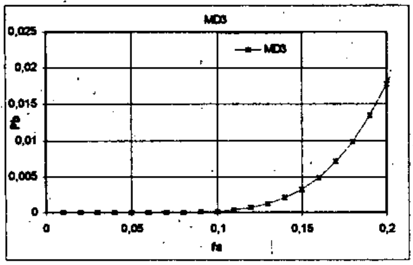

Fig. 6 - Blocking probability as a function of $f_a$ (ROA scenario, uplink).

Comparing the results between the absence and presence of mobility, Table 7, one concludes that there is a strong degradation in high mobility scenarios. While the reduction is only 17% in the BCC scenario, in the URB and ROA ones the reduction is 45-55%.

Table 7 - Results for the supported $f_a$ and the number of supported users per km with 100 channels per link.

| Sce-nario | Link/ chan | $f_a$ [%] | | $(P_{hf})_{max}$ | Users per km | |
|---|---|---|---|---|---|---|
| | | $P_b = 2\%$ | $P_{hf} = (P_{hf})_{max}$ | | absence | presence |
| BCC | U 98 | 4.9 | 4.02 | $77.02 \times 10^{-4}$ | 60 | 50.25 |
| | D 102 | 4.8 | 4.03 | $77.02 \times 10^{-4}$ | | |
| URB | U 101 | 12.3 | 6.5 | $77 \times 10^{-5}$ | 60.5 | 32.5 |
| | D 99 | 12.1 | 6.6 | $77 \times 10^{-5}$ | | |
| ROA | U 102 | 20.6 | 9.0 | $206 \times 10^{-6}$ | 67 | 30 |
| | D 98 | 20.1 | 9.1 | $104 \times 10^{-6}$ | | |

In the absence of mobility results for the number of supported users are: 60 for the BCC scenario, 60.5 for the URB one, and 67 for roads, i.e., in the BCC scenario, fewer users are supported than in the other two scenarios. This is because of the higher maximum load per user in the downlink, the link with lower $f_a$ ($b_{1DOWN}$ = 469.9 kb/s in the BCC scenario, against 437.7 and 309.3 kb/s in the URB and ROA ones). In the presence of mobility, results are: 50.25, 32.5 and 30 user/km in the BCC, URB and ROA scenarios. In this case, there is also a high reduction of users between BCC scenario and the other ones.

## VI. CONCLUSIONS

One can extract conclusions from three different points of view: mobility, scenarios, and number of channels. When no mobility is taken into account, the difference between the number of users in each of the scenarios is not relevant. However, when mobility is considered, from BCC to the other two scenarios, the difference in the number of users is higher than 50% with 75 channels per link (each with a data rate of 128 kb/s), and decreases around 40% with 100 channels per link. Within each of the scenarios, comparing the cases of presence and absence of mobility, while in the BCC one the difference is small (17% reduction), in the other two scenarios the difference is higher than 50 % (example for 100 channel/cell). Finally, it is worthwhile to note that in URB and ROA scenarios, the number of supported users is incremented in 100% (from ~15 to ~30) when the number of channels increases only 33% (from 75 to 100), corresponding to a statistical multiplexing gain.

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