Impact of Mobility in Mobile Broadband Systems Multi-service Traffic

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Abstract

Multi-service traffic engineering has a strong impact in Mobile Broadband Systems (MBS) revenues, and it will allow one to obtain merit functions for optimisation purposes, a key aspect in cellular planning. MBS applications have access to different service components, with different data rates and average durations. Fast mobility has an important impact in handover failure probability, hence, in system capacity. While in the business city centre and other urban scenarios mobility has no significant effect, it affects the supported traffic in main roads. A reduction up to 54 % may come as a consequence.

I. INTRODUCTION

Around 10 years from now, Mobile Broadband Systems (MBS) [1] will play an important role in the mobile communications market, to cover hotspots in the centre of large cities where a very high demand is foreseen. Although it is not necessary that future MBS will be based on ATM technology, the work from RACE-MBS [1] and ACTS-SAMBA [2] projects considered so, this being the approach one follows here. In ATM networks the available resources are shared in a way that allows multiplexing of different traffic sources, enabling a gain from this statistical multiplexing [3].

In order to model multi-services in MBS one needs first to model the air interface access, as well as the slot arrival process. Because traffic can be generated from different mixtures of voice, data and video sources, it is important to obtain performance measures for resource usage, making use of the characteristics of the frame structures [2] and of the MAC (Medium Access Control) protocol, the DSA++ (dynamic slot allocation) one.

The DSA++ protocol has an important characteristic: it allows one to consider connection-oriented communications [4]. By allocating a so-called container, formed by a number of slots, a base station defines channels like in circuit-switched connections. Thus, the methodologies for circuit-switched network analysis supporting heterogeneous traffic can be applied, while the MAC protocol guarantees that the maximum delay is kept under values that do not affect the performance of applications [5], namely real-time ones.

According to this approach, one assumes that a minimum data rate is guaranteed by the system for non-real time applications, e.g., in ABR (available bit rate) ones, only this minimum is considered in tele-traffic computations. The access to supplementary resources (if needed) is only possible if they are available, but it has not to be taken into account in the computations of the blocking probability, because it does not correspond to the worst-case situation.

Multi-service traffic engineering will be a key aspect in cellular planning, the feasibility of the aggregate traffic model being crucial. An MMPP (Markov-Modulated Poisson Processes) model is proposed for the modelling of the superimposition of data and video IPP (Interrupted Poisson Process) sources [6]. Given the correspondence between applications and their bearer service components, an algorithm for the Bernoulli case of the Bernoulli-Poisson-Pascal model is used to compute the blocking probability [6].

A simple approach is followed to take traffic from mobility into account, considering that handover failure probability can be obtained using the equation for the blocking probability [7]. For non-static applications, terminals can have the following types of mobility: pedestrian, urban, main roads or highways [7]. These models are a generalisation of the Erlang B/ Engset ones to multi-dimensional systems, supporting different applications, and allowing to generalise the models for single-service traffic from mobility to multi-service systems. This is possible owing to the use of ATM just at the air interface, enabling the modelling of the superimposition of different service components.

This paper is organised as follows. In Section II, a correspondence between service components and applications is proposed, and the user model is presented. In Section III, the impact of terminal mobility in the service components handover failure probability threshold is analysed, and the components that limit system performance are identified. In Section IV, results are presented for the supported fraction of active users and for the spectral efficiency, a comparison being made between the cases of presence and absence of mobility. Conclusions are drawn at the end.

II. COMPONENTS AND APPLICATIONS

A. Characterisation

One considers the set of 21 applications defined in [8], operating in the BCC (business city centre), URB (urban) and ROA (main roads) scenarios. Their main parameters (i.e., intrinsic time dependency, delivery requirements, directiona-lity, symmetry of the connections, interactivity and number of parties) are presented in [9]. Their characteristics were defi-ned knowing their average

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duration, burstiness and asymme-try factors [9]. For example, High Definition Video-telepho-ny is a symmetric real time application (b_{HVT} = 1920 kb/s) with 3 min duration and burstiness equal to 1. In contrast, Electronic Newspaper is a strongly asymmetric bursty application with 20 min duration, (b_{ENP} = 243 kb/s in the downlink).

Bearer service components are assumed to be BAS (basic) at 384 kb/s, MD1, MD2 and MD3 (medium data rate at 1152, 1536 and 1920 kb/s, respectively), HDV (high definition video) at 8 064 kb/s, and HID (high data rate data) at 31 872 kb/s. Their characterisation was extracted from [6], as well as their correspondence with applications, and the assumptions for usage. The list of the applications follows:

HVT	HD Video-telephony	FFM	Freight & Fleet Management
IVC	ISDN-Videoconference	EMB	E-mailbox Serv. for Multime.
MVS	Mobile Video Surveillance	ECO	E-commerce
HOB	HDTV Outside Broadcast	MML	Multimedia Library
WLI	Wireless LAN Interconnect.	TIN	Tourist Information
FTP	Data File Transfer (FTP)	RPC	Remote Procedure Call
PIM	Professional Images	UGD	Urban Guidance
DMM	Desktop Multimedia	ATR	Assistance in Travel
MES	Mobile Emergency Servic.	TVD	TV Programme Distribution
MRA	Mobile Repair Assistance	ENP	E-newspaper
MTW	Mobile Tele-working		

B. *User Model*

Applications have access to MBS resources via different (sound, data and video) service components, i.e., system resources support service components, which, in turn, serve applications. Different applications have different durations, and different associated data rates, which are obtained by summing the data rates of associated service components, weighted by the average proportion of time they area active during the application. As far as each component can be 'turned' *on* and *off* several times during an application, the proportion of time it is active also depends on the number of times it is activated. Thus, one is dealing with a mixture of different service components, whose correspondence with applications is completely defined by the user model [6].

In particular, considering voice, data and video sources being modelled by the IPP model, one can use the Bernoulli case of the BPP model [10]: the arrival process of service component j, with capacity demand, a_j, arrival rate, α_j, and activation rate, β_j, can be interpreted as the superposition of $N_j = -\alpha_j/\beta_j$ IPP sources, where the resource requirement in the ON state is a_j [10]. The arrival intensity (corresponding to an exponential distribution of the inter-arrival times), conditioned to n_j customers being in the system, is of the form

$$\lambda_j(n_j) = \alpha_j + n_j \cdot \beta_j = (N_j - n_j) \cdot (-\beta_j), \qquad (1)$$

with $\alpha_j > 0$, and $\beta_j < 0$, where N_j is the total potential number of users of component j. This model can be viewed as a multidimensional generalisation of the classical Erlang B/ Engset loss models; thus, the state distribution depends on the residency time distributions only through their respective mean, known as the *insensitivity property*.

The activation of each of the 21 applications was modelled in [6], Figs. 1-2. Besides, one assumes that there is a total of c available channels in each cell, which are used by a number of equivalent potential users, M.

Each user can be either in an idle state or using one of the 21 applications, k = HVT, ..., ENP, with generation rate, Λ_k, and total service rate, H_k, respectively. The total service rate is introduced in order to take into account the effect of terminal mobility in the service rate, μ_k, which depends on the cross-over rate, η_k, i.e., $H_k = \mu_k + \eta_k$.

Once the application k is active, each of the six service components (identified by $j = 1, \ldots, J$) are activated with rate $\Lambda_{j|k}$ (note that $\Lambda_{j|k} = n_{j|k} \cdot H_k$, where $n_{j|k}$ is the number of times the service component j is activated during application k), and extinguished with total service rate $H_{j|k}$; they can be simultaneously active, or not, and some can even not be activated for a given application.

As consequence, the activation rate of the service component j is given by the expectation of $\Lambda_{j|k}$, leading to

$$\left(-\beta_j\right) = \sum_{k=\mathrm{HVT}}^{\mathrm{ENP}} \Lambda_{j|k} \cdot p_k = f \cdot \sum_{k=\mathrm{HVT}}^{\mathrm{ENP}} \Lambda_{j|k} \cdot prop_k , \qquad (2)$$

where p_k is probability of a user having an active application, f is the fraction of active users, and $prop_k$ represents the usage of application k (defined as the percentage of an application use relatively to the total number of active applications), such that $p_k = f \cdot prop_k$.

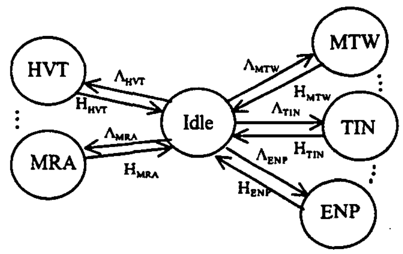

Fig. 1. Model for applications activation.

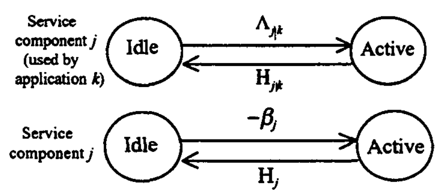

Fig. 2. Model for service components activation.

If the system is stationary, the average occupancy of service component j is given by the following ratio

$$\left(-\beta_j^{norm}\right) = \frac{-\beta_j}{H_j} = \sum_{k=\mathrm{HVT}}^{\mathrm{ENP}} \frac{\Lambda_{j|k}}{H_{j|k}} \cdot p_k \qquad (3)$$

here called normalised activation rate, meaning that the service component j service rate is

$$\mathrm{H}_j = \sum_{k=\mathrm{HVT}}^{\mathrm{ENP}} \Lambda_{j|k} \cdot \frac{\Lambda_k}{\mathrm{H}_k} \Bigg/ \left(\sum_{k=\mathrm{HVT}}^{\mathrm{ENP}} \frac{\Lambda_{j|k}}{\mathrm{H}_{j|k}} \cdot \frac{\Lambda_k}{\mathrm{H}_k} \right). \quad (4)$$

This does depend on mobility, because of the dependence of the numerator on it, details being given in Section III.

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

As $N_j = M$ for every j, the system average load is [11]

$$L = f \cdot b_1 \cdot M, \quad (5)$$

where b_1 is the maximum load per user, it being given by

$$b_1 = \sum_{k=\mathrm{HVT}}^{\mathrm{ENP}} prop_k \cdot b_k . \quad (6)$$

b_k is the application k data rate [6], which depends on a_j. Using the values of $prop_k$ from [8], the maximum load per user allows one to define the asymmetry factor, A_f, the ratio of b_1 between the down- and uplinks, Table 1.

Table 1 – Asymmetry factor for the various scenarios.

	BCC		URB		ROA	
	UP	DOWN	UP	DOWN	UP	DOWN
b_1 [kb/s]	657	1868	597	1678	801	1734
A_f	2.688		2.643		2.095	
$b_{1\text{-}UP}+b_{1\text{-}DOWN}$	2 525		2 275		2 535	

In the presence of mobility, the supported fraction of active users is obtained from the worst case between solving either the equation $P_{hf} = (P_{hf})_{max}$ or $P_b = 2\%$. Given the supported fraction of active users, f, the number of supported users in a cell is given by $N_{SU} = f \cdot M$, while the total spectral efficiency comes from

$$\left(S_{ef}\right)_{TOT} = \frac{f \cdot M \cdot \left(b_{1\text{-}UP} + b_{1\text{-}DOWN}\right)}{\left(c_{UP} + c_{DOWN}\right) \cdot UBR_{slot}}, \quad (7)$$

where c_{UP} and c_{DOWN} are the number of available channels for the up- and downlinks, respectively, and UBR_{slot} is the user data rate directly associated with a slot, the basic channel considered here; one considers $UBR_{slot} = 384$ kb/s.

III. INFLUENCE OF TERMINAL MOBILITY

Although a much more accurate approach could be followed (e.g., the one with Markov Additive Processes [12]), one is looking here for a first simple approach to take the traffic from mobility into account in MBS multi-service traffic analysis/engineering.

In the considered deployment scenarios, the characteristics of terminal mobility for non-static applications are the following: pedestrian (PD), urban (UB), main roads (MR) or highways (HW). The mobility scenarios are described in [7] (triangular distribution with average velocity, $V_{av} = 1$, 10, 15 and 22.5 m·s^{-1}, for the four mobility scenarios, respectively). Among several possible choices for each application, one suggested the characterisation proposed in Table 2, where the static type of mobility is represented by ST.

Table 2 – Type of mobility for the various scenarios.

Application	Scenario BCC	URB	ROA	Application	Scenario BCC	URB	ROA
HVT	PD	UB	HW	FFM	ST	UB	HW
IVC	PD	ST	MR	EMB	ST	ST	MR
MVS	PD	UB		ECO	ST	UB	
HOB	ST	ST		MML	ST	ST	
WLI	ST	ST		TIN	PD	UB	HW
FTP	ST	UR		RPC	ST	ST	MR
PIM	ST	ST		UGD	PD	UB	
DMM	ST	ST		ATR	ST	UB	
MES	ST	UB		TVD	ST	ST	
MRA	ST	ST		ENP	ST	ST	
MTW	ST	ST					

In the single-service case, when no guard channels for handover are considered, the equation for the blocking probability is equal to the one for the handover failure probability [7]. In this work, one is considering that this equality also stands in the multi-service case. Given the fraction of resource occupancy (usage) of an application [8], it seems that the mobility does not affect the computation of the blocking probability for given density of users and fraction of active users, determining, however, the proportion of new/handover connections.

Besides, for each service component j, the mobility of terminals has influence on the handover failure probability threshold [7], given by

$$\left(P_{hf}\right)_{max j} = \left(\mu_j \Big/ \eta_j \right) \cdot \left(P_d\right)_{max} \quad (8)$$

where μ_j and η_j are the component j service and cross-over rates, respectively, j = BAS, ..., HID, η_j being inversely proportional to the cell range, R. $(P_d)_{max}$ is the maximum allowed connection dropping probability. The handover rate, the ratio between the cross-over and the service rates, $\gamma_j = \eta_j/\mu_j$, is obtained from the total service rate for each component H_j, knowing the service rate for the static case μ_j,

$$\gamma_j = \frac{\eta_j}{\mu_j} = \frac{\mathrm{H}_j}{\mu_j} - 1. \quad (9)$$

Results for $\gamma_j(R)$ are presented in Fig. 3 for the downlink in the ROA scenario. It is a decreasing function with R, taking higher values for the HDV, MD1, MD3 and HID components. As the MD3, HDV and HID are the highest data rate components, they are the most limitative ones.

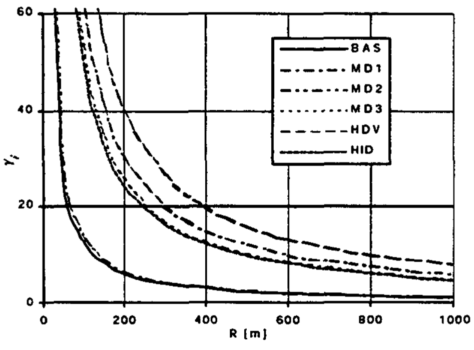

Fig. 3. $\gamma_j(R)$, for the downlink in the ROA scenario.

The generation rate has the influence of both new and handover connections, hence the difference in traffic computations consists of re-computing H_j multiplying Λ_{jjk} by $(\mu_k+\eta_k)/\mu_k$ in the numerator of (4) when mobility is considered. From the results one also concluded that, except for the BCC deployment scenario, where only few applications have PD mobility, the remaining ones being static, the handover rate γ_j is higher for the downlink case.

For a connection dropping probability $(P_d)_{max}$ = 0.5 %, the value of the handover rate has important consequences on the maximum handover failure probability, whose dependence on R is linear. For some service components, $(P_{hf})_{maxj}$ cannot be computed, because $\eta_j = 0$ (either because the applications using that service component are 'static', or because no application uses that service component, e.g., the case of the MD2 and the HID service components).

As a consequence of the previous analysis, the maximum handover failure probability (corresponding to P_d = 0.5 %) takes higher values for the downlink (in comparison to the uplink), except for the BCC deployment scenario. The service components that limit system performance, in terms of P_{hf}, are the following: MD3 and HDV at both links in the BCC and URB scenario, respectively, whereas in the ROA scenario, the limitation comes from HDV and HID for the up- and downlinks, respectively. For a given link (up- or downlink), it is the highest bit rate service component that has at least one no static application (i.e., non-null η_j) associated with it. In some cases, however, the blocking probability constraint can be the most limitative.

IV. RESULTS

One considers the assumptions for channel usage from [6]. The total amount of channels in each cell is a fraction of the total number of channels, depending on the number of operators and on the re-use factor, K [2]. In this paper, one considers the cases of 432 and 288 channel/cell. The former corresponds to 4 operators and K = 3, while the latter corresponds either to 4 operators and K = 3 or 3 operators and K = 4). Another assumption is that four-leaf cells are suitable for coverage in BCC and URB scenarios, whereas cigar-shaped cells are suitable for roads coverage [6].

The starting point of MBS optimisation consists in obtaining the variation of the spectral efficiency with the coverage distance. However, in [6] the spectral efficiency was only computed for fixed values of R, taking into account both the blocking and handover failure probabilities thresholds, but not taking into account its variation with R. Furthermore, those results were obtained considering that the distribution of resources between the up- and downlinks has only slight changes relatively to the one defined by the asymmetry factor, and the results for the supported f is balanced only for P_b = 2%. In that case, the HDV and HID components limits the up- and downlinks, respectively.

In this paper, our approach is redefined in order to have a balance of the supported traffic between the links according to $P_{hf} = (P_{hf})_{maxj}$, Table 3. The computations are redone, in order to have also a set of results for different values of R, say, $10 \leq R \leq 500$ m. While in [6] one has considered a num-ber of user per cell of M = 250, 100 and 100 (for R = 100, 100 and 150 m), in the BCC, URB and ROA scenarios, respectively, in this paper one is considering that M is directly proportional to R, being computed by $M = 2.5{\cdot}R$, $M = R$ and $M = 0.67{\cdot}R$, respectively. As an example, results for the blocking probability, as a function of the fraction of active users, are presented in Fig. 4 (for the ROA scenario).

Table 3 – Distribution of channel between the links.

C_{LINK}	LINK	288 channel/cell	432 channel/cell
BCC	UP	66	99
	DOWN	222	333
URB	UP	90	110
	DOWN	198	322
ROA	UP	63	99
	DOWN	225	333

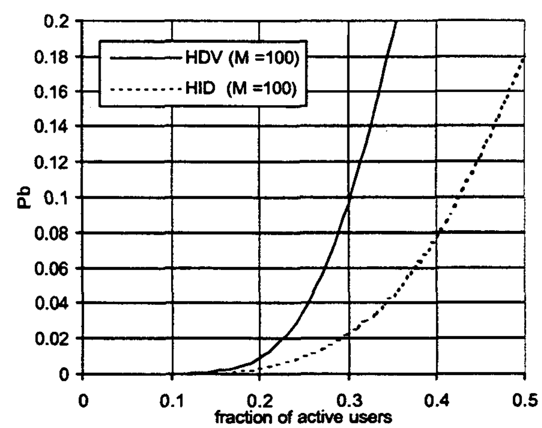

Fig. 4. Blocking probability for the ROA scenario, K = 2.

Thus, as in the absence of mobility the restriction comes from P_b = 2%, one can conclude that the supported fraction of active users in the ROA scenario is $f = 22.6$ %. Besides, some asymmetry is verified between links, because the distribution of the resources from Table 3 was done according to the handover failure probability restriction. Results for the supported f, as a function of R, are presented in Fig. 5 (the example is also for the ROA scenario).

The variation with R of the spectral efficiency and of the supported number of user/km was also studied (although detailed results are not presented here [13]). It allows one to choose $K = 3$ for the URB scenario, whereas $K = 2$ is needed in the BCC and ROA scenarios (according to RACE-MBS forecasts, the initial objective was to obtain, at least, 200, 58 and 39 users in the BCC, URB, and ROA scenarios, respectively), Table 4. Whereas in the BCC and URB scenarios the initial objective is overcome, in the BCC scenario the goal of supporting 200 user/km cannot be achieved only with a single operator. It is worthwhile to note that, whereas $K = 3$ corresponds to using the 40 GHz band and/or the upper 1 GHz sub-band of the 60 GHz band, $K = 2$ corresponds to the lower 1 GHz sub-band of the 60 GHz band [13].

As in presence of mobility, the HID component is not limitative, high terminal mobility only imposes a strong limitation in the ROA scenario ($f = 10.3$ % against $f = 22.6$ % in the ROA scenario, for $R = 150$ m).

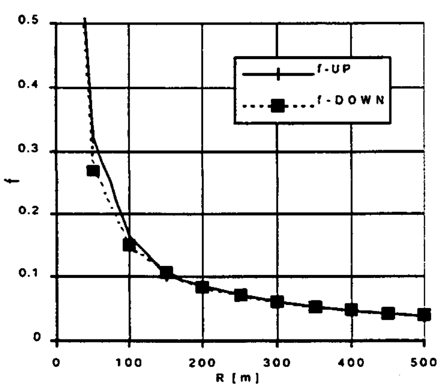

Fig. 5. Supported f as a function of R, for the ROA scenario, and presence of mobility, $K = 2$.

Table 4 – Summary of the results for $R = 100$ m.

Scenario	K	Limiting link	f [%]	R [m]	Supported no. user/km	$(S_{ef})_{TOT}$ [%]
BCC	2	DOWN	10.4	100	137	39.5
URB	3	DOWN	14.1	100	74	29.1
ROA	2	DOWN	15.1	100	50	15.2
			10.3	150	34	16.3

V. CONCLUSIONS

In this paper one analyses MBS multi-service traffic in pre-sence of mobility, based in a correspondence between service components and applications. Besides its strong dependence on the mixture of applications and their characteristics, the traffic from mobility imposes degradation in scenarios with higher mobility. In main roads, the HDV and HID compo-nents limit the up- and downlinks, respectively; the impact of mobility being important (there is a reduction of 54 % in presence of mobility). These results can be fed into the MBS economic analysis for system optimisation purposes.

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