

# Multi-service Traffic Analysis in Mobile Broadband Systems

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## Abstract

*A model for multi-service traffic analysis in Mobile Broadband Systems is proposed, which takes into account the way in which mobility of terminals affects the occupancy of service components for a typical set of applications. The Bernoulli-Poisson-Pascal theory is used to model the traffic. For scenarios where HDV based applications are mostly used the system performance is affected. When a high mobility of terminals is considered, at least 72 channels of 8 Mbit/s are needed to obtain a fraction of active users of the order of 10 %.*

## 1. Introduction

Mobile Broadband Systems (MBS) will allow going beyond third generation mobile communications systems [1], resolving the limitations in system capacity and terminal mobility of the 2 Mbit/s UMTS applications, and also supporting Broadband-ISDN applications with data rates up to 155 Mbit/s. In order to evaluate the upper bounds for supported traffic and system capacity, it is presented the traffic analysis for a multi-service public MBS with a typical set of applications [2]. The following mobility environments are considered for system operation: static, downtown and large avenues.

The BPP (Bernoulli-Poisson-Pascal) process theory is used to model the traffic [3]. More specifically, one considers the Bernoulli case, because the population is small and it correctly models the reduction of the call arrival intensity when the number of active users increases, and consequently the number of idle users decrease. There are 500 users per kilometre using five different applications. For each application in an individual micro-cell with length  $2R$ , where  $R$  is its maximum coverage distance (typically  $R = 100-150$  m [4]), from a total of 100-150 users in each cell, only a "little" fraction can be using one of the five applications, because the others are accessing other applications. Despite considering the Bernoulli model for new calls one still uses, as an approximation, the flow equilibrium equation for new and handover calls generation rate valid for the Poisson distribution case [5].

In Section 2, the assumptions for the problem being dealt are described and a complete characterisation of applications and service components is done. In Section 3, the user model is presented. The process of application activation/deactivation is described and the process to compute the average load is presented. Then, the way how equivalent users origin actual service components users is described. Finally, aspects related to the influence of terminal mobility are addressed. In Section 4, the methodology to obtain system capacity is briefly described. Results are then obtained for system capacity for a given  $R$ , and for the dependence of the fraction of active users, the maximum number of active users per kilometre and the average number of new calls per kilometre on  $R$  is highlighted. Conclusions are drawn at the end.

## 2. Characterisation of Applications

Although the future broadband communications market will possibly support hundreds of applications simultaneously [6], the work performed in the RACE II-MBS project identified some killer applications for the mobile domain [2], which are being considered in this analysis. Assumptions are made for the number of channels available per cell and the fraction of occupancy of each application in the whole system: 10% for Emergency Services (ES), 15% for Repair Assistance (RA), 40-45% for Urban Guidance/Assistance in Travel (UG), 10-5% for HDTV Outside Broadcast (HDTV-OB), and 15% for Tele-working (TW), where the values presented are the occupancies,  $prop_k$ ,  $k = ES, \dots, TW$ . The two values presented for the occupancies

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of Repair Assistance and HDTV Outside Broadcast correspond to two case studies, 1 and 2, respectively, which allow a comparison between the results with different loads.

Applications have access to three service components, which fully support them<sup>1</sup>: i) high definition video (HDV) at 8 Mbit/s, typically using the MPEG2 standard, ii) interactive video and image (IV) at 2 Mbit/s, typically using the MPEG1 or H.621 standards [7], and iii) data at 1 Mbit/s. It is assumed that 8 Mbit/s will be enough to provide broadcast quality HDV in the future. Although the static assignment is a simple way to assign the available spectrum, it is not efficient, there being a waste of resources. Therefore, it is preferable to assign resources, i.e., service components, whenever each application needs it, decreasing the allocated system bandwidth. In order to simplify the analysis, symmetric communications are assumed here (i.e., using the same data rate in both up/downlink), although it can not be generally true.

The average duration of each permanent service component is equal to the average duration of the application. If a service component is not permanent, its average duration is lower, being used several times during the application. The characteristics proposed for service components in this first configuration are partly based on [2] and [8], Table 1. The average utilisation of applications is described in Table 2.

Table 1 - Characteristics of service components.

Component	$\bar{\tau}_s$ [min]	$a_j$ [Mbit/s]	$\mu_j$ [ $\text{min}^{-1}$ ]
HDV	0.5; 50	8	0.02; 2
IV	20 - 40 - 60	2	$\{1.67-2.5-5\} \cdot 10^{-3}$
DATA	$8.3 \cdot 10^{-3}$	1	120

Table 2 – Average utilisation of service components.

Application	HDV	IV	DATA	$\bar{\tau}$ [min]	$\mu_k$ [ $\text{min}^{-1}$ ]	$prop_k$ [%]
ES	4 times	Permanent	10 times	20	0.05	15
RA	4 times	Permanent	20 times	40	0.025	20
UG	0	Permanent	30 times	60	0.0167	40-45
HDTV	Permanent	0	20 times	50	0.02	10- 5
TW	0	Permanent	20 times	20	0.05	15

### 3. User Model

#### 3.1 Applications Activation

There is a total number of  $c$  available resources in each cell, being used by a number of equivalent users,  $M$ . Given a traffic mix, the model for applications activation by users is the presented in Fig. 1. a). Each user can be either in an idle state or using one of the five applications,  $k = \text{ES}, \dots, \text{TW}$ , with generation and total service rates,  $\Lambda_k$  and  $H_k$ , respectively. Once the application  $k$  is active, the three service components are activated with rate  $H_{jk}$  and extinguished with total service rate  $H_{jk}$ ,  $j = \text{HDV}, \text{IV}, \text{DATA}$ , Fig. 1.b); they can be simultaneously active, or not. 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 three components, and not each application.

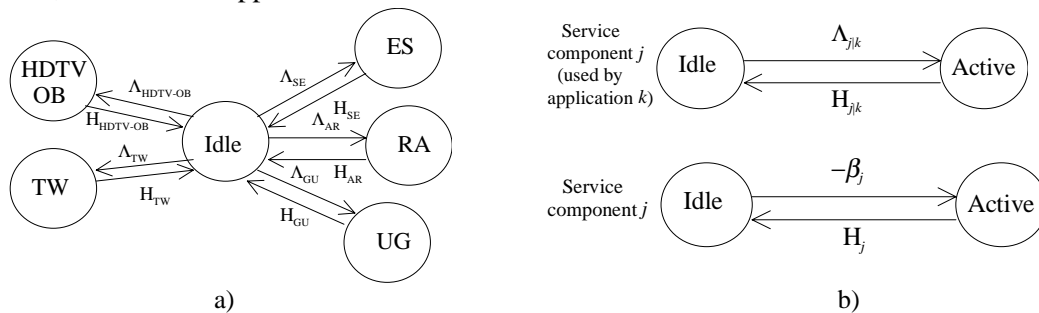


Figure 1: Models for (a) applications and (b) service components activation.

<sup>1</sup> Voice transmission is not relevant in this analysis (because of the relative much lower data rates associated).

### 3.2 Average Load

From Fig. 1 it is straightforward to derive the probability of an user having an active application

$$p_k = \frac{\Lambda_k / H_k}{1 + \sum_{i=SE}^{TW} \Lambda_i / H_i}. \quad (1)$$

Should  $\Lambda_k$  be given, as a function of the occupancy, by  $\Lambda_k = \lambda \cdot prop_k \cdot H_k$ , the normalised generation rate will be then  $\Lambda_k^* = prop_k \cdot H_k$ , such that  $\sum_{i=SE}^{TW} \Lambda_i^* / H_i = 1$ . Replacing  $\Lambda_k$  in (1), the following simplification is achieved

$$p_k = \frac{\lambda}{1 + \lambda} \cdot \left( \frac{\Lambda_k^*}{H_k} \right). \quad (2)$$

The load from each user is obtained by computing the expectation of every application data rate, i.e.,

$$L_u = \sum_{i=SE}^{TW} p_i \cdot b_i, \quad (3)$$

leading (multiplying by  $M$ ) to the system average load

$$L = \frac{\lambda}{1 + \lambda} \cdot c_1 \cdot M \quad (4)$$

where one has  $c_1 = \sum_{i=SE}^{TW} (\Lambda_i^* / H_i) \cdot b_i$ , and consequently the fraction of active users being  $f = \lambda / (1 + \lambda)$ .

### 3.3. Equivalent User

In this model, each equivalent user origins three actual users, one for each service component, using resources with data rates  $a_j$ , during a time exponentially distributed with average  $1/H_j$ ,  $j = \text{HDV, IV, DATA}$  (one has  $H_j = \mu_j$  in the static case); so the number of users accessing each individual service component is also  $M$ . Because of the independence in activation of each service component, the Bernoulli model is used [3].

The activation rate of each component given an application  $k$  is defined by [8]

$$\Lambda_{j|k} = \frac{E[\text{number of active s. component } j \text{ requests}]}{E[\text{duration of application } k]} = \frac{n_{j|k}}{1/\mu_k} = n_{j|k} \cdot \mu_k \quad (5)$$

where the values of  $n_{j|k}$  can be extracted from Table 2, being unitary for permanent service components. The values for  $H_{j|k}$  can be extracted from Table 1, according to Table 2. Although the values of  $\Lambda_{j|k}$  and  $H_{j|k}$  change when the influence of mobility of terminals is considered [9], their ratio is maintained constant, and no change will exist for traffic analysis purposes, except for the blocking/ handover failure threshold.

The BPP model theory was used [3]. The number of active users of class/component  $j$  using their resources,  $a_j$ , - at time  $t$  - are represented by the random variable  $N_j(t)$ , the system state being represented by  $N(t) = (N_1(t), \dots, N_f(t))$ . When the system is in state  $N(t) = \mathbf{n}$ , the time until next user class  $j$  arrival is exponentially distributed with parameter  $\lambda_j(n_j)$ , it being given by

$$\lambda_j(n_j) = \alpha_j + n_j \cdot \beta_j = (N_j - n_j) \cdot (-\beta_j) \quad (6)$$

in the Bernoulli case, where  $(-\beta_j)$  is the activation rate of the component  $j$ , Fig. 1.b)  $\alpha_j = -\beta_j \cdot N_j$ ,  $N_j = M$ , and  $n_j$  is the actual number of active users accessing the component  $j$ . These parameters should be normalised with respect to the total service rate of component  $j$ , leading to  $\beta_j' = \beta_j / H_j$  and  $\alpha_j' = \beta_j' \cdot N_j$ , meaning that different time scales are introduced for each  $j$ .

The activation rate of each service component,  $(-\beta_j)$ , is given by the expectation of  $\Lambda_{j|k}$ , leading to

$$(-\beta_j) = \sum_{k=SE}^{TW} \Lambda_{j|k} \cdot p_k = \frac{\lambda}{1 + \lambda} \cdot \sum_{k=SE}^{TW} \Lambda_{j|k} \cdot prop_k. \quad (7)$$

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

$$(-\beta_j') = \frac{-\beta_j}{H_j} = \sum_{k=SE}^{TW} \frac{\Lambda_{j|k}}{H_{j|k}} \cdot p_k \quad (8)$$

here called normalised average occupancy, meaning that

$$H_j = \sum_{k=SE}^{TW} \Lambda_{jk} \cdot \frac{\Lambda_k^*}{H_k} / \left( \sum_{k=SE}^{TW} \frac{\Lambda_{jk}}{H_{jk}} \cdot \frac{\Lambda_k^*}{H_k} \right). \quad (9)$$

This does depend on the mobility because of the dependence of the numerator on it (a factor  $(\mu_k + \eta_k)/\mu_k$  times  $\Lambda_{jk}$ , where  $\mu_k$  and  $\eta_k$  are the service and the cross-over rates associated with application  $k$ ).

The data rates associated with each application are

$$b_k = \sum_{j=HDV}^{DATA} \frac{n_{jk} \cdot 1/H_{jk}}{1/\mu_k} \cdot a_j \quad (10)$$

the results being:  $b_k = 2.804, 2.404, 2.004, 8.003$  and  $2.008$  Mbit/s, for the respective applications  $k = ES, \dots, TW$ , also leading to  $c_1 = 3.144$  Mbit/s (which is the maximum load per user).

### 3.4. Influence of Terminal mobility

The characteristics of terminal mobility for non-static applications are the following. For downtown, it is considered that only two applications are not static (UG and HDTV-OB), being characterised by the values for the pedestrian scenario described in [10] (triangular distribution with average velocity,  $V_{av}$ , and deviation,  $\Delta$ , both of  $1 \text{ m}\cdot\text{s}^{-1}$ ). In large avenues, all applications have urban mobility ( $V_{av} = \Delta = 10 \text{ m}\cdot\text{s}^{-1}$ ), except ES and TW, which are characterised by the main roads scenario ( $V_{av} = \Delta = 15 \text{ m}\cdot\text{s}^{-1}$ ).

Given the fraction of resource occupancy of an application, Table 2, 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 calls. Besides that, for each service component  $j$ , the mobility of terminals has influence on the handover failure probability threshold [10]  $(P_{hf})_j$ , given by

$$(P_{hf})_j = \left( \frac{\mu_j}{\eta_j} \right) \cdot (P_d)_{\max} \quad (11)$$

where  $\mu_j$  and  $\eta_j$  are the service and cross-over rates for the service component  $j$ , respectively,  $j = HDV, IV, DATA$ ,  $\eta_j$  being inversely proportional to  $R$ ; and  $(P_d)_{\max}$  is the maximum allowed call dropping probability. The handover rate, the ratio  $\eta_j/\mu_j$ , is obtained from the total service rate for each component  $H_j$ , knowing the service rate for the static case  $\mu_j$ , both obtained from (9), Fig. 2 (case study 1)

$$\frac{\eta_j}{\mu_j} = \frac{H_j}{\mu_j} - 1. \quad (12)$$

As the generation rate has both the influence of new and handover calls [10], the difference consists of multiplying  $\Lambda_{jk}$  by  $(\mu_k + \eta_k)/\mu_k$  in (9) when mobility is considered. For case study 2 minor differences exist. One concludes that a much higher handover rate is obtained for the large avenues environment.

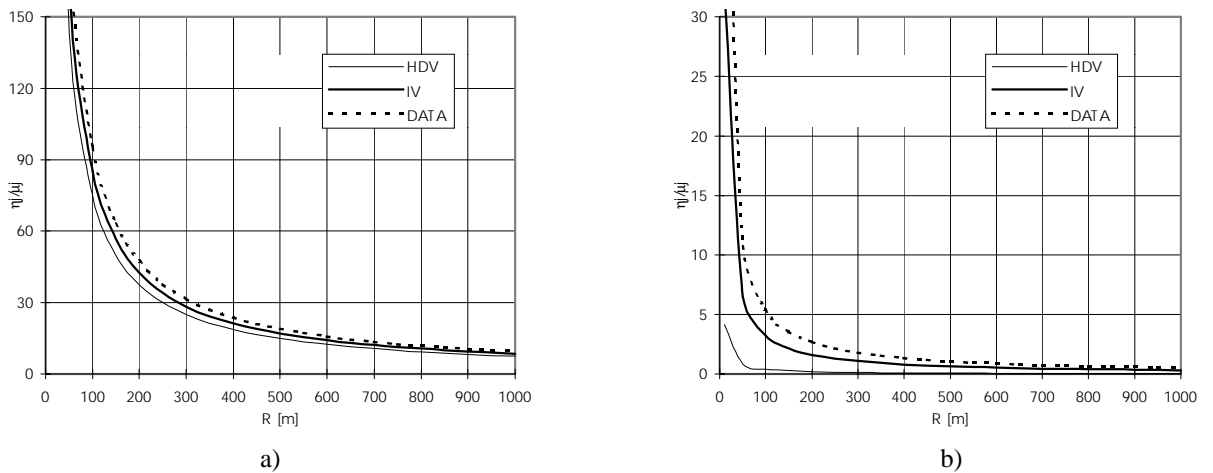


Figure 2 – Handover rate for a) the large avenues and b) the downtown environments, case study 1.

## 4. System Capacity

There is an amount of  $c$  1 Mbit/s resources and three user classes (HDV, IV and DATA). The capacity demand matrix is  $A = [a_j]$ ,  $j = \text{HDV, IV, DATA}$ ,  $a_j \in \mathbb{IN}$ , there being an average service rate  $\mu_j$  associated with each class. The occupancy of resources at time  $t$ ,  $Y(t)$  can be then defined by  $Y(t) = N(t) \cdot A$ , the *pmf* for  $Y(t)$  being denoted by  $q(y)$  [3]. As the set of possible states is bounded, owing to the finite number of available resources (a total sharing policy is considered), there is blocking if a service request is not completely satisfied. In order to compute the blocking probability, it is first needed to compute the *pmf* and PDF for the occupancies,  $q(y)$  and  $Q(y)$ , using the parameters  $\beta^j$  and  $\alpha^j$ , details given in [3].

A linear coverage geometry was considered [10]. Using the results for  $(P_b)_j$ , obtained from the previous analysis,  $j = \text{HDV, IV, DATA}$ , one concluded that the HDV component limits the system performance because of the highest values obtained for  $(P_b)_j$  for each  $f$ . If new and handover calls traffic were Poisson distributed, the blocking probability would be numerically equal to handover failure probability [5]. In this work, despite the consideration of a Bernoulli distribution for the new calls, the previous equality still stands (as an approximation), which is very useful to have a first insight on the influence of mobility in the supported traffic.

Results were obtained for  $f$  and the number of active users per kilometre, inverting the computation procedure for each value of  $P_b = P_{hf}(R)$ , Table 3,  $R = 100$  m. This was made for the HDV component using (11) and considering  $(P_d)_{max} = 0.005$  and  $(P_b)_{max} = 0.02$ . The number of 8 Mbit/s channels in each cell is  $c_h = 72$ , which can be faced as  $c = 576$  channel units of 1 Mbit/s. In the large avenues environment, the requirements for handover failure probability is  $(P_{hf})_{max} = 6 \cdot 10^{-5}$  (only for  $R = 100$  m). In the other two environments, it is  $(P_b)_{max} = 2 \cdot 10^{-2}$ , except for the downtown environment in the case study 1, where  $(P_{hf})_{max} = 10^{-2} < (P_b)_{max}$ .

Table 3 - Results for the fraction of active users,  $f$ , for  $R = 100$  m.

Environment	Case study 1	Case study 2
Static	15.0 %	18.5%
Downtown	13.5 %	18.5 %
Large avenues	7.0%	9.2%

From the static environment to the downtown one the differences on  $f$  are almost negligible. Nevertheless, from the downtown environment to the large avenues, the differences are drastic, only being supported approximately half of the active users. The difference between the two case studies is justified by the high weight of HDV based applications for case study 1.

In order to analyse the impact of terminal mobility on the results, it is also important to present results for  $f$  as a function of  $R$ , Fig. 3 (case study 2).

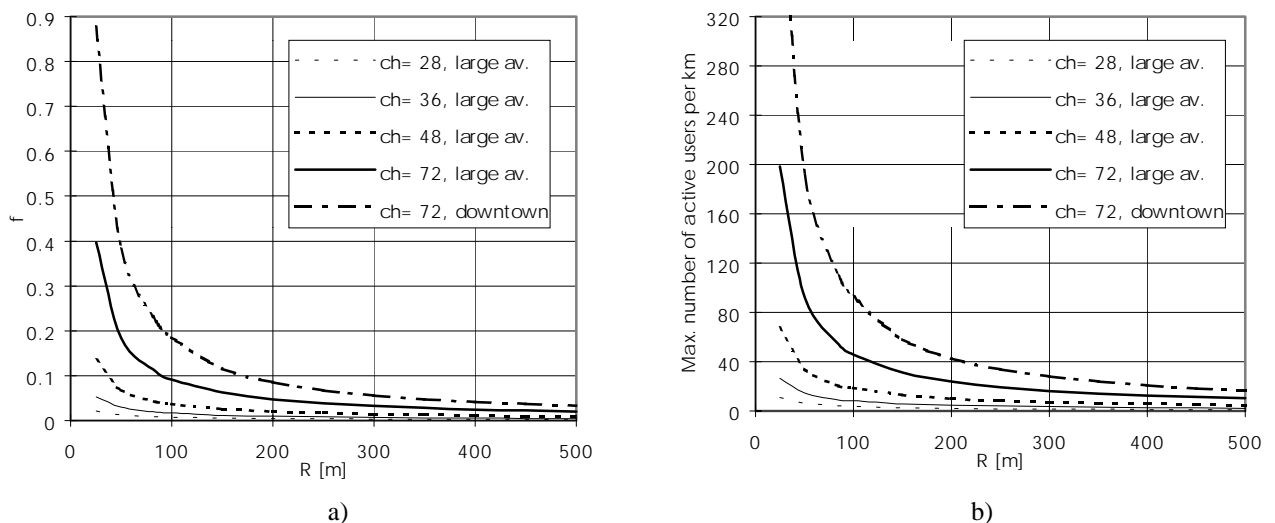


Figure 3 – a) Supported fraction of active users and b) maximum number of active users per km.

For the large avenues environment one considers  $c_h = 28, 36, 48$  and  $72$ , while only  $c_h = 72$  was considered for the downtown environment. For  $R > 85$  m, the results for downtown are coincident to the ones of the static environment, being not necessary to present a different curve for the last. From these values one can also determine the maximum number of active users per kilometre,  $f \cdot M \cdot (1000/(2R)) = f \cdot 500$ , the equality resulting from  $R$  being numerically equal to  $M$ , Fig. 3.b). The maximum number of active users per kilometre increases with the decrease of  $R$ , being much higher for the downtown environment because of the influence of terminal mobility. The maximum load per km,  $L \cdot (1000/2R)$ , in Mbit/s/km, is obtained multiplying it by  $c_1$ . It is worthwhile note that, e.g. for  $R = 100$  m, at least  $c_h = 72$  channels of 8 Mbit/s are needed to obtain a fraction of active users of the order of 10 %, a value that is usually reported. Although numerical results are not presented here, the values for the average number of new calls per kilometre,  $f \cdot M \cdot (\mu_j/H_j) \cdot (1000/(2R))$ , numerically equal to  $500 \cdot f \cdot (\mu_j/H_j)$ , are much higher for the downtown environment, being the difference justified by the differences in handover rate  $\eta_j/\mu_j$ . Note again that  $H_j = \mu_j + \eta_j$ . This means that much more new calls can be accepted per kilometre in environments with lower mobility, leading to a much higher system capacity.

## 5. Conclusions

An approach of for MBS multi-service traffic analysis was presented where several mobile applications have access to three basic service components. The Bernoulli model was used to characterise the traffic (as a particular case of the BPP one), because it correctly models the reduction of call arrival intensity when the number of active users increases. The mapping between the equivalent users and the actual three service components users was described, results being presented for the fraction of active users taking into account the mobility of terminals. From these, results were obtained for the maximum number of active users per kilometre. For scenarios where HDV based applications are mostly used (case study 1), the system performance is affected. The mobility of terminals also imposes a strong limitation in system capacity, being the consequences drastic in high mobility environments. Further work should be done in order to cope with applications asymmetry in up/downlink, and to investigate the consequences of extending the flow equilibrium for the traffic and the handover failure threshold equations, valid for Poisson distributed traffic, to the Bernoulli case.

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