Influence of Traffic from Mobility on the Microcellular Coverage Distance in Mobile Broadband Systems

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Abstract: *Models allowing the study of the influence of coverage distance and velocity on the supported traffic and on the new calls traffic linear density are examined, and results are obtained for typical scenarios in a Mobile Broadband System (MBS) with a linear coverage geometry. For situations without using guard channels for handover, for a fixed bounding value for the blocking probability, the new calls traffic linear density has been analyzed, increasing with the decrease of the coverage distance R, and being upper limited by a value which depends on the characteristics of the mobility scenario. However, call-dropping probability requirements also need to be fulfilled, leading to a new calls traffic linear density that only increases with the decrease of R down to an optimum value of R, and being lower for scenarios with higher mobility. This situation leads to limitations in system capacity for lower values of the coverage distance, mainly for high mobility scenarios.*

1. Introduction

The number and type of services and applications demanding higher and higher data rates has increased in the last years, and it is expected to continue that way in the coming years. MBS (Mobile Broadband System) [Fern95] is foreseen to be an answer to these needs, by extending the access of Broadband-ISDN to mobile users. The large bandwidths to be implemented in the system require the carrier frequency to be allocated in the millimetre waveband; besides that, the system will be deployed mainly in urban centres, having as a consequence that it will be based in a microcellular structure, i.e., cells will be confined to streets, with dimensions of the order of a few hundreds of metre. The MBS concept foresees high terminal mobility, where handover calls will play an important role in the overall traffic; so, besides the traffic originated by new calls, handover calls contribution to the global traffic has to be taken into account.

Although future MBS will be a multi-service system, providing multimedia mobile communications (including voice, data and video), in this paper only a single service will be taken into account, in order to simplify the analysis: videotelephony at 34 Mb/s, which will have a large demand, is considered as example [CBMF94]. An analysis of traffic from mobility for such microcellular communication systems is done assuming that handover traffic is Poissonean [ChLu95], that users in each cell are independent random variables among each other [Jabb96], and that new calls traffic is also Poisson distributed, which will be verified. A linear coverage geometry, where mobiles travel randomly with a given velocity, is considered; in this typical and easy to analyze configuration, cells, with coverage

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length R, total length $L = 2R$, and base stations located in the centre, are located side by side, covering a whole street or highway.

At a first glance, one could consider that the new calls traffic per unit length (or new calls traffic linear density) x_n should be proportional to $(1/R)$; however, this is only valid for the static scenario, where there are no handovers. In scenarios with mobility, the number of calls generated by handover increases as the length of the cells L decreases and the velocity increases, implying that x_n does not increase linearly with $(1/R)$. Furthermore, call dropping probability requirements also need to be fulfilled. These situations originate limitations in system capacity for some values of the coverage distance, mainly for high mobility scenarios. Thus, the influence of coverage distance and velocity on the supported traffic and on the new calls traffic linear density is examined, and results are obtained.

In Section 2, the assumptions considered in the traffic analysis are discussed, namely the ones related to the supported, the new calls and the handover traffics, and the handover probability. In Section 3, the new calls traffic linear density variation with the coverage distance is presented and, as call-dropping probability restrictions also have to be fulfilled, its dependence on the coverage distance is analyzed. Results for the supported traffic and for the new calls traffic linear density are presented in Section 4, and the approximation of new calls traffic being Poisson distributed is validated. Finally, some conclusions are drawn.

2. Traffic Analysis

The objective of the design is to obtain values for R that verify the requirements of system quality. These requirements consist of values lower than 1-2% for the blocking probability P_b, and lower than 0.1-0.5% for the call dropping probability P_d [ITUT96]. The parameters involved in the design depend on the velocity of mobiles v, the call generation rate l, the service rate m, the total number of available channels m_{tot}, and the reuse pattern k; the number of channels at each cell is $m = m_{tot}\backslash k$, where \ denotes the integer division.

The simple situation of homogeneous traffic (constant value of new calls traffic in the whole service area) and linear coverage geometry (where mobiles roam between the first and the last cells, typical for circular geometries [SiSt97]) will be considered here as first step to a more complicated (and closer to reality) analysis. In these conditions the handover failure probability is equal to the blocking probability $P_{hf} = P_b$. For a given value of m and P_b, and a configuration which does not use guard channels for handover calls, one can calculate the corresponding supported traffic $r_m = l/m$, by using the well known Erlang-B model [Yaco93]. It is worth to note that, for each m, r_m is independent of the coverage distance, e.g., for $m = 11$, r_m is approximately equal to 6 Erl.

The new calls traffic, r_n, and the traffic coming from handover, r_h, can then be obtained as [Jabb96]

$$r_n = \frac{m}{h+m}\cdot r_m = \frac{2mR}{h^* + 2mR}\cdot r_m \qquad (1)$$

$$r_h = \frac{h}{h+m}\cdot r_m = \frac{h^*}{h^* + 2mR}\cdot r_m \qquad (2)$$

where the dependence on the cell length has been made explicit by introducing the cross-over average velocity

$$h^* = h\cdot(2R) \qquad (3)$$

h being calculated from

$$h = \frac{1}{\int_0^{V_{max}} \left(\frac{2R}{v}\right)\cdot f(v)dv} \qquad (4)$$

where f is the velocity probability density function and V_{max} is the velocity maximum value. Note that $r_m = r_n + r_h$.

The handover probability is given by [Jabb96]

$$P_h = \frac{h}{h+m} \tag{5}$$

and it depends on the coverage distance and on the mobility scenario through h. Considering a service rate of m=1/3 min^{-1}, and a triangular shape for $f(v)$ [ChLu95], with values for the average velocity V_{av} and the velocity deviation Δ, as presented in Table 1, which depend on the scenario (static, pedestrian, urban, main roads and highways), the curves in Fig. 1 were obtained for the handover probability. Note that $P_h = 0$ for the static scenario.

Table 1 - Characteristics of mobility scenarios.

Scenario	V_{av}[m·s^{-1}]	Δ [m·s^{-1}]
Static	0	0
Pedestrian	1	1
Urban	10	10
Main roads	15	15
Highways	22.5	12.5

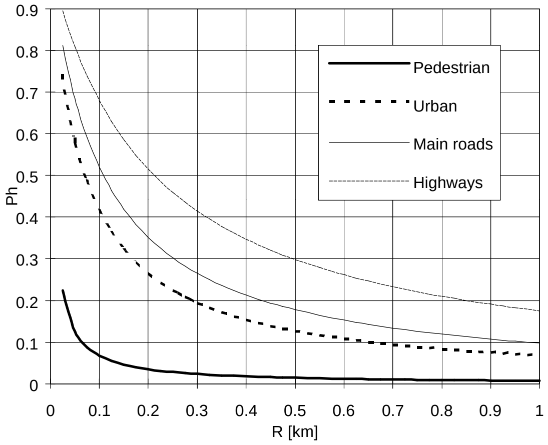


Fig. 1 - Handover probability as a function of R for all scenarios.

From (1) and (2) one can see that P_h gives the proportion of handover calls in each cell, while (1-P_h) is the proportion of new calls. Thus, for small coverage distances as the ones involved in MBS (in the range 100-350 m) [VeCo97], a large percentage of calls is originated by handover, mainly for scenarios with high mobility.

3. Capacity Trade-offs

A new calls traffic linear density can be obtained from r_n and the cell length

$$x_n = \frac{r_n}{2R} = \frac{m}{\left(h^* + 2mR\right)} \cdot r_m \tag{6}$$

which can be normalized as follows

$$y = \frac{x_n}{r_m \cdot m/h*} = \frac{1}{1+m(2R)/h^*} = \frac{1}{1+x} \tag{7}$$

where $x = m(2R)/h^*$. For the static scenario one has $x_n = r_m/(2R)$, because $v = 0$ and $h^* = 0$; consequently, in a non-static scenario, if the contribution of mobility was not considered, one would obtain $y = 1/x$. From the operator's point of view, the objective is to maximize x_n, thus the dependence of this parameter on R should be analyzed. Given a fixed value for the blocking probability, one obtains the graphs from Fig. 2 for the normalized new calls traffic linear density for both situations (with and without mobility).

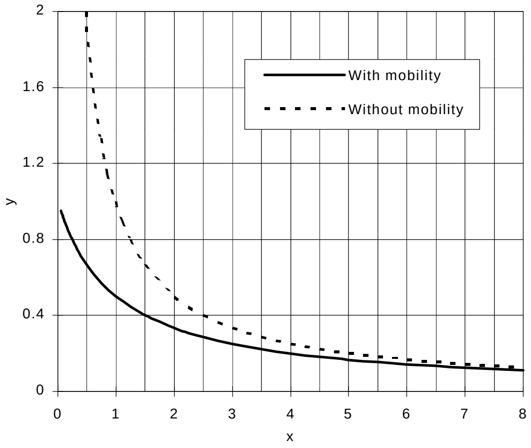


Fig. 2 - Normalized new call traffic linear density y as a function of x.

One could conclude that x_n is upper limited by $(r_m m/h^*)$, which decreases with velocity, but it should be noted as well that, for a given R, x will be lower for higher velocities, and so y will be larger, which partly compensates the lower values of $(r_m m/h^*)$ in (7).

The call-dropping probability can be computed according to [Jabb96]

$$P_d = \frac{h^*}{\left[(2R)m\right]} P_{hf} \ . \tag{8}$$

If a fixed value for the blocking probability is considered, e.g., P_b = 2%, a call-dropping probability below 0.5% is only obtained at the pedestrian scenario, and only for R > 300 m, Fig. 3.

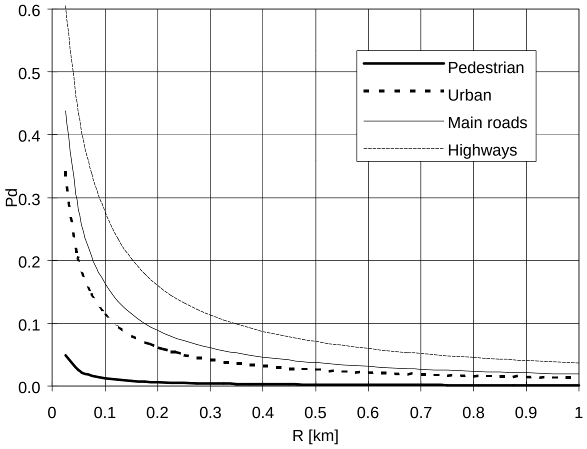
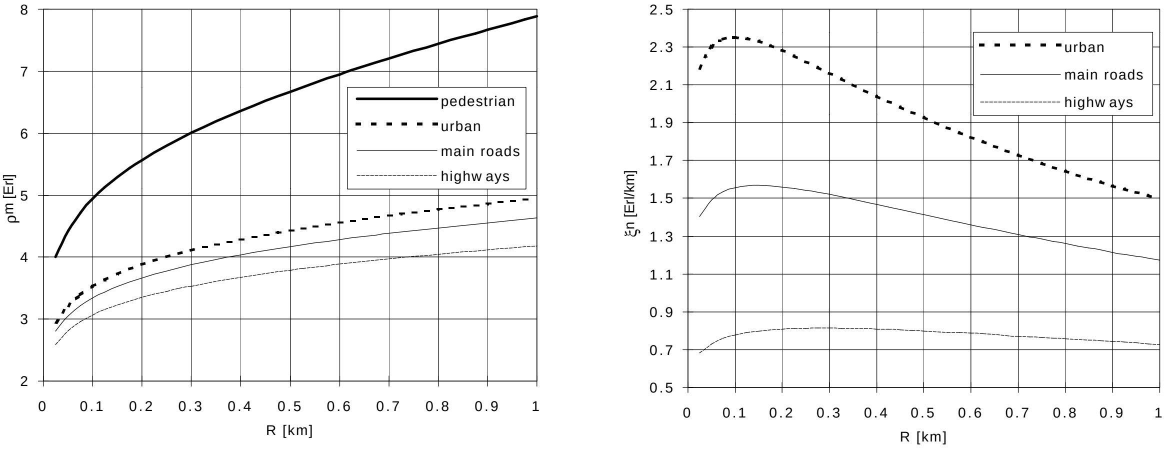


Fig. 3 - Call dropping probability for P_b = 2%.

However, call dropping probability restrictions also need to be fulfilled. Because $P_b = P_{hf}$, the blocking probability should then be computed according to (8), considering P_d = 0.5%, and replacing P_{hf} by P_b. Because of that, the blocking probability will be a linear function of R with slope $2m\,(P_d)_{max}/h^*$ and the supported traffic will be obtained accordingly, decreasing with R.

4. Results

From the previous analysis one concludes that, taking into account both blocking and call-dropping probability requirements, the traffic supported by m channels will depend on R. Considering, as an example, that $m=11$, $P_d = 0.5\%$, $m_{tot} = 34$ and $k=3$, one gets the results of Fig. 4.



a) Supported traffic

b) New calls traffic linear density

Fig. 4 - Traffic for m = 11 channels, according to call dropping probability restrictions.

As it can be seen, the supported traffic will not be constant, rather having a decreasing behaviour with the decrease of R. In this case, the dependence of x_n on R will be as presented in Fig. 4 b) for the three scenarios with higher mobility, i.e., for each scenario, there is an optimum value for the coverage distance which maximizes x_n. This maximum corresponds to lower values of R for the scenarios with lower mobility, being lower for the scenarios with higher mobility. For coverage distances lower than this optimum value, x_n decreases with the decrease of R. This is due to call dropping probability restrictions, which contradicts the behaviour expected with the simple analysis without considering it. It is also worth to note that the new calls traffic linear density is much more sensitive to the mobility scenario than the supported traffic because the former, besides the dependence on r_m, also depends on P_h.

In order to verify if one can consider the new calls traffic as Poisson distributed, a numerical comparison between the number of users in each cell, U_{cel}, and the new calls traffic can be done. Since $r_n = r_m(1-P_h)$, if the condition $U_{cel} >> r_m(1-P_h)$ is verified, the new calls traffic is Poissonean. Therefore, it is worthwhile to evaluate the minimum value of R which validates this assumption.

Considering that the density of users for the pedestrian and urban scenarios is 500 users/km, while for the road scenarios (main roads and highways) it is 300 users/km, the following equations for the number of users in a cell are obtained: for the former $U_{cel} = 500/(1000/2R) = R_{[m]}$, and for the latter $U_{cel} = 300/(1000/2R) = 3/5 \cdot R_{[m]}$.

Defining c as the ratio

$$c = \frac{U_{cel}}{r_m(1-P_h)} \tag{9}$$

the results for $c(R)$ for the scenarios considered in this paper are presented in Fig. 5. Usually the minimum value for the condition “>>” is 10 times larger, thus, in all the cases the assumption that the new calls traffic is Poisson distibuted is valid, namely for the scenarios with lower mobility, where the associated supported traffic is lower.

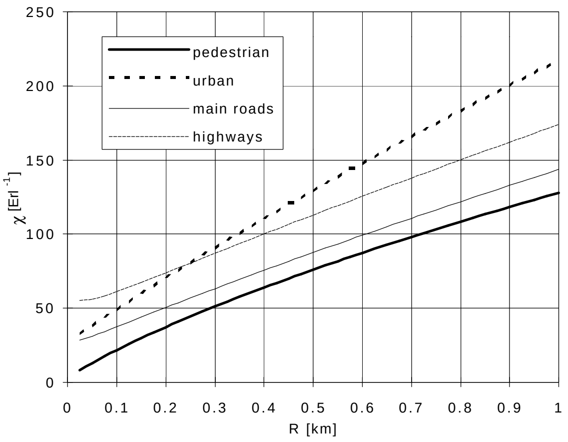


Fig. 5 - *c* as a function of *R*.

These values also agree with the small values for the coverage distance foreseen for MBS.

5. Conclusions

The influence of traffic from mobility on the microcellular coverage distance in MBS was analyzed. For higher and higher mobility scenarios, the percentage of new calls traffic on the overall traffic decreases owing to the influence of the handover traffic. In order to simultaneously fulfil the requirements for blocking and call-dropping probabilities, feasible values for the new calls traffic linear density were obtained, where there are optimum values of the coverage distance that maximizes it. These maxima correspond to lower values of the coverage distance for scenarios with lower mobility, being lower for scenarios with higher mobility. The approximation that new calls traffic has a constant generation rate, i.e., the generation of calls being Poisson distributed, is only valid above minimum threshold values for the coverage distance, which seems to be verified in MBS scenarios.

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