

# New Calls Traffic Performance in Micro-cellular Mobile Broadband Systems with High Mobility Handover

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## Abstract

The maximisation of system capacity in Mobile Broadband Systems (MBSs) is addressed via an approach for traffic analysis that considers different scenarios for the mobility of terminals and two different types of services: short and long duration ones. For short duration services, the maximum of the new calls traffic linear density,  $\xi_n$ , occurs for the typical coverage distances,  $R$ , of MBS, i.e., 100-350 m, except for the highways scenario, where it occurs for  $R = 500$  m. However, for long duration services, these maxima are obtained for  $R$ s approximately four times the previous values,  $\xi_n$  being 16% lower; feasible values, lower than the optimum ones, are obtained for lower coverage distances in high mobility scenarios. The use of guard channels for handover improves system performance only for short duration services, 2 being the recommended value for the number of guard channels in the considered cases.

## I. INTRODUCTION

Mobile Broadband Systems (MBSs) will extend high data rates (from 2 up to 155 Mb/s), provided by the fixed Broadband-ISDN, to the cellular communications market, supporting high speed communications in high mobility outdoor scenarios [1]. These system will use millimetre wavebands and are expected to be deployed mainly in urban centres; as a consequence, they will be based in a micro-cellular structure, i.e., cells will be confined to streets, with dimensions of the order of a few hundreds of metres [2].

One of the goals of planning the cellular structure of such system may be the maximisation of the new calls traffic in terms of cell dimension. This approach has been done for a linear coverage geometry, where mobiles travel randomly through cells located end-to-end, by obtaining the cell coverage range that leads to a maximum new calls traffic linear density,  $\xi_n$  [3]. To have an insight into the trade-offs involved in the optimisation procedure, the behaviour of  $\xi_n$  in terms of the maximum coverage distance of a cell,  $R$ , needs to be studied for typical values of  $R$ , and for various mobility scenarios [3]: pedestrian, urban, main roads and highways.

Due to the small length of cells and to the possibility of high mobility for terminals, handover will play a key role. The existence of guard channels exclusively for handover is then foreseen, i.e., from a total of  $m$  channels,  $g$  are used only for calls coming from handover (thus remaining  $c$  for both new and handover calls).

The main focus of this work is the study of the dependence of  $\xi_n$  on  $g$  and  $m$ , for a fixed value of each one and for a fixed value of their ratio. This analysis is made assuming that handover traffic is Poisson distributed, and that there is independence among the number of calls being served at each cell [4]. Although MBS will be a system with multiple services, providing mobile multimedia communications, in this paper only two types of applications will be taken into account, in order to simplify this first analysis of the problem: short duration ones, with an average duration of 3 min (e.g., video-telephony, public transport information, fleet management or file transfer), and long duration ones, with an average duration of 20 min (e.g., emergency services, repair assistance, city guidance, multimedia library, TV outside broadcast, interactive games and video on demand) [5].

The remainder of the paper is organised as follows. In Section II, the meaning of handover probability is presented. An analysis of handover probability for services of both types is done and the differences among the various mobility scenarios are highlighted. In Section III, a traffic study is done, in which the appropriate variables for the characterisation of system capacity are derived, and a distinction between new and handover calls traffic is presented. Results for the supported traffic are shown, and differences between short and long duration services are discussed for the considered mobility scenarios. In Section IV, the new calls traffic linear density is suggested as an appropriate measure for system capacity; the trade-offs involved in the design are described, and results are obtained for its dependence on  $R$ , comparing the cases with and without guard channels for handover. In Section V, the variation of the new calls traffic linear density is addressed and an interpretation of the consequences on MBS capacity is done. Finally, some conclusions are drawn.

## II. HANDOVER PROBABILITY

When a call from a mobile is being served in a cell, the probability of occurrence of a handover (handover probability) is given by [4]

$$P_h = \frac{\eta}{\eta + \mu} = \frac{\eta^*}{\eta^* + 2\mu R} \quad (1)$$

where  $\eta$  is the cross-over rate,  $\mu$  is the service rate, and the dependence of the former on the coverage distance has been made explicit by introducing the average cross-over velocity

$$\eta^* = \eta(2R). \quad (2)$$

$\eta$  is computed from [3]

$$\eta = \frac{1}{\int_0^{v_{\max}} \left(\frac{2R}{v}\right) \cdot f(v) dv} \quad (3)$$

$v$  being the velocity (with a maximum value of  $V_{\max}$ ) and  $f$  the velocity probability density function (note that in the linear geometry the cells length is  $2R$ ). For the considered four mobility scenarios,  $P_h$  has been plotted as a function of  $R$ , for the two mentioned service rates,  $\mu = 1/3, 1/20 \text{ min}^{-1}$ , respectively, Figs. 1-2; the values for  $\eta^*$  presented in [3] were taken into account, corresponding to a triangular distribution of  $v$ .

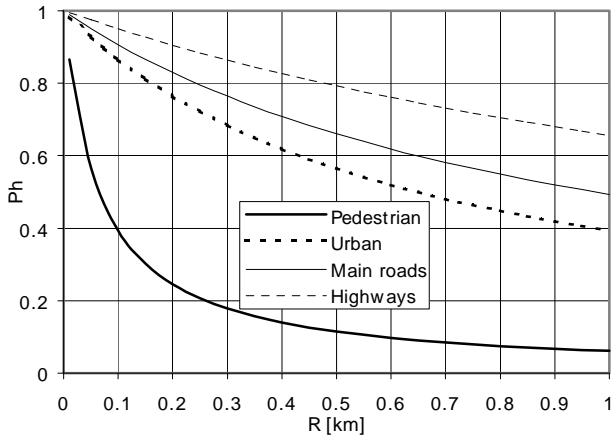


Fig. 1 – Handover probability for short duration calls,  $\mu = 1/3 \text{ min}^{-1}$ .

Coverage distances up to 1000 m were considered, a value that is slightly larger than the envisaged coverage distances foreseen for MBS, typically 100-350 m. As  $P_h$  gives the percentage of calls coming from handover (both entering or quitting a cell),  $(1-P_h)$  gives the percentage of calls terminated in a given cell – the case for new calls, derived from the flow equilibrium equation, is presented in [4]. Therefore, in high mobility scenarios, for short duration calls, more than 70% of calls in each cell suffer handover. This value rises up to 95% for long duration calls, Table I.

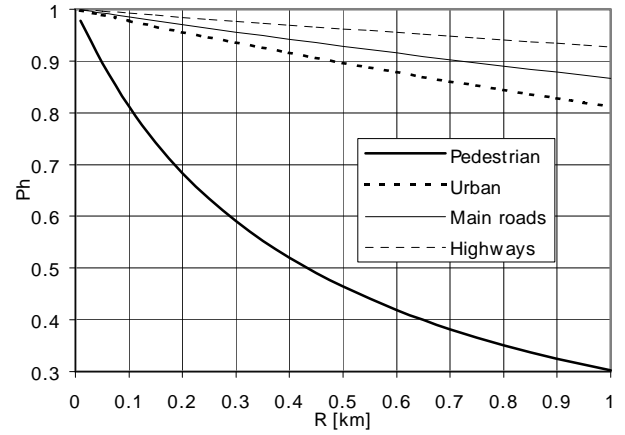


Fig. 2 – Handover probability for long duration calls,  $\mu = 1/20 \text{ min}^{-1}$ .

Table I

$P_h$  [%] for high mobility scenarios and  $R = 100, 200, 350 \text{ m}$ .

Scenario	$\mu = 1/3 \text{ min}^{-1}$			$\mu = 1/20 \text{ min}^{-1}$		
	100m	200m	350m	100m	200m	350m
Urban	86.6	76.4	65.0	97.7	95.5	92.5
Main roads	90.7	83.0	73.6	98.4	97.0	94.9
Highways	95.0	90.5	84.5	99.2	98.5	97.3

As it would be expected, handover is more likely to occur in long duration calls, because mobiles will traverse more cells on average. These results motivate the inspection of using guard channels for handover as a possible solution to avoid system capacity degradation.

## III. TRAFFIC ANALYSIS

Considering the use of guard channels for handover, some assumptions are done: the handover traffic can be approximate by a Poisson process, new calls one has the same distribution, and no queuing of new or handover calls is performed. With these assumptions the blocking and handover failure probabilities are then given by [4]

$$P_b = \frac{(\rho_n + \rho_h)^c \sum_{k=c}^{c+g} \frac{\rho_h^k}{k!}}{\sum_{k=0}^{c-1} \frac{(\rho_n + \rho_h)^k}{k!} + (\rho_n + \rho_h)^c \sum_{k=c}^{c+g} \frac{\rho_h^k}{k!}} \quad (4)$$

$$P_{hf} = \frac{(\rho_n + \rho_h)^c \frac{\rho_h^g}{(c+g)!}}{\sum_{k=0}^{c-1} \frac{(\rho_n + \rho_h)^k}{k!} + (\rho_n + \rho_h)^c \sum_{k=c}^{c+g} \frac{\rho_h^k}{k!}} \quad (5)$$

where  $\rho_n$  is the new calls traffic, and  $\rho_h$  is the handover one, the total traffic supported by  $m$  channels being  $\rho_{m,g} = \rho_n + \rho_h$ . If the hypothesis of handover traffic being Poisson distributed is dropped, the considerations made in [6] for  $g = 0$  would prevail, mainly for large values of  $\eta/\mu$ .

If guard channels for handover were not used, the handover failure probability,  $P_{hf}$ , would be equal to the blocking probability,  $P_b$ , which imposes a strong limitation:  $P_b$  would be as low as the call dropping probability,  $P_d$ , determines. The use of guard channels for handover allows to overtake this limitation, because in this case  $P_b$  and  $P_{hf}$  are uncoupled [4]; the supported traffic should be computed from  $P_{hf}$ , according to call-dropping probability requirements [3]

$$P_d = \frac{\eta}{\mu} \cdot P_{hf} \cdot \quad (6)$$

This approach allows simultaneously to fulfil the requirements for both blocking and call dropping probabilities. These requirements are stringent, typically  $P_b = 2\%$  and  $P_d = 0.5\%$ , distinctly limiting system performance, in a way that depends on the average velocity of mobile terminals and on  $R$ .

The new calls traffic and the one coming from handover,  $\rho_n$  and  $\rho_h$ , can be easily obtained as [3]

$$\rho_n = \frac{\mu}{\eta + \mu} \cdot \rho_{m,g} = \frac{2\mu R}{\eta^* + 2\mu R} \cdot \rho_{m,g} \quad (7)$$

$$\rho_h = \frac{\eta}{\eta + \mu} \cdot \rho_{m,g} = \frac{\eta^*}{\eta^* + 2\mu R} \cdot \rho_{m,g} \cdot \quad (8)$$

The new calls traffic linear density is then given by

$$\xi_n = \frac{\rho_n}{2R} = \frac{1}{1 + 2\mu R/\eta^*} \cdot \frac{\mu}{\eta^*} \rho_{m,g} \quad (9)$$

which, for a fixed  $\rho_{m,g}$  and a given  $\mu$ , is upper bounded by  $\mu/\eta^*$ , decreasing with the decrease of the service rate and the increase of the cross-over average velocity. Assuming a total of  $m = 11$  channels, and that no guard channels are used ( $g = 0$ ), the supported traffic increases with the increase of the coverage distance [3], being higher for the short duration calls, Table II.

Table II

Supported traffic without guard channels for handover.

$\rho_{m,g}$ [Erlang]	$\mu = 1/3 \text{ min}^{-1}$			$\mu = 1/20 \text{ min}^{-1}$		
	100m	200m	350m	100m	200m	350m
Pedestrian	5.0	5.6	6.2	4.1	4.6	5.0
Urban	3.5	3.9	4.2	3.0	3.3	3.5
Main roads	3.3	3.7	3.9	2.9	3.1	3.3
Highways	3.1	3.3	3.6	2.6	2.9	3.1

For long duration calls, one observes that the supported traffic is approximately 85% of the one for short duration calls. Nevertheless, system capacity should be measured using the new calls traffic linear density, which is being done in the next Section.

#### IV. NEW CALLS TRAFFIC LINEAR DENSITY

Depending on the maximum coverage distance of the cells, the curves for the supported traffic and new calls traffic linear

density are different. Although traffic increases with  $R$  and the traffic linear density,  $\rho_{m,g}/(2R)$ , decreases with it, the new calls traffic linear density increases up to an optimum value of  $R$ , after which it starts to decrease, except for case of the pedestrian scenario with short duration services. The values for the coverage distance where  $\xi_n$  has a maximum are sought for the various mobility scenarios such that system capacity is maximised, Figs. 3-7.

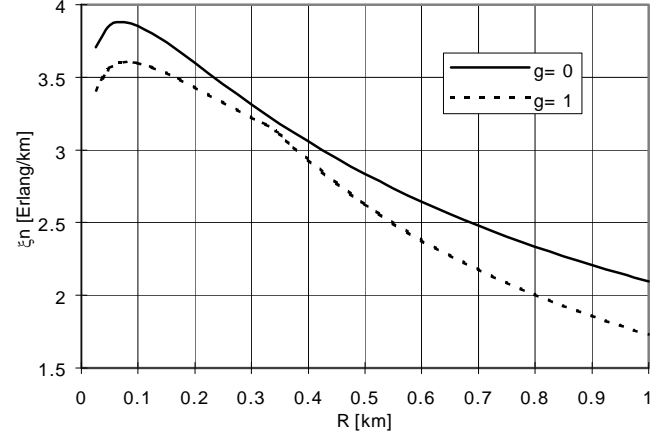


Fig. 3 -  $\xi_n$  for the pedestrian scenario and long duration services.

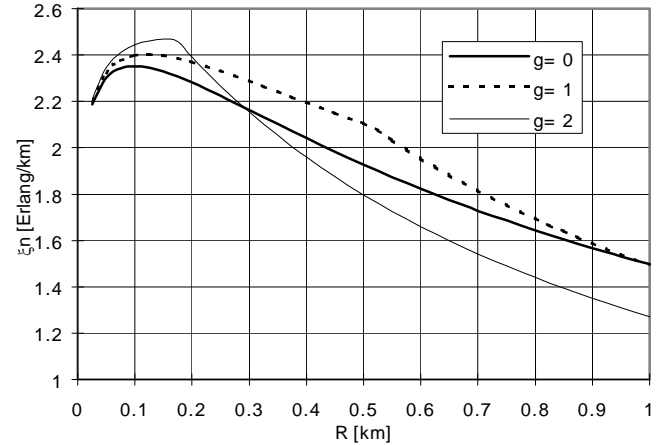


Fig. 4 -  $\xi_n$  for the urban scenario and short duration services.

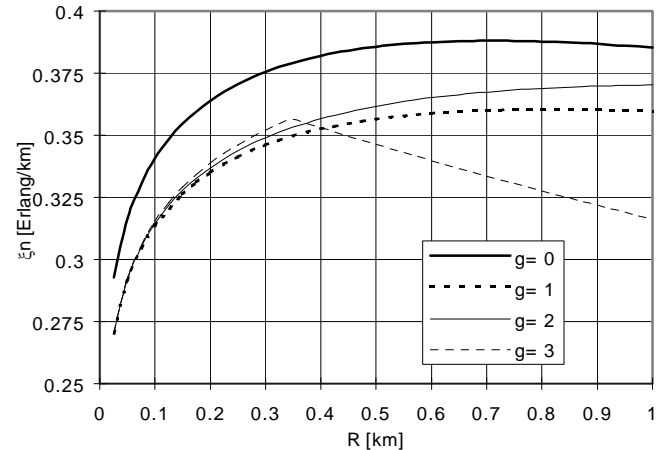


Fig. 5 -  $\xi_n$  for the urban scenario and long duration services.

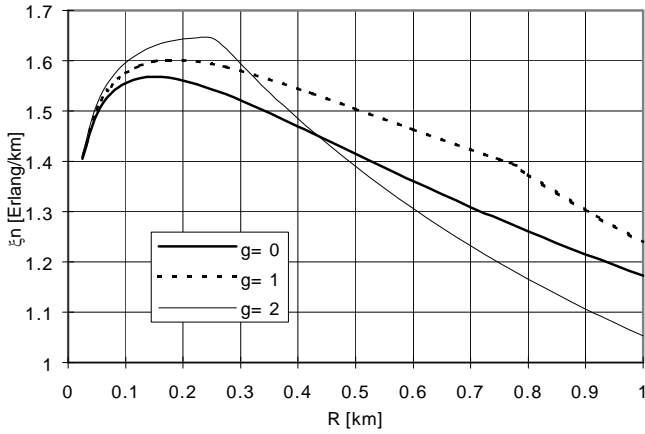


Fig. 6 -  $\xi_n$  for the main roads scenario and short duration services.

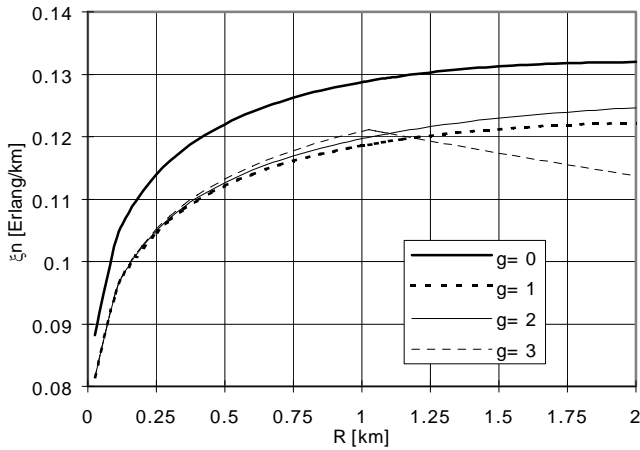


Fig. 7 -  $\xi_n$  for the highways scenario and long duration services.

For higher mobility scenarios, and long duration services, maxima occur for larger values of  $R$ . Results are presented for coverage distances up to 2 km in one case, although they will not be reached in actual cells to show the shift to higher values of  $R$  coming from the increasing velocity. The cases with  $g = 3$  channels for handover were only considered for the situations (mobility scenario/type of application) where an improvement occurs relatively to  $g = 2$ .

For short duration services, higher optimum values for  $\xi_n$  were obtained with  $g = 2$  and  $R = 175, 250$  and  $475$  m ( $\xi_n = 2.47, 1.65$  and  $0.84$  Erlang/km), for the urban, main roads and highways scenarios, respectively. For long duration services, lower optimum values for  $\xi_n$  were obtained for  $g = 0$  and  $R = 75, 700, 1000$  and  $2000$  m ( $\xi_n = 3.9, 0.39, 0.26$  and  $0.13$  Erlang/km), approximately, for the four respective scenarios. It is worthwhile to verify that, in this case, the utilisation of guard channels for handover does not improve system performance. One could suppose that the increasing of  $g$  would improve it, but the consequent degradation on blocking probability performance imposes a limitation [3] that is not possible to solve. From long duration services to short duration ones there is a ratio of approximately  $1/6$  between the values of new calls traffic

linear density, while the corresponding coverage distances are four times larger. As the optimum coverage distances, for the former, are near the feasible ones, this implies that long duration services will operate in systems with coverage distances lower than the optimum values, being the feasible values, e.g., for  $R = 150$  m,  $\xi_n = 3.4, 0.36, 0.23$  and  $0.11$  Erlang/km (respectively 87%, 91%, 88% and 82 % lower than the optimum ones). Note that  $R = 150$  m is higher than the optimum coverage distance in the pedestrian scenario, being however lower than it in the remaining cases. For the envisaged coverage distances, although the use of guard channels for handover leads to benefits in system performance for short duration services, it causes some degradation when long duration ones are considered.

## V. GUARD CHANNELS FOR HANDOVER

Considering  $m$  fixed, and  $g$  as a parameter, one can observe that there are values of  $R$  which maximise  $\xi_n$  for each pair  $(m, g)$ . Defining the variation of new calls traffic linear density for  $g \neq 0$  relatively to the case  $g = 0$  by

$$\chi_n[\%] = (\xi_n[g \neq 0] / \xi_n[g=0]) \cdot 100 \quad (10)$$

it is important to quantify how much the improvement is achieved, as one has already seen for short duration services. For the pedestrian scenario, although the graph is not presented here, there is only a slight improvement for  $R < 100$  m. In the urban scenario, the improvement is relevant for  $0 < R < 1000$  m with  $g = 1$  (10% maximum), and for  $0 < R < 280$  m with  $g = 2$  (7% maximum), Fig. 8.

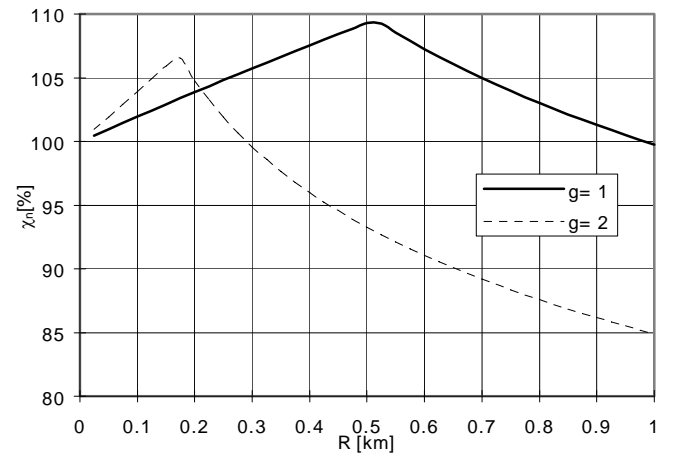


Fig. 8 -  $\chi_n$  for the urban scenario.

The use of two guard channels for handover in the main roads scenario leads to an improvement on performance exactly for the range of coverage distances foreseen for MBS, i.e.,  $100 < R < 350$  m (7% maximum). In the case of the highways scenario,  $g = 2$  is recommended for coverage distances up to 500 m, a maximum improvement of 5% being achieved; however  $g = 3$  also leads to some improvement in a small range of coverage distances,  $0 < R < 150$  m, Fig. 9.

## VI. CONCLUSIONS

A micro-cellular Mobile Broadband System, with linear coverage geometry, was analysed for four typical mobility scenarios. The distinction between short and long duration calls services was done and the use of guard channels for handover was considered for the former; this allows an increase of system capacity around 10% (for 2 guard channels), mainly for lower values of the coverage distance, where limitations are more demanding. Comparing long duration calls with short duration ones, the new calls traffic linear density is 1/6 lower, approximately the ratio between the service rates, while the optimum coverage distances are four times larger. For fixed values of the ratio between the number of guard channels ( $g$ ) and the total number of channels ( $m$ ), and for the coverage distances of interest, the improvement in new calls traffic linear density is similar for different values of  $m$  and  $g$ , it being however slightly higher for larger values of  $m$ .

## ACKNOWLEDGMENTS

This work was partially funded by the European Commission ACTS Project SAMBA and by the Portuguese Foundation for Science and Technology (FCT).

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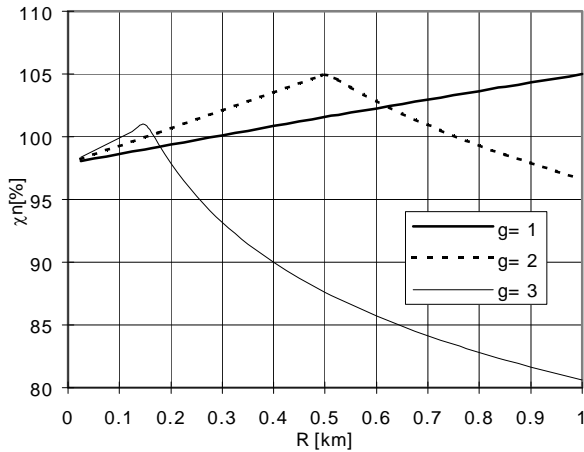


Fig. 9 - Variation of new calls traffic linear density, highways.

Results for the fixed  $g/m$  case are presented in Figs. 10-11. The use of guard channels results on a slightly better performance for  $100 < R < 900$  m, with  $m = 6$  (10% maximum), while for  $m = 11$  a little extra improvement exists for low values of  $R$ , i.e.,  $100 < R < 300$  m (7% maximum). Therefore, for fixed values of  $g/m$ , and for coverage distances of interest, the improvement in system capacity is similar for different values of  $g$ , it being however slightly higher when larger  $m$  and  $g$  are used.

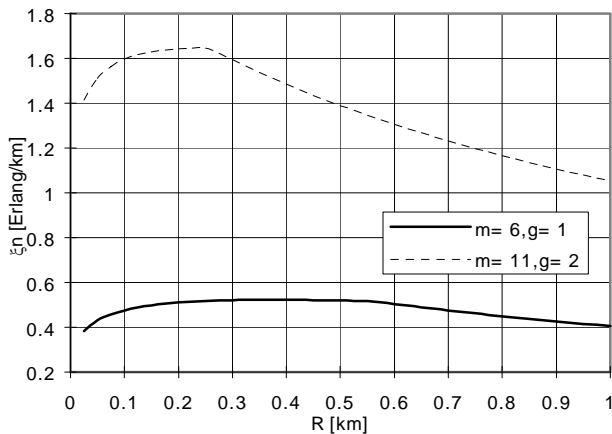


Fig. 10 -  $\xi_n$  for the main roads scenario,  $g/m \sim 17-18\%$ .

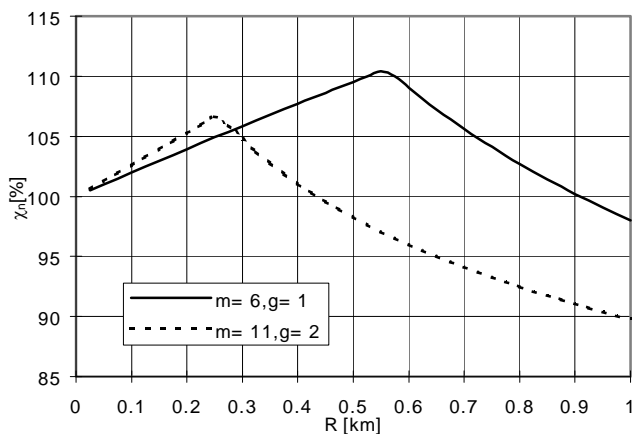


Fig. 11 -  $\chi_n$  for the main roads scenario,  $g/m \sim 17-18\%$ .