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Conference Paper in Vehicular Technology Conference, 1988, IEEE 38th · May 1996

DOI: 10.1109/VETEC.1996.504082 · Source: IEEE Xplore

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PERFORMANCE OF A HIERARCHICAL CELLULAR NETWORK WITH MOBILITY-DEPENDENT HAND-OVER STRATEGIES

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VTC'96 pp 1868-1872

Abstract—This contribution deals with the blocking probability in a hierarchical network with two mobility behaviors. A continuous coverage is achieved with micro-cells that accommodate both fresh calls and handover requests. Over this micro-cell coverage umbrella-cells, which only accept handover, are implemented. At every handover, the sojourn time of the terminal in the cell is measured. If it is lower than a threshold, the terminal is considered as rapid and directed towards an umbrella cell. Otherwise the communication stays at the microcell level. Furthermore, if there is no available channel in a micro-cell, the call is handed over the corresponding umbrella-cell.

The strategy tends to favor handover to umbrella-cells for high-speed terminals. An analytical model for the teletraffic performance is developed and used to calculate the forced termination probability in different configurations. The performance of the strategy is then studied.

I. INTRODUCTION

Teletraffic design of a cellular network is a key point of the operator task. In classical networks, the famous Erlang B formula is generally used to calculate the blocking probability [1]. In radio networks with homogenous cells where users are moving from cell to cell the Erlang B can still be used if mobility is included [2]. Generally a mean speed is considered for all users. A more realistic approach is to divide the users in two groups : the pedestrians, which are quasi-static, and the vehicles that are quickly moving [3]. We use the generic term mobile station to denote a terminal, whatever its mobility type is.

This contribution deals with the blocking probability calculation in a hierarchical network with two mobility behaviors. In such a network, a continuous coverage is made by both micro-cells and macro-cells. The macro-cells cover several micro-cells and are called umbrella-cells. These umbrella-cells may be deployed to improve the coverage of a zone and to reduce the handover failure probability.

It is advantageous to direct as far as possible the pedestrian calls to the micro-cell level and the vehicle ones to the umbrella-cell level, but the network does not know which type a terminal is. A user may alternately be in his car or go on foot in a street. It is not possible to consider that each user definitively belongs to a particular group. Therefore, the system has no mean to record the user type in a data-base.

However, we can consider that the user type is constant once the communication starts. The system is able to evaluate *a posteriori* the user type by comparing the sojourn time in the cell with a threshold : if the sojourn time is longer than the threshold, the user is declared as a pedestrian, otherwise it is considered as a vehicle. This selection may be executed at every handover. It is very rough and not perfect.

II. DESCRIPTION OF THE MODEL

Let us consider a two level coverage of a particular area. This area is continuously covered by a set of micro-cells. Each group of N micro-cells is covered by one umbrella-cell [4]. We consider that each micro-cell is fully covered by one and only one umbrella-cell.

Mobile stations are uniformly distributed on the area. The time spent by a mobile in a cell is assumed to have a negative exponential distribution of parameter α_p for pedestrians and α_v for vehicles. Mobiles can move from one cell to any other cell within the considered area. Parameters α_p and α_v give the mean cell cross-over rate for a given mobile [5].

In a given micro-cell, the arrival of fresh calls is assumed to be a Poisson process of parameter λ_p for pedestrians and λ_v for vehicles. The service law of communications follows an exponential law of parameter μ , which is the same for all user types. Guard channels are implemented in the micro-cells to reduce the handover failure probability compared to the fresh call blocking probability.

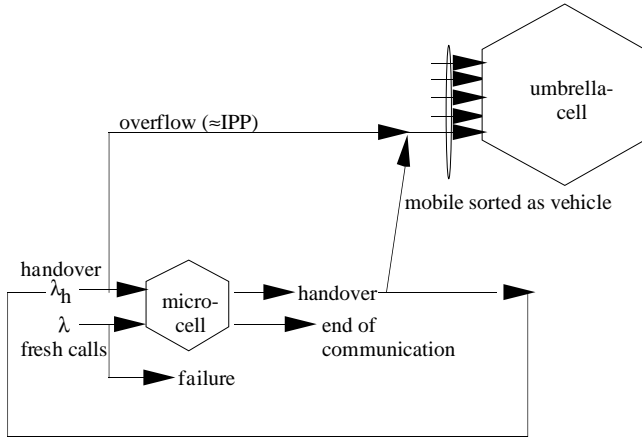


Figure 1 : Management of calls

Let us define a *session* as the time spent by a mobile that is involved in a call in a particular cell (micro-cell or umbrella-cell). A call is therefore a succession of sessions in various cells. The duration of a session in a micro-cell is exponentially distributed with parameter $\alpha_v + \mu$ for vehicles and $\alpha_p + \mu$ for pedestrians. For pedestrians the mean session duration is quite bigger than for vehicles.

At the end of every session, the network compares the session duration with a threshold T_s . A pedestrian (resp. a vehicle) is classified as a vehicle with probability ξ_p (ξ_v) or as a pedestrian with probability $1 - \xi_p$ (resp. $1 - \xi_v$). Parameters ξ_p and ξ_v may be easily calculated as a function of T_s .

All calls are first directed on the micro-cells. At the end of each session, the user is sorted : if he is considered as a pedestrian, the call is directed towards a microcell if a channel is available on the new microcell. In all other cases, the handover is made on an umbrella-cell. Once camped on an umbrella-cell, a mobile stays in the umbrella-cell level until the end of the call. Consequently, it can execute U-to-U handovers (Umbrella-cell to Umbrella-cell handovers) only.

Let us consider a pedestrian at the end of a session in a microcell :

- with probability $1 - \theta_p$, the communication ends, (with $\theta_p = \alpha_p / (\alpha_p + \mu)$)
- with probability $\theta_p(1 - \xi_p)$ the call is directed to another microcell (a part of the request overflows to the umbrella cell),
- with probability $\theta_p \xi_p$ the call is directed to the umbrella-cell.

The same analysis may be made for vehicles in a microcell and for both user types in an umbrella cell. The

crossover rates in umbrella cell α'_p and α'_v may be deduced from the microcell crossover rate :

$$\alpha'_p = \frac{\alpha_p}{\sqrt{N}} \quad \text{and} \quad \alpha'_v = \frac{\alpha_v}{\sqrt{N}} \quad (1).$$

III. ANALYSIS OF THE MICRO-CELL TRAFFIC

Sessions in a micro-cell are generated by new calls and handover requests. Fresh call arrivals follow a Poisson process, whose parameters λ_p for pedestrians and λ_v for mobiles are assumed to be known. The handover requests may be approximated by a Poisson process with parameters λ_{ph} and λ_{vh} . The global session request on a micro-cell is defined by parameters $\lambda_v + \lambda_{vh}$ for mobiles and $\lambda_p + \lambda_{ph}$ for pedestrians.

Parameters λ_{ph} and λ_{vh} are determined using the flow equilibrium equation for each type of clients [6] :

$$\lambda_{vh} = (\lambda_v(1 - P_{bfm}) + \lambda_{vh}(1 - P_{bhm})) \frac{\alpha_v}{\alpha_v + \mu} (1 - \xi_v) \quad (2)$$

$$\lambda_{ph} = (\lambda_p(1 - P_{bfm}) + \lambda_{ph}(1 - P_{bhm})) \frac{\alpha_p}{\alpha_p + \mu} (1 - \xi_p) \quad (3).$$

The solution may be easily found by successive iterations applied on (2) and (3). The blocking probabilities for fresh calls P_{bfm} and for hand-over P_{bhm} are calculated numerically at every iteration from the equilibrium equations of the Markov chain.

IV. ANALYSIS OF THE UMBRELLA-CELL TRAFFIC

a. Micro-cell to Umbrella cell handover

Sessions on umbrella-cells are produced by m-to-U handovers (micro-cell to Umbrella-cells handovers) and U-to-U handovers. To estimate the various handover blocking probabilities, we first consider that the U-to-U handover rate is null and calculate the m-to-U handover blocking probabilities. The calculated values are upper bounds of the real m-to-U and U-to-U handover blocking probability [4].

Without mobility at the umbrella cell level, the duration of a session in an umbrella-cell is then exponentially distributed with parameter μ both for vehicles and for pedestrians.

The m-to-U handovers are due to the users that are considered as vehicle and to the overflow from the m-to-m handovers that fail. The overflow of one microcell may be approximated by an IPP [7,9]. The global arrival rate on one umbrella cell is an MMPP process, whose transition matrix Q_U is the Kronecker sum of the IPP transition

matrices. Therefore the global MMPP process is associated with matrices Q_U and Λ_U :

$$\Lambda_U = N \cdot \lambda_u \cdot I + \Lambda_o \quad (4)$$

where I is the identity matrix,

$$\lambda_u = (1-\theta_v)\xi_v (\lambda_v + \lambda_{hv}) + (1-\theta_p)\xi_p (\lambda_p + \lambda_{hp}),$$

$$\text{and } \Lambda_o = \begin{pmatrix} 0 & & & & \\ & \lambda_h & & & \\ & 2\lambda_h & & & \\ & & \dots & & \\ & & & N\lambda_h & \end{pmatrix}$$

b. Calculation of the blocking probability in umbrella-cells

Let us consider the global process of an umbrella-cell with C channels. The infinitesimal generator of the process is defined by the following $(C+1)(N+1) \times (C+1)(N+1)$ matrix :

$$\bar{Q}_U = \begin{pmatrix} Q_U - \Lambda_U & \Lambda_U & & & \\ \mu I & Q_U - \Lambda_U - \mu I & \Lambda_U & & \\ & 2\mu I & Q_U - \Lambda_U - 2\mu I & \Lambda_U & \\ & & \dots & \dots & \dots \\ & & & c\mu I & Q_U - c\mu I \end{pmatrix} \quad (5)$$

The equilibrium of the Markov chain may be found by the calculation of the stationary vector Π . The system to solve is :

$$\Pi \bar{Q}_U = 0 \quad \text{and } e\Pi = 1 \quad (6)$$

where $e = (1, 1, 1, \dots, 1)$.

The stationary vector may be detailed in C vectors, each of dimension $N+1$:

$$\pi = (\pi^0, \pi^1, \pi^2, \dots, \pi^C)$$

This gives $(C+1)$ systems of equations, which can be solved by a Gauss-Seidel iteration without writing the complete \bar{Q} matrix [8].

The blocking probability is the probability that an arriving request sees all the channels of the umbrella-cell busy. For sessions that have overflowed, the blocking probability P_{buf} is :

$$P_{buf} = \frac{\sum_{i=0}^N \pi_i^C}{\sum_{k=0}^C \sum_{i=0}^N \pi_i^k} \quad (7)$$

For sessions that have been directed towards umbrella cells, the blocking probability P_{buo} is :

$$P_{buo} = \frac{\sum_{i=0}^N i \pi_i^C}{\sum_{k=0}^C \sum_{i=0}^N i \pi_i^k} \quad (8)$$

c. Quality of service

Let us consider a pedestrian involved in a call that has already made $i-1$ handover in microcells only. At the end of the session in the current cell, there is 4 possibilities ;

- the call is released with probability $1-\theta_p$
- the call is handed over to another microcell with probability $\theta_p(1-\xi_p)(1-P_{bm})$,
- the call is handed over to an umbrella cell with probability $\theta_p[(1-\xi_p)P_{bm}(1-P_{buo}) + \xi_p(1-P_{buf})]$,
- the call is dropped because the umbrella cell has no available channel with probability $\theta_p[(1-\xi_p)P_{bm}P_{buo} + \xi_p P_{buf}]$.

Similarly for a pedestrian in an umbrella cell, a call may be :

- released with probability $1-\theta'_p$,
- handed over to another umbrella cell with probability $(1-P_{buu})\theta'_p$,
- dropped because of an handover failure $P_{buu}\theta'_p$.

The handover failure probability P_{buu} is approximated by P_{buf} .

The probability for a pedestrian call that has not been initially blocked to end without any failure is the sum of the probability of the following events :

- the call is released in the first micro-cell,
- the call is released after several m-to-m only successful handovers,
- the call is released after several handovers (m-to-m, m-to-U then U-to-U handovers).

The probability P_{pd} for a pedestrian call to be interrupted prior to the normal completion is then :

$$1-P_{pd} = (1-\theta_p) + (1-\theta_p) \sum_{i=1}^{\infty} \theta_p^i (1-\xi_p)^i (1-P_{bhm})^i \\ + (1-\theta'_p) \sum_{i=1}^{\infty} \sum_{j=1}^i \theta_p^j (1-\xi_p)^{j-1} (1-P_{bhm})^{j-1} k (1-P_{buu})^{i-j} \theta_p^{i-j} \\ \text{with } k = [(1-\xi_p)P_{bhm}P_{buo} + \xi_p P_{buf}]$$

By calculating the sum, we can deduce P_{dp} for pedestrians (and similarly for vehicles) :

$$P_{pd} = \frac{\theta_p [P_{bm}(1-\xi_p)(P_{buo}-\theta'_p(P_{buo}-P_{buf})) + \xi_p P_{buf}]}{[1-\theta'_p(1-P_{buf})][1-\theta_p(1-P_{bhm})(1-\xi_p)]}$$

Similarly the mean number of handover for non interrupted calls may be expressed as :

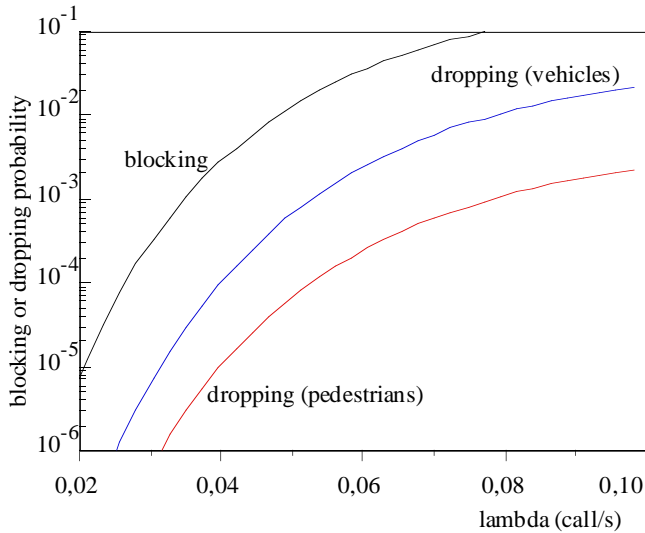
$$(1-P_{pd})N_{ho} = (1-\theta_p) + (1-\theta_p) \sum_{i=1}^{\infty} i \theta_p^i (1-\xi_p)^i (1-P_{bhm})^i \\ + (1-\theta'_p) \sum_{i=1}^{\infty} i \sum_{j=1}^i \theta_p^j (1-\xi_p)^{j-1} (1-P_{bhm})^{j-1} k(1-P_{buu})^{i-j} \theta_p'^{i-j}$$

In the operating conditions, all the blocking probabilities are close to 0. Therefore, N_{ho} may be approximated as :

$$N_{ho} = \frac{\theta_p}{[1-\theta_p(1-\xi_p)]^2} \left[(1-\theta_p)(1-\xi_p) + \frac{\xi_p(1-\theta'_p\theta_p(1-\xi_p))}{1-\theta'_p} \right]$$

IV. RESULT ANALYSIS

The performance of the system was studied for the following configuration : one umbrella-cell is equivalent to 20 micro-cells ; there is a nominal proportion of 20% vehicles ; $1/\mu=120s$; $\theta_v=0.7$ (i.e. $1/\alpha_v=51s$) and $\alpha_p=\alpha_v/10$.



Mean number of hand-over : 0,23 for pedestrians
2,33 for vehicles

Figure 2 : Dropping probability without umbrella-cells

For each configuration, the analysis was made by numeric calculation as described previously. A computer simulation based on an event-driven method was conducted and gave very close results.

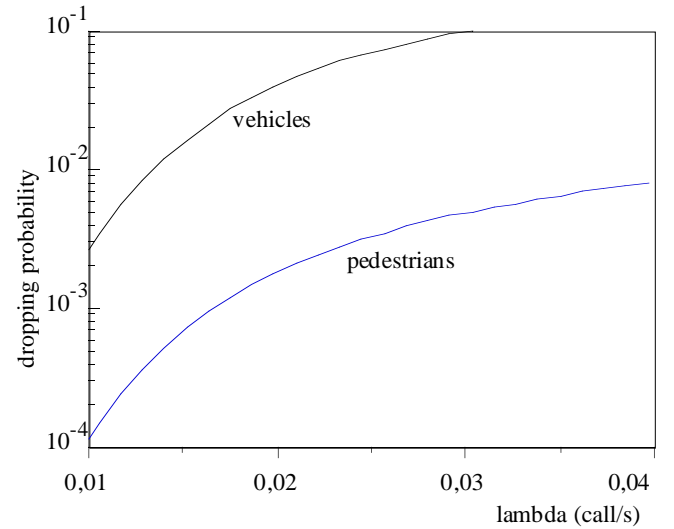
a. System without umbrella cells

The performance of a system without any umbrella cell was first studied. Every micro-cell has 14 traffic channels including 2 guard channels. The dropping probability is shown in figure 2 as a function of the call arrival rate.

b. System with umbrella cells

Umbrella cells were considered with the same number of channels as in the previous paragraph. Seven channels including one guard channel are put in every micro-cell and seven channels in the umbrella cells. The dropping probability was calculated with threshold $T_s=10s$ for vehicles and pedestrians and is plotted in picture 3. The dropping probability is higher for the same call arrival rate but the number of handovers are reduced for vehicles by about 30%.

The influence of the threshold T_s was studied and is shown in figure 4. For high values of T_s , a lot of mobile stations are directed to the umbrella cells, which are overloaded and the global dropping probability is not acceptable. It is therefore necessary to increase the number of channels in the umbrella cells.



Mean number of hand-over : 0,23 for pedestrians
1,67 for vehicles

Figure 3 : Dropping probability with umbrella-cells

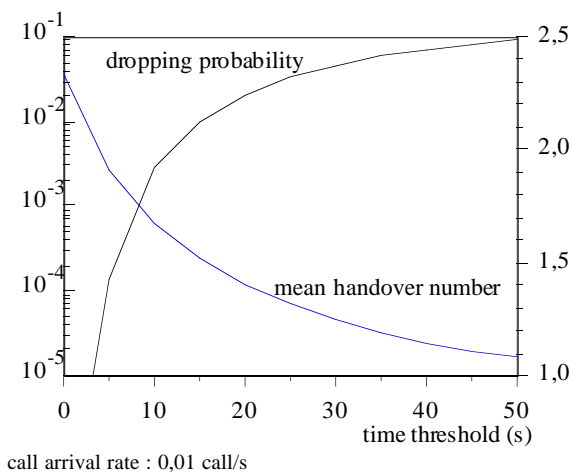


Figure 4 : Mean number of hand-over versus time threshold

IV. CONCLUSION

A simple selection strategy on a double layer coverage was proposed and evaluated in this contribution. This strategy favors the handover towards macro-cells for high-speed terminals and reduces the mean number of handover per communication. On the spectrum efficiency point of view, the best choice is to deploy microcells only in order to maximize the traffic per square kilometer. However, this strategy leads to a high number of handover for high-speed terminals. It would be advantageous to consider a cost function that includes both the spectrum efficiency and the handover cost. It would quantify the best trade-off between the two aspects and determine the optimal configuration.

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