Traffic and Performance Analysis of Personal Wireless Communication Networks

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Abstract – **Analysis of wireless networks are performed in this paper. Using simulation techniques, we obtain the dependence of performance parameters, such as call blocking and call dropping probability, from traffic and mobility parameters, such as cell capacity, traffic intensity, number and distribution of subscribers, mobility pattern and guard channels.**

Keywords – **Call blocking probability, call dropping probability, handovers per call**

I. Introduction

Cellular mobile networks are characterized with different traffic characteristics than wired networks. This is mainly due to cellular structure of the network, in which the coverage area is divided in smaller areas called cells. In such case, during a single ongoing call a subscriber is allowed to handover from its current cell to another neighboring cell. In the handover process the user is releasing the channel in the old cell and occupies another channel in the target cell. However, if all channels in all target cells are busy then the call is dropped. On the other side, new calls can also be blocked if there are no available channels in the serving cell at the call initiation.

In our analysis we consider channel-based allocation policy in the mobile network. Our aim is to analyze the Grade of Service (GoS) of the mobile network under various mobility and traffic scenarios. Mobility pattern of the users is very important in such analysis, because it directly influences handover intensity and hence the GoS. For modeling the mobility we use two-state mobility model, with a stationary state and mobile state. Mobility modeling in personal communication networks is investigated in details in [1]. Furthermore, overwhelming traffic analysis of cellular mobile networks with single-state mobility model can be found in [2]. Application of well-known loss formulas (e.g., Erlang loss formula) to cellular networks is performed in [3,4].

However, different users show different mobility behavior. So, with two-state mobility model we are targeting two main types of users: users at office or at home (stationary-state), and users in cars or trains (mobile-state).

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In this paper, we analyze the dependence of call dropping probability, call-blocking probability, and carried traffic, from variations in network, traffic, or subscriber parameters. In the analysis we consider channel allocation scheme with prioritized handover.

The paper is organized as follows. In next section we define mobility and traffic models used in the analysis. Simulation results are presented in Section 3. Finally, Section 4 concludes the paper.

II. Mobility and Traffic Models

We created a simulation environment in Matlab. Here, we briefly report on our simulation model.

The coverage area of the mobile network is divided into hexagonal cells. Each cell is further divided into elements to be able to track and locate subscribers in the network. Every cell is assigned a certain number of channels. The subscribers can be served only by one cell at a moment that is the current cell.

We define a users (i.e. subscribers) matrix. That is a look up table for all subscribers in the wireless network, which contains the most important data for each subscriber, such as: his current position (location in the area), his motion status (whether he is a stationary one or a moving subscriber), his speed, current cell, direction of his movement, and number of handovers that he has performed. Speed of each subscriber in mobile state is modeled with normal (Gaussian) distribution truncated at 0, given by:

$$P_{\text{speed}}(x) = k\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-v)^2}{2\sigma^2}}, \quad x \geq 0 \tag{1}$$

where v is the average speed, and σ^2 is the variance.

Position of each subscriber in the users matrix is represented with 2 coordinates (x and y). Direction of subscriber movement is defined with 2 coefficients, one for the movement in x-direction and the other for y-direction. Coefficients for subscriber elementary movements are randomly obtained, but combination of both zeros is prevented, because that subscriber would be stationary subscriber. So, subscriber movement is defined in the following manner: in every step of the simulation, each subscriber is allowed to move in either x- and y-directions or in both. The length of the trajectory is dependent upon the user speed. However, each user may be in one of two possible states: moving or stationary.

In next step, one should define traffic matrix, which consists of traffic data for all subscribers during the simulation. The traffic matrix has number of rows same as number of subscribers in the area, and number of columns same as number time slots (steps) in the simulation. For each subscriber in each step corresponds exactly one element of the traffic matrix. For example, if that element is “1”, the subscriber is using the network (e.g., he is talking on the phone) and he occupies one channel in his cell; if that element is “0”, the subscriber is inactive.

We consider primarily voice traffic in a mobile network. Call arrival process for voice traffic is usually modeled with Poisson distribution [4]. Furthermore, call duration time for voice connections are traditionally modeled with exponential distribution.

The last preparation step is defining the cell matrix, which contains information for each cell in the area. For each cell we assign the total number of channels in that cell (its hard capacity), as well as number of channels reserved for handovers only (i.e. guard channels). The aim of guard channels (which number is always small amount of total channels) is to obtain higher reliability of ongoing calls compared to the new ones, because blocking of a new call is less sensitive to the user than dropping of an ongoing call. The call is dropped when there are no free channels in the target cell at handover. However, number of guard channels should be small compared to the cell capacity. In our model, we use channel policy “blocked calls cleared”, that is, an already blocked new call or handover is cleared from the system.

Fig. 1. Hexagonal cell structure

Finally, we may state the main assumptions used in the simulation model:

- Each subscriber in every time slot can be in one of two mobility states: in stationary state with probability P_S, or in mobile state with probability $1 - P_S$.
- Direction and speed for each subscriber are initially set at the start of the simulation, and latter they change randomly in each simulation step.
- We assume equilibrium of the subscribers in the whole coverage area of the mobile network.

III. Simulation Results

We performed several simulation experiments to obtain performances of mobile networks with guard channels and two-state mobility model. With the given input data we have the network structure shown in Figure 1. We consider centered cell A, and six neighboring cells (i.e. cells B to G).

However, one should remember that the traffic parameters in the simulations refer to the “busy hour”. So, if we obtain certain call blocking probability in the “busy hour”, it is straightforward to conclude that blocking probability will be smaller in the rest of the time.

For the first simulation scenario we use the following mobility and traffic parameters: average number of subscribers per cell $= 80$; probability of stationary subscribers $= 0.5$; average number of calls per subscriber per one hour $= 3$; mean call duration $= 120$ seconds (120 time slots); total number of channels in one cell $= 12$; number of “guard channels” $= 2$.

The results of this simulation are presented in the Figure 2, which shows the dependence of handovers per call from the user velocity and standard deviation σ.

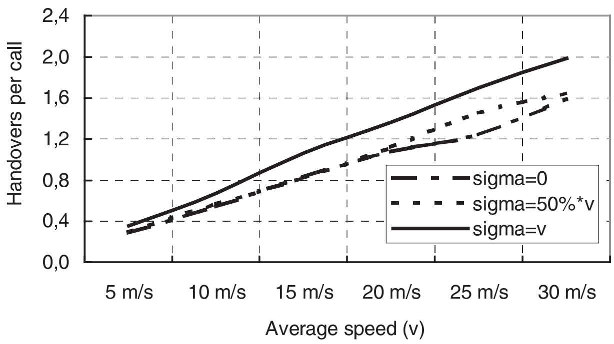

Fig. 2. Dependence of number of handovers per call from average subscriber speed, and standard deviation sigma

The average number of handovers per call increases with the speed of subscribers, showing a quite good linearity. Also, average number of handovers per call slightly increases with the standard deviation of the speed. This can be explained with higher standard deviation of the speed, when the probability of appearance of subscribers with high speeds is higher, which are increasing the average number of handovers. On the other side, we also have higher probability of appearance of subscribers with low speeds, but they cannot generate less than zero handovers in their calls, so their influence is insufficient to compensate that of the users with higher speeds.

In the second simulation experiment we investigate the GoS as a function of the average number of subscribers per cell. In this case, we use the following parameters: average subscriber speed $= 10$ m/s; standard deviation of average subscriber speed $= 2$ m/s; average number of calls per subscriber per one hour $= 3$; mean call duration $= 120$ seconds (120 time slots); total number of channels in one cell $= 12$; number of “guard channels” $= 2$.

The results of this simulation are presented in Figures 3-5; in which we show dependence of call dropping, call blocking

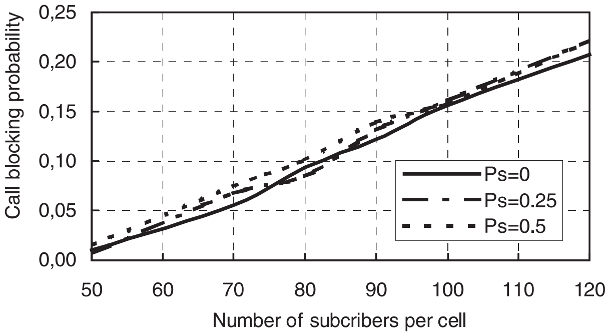

Fig. 3. Dependence of call blocking probability from number of subscribers per cell, and stationary probability P_S

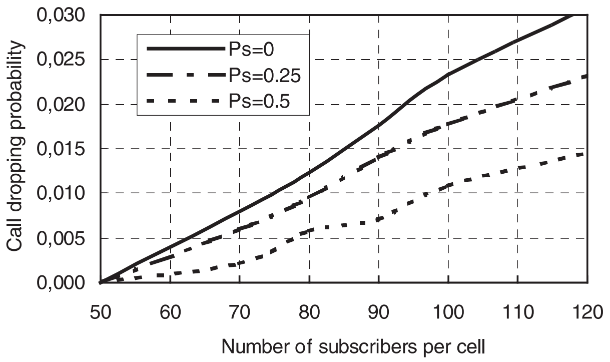

Fig. 4. Dependence of call dropping probability from number of subscribers per cell, and stationary probability P_S

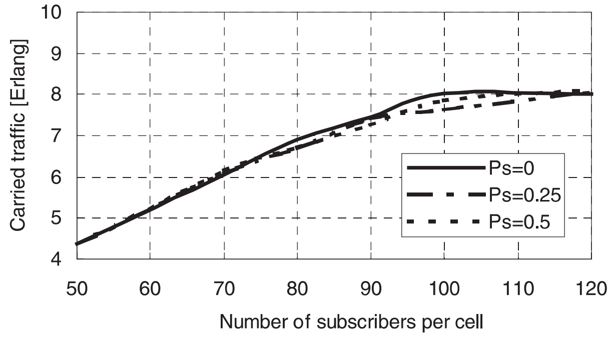

Fig. 5. Dependence of carried traffic from number of subscribers per cell, and stationary probability P_S

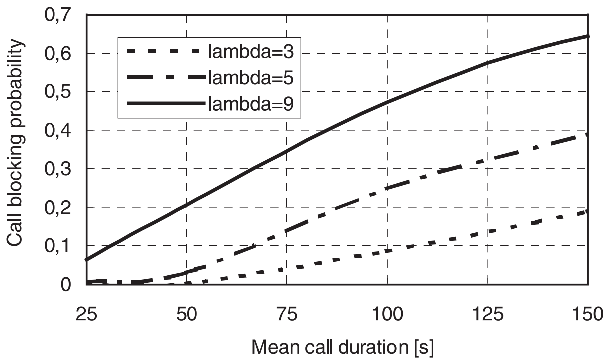

Fig. 6. Call blocking probability vs. mean call duration and average number of calls per subscriber per hour λ

probability, and carried traffic, from the average number of users per cell and probability of stationary user P_S.

As it is shown in Figures 3 and 4, both call blocking and call dropping probabilities increases with the number of subscribers per cell, but only call dropping probability shows significant dependence from stationary probability P_S. This result can be explained by the nature of call dropping, that is, it occurs at handovers. So, lower P_S results in more users in mobile state, leading to higher handover intensity per user and hence higher dropping probability. In the area in which all subscribers are stationary, there are no handovers and call-dropping probability equals zero.

According to our previous discussion on user sensitivity to call blocking and call dropping events, we have deliberately chosen system parameters (i.e. cell capacity, number of guard channels etc.) to have dropping probability for one order of magnitude smaller than call blocking probability. Figure 5 shows the carried traffic, which is higher for larger number of subscribers. In this case carried traffic does not depend upon the mobility parameters, because call-dropping probability is many times smaller then new call blocking probability.

We also examined the behaviour of the GoS at different traffic parameters for the cellular access network. Here, the following parameters are common in this simulation: average subscriber speed $= 10$ m/s; standard deviation of the subscriber speed $= 2$ m/s; average number of subscribers per cell $= 80$; probability of stationary subscribers $= 0.5$; total number of channels in one cell $= 12$; number of “guard channels” $= 2$.

The results of this simulation are presented in Figures 6-8, where are shown call blocking probability, call dropping probability, and carried traffic, versus mean call duration (t), and average number of calls per hour (lambda) respectively.

In this simulation call blocking probability (Figure 6) and call dropping probability (Figure 7) show similar dependence upon both input parameters: mean call duration and average number of calls per user per hour. This is a consequence of the fact that increasing each of the input parameters causes increasing in the offered traffic to the network. However, traffic increase results in higher losses as well.

If we analyze the results shown in Figure 8, we can observe some kind of saturation in the carried traffic that is a result of exploiting the whole cell capacity. When all channels are busy in a given cell, arrival calls are rejected either new calls or handovers. As expected, higher call arrival intensity leads to faster saturation of the carried traffic.

Finally, we analyze the cell capacity in a cellular network with prioritized handovers. In these simulations the following set of parameters is used: average number of subscribers per cell 80; average subscriber speed 10 m/s; standard deviation of subscriber speed 2 m/s; probability of stationary subscribers 0.5; average number of calls per subscriber per one hour 3; and 150 seconds mean call duration (150 time slots). The results of these simulations are presented in Figures 9-10, which show the dependences of call dropping probability, and call blocking probability, upon cell capacity (c) and number of guard channels (th).

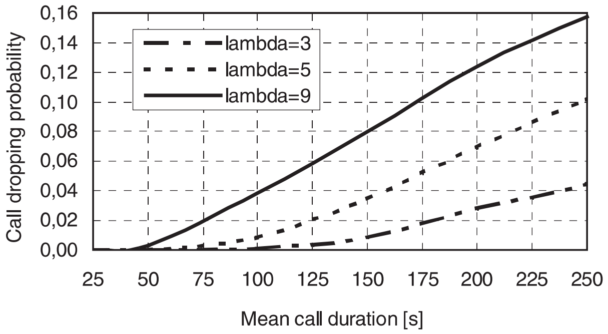

Fig. 7. Call dropping probability vs. mean call duration and average number of calls per subscriber per hour λ

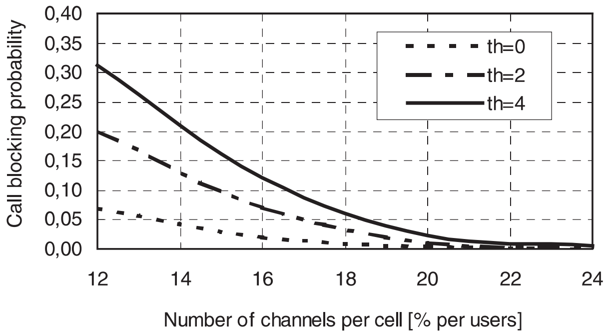

Fig. 9. Call blocking probability vs. number of channels per cell, for different numbers of guard channels "th"

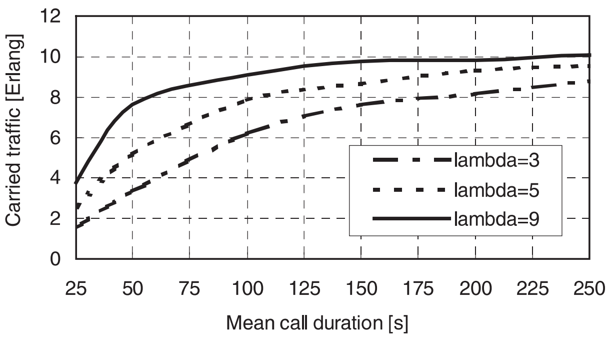

Fig. 8. Carried traffic vs. mean call duration and average number of calls per subscriber per hour λ

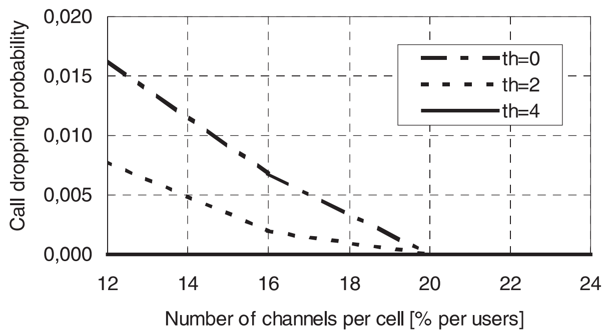

Fig. 10. Call dropping probability vs. number of channels per cell, and number of guard channels "th"

From Figures 9 and 10, it is easy to notice the influence of guard channels on blocking probabilities. However, guard channels can be allocated only to handovers calls. So, higher number of guard channels causes decrease of the call dropping probability because less new calls are accepted by the network, but at the same time it results in increase of the new call blocking probability, and vice versa. Considering the dependence of these two GoS parameters from the cell capacity, it is straightforward to conclude that higher cell capacity results in lower blocking and dropping probabilities.

Finally, it is a subject of an optimization process to derive the optimum number of guard channels under given constraints on blocking and dropping probabilities in the mobile network.

IV. Conclusion

In this paper we presented performance analyses of personal mobile communication networks with prioritized handovers. The performance of the networks was considered through its Grade of Service (GoS), defined by new call blocking and call dropping probabilities. For the purpose of the analyses we performed simulations with various mobility and traffic parameters in cellular access network. The influence of the guard channels of the network performance was investigated. Simulation analyses showed the dependence between the GoS, network capacity and mobility pattern of the users. Using the two-state Markov model for mobility, we showed that network performance is strongly dependent upon the mobility of the users (i.e. percentage of stationary and mobile users).

Higher mobility causes higher handover intensity, leading to higher dropping probability. On the other hand, it was shown that we can control the dropping probability by using prioritized handovers, i.e. dedicating small number of guard channels to handovers calls only. However, prioritized handovers cause lower carried traffic and higher new call blocking probability. Practically, we should use the offered traffic and given constraints on GoS at the design phase of the mobile network, to obtain the optimal cell capacity and number of channels dedicated to handovers.

Finally, the performance analysis in this paper is done on a call-level basis and for hard capacity in the mobile network. Future work should include packet-level analysis as well as soft capacity in the cellular access network.

References

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