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A Simulation System for Allocation of Base Stations in Mobile Communication Networks: A Case Study

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In actual mobile communication networks, the distribution of users' locations in a service area is not uniform. In the daytime, they are concentrated in specific cells that cover business areas, and at night they are concentrated in cells that cover residential areas. The users' locations, the number of mobile communication users, and their behavior change depending on the time zone. This dependency affects the cell traffic; thus, the allocation of Base Stations (BSs) in the service area is an important problem to be investigated. In this paper, we propose a new model for allocation of BSs in mobile communication networks, taking account of user distribution, user movement, channel occupancy, and handover. On the basis of this model, we developed a simulation system and carried out many simulations to evaluate the system performance. Our system uses a queuing model with many service stations and customers identified by their locations. For simulations, we consider the actual location of road network and the population distribution in Yamagata City, Japan. By using the simulation system, we can generate various networks with different patterns of BS allocations and evaluate the networks' performance. In this paper, we consider only the Japanese Personal Handy-phone System (PHS). However, the same model can easily be applied to large scale mobile networks. We carried out many simulations for various numbers of BSs, various numbers of channels in a BS, and various allocations of BSs. The performance evaluation based on the simulations shows that the cell size is an important factor in the efficiency of mobile communication networks, especially in starting a new business. Various BS allocation scenarios show that a trade-off exists between the users' Quality of Service (QoS) and the size of the area covered.

1. Introduction

Recently, mobile communication networks have developed very rapidly, opening up a new era in personal communication. Wireless communication networks are expected to become a new radio-based infrastructure in many countries. The reason is that the construction of wireless loops in communication networks requires less investment than the subscriber loops in public communication networks. With subscriber loops, each user location and switching center must be connected individually, whereas with wireless loops, it is only necessary to construct transmitting Base Stations (BSs) to cover users' mobile terminals.

In Japan, mobile communication networks have adopted the micro-zone system in which a large service area is covered with a number of small cells, to make efficient use of radio channel frequencies. In such mobile communication networks, the BS locations have a strong effect on the network performance.

In actual mobile communication networks, the distribution of users' locations in a service area is not uniform. In the daytime, they are concentrated in specific cells that cover business areas, and at night they are scattered in cells that cover residential areas. The users' locations, the number of mobile communication users, and their behavior change depending on the time zone. This dependency affects the cell traffic; thus, the allocation of BSs in the service area is an important problem to be investigated.

In Ref. 1), two simple Markov chain models are introduced to estimate the call loss and time congestion rate. These models can serve as basic mathematical models for analytical performance evaluation. The partition of location areas for paging domain is discussed in Ref. 2). A new scheme is introduced for partition and tracking of mobile users. Many papers have also dealt with mobile communication systems, but, to the best of the authors' knowledge, only a few papers have discussed how to cover the service area efficiently 3),4). Ref. 3) presents an overview of the application of teletraffic methods for the planning of mobile communication networks. It is shown that an accurate spatial traffic description is necessary in order to perform demand-based planning. In Ref. 4), by us-

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ing a novel representation technique, it is shown how the geographical information can be used to estimate the teletraffic demand in the network design process.

Some related works are proposed in Refs. 6)–8). In Ref. 6), a mathematical formulation is developed for the random movement of a mobile station in a cellular environment. This model is used to characterize different mobility-related traffic parameters in cellular systems, such as the distribution of the cell residence time of both new and handover calls, the channel holding time, and the average number of handovers. In Ref. 7), the distribution of channel occupancy time in a cellular radio system is studied. In Ref. 8), a basic model for the Personal Handy-phone System (PHS) is developed. It is shown that the distribution of customers in a service area is not uniform. This is an important conclusion for allocation policies in mobile communication networks. Therefore, in Refs. 9) and 10), the authors developed a new model to take account of realistic situations in mobile communication systems.

In this paper, we propose a new model for the allocation of BSs in mobile communication networks, taking account of user distribution, user movement, channel occupancy, and handover. On the basis of this model, we develop a simulation system and carry out many simulations to evaluate the system performance. Our system is based on a queuing model with many service stations and customers identified by their locations. The mobile communication users arrive one by one in the service area. The location of each new user is determined according to a given probability distribution. A user can make a call when his or her location at that moment is covered by a BS. But if the user is not covered by a BS, the user has to move to another place within radio range of a BS.

In this case study, we consider the actual locations of roads and the population distribution in Yamagata City, Japan. By using the simulation system, we can generate various networks with different patterns of BS locations and evaluate the networks' performance. In this paper, we consider only Japanese PHS. However, the same model can easily be applied to large scale mobile networks. We carried out many simulations for various numbers of BSs, various numbers of channels in a BS, and various allocations of BSs. The performance evaluation based on the simulations shows that our policy results in a good allocation of BSs, thus increasing the users' Quality of Service (QoS).

The remainder of this paper is organized as follows. The next Section introduces the considerations for simulations. In Section 3, we present a simulation flowchart. In Section 4, we discuss the simulation parameters. In Section 5, we deal with the BS allocation procedure. The simulation results are discussed in Section 6. Finally, our conclusions and plans for future work are stated in Section 7.

2. Considerations for Simulations

For our simulations, we consider Yamagata City in Japan. The service area is a rectangle with a size of 14.4 × 17.4 km, as shown in **Fig. 1**, and has a population of 200,000 inhabitants. The population of this service area is concentrated in the center and along the roads. Thus, the location of roads strongly affect the user distribution. In our simulations, therefore, we consider prefectural roads, national roads, and expressways.

In simulations, the users are generated randomly and move freely in any direction. When a mobile user wants to make a call, he or she first dials a number and then pushes the "send" key. In this way, a control message is sent to the nearest Mobile Switching Center (MSC). The MSC determines which BS has the highest signal strength, and on the basis of this information decides in which cell the mobile user is located. After a BS has been selected by the MSC, this BS allocates the channels simultaneously. If none of the BSs tried has any free channels then the call fails. When the call finishes, the radio channels are released.

If a mobile station moves from one cell to another one (this can happen many times, because the cells are small), the MSC should transfer the call via a different BS appropriate to the user's new position. To ensure a smooth transition of a call from one cell to another a hand-off or handover process is carried out. It can be initiated by an active BS or by the mobile station when the relative strength of signals received at all the nearest stations falls below a pre-determined threshold or when the signal strength of an adjacent BS is stronger than the signal strength of the present BS. The handover area is shown in **Fig. 2**. The MSC establishes a duplicate radio and telephone channel in the new cell. After the call has been established, a new radio path is transferred to the mobile ter-

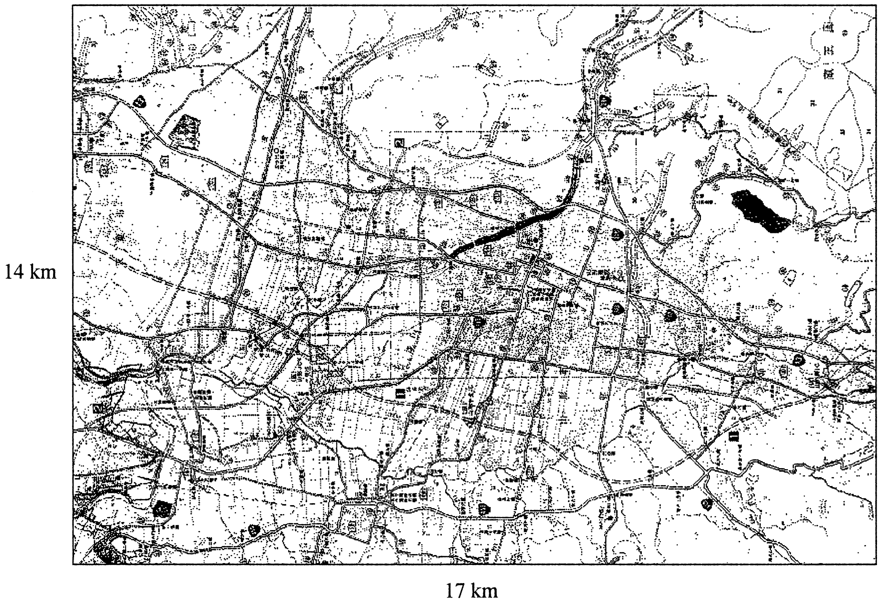

Fig. 1 Map of a service area.

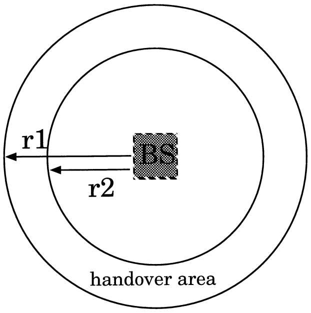

Fig. 2 Cell handover area.

minal. When the new channel is confirmed by the new BS, the original connection is closed.

3. Simulation Flowchart

The simulation flowchart is shown in **Fig. 3**. The simulation starts at time zero. The users arrive randomly according to a Poisson distribution. Their locations are selected randomly according to the user population in the service area. The channel occupancy time is generated according to an exponential distribution.

When a user is inside a cell, he begins to talk if there is a free channel in the BS. While the user is talking, he can move in one direction, but when he goes into the handover area of the cell, a free channel of the nearest neighbor BS is allocated for him. After finishing talking he leaves the system. When a user is generated outside of the cell, his call fails and he leaves

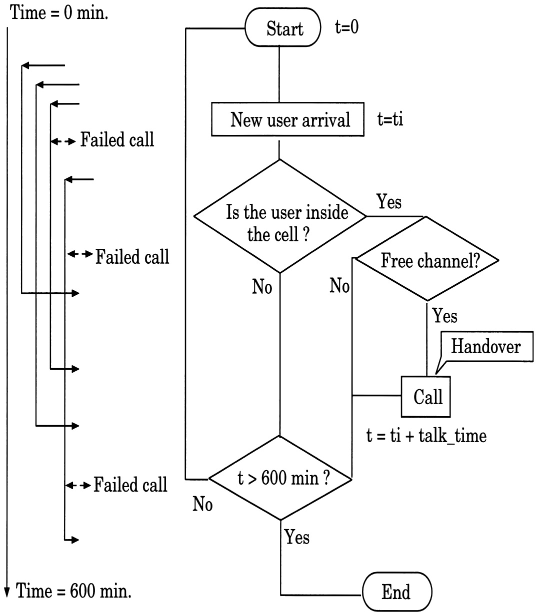

Fig. 3 Simulation flowchart.

the system. During the handover, if the BS has no free channel, the user call fails. When the simulation time "t" is greater than 600 min (10 hours), then the simulation stops. Otherwise, the remaining users continue to be generated, talk, and leave the system.

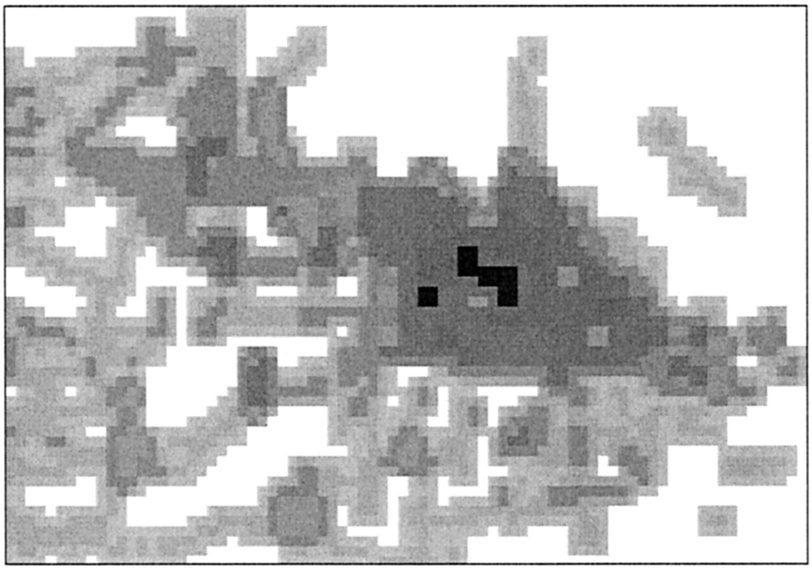

Fig. 4 Example of a population distribution.

4. Simulation Parameters

4.1 User Parameters

The user arrival interval has an exponential distribution with mean 1/360 min. This value means that about half of the inhabitants have mobile stations and use their terminal once in a simulation. We consider two distribution types for the user holding time. The first type consists of users who have a long holding time, and the second one consists of users with a short holding time. As first-type users, we consider people who use mobile stations for business purposes, and as second-type users, we consider young people who talk for more than 20 min.

The short-holding-time users have an exponential distribution with an average holding time of 4 min, while long-holding-time users have an exponential distribution with an average holding time of 20 min. The two types of users are selected with probability 0.1 and 0.9, respectively. We assume that the users can move in one direction and that they are selected randomly. The users' movement speed has an exponential distribution with a mean speed 80 m/min.

4.2 Distribution of Mobile Communication Users

The user location distribution is determined by a weighting function based on the user distribution in the service area of Yamagata City. To generate a population, we used the customer distribution of the Public Telephone Network (PTN) and the actual population distribution in Yamagata City. The complete service area is divided in 4800 (60 × 80) rectangles, each divided in 100 smaller rectangles. The population distribution in the service area is shown in **Fig. 4**. We give eleven weights (0, 0.1, 0.2, 0.5, 1, 2, 4, 8, 16, 32, 64) for each rectangle. To ensure a smooth population distribution, we calculate the moving average of weights for each rectangle with the weights of neighboring rectangles. The picture color varies from bright color to dark one according to the number of users in the rectangles.

Table 1 Cell size.

Cell Size	$r1$	$r2$
L type	360 m	300 m
M type	200 m	160 m
S type	80 m	60 m

4.3 Cell Parameters

We use three cell sizes: Small (S), Medium (M), and Large (L). The cells have a circular shape and the BS is located in the cell center, as shown in Fig. 2. The radius of each cell is $r1$, while the distance between the BS and the handover area is $r2$. The parameter values of $r1$ and $r2$ are shown in **Table 1**. We assume that all BSs have the same performance, but different numbers of channels (each BS has 3 or 10 channels).

5. BS Allocation Procedure

We allocate the BSs according to the follow-

Table 2 *PU* types.

Type	Number of *PU*
a type	100
b type	500
c type	1000
d type	2000
e type	4000

ing procedure. At the beginning of the simulations, we consider that each user may be in covered or uncovered state. Let us consider *PU* to be the number of uncovered users in a cell. This parameter is used as a weight in order to decide the degree of selection probability for BS allocation.

(1) First, there are no BSs in the service area and none of population is covered by a BS.
(2) Next, the location of a new BS is selected to maximize the weight (uncovered population) of the area that the BS covers.
(3) Then, subtract a value *PU* from the weight.
(4) Repeat steps 2 and 3 until all BSs are allocated.

Table 2 shows the number of *PU* used in our simulation. When *PU* is large, many users are able to use the BS, and as a result, the other rectangles which do not have a BS will tend to be selected in the next allocation phase.

6. Simulation Results and Discussion

We carried out the simulation for about 10 hours considering the users' distribution and their talking time. At the beginning, we ran the simulation for three hours and then collected data on the user distribution and the number of users who had not finished talking. This is considered as the initial state for the real simulation.

The user arrival interval is generated by an exponential distribution function, and the parameter λ is 1/360. The total number of generated users (in 10 hours) is about 215000. For each new user, one point in the service area is selected according to the population number given for each small rectangle. A new user can use a free channel of the nearest BS if this BS covers the user location.

We consider various scenarios for BS allocation policies. To explain the meaning of the scenario names, let us consider the scenario "Le100". The first letter "L" represents the cell size, which in this case is large, "e" shows the type of potential user, which in this case is "e" type, and 100 indicates that 100 BSs are allocated inside the service area.

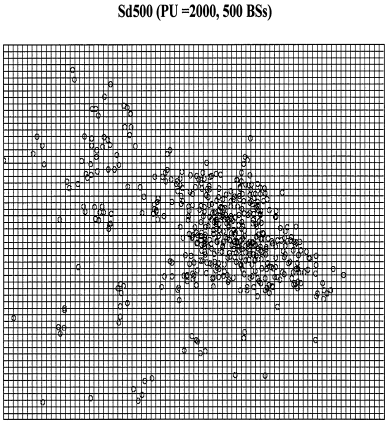

Fig. 5 Example of BS allocation: Sd500 scenario.

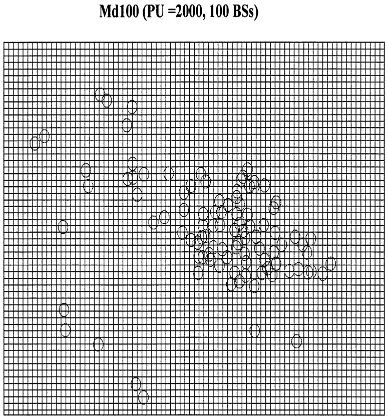

Fig. 6 Example of BS allocation: Md100 scenario.

6.1 BS Allocation

In this subsection, we show some BS allocation scenarios. In **Fig. 5**, there are 500 BSs allocated in the service area, and *PU* is assumed to be 2000. The radius of each cell is 80 m, which is close to the actual size of PHS cells. Five hundred BSs can cover only 4% of the service area. When this BS allocation scenario is used, 34.7% of the population is covered. It should be noted that each user is counted only once, even if he is covered by more than one cell. In **Fig. 6**, only 5% of the service area is covered by 100 BSs and 40% of the population is covered by a cell with a radius of 200 m. For mobile communication system such as PHS, even 1000 BSs might not be enough to cover the service area.

Figures 7 and **8** show how *PU* affects the BS allocations. In Fig. 7, where $PU = 100$, the BSs tend to cover the downtown area, where

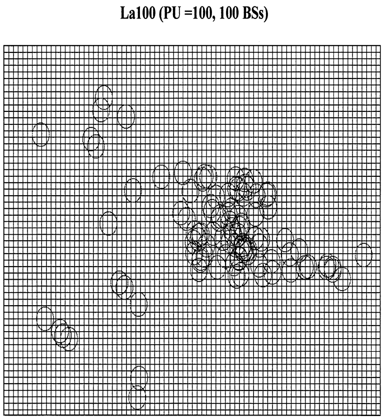

Fig. 7 Example of BS allocation: La100 scenario.

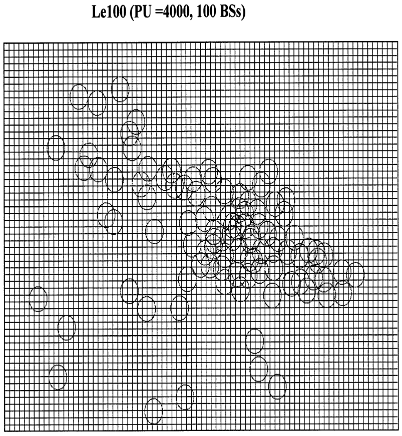

Fig. 8 Example of BS allocation: Le100 scenario.

the population density is high. In this case, the BSs can cover 75% of the population. In Fig. 8, a value of $PU = 4000$ is used to scatter the BSs throughout the service area. Here, 99% of the population is covered by the cells, though users must share the BSs with other users and finding free channels will be difficult.

A simulation example for the "Ld100" scenario is shown in **Fig. 9**. The background of the figure shows the population distribution. The lines inside the figure show expressways, national roads, and prefectural roads. The circles show the cells, and BSs are located in the cell centers. To cover the users better, the BS allocation procedure tries to allocate more BSs in the parts where population distribution is high (dark and black areas). Thus, the users' QoS can be improved.

6.2 Evaluation Parameters

To evaluate the proposed BSs allocation procedure, we consider the following parameters:

- U_{Total}
  the total number of generated users;
- $U_{Complete}$
  the number of users who completed their calls during a simulation;
- U_{Out}
  the number of users who tried to make a call outside the cell but failed;
- $U_{Channel}$
  the number of users who failed to talk because there were no free channels;

Fig. 9 Simulation example.

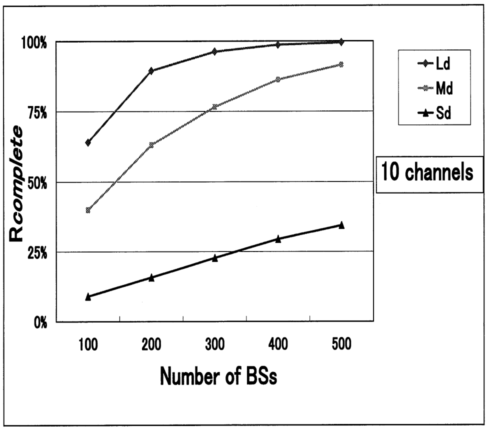

Fig. 10 Number of BSs and $R_{Complete}$.

- U_{Stop}
  the number of users who failed to find a free channel when they moved to another cell.

On the basis of the abovementioned parameters, the following call rates are calculated:

- $R_{Complete} = U_{Complete}/(U_{Total} - U_{Out})$
  the call rate for calls that finished normally;
- $R_{Out} = U_{Out}/U_{Total}$
  the call rate of users who tried to make a call outside the cell but failed;
- $R_{Channel} = U_{Channel}/U_{Total}$
  the rate of failed calls for users who did not find a free channel;
- $R_{Stop} = U_{Stop}/U_{Total}$
  the rate of failed calls during handover.

6.3 Cell Size and $R_{Complete}$ Parameter

Figure 10 shows the relation between the cell size and $R_{Complete}$ when the number of channels for each BS is 10. When the number of cells and the cell size are both large, the number of users who failed to find free channels and of users who tried to start their calls outside the cells decreases and $R_{Complete}$ becomes high. In the case where the cell size is "L" for 500 BSs, more than 90% of users completed their calls, while in the case where the cell size is "S", only 30% of users completed their calls. This result indicates the difficulties in starting a mobile communication business such as PHS.

6.4 Cell Size and R_{Stop} Parameter

The relation of the number of BSs and R_{Stop} is shown in **Fig. 11**. For three different cell sizes "S", "M", and "L", we have changed the number of BSs from 100 to 500 and measured the R_{Stop} parameter. When the cell size is "S", the use of 500 BSs can decrease R_{Stop} by only 5% in comparison with the case in which 100 BSs are used, whereas, when the cell size is "M", the R_{Stop} for 500 BSs is 17% and for 100 BSs decreases to 38%. For "L" size cells, the values of R_{Stop} for 500 BSs and 100 BSs are 4% and 18%, respectively. These results show that the larger the cell size is, the greater the effect is on the users' QoS.

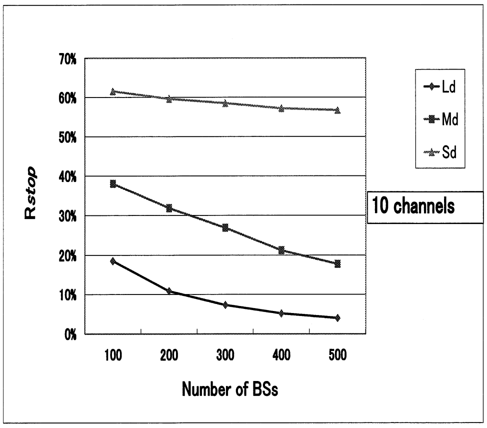

Fig. 11 Cell size and R_{Stop}.

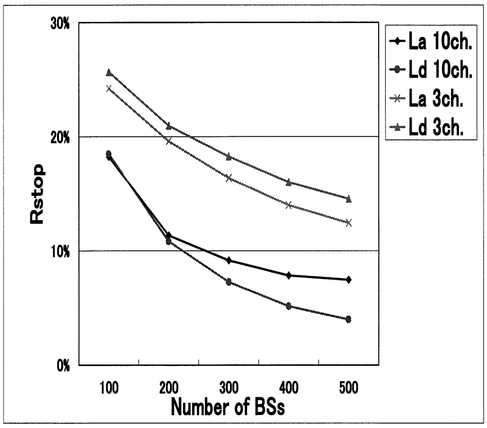

Fig. 12 Number of channels and R_{Stop}.

6.5 Number of Channels and R_{Stop} Parameter

Figure 12 shows the relation between number of channels in a BS and the R_{Stop} parameter for "La" and "Ld" scenarios. The R_{Stop} parameter is always greater for cases with 3 channels than for cases with 10 channels. When the number of channels is 3, the R_{Stop} parameter for the "La" scenario is lower than that for the "Ld" scenario. This is because many users in the downtown area fail to find free channels during handover. When the number of channels is 10 and the number of BSs changes from 100 to 200, most of the BSs are allocated in the downtown area in both "La" and "Ld" scenarios. There-

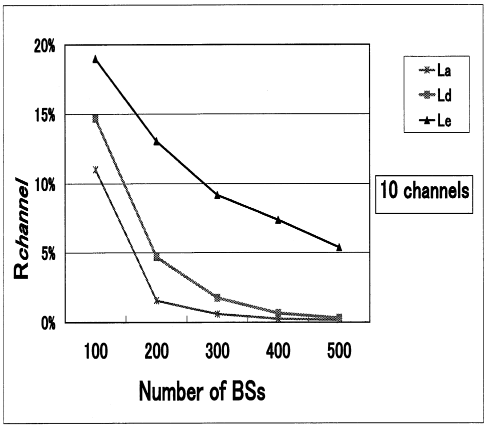

Fig. 13 Number of BSs and $R_{Channel}$.

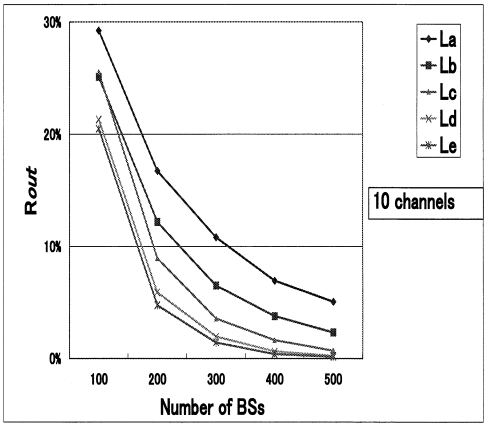

Fig. 14 Number of BSs and R_{Out}.

fore, the R_{Stop} parameter is almost the same. When the number of BSs is changed from 200 to 500, the R_{Stop} value for the "Ld" scenario is lower than that for the "La" scenario. This is because many users in the downtown area can find free channels during handover. In the "Ld" scenario, BSs are scattered around the service area, while in the "La" scenario, the BSs are concentrated in the service area. Thus in "Ld" scenario, even when users are moving in other cells, they can find free channels.

6.6 BS Allocation and $R_{Channel}$ Parameter

Figure 13 shows the relation between the allocation of BSs and $R_{Channel}$. The ratio of failed users who did not find a free channel is small for "La" scenario and large for "Le" scenario. This means that in "La" scenario, the BSs are concentrated in a specific part of service area where many users exist, while in "Le" scenario, the BSs are scattered throughout the service area. This result indicates that there are trade-offs between the users' QoS and the size of the area covered. This is very important for mobile communication companies, because they are interested in covering a large service area and also in increasing the users' QoS.

6.7 BS Allocation and R_{Out} Parameter

The R_{Out} parameter denotes the percentage of users who could not start to talk because they were outside the cells. This percentage depends on the number of BSs and on how BSs are allocated in the service area. The number of channels in a BS is not affected by the R_{Out} parameter. **Figure 14** shows the distribution of BSs in the service area. When *PU* is large, R_{Out} decreases and the BSs are scattered throughout the service area. When *PU* is small, R_{Out} value increases and the BSs are concentrated in a specific part of the service area.

7. Conclusions and Future Work

In this paper, we have proposed a simulation system for BS allocation in mobile communication networks, taking account of the user distribution, user movement, channel occupancy, and handover. The proposed system is based on a queuing model with many service stations and customers identified by their locations. Using the simulation system, we generated various networks with different patterns of BS allocation and evaluated the networks' performance. In this paper, we only considered PHS. However, this model can easily be applied to large scale mobile networks. For simulations, we considered the actual locations of road network and population distribution in Yamagata City, Japan. We carried out many simulations for various numbers of BSs, various numbers of channels, and various allocations of BSs. To evaluate the system performance, we considered many scenarios and parameters. From the simulation results we conclude that:

- the *PU* parameter affects the BSs' allocation: when *PU* is large, the BSs are widely scattered and a large area can be covered;
- assuming *PU* to be 2000, 500 "S" size cells can cover only 4% of the service area and 34.7% of the population, while 100 "M" size cells can cover 5% of the service area and 40% of the population;
- when *PU* is 100, the BSs tend to cover the downtown area, where the population density is high: for the "La100" scenario 75% of the population is covered;
- for the "Le100" scenario when *PU* is 4000,

the BSs are scattered throughout the service area and 99% of the population is covered;
- to obtain a better covering of users, the BS allocation procedure tries to allocate more BSs in the parts where the population distribution is high, thus improving the users' QoS;
- when the number of cells and the cell size are both large, the number of users who fail to find free channels and of those who try to call outside the cells decreases;
- in the case where the cell size is "L" for 500 BSs, more than 90% of users completed their calls, while in the case where the cell size is "S", only 30% of users completed their calls;
- the larger the cell size is, the greater the effect is on the users' QoS;
- if the number of channels in each BS is small, a user call may fail because the channels are already occupied by other calls;
- there are trade-offs between the users' QoS and the size of the area covered;
- the handover failure rate depends on the number of BSs and how the BSs are allocated in the service area.

In the future, the authors plan to address the following issues:
- extension of the model in order to take account of users' movements along roads;
- consideration of specific cases such as concentrations of users in stadiums and stations where the traffic can be increased in a specific period of time;
- consideration of scenarios that include various cell sizes;
- expansion of the model for Code Division Multiplexing (CDM) and mobile data communication;
- use of intelligent algorithms for flexible handover.

References

1) Machihara, F.: Application of the Mobile Customer Model to Personal Communication System (in Japanese), *Proc. 25th Symposium on Queuing Theory – Modeling and Analysis*, pp.40–45 (1991).
2) Hác A. and Zhou, X.: Locating Strategies for Personal Communication Networks: A Novel Tracking Strategy, *IEEE J. Select. Areas in Commun.*, Vol.15, No.8, pp.1425–1436 (1997).
3) Tran-Gia, P., Leibnitz, K. and Tutschku, K.: Teletraffic Issues in Mobile Communication Network Planning, *Proc. 11th ITC Specialist Seminar*, pp.48–57 (1998).
4) Tutsuchku, K. and Tran-Gia, P.: Spatial Traffic Estimation and Characterization for Mobile Communication Network Design, *IEEE J. Select. Areas in Commun.*, Vol.16, No.5, pp.804–811 (1998).
5) Hong, D. and Rappaport, S.S.: Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Nonprioritized Handoff Procedures, *IEEE Trans. Vehicular Tech.*, Vol.VT-35, pp.77–92 (1986).
6) Zonoozi, M.M. and Dassanayake, P.: User Mobility Modeling and Characterization of Mobility Patterns, *IEEE J. Select. Areas in Commun.*, Vol.15, No.7, pp.1239–1252 (1997).
7) Guérin, M.A.: Channel Occupancy Time Distribution in a Cellular Radio System, *IEEE Trans. Vehicular Tech.*, Vol.VT-35, No.3, pp.89–99 (1987).
8) Yamada, T. and Takahashi, Y.: The Location of Base Stations in Personal Handy Phone Systems (in Japanese), *Proc. Symposium on Performance Models for Information Communication Networks*, pp.155–164 (1998).
9) Yamada. T. and Takahashi, Y.: The Policies of Base Stations in the Mobile Communication Networks (in Japanese), *Proc. Symposium on Performance Models for Information Communication Networks*, pp.336–345 (1999).
10) Yamada, T., Takahashi, Y. and Barolli, L.: Evaluation by Simulations of a Base Station Location Policy for Mobile Telephone Networks (in Japanese), *IPSJ Symposium Series*, Vol.99, No.18, pp.177–182 (1999).

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