A Mobile Communication Simulation System for Urban Space with User Behavior Scenarios

Takako Yamada, Masashi Kaneko, and Ken'ichi Katou

The University of Electro-Communications, Graduate School of Information Systems,
1-5-1 Choufugaoka, Choufu-shi, Tokyo, 182-8585, Japan
{takako, masashi, kkatou}@ymd.is.uec.ac.jp

Abstract. We present herein a simulation system to model mobile user behavior in urban spaces covering roads, railways, stations and traffic signals. The proposed simulation system was developed in order to provide analysis in situations that cannot be dealt with analytically, such as mobile users moving along roads and the arrival or departure on commuter trains of group users at stations. In the present paper we observe mobile traffic, which changes with the user distribution, in order to discuss base station location policies. The proposed simulation system can deal with these user behaviors in actual urban space with roads, crossings and stations. The movement of mobile users and the effects thereof on the performance of the mobile system are examined with respect to service quality, such as call loss probability (C.L.P). Using the proposed simulation system, we observe and compare several cell location patterns and discuss the influence of retrial calls.

1 Introduction

The number of mobile phones in Japan is approximately 80 million and continues to increase. Mobile phone networks are considered to be an important component of the infrastructure of Japan. In addition, the demand for data packet service in mobile communication networks is increasing. New communication services are emerging, including high-speed data packet transfer in 3rd generation mobile services and wireless LAN and IP phone services using PHS networks. Thus the importance of reliability and service quality for these services has become a very important issue. The utilization of channels in wireless communication services is quite important because radio frequency is a finite resource.

In cellular mobile services, service areas are divided into small areas called cells, each of which has a base station at the cell center. Recently, hot spots served by public area wireless networks (PAWNs) have been expected to become a cost-effective complementary infrastructure for third-generation cellular systems. PAWNs are base-station-oriented wireless LANs that offer tens of megabits per second to public or private hot spot users. One of the important problems for mobile communication services is to provide homogeneous service. In cellular service, the resource provided by a single base station is limited. Channel exhaustion in crowded cells is more frequent than in cells with fewer users. Thus, accurate estimation of traffic demands in the service area is important with respect to base station allocation. Moreover, the traffic due to mobile users who

L.T. Yang et al. (Eds.): HPCC 2005, LNCS 3726, pp. 979–990, 2005.

move from one cell to another requires handover procedures between related base stations, and such handover calls are lost when there are no free channe ls in the following cells.

Performance evaluation has been discussed analytically in previous studies[1,2,3,4]. In most of these studies, the queueing models, such as M/M/k/k models (in which channels are regarded as servers in the system)[5], are used to evaluate the stochastic characteristics, such as channel occupancy time. Typical analytical models assume an exponential distribution for call arrival intervals, channel occupation time, and user sojourn time in each cell. Thus, in analytical models, the following situations are difficult to consider.

- Arrival of groups of users at stations and crosswalks.
- Uneven distribution of users, moving directions caused by roads and buildings and fluctuations of these distributions which may change from time to time.
- Retrial calls that independently arrive after failed calls.

The distribution by computer simulation in two-dimensional space of actual population distribution data and road traffic data were used by Tutschku[6] and Matsushita[7]. Nousiainen, Kordybach, and Kemppi[8] investigated user movement using a city map, although the movement behavior was very simple. However, few models have discussed user mobility along roads and user call retrial behavior. We have been investigating walking pedestrian models[9] based on rogit model[10] and mobile user models[11]. In the present paper, we propose a moving pedestrians (users) model in an urban space in order to consider urban congestion in areas that include crosswalks, signals along sidewalks, stations and buildings. The walking mobile users in the proposed model call and retry their calls when the call fails. We develop a simulation system based on the proposed moving user model. The variations of users having different call behavior features and movement characteristics are generated by scenarios written in custom macros. Using these scenarios, the simulation has sufficient flexibility to deal with various situations easily.

The proposed simulation system can evaluate traffic for a cellular telecommunication system using user distribution data together with actual city maps, as shown in Figure 1. We can confirm and clarify the simulation process and the traffic situation in each cell through graphical user interfaces and visualization of user behavior on the map. In the present paper, we selected Choufu city, a typical suburb of Tokyo. Based on statistics for pedestrians, population distribution for daytime and nighttime and on the railroad traffic data for Choufu station, we present the user distribution, movement, and call behavior in order to evaluate the call loss probability (C.L.P.). Furthermore, we examine the effect of retrial calls and base station location policies.

2 Mobile Communication Simulation System

A schematic diagram of the simulation system is shown in Figure 1. Input data of the simulation system are initial user location distribution, road network data, route connection data, cell data and simulation scenarios of user behavior, traffic signals and train schedules. The proposed simulation system can deal with service areas of several square kilometers, through which users move on foot along roads, or remain in residential areas or offices. With a simple editor developed for this simulation system, we can edit road networks that are converted into non-directional graph networks data. Furthermore, we can edit traffic signals, crossings, and other factors in order to organize the urban space and influence user movements. A macro language developed for this simulation is used to describe the simulation scenario. Scenarios are prepared for each simulation execution. The scenarios control the traffic equipment and define files for the initial user location distribution and the user movement patterns with origin and destination map data and route selection settings. Other distribution functions for call arrival rate, holding time and call retrial intervals can be included in the scenarios. By applying scenario files using the macro language, we can provide high flexibility to the proposed simulation system. Figure 2 is a map of the road network for pedestrians around Choufu station.

In this simulation, mobile phone users are connected to the nearest base station, and thus the service area is divided by a Voronoi diagram[12] of individual cells. When a mobile user moves from one cell to another cell while the user is talking, the base station should transfer the call to next base station. This procedure is called the handover process. The mobile user has a single chance to find a free channel in the approaching cell. If there is a free channel, then the base station transfers the call to the base station in the approaching cell. If there is no empty channel, then the call fails. We count the number of call failures as the number of terminated calls.

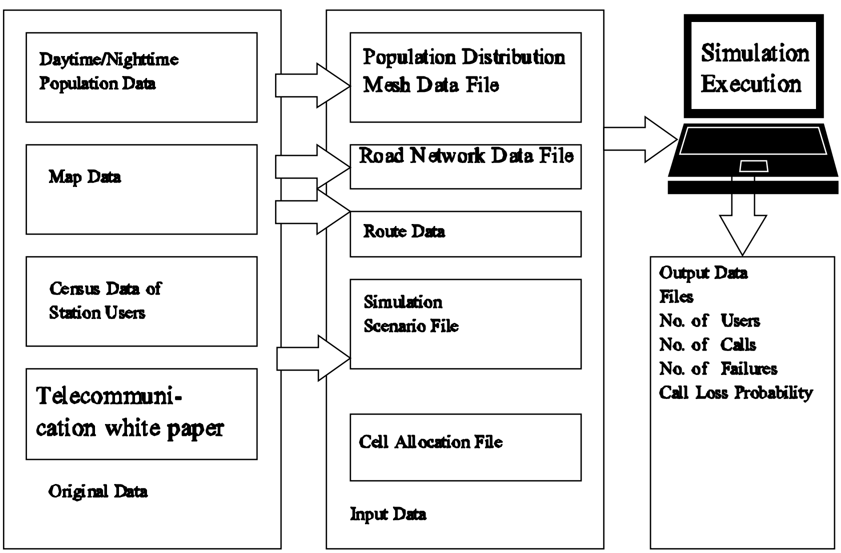

Fig. 1. Schematic diagram of the simulation system

Fig. 2. Pedestrian road network around Choufu Station (graph diagram)

2.1 Simulation Setting by Scenarios

In the simulation scenarios used herein, we can define various simulation parameters, such as simulation clock, execution time, and file path, to indicate data file locations. These parameters and files define user behaviors according to type, as well as urban spaces in the service area. Table 1 shows an example of the description of a signal, "TESTSIGNALB", which controls user arrival. When the system receives the signal, one user is generated. By repeating this procedure, the users are generated according to an exponential distribution with average of 1.5-second time interval. Similarly a control signal, "TRAIN" generates commuter trains that arrive periodically at Choufu station in 150-second intervals.

2.2 Presentation of User Behavior

When we see pedestrians in a downtown area, each pedestrian has a unique destination and selects a unique route. The compilation of the walking patterns of each pedestrian consists of the flow of pedestrians on roads. In the proposed simulation system, we define typical movement patterns of pedestrians, who may or may not be mobile users. The pedestrian type defines the arrival and

Table 1. Example of signal definition

@SIGNAL TESTSIGNALB
@@LABEL
@@WAITE@1.5
@@ACTIVE
@@GOTO
@SIGNAL TRAIN
@@LABEL
@@WAITD@150
@@ACTIVE
@@GOTO

Table 2. Example of a scenario for the "USERA" pedestrian type

@USER USERA TESTSIGNALB 1 PDMESH
@@200000/30.0 300.0 GM
@@MOVE STATIONMESH
@@WAITSIGNAL TRAIN
@@END

departure of the pedestrian from the system by scenarios in which the probability distribution is written. The pedestrians walk from each origin to each destination according to the origin-destination distribution file. The walking patterns and average speeds are also defined in the scenarios.

The example shown in Table 2 is for a user type. The first line of the scenario defines the user generation procedure. In this scenario, a user is generated according to an exponential distribution given by "TESTSIGNALB" in Table 1 and the initial population density is defined by a data file called "PDMESH". The second line defines user behavior in using mobile phone. In this scenario, the average call interval has an exponential distribution with an average of 200,000 seconds. The average time interval for retrial calls is 30 seconds, and the average holding time for each call has an exponential distribution with an average of 300 seconds. The third line defines user walking behavior with regard to traffic signals and commuter trains.

The initial user population distribution file "PDMESH" is based on national census data. The file "STATION MESH" defines the movement pattern as origin-to-destination (OD pairs). This file is generated according to the difference between the daytime and nighttime populations. The number of pedestrians who walk from residential areas to Choufu Station in the morning is calculated by subtracting the nighttime population from the daytime population, and these pedestrians leave the service area by commuter trains. On the other hand, the pedestrians who arrive at the station move from the station to the business area. Their destinations are selected randomly according to the population density in the service area. The number of pedestrians arriving at the station is determined according to statistical census data on station users. In the present simulation, the traffic signals change every 60 seconds. Commuter trains arrive periodically every 150 seconds, based on the arrival schedule of Choufu station during the morning rush hour.

The pedestrians walk according to type, for example, moving straight toward his or her destination by the shortest route or taking detours along the way. The degree of detour from the shortest route is also defined in the scenarios. The basic route of each pedestrian is the shortest route, and alternative routes that involve random detours are given according to the logit model[10]. The speed of each pedestrian is calculated periodically by considering individual ideal walking speeds and the effects of road congestion caused by other pedestrians, traffic signals or the widths of roads.

2.3 User Parameters for Simulation

From the 2000th telecommunications white paper, which reports the current statistics of mobile phone usage in Japan, we set the average user holding time as 300 seconds (2.5 minutes) and the average time interval of mobile phone calls as 21,221 seconds (approximately 6 hours). The other parameters used in the simulation are shown in Table 3.

Table 3. Fixed simulation parameter

Simulation time	13 hours
Data Extraction	from 1 to 13 hours
Type1 (Pedestrians in residential area)	Poisson arrival with 4.27/sec.
Type2 (Pedestrians arrive at Choufu Station)	426 pedestrians arrive per 150 sec.

3 Simulation Results and Discussion

3.1 Regular Cell Allocation and Simulation Results

Cells having a 100-m radius and five channels cover the service area of this report. The cells are located regularly and are called Pattern “A”, as shown in Figure 3. An example of the statistics of the cell that covers Choufu Station and its adjacent five cells are shown in Table 4. These cell traffic statistics show the number of new calls in each cell, the number of call failures, the number of handover failures and the rate of call failure for all calls in the cells under consideration. When the cells are located regularly, the cell for Choufu station has a high call loss probability of 0.66. However, the call loss probabilities of the other cells, which are not included in Table 4, are less than 0.1, even though some of these cells covering crossings with signals. In the following tables, we denote the number of new calls as “N.C.”, the number of handover calls as “H.C.”, the number of failed new calls as “F.N.C.”, the number of failed handover calls as “F.H.C.”, and the call loss probability as “C.L.P.”

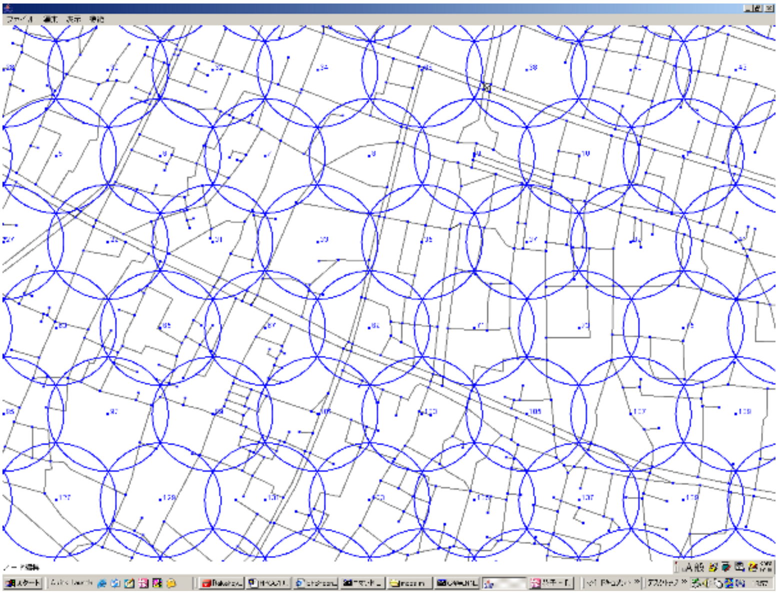

Fig. 3. Pattern A cell allocation

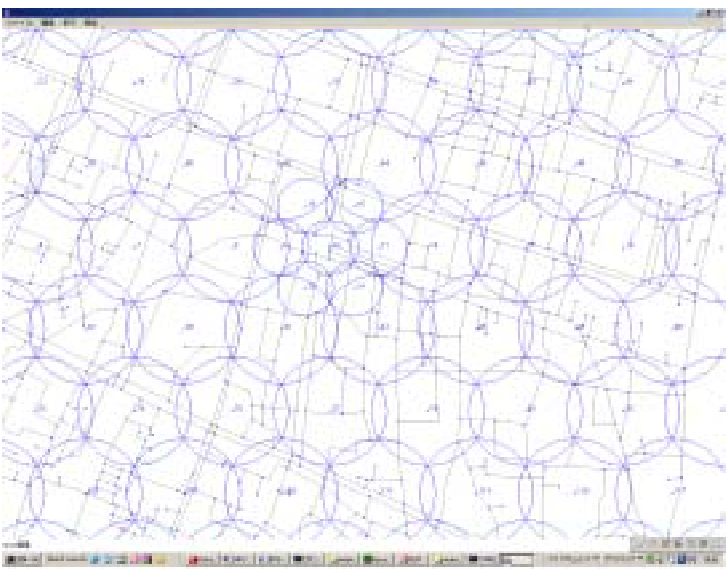

Fig. 4. Pattern B cell allocation

3.2 Variations of Cell Allocations

Figure 4 shows another cell allocation pattern, in which the cell that covers Choufu Station is divided and replaced by six smaller cells. This allocation pattern is called "Pattern B". Figure 5 and 6 shows the distribution of call loss probability for the "Pattern A" allocation pattern and "Pattern B" allocation pattern respectively. The replacement of a congested cell with smaller cells decreases call loss probability by half. In Tables 4 and 5, the numbers of new calls, handover calls, and failure calls are shown for the seven center cells of the "Pattern A" cell allocation and for 13 cells for the "Pattern B" cell allocation. When "Pattern A" allocation is applied, the call loss probability within the cells marked by the bold line in Figure 5 is 0.344, whereas the corresponding call loss probability is 0.147 for the "Pattern B" allocation in Figure 6. The number of handover calls increases when "Pattern B" allocation is applied because the length of the cell border increases. In contrast, the performances of the individual cells are approximately the same, even if the total traffic in the congested cells increases.

Let us consider two allocation Patterns A and B. First, we compare the number of pedestrians in the cells covering the station and the surrounding cells.

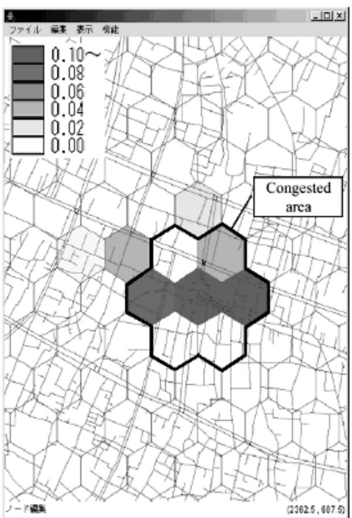

Fig. 5. Distribution of C.L.P. for Pattern A allocation

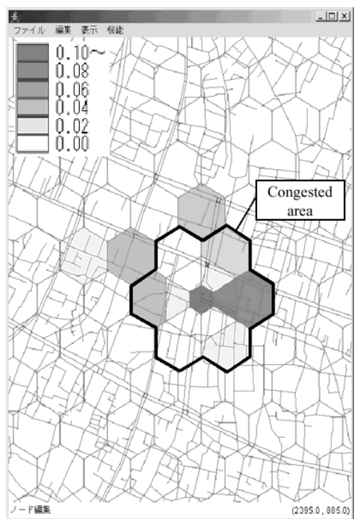

Fig. 6. Distribution of C.L.P. for Pattern B allocation

Table 4. Performance values for Pattern A allocation(without retrial calls)

	Cell 9	Cell 10	Cell 8	Cell 38	Cell 37	Cell 35	Cell 36	Total
N.C.	3010	888	569	539	301	207	136	5650
H.C.	1860	947	905	595	376	302	157	5142
F.N.C.	2059	114	49	15	2	0	0	2239
F.H.C.	1238	133	73	24	3	0	0	1471
C.L.P.	0.677	0.135	0.083	0.034	0.007	0.000	0.000	
C.L.P. of bordered area								0.344

Table 5. Performance values for Pattern B allocation(without retrial calls)

	Cell 10	Cell 11	Cell 16	Cell 8	Cell 44	Cell 9	Cell 15
N.C.	1869	799	672	398	391	284	357
H.C.	1761	1068	1012	1022	1003	1018	752
F.N.C.	956	89	59	13	17	2	3
F.H.C.	881	119	61	34	21	3	3
C.L.P.	0.593	0.188	0.074	0.043	0.025	0.011	0.011
	Cell 43	Cell 42	Cell 41	Cell 12	Cell 13	Cell 14	Total
N.C.	322	170	149	92	84	24	5611
H.C.	429	172	355	226	906	101	9825
F.N.C.	4	0	0	0	0	0	1143
F.H.C.	2	0	0	0	1	0	1125
C.L.P.	0.020	0.000	0.002	0.000	0.000	0.000	
C.L.P. of bordered area							0.147

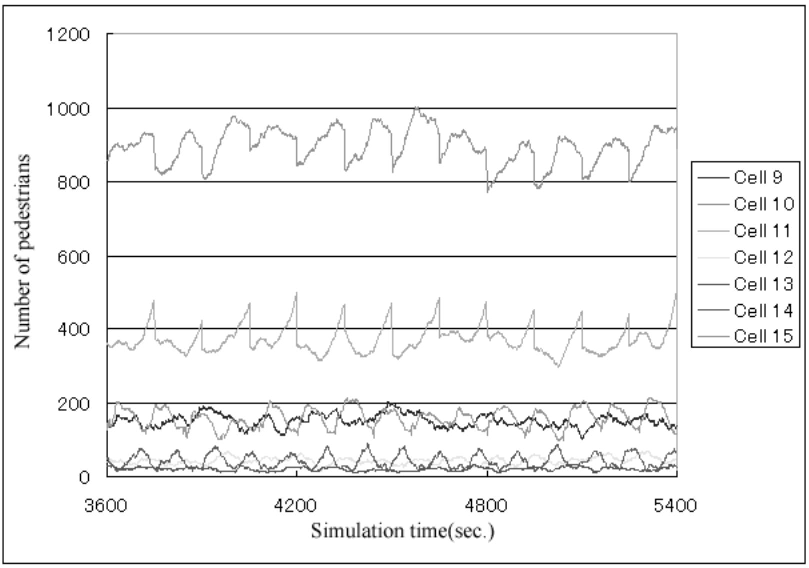

Fig. 7. Number of pedestrians in congested cells

The results are shown in Figure 5 and Figure 6. The observed area corresponds to the congested cells in the service area. The number of pedestrians in these cells periodically changes as commuter trains arrive at the station and groups of passengers arrive. Figure 7 shows the number of pedestrians in the congested cells around the station. This figure shows the transition of the number of pedestrians in the stable state. The number of pedestrians in the cells around the station changes periodically as commuter train passengers arrive at the station and walk through the cells. In Figure 8, we can see a transition of the number of

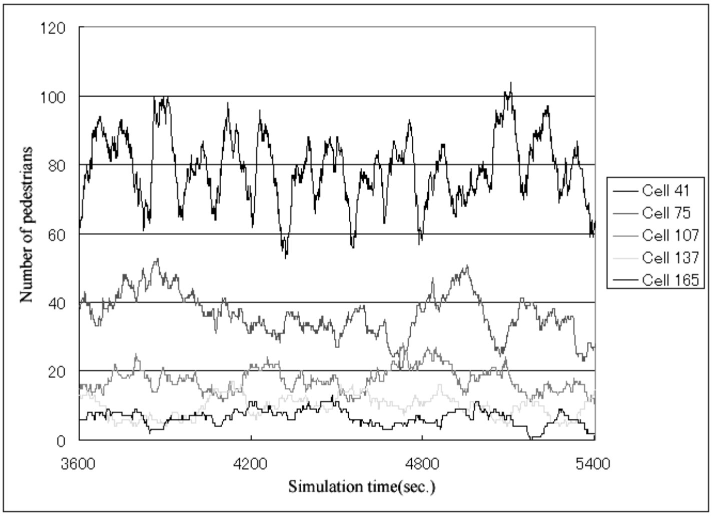

Fig. 8. Number of pedestrians in cells to southwest direction

pedestrians in Cells 41,75,107,137 and 165. As the cell number becomes larger, the locations of the cells separate from the station to the southwest direction. We can see that the periodic change subsides as the distance from the station becomes larger.

3.3 Considerations for Retrial Calls and Channel Allocation

In this section, we examine the effect of retrial calls at first. Here, we assume that the interval time of each retrial call has an exponential distribution with an average of 30 seconds. By comparing Tables 6, the call loss probability increases in the congested Cells 8 and 9 when we consider retrial calls. In such cells, the number of users experiencing call failure and retry increases. These users move from one cell to another while they continue call retrial. Therefore, the traffic of related cells increases. As a result, the call loss probability of these related cells increases. This result implies that the error due to the retrial calls appears in neighboring cells around congested cells. A number of studies on traffic evaluation of cell phone systems have assumed independent call arrival. However, the present result indicates that the interactions of related calls should be considered for more precise traffic evaluation.

When we consider retrial calls, cells with shorter call arrival intervals and higher traffic by group users, such as Cell 9, which covers Choufu Station, increase the call loss probability. In Cell 9, the users who continue to retry calls increase, and these users move to adjacent cells as they continue to dial. Thus, the traffic of adjacent cells around Cell 9 become heavier, and this leads to higher call loss probability. This observation indicates that the interaction of Cell 9 and its adjacent cells caused by retrial calls of moving users amplifies the estimation gap of traffic.

Table 6. Performance values for Pattern B allocation(without retrial calls)

	Cell 10	Cell 11	Cell 16	Cell 8	Cell 44	Cell 9	Cell 15
N.C.	1869	799	672	398	391	284	357
H.C.	1761	1068	1012	1022	1003	1018	752
F.N.C.	956	89	59	13	17	2	3
F.H.C.	881	119	61	34	21	3	3
C.L.P.	0.593	0.188	0.074	0.043	0.025	0.011	0.011
	Cell 43	Cell 42	Cell 41	Cell 12	Cell 13	Cell 14	Total
N.C.	322	170	149	92	84	24	5611
H.C.	429	172	355	226	906	101	9825
F.N.C.	4	0	0	0	0	0	1143
F.H.C.	2	0	0	0	1	0	1125
C.L.P.	0.020	0.000	0.002	0.000	0.000	0.000	
C.L.P. of bordered area							0.147

Table 7. Effect of channel increment (without retrial calls)

Cell Number	8	9	10	11	38	40
C.L.P.						
no retrial calls	0.080	0.665	0.129	0.000	0.033	0.000
retrial calls	0.178	0.838	0.254	0.005	0.112	0.000

In many studies on performance, the evaluation of cellular mobile communication systems assume independent call arrivals, although our observations assert the estimation for the traffic interactions among related cells.

4 Future Works

In the present paper, we propose a model with moving mobile users for a service area of several square kilometers. This model deals with mobile users who move in an urban space with road networks, traffic signals and commuter trains. We developed a computer simulation system using map data, population data and road data. In this simulation system, we examined various user behaviors, including retrial calls, by applying various scenarios and discussing the base station allocation policy effect of additional channels and the effect of user retrial calls. At the same time, this simulation dealt with group arrival by commuter trains. We determined that group arrival by commuter train and the deviation caused by this arrival process causes an estimation error in call loss probability and other estimations of traffic in cells.

References

1. T.Takahashi,T.Ozawa,Y.Takahashi, "Bounds of Performance Measures in Large-Scale Mobile Communication Networks",*Performance Evaluation*,Vol.54,pp.263-283.2003.

2. M. Kanno, M. Murata, H. Miyahara, "Performance Evaluation of CDMA Cellular Network with Consideration of Softhandoff", *IEICE Technical Report(SSE99-37)*, RCS99-61, pp.43-48, July 1999 (in Japanese).
3. Takashi Okuda, Yohei Ando, Tetsuo Ideguchi, Xejun Tian "A Simplified Performance Evaluation for Delay of Voice End-User in TDMA Integrated Voice/Data Cellular Mobile Communications Systems" C*IEEE Globecom2002*, Taipei, 2002.
4. Kenneth Mitchell, Khosrow Sohraby , "An Analysis of the Effects of Mobility on Bandwidth Allocation Strategies in Multi-Class Cellular Wireless Networks", *IEEE Infocom 2001 Technical Program.*, pp.1005-1011, 2001.
5. L. Kleinrock, "Queueing Systems Volume I:Theory", Wiley&Sons, 1975.
6. Kurt Tutschku, "Models and Algorithms for Demand-oriented Planning of Telecommunication Systems", Thesis, Wurzburg University, pp.37-47, 1999.
7. Satoshi Matsushita, Shigeyuki Okazaki, "A study of simulation model for pedestrian movement with evacuation and queuing", *Proc. of the International Conference on Engineering for crowd safety*, pp.17-18 march, 1993.
8. VTT Information Technology(Finland), Sami Nousiainen, Krzysztof Kordybach, Paul Kemppi, "User Distribution and Mobility Model Framework for Cellular Network Simulations" , *IST Mobile & Wireless Telecommunications Summit 2002*, 2002.
9. M. Kaneko, T. Yamada, K. Katou, "A Pedestrian Model and Simulation System for Mobile Communication with Urban Space", Proc. Queue Symposium, pp.218-227, Jan 2004 (in Japanese).
10. E. Teramoto CH. Kitaoka CM. Baba CI. Tanahashi, "Broadarea Traffic Simulator NETSTREAM *Proc. 22th Japan Society of Traffic Engineers* Cpp.133- 136 C2002 (in Japanese).
11. T.Yamada,Y.Takahashi,and L.Barolli,"A Simulation System for Allocation of Base Stations in MobileCommunication Networks: A Case Study", *IPSJ Journal*,Vol.42,No.2,pp.276-285,2001.
12. A. Okabe, A. Suzuki, "Mathematics for Optimal Allocation", Asakura, 1992(in Japanese).