State University of New York at Stony Brook
College of Engineering and Applied Sciences

Technical Report No. 743

Simulation of Blocking, Hand-off and Traffic Performance for Cellular Communication Systems with Mixed Platforms

by

Guodong Zhang and Stephen S. Rappaport

Department of Electrical Engineering
State University of New York
Stony Brook, New York 11794-2350

e-mail: gzhang@sbee.sunysb.edu , rappaport@sunysb.edu

Date: August 4, 1997

Simulation of Blocking, Hand-off and Traffic Performance for Cellular Communication Systems with Mixed Platforms

Guodong Zhang and Stephen S. Rappaport

Department of Electrical Engineering
State University of New York
Stony Brook, New York 11794-2350

Abstract

A ***simulation*** model is developed to find traffic performance characteristics for a mobile cellular communication system. Results are compared to those obtained using a previously described analytically tractable model based on multi-dimensional birth-death processes. In the analytical model, hand-offs to a cell were assumed to occur according to a Poisson point process with a fixed long-term average rate needed to satisfy conditions of statistical equilibrium. This assumption was made to allow consideration of a single (typical) cell and thereby avoid the difficulty of having to deal with an overwhelmingly large number of ***system*** states. In the simulation model, a large number of cells are considered simultaneously and the fixed arrival rate assumption is relaxed. Simulation and analytical results are compared.

1. Introduction

A framework for analytically tractable analytical models of traffic performance for mobile cellular communications is described in [1]. The framework, which is based on multi-dimensional birth-death processes, uses a conservation rule that relates average hand-off arrival and departure rates. The approach allows consideration of homogeneous and non-homogeneous systems as well as a broad class of dwell time distributions. A

The research reported in this paper was supported in part by the U. S. National Science Foundation under Grant no. NCR 94-15530 and in part by BMDO/IST under Grant no. N00014-9511217 administered by the U.S. Office of Naval Research. General research support from Hughes Network Systems is gratefully acknowledged.

simulation model is developed for comparison with the analytical models with little modification, the model can be used to represent cellular systems with following features that are described more fully in [3]-[10]: single and multiple call platforms and hand-offs, different types of calls, priority and no priority for hand-off calls, mixtures of platforms having different mobility characteristics, loss systems, delayed systems, combined delay and loss systems, platforms limits and quotas, channel limits and quotas, a broad class of platform mobility characteristics, and mixed macro and micro-cell configurations. Here we consider a cellular system that has many cells. The Monte-Carlo simulation was devised using the discrete-time simulation language, SIMSCRIPT II.5. The results and aspects of the simulation are discussed, summarized and compared with those obtained by analytical calculation.

The simulation method is presented in Section 2. Section 3 contains a description of the realization of the simulation model. The parameters and layout of the simulation are described in Section 4. The results of simulation are presented in Section 5. Finally, the conclusion is made in Section 6.

2. Simulation Method

Discrete-time simulation describes a system in terms of logical relationships that cause changes of the states of the system at discrete points in time rather than continuously over time. Discrete-time simulation is especially suitable for queuing situations: objects (calls in a mobile system, jobs in a computer system) arrive at the system and request the resources (radio channels in mobile system, CPU time split in computer system), then relinquish the resources and leave the system. But not all discrete-time simulation involves queuing. Many communications systems are memoryless and then have no queuing [2].

SIMSCRIPT II.5, a powerful, free form, English-like, general-purpose simulation programming language was selected for this simulation. It supports the application of software engineering principles, such as structured programming and modularity, which provide orderliness and manageability to the simulation models [2].

The model of the mobile system consists of M cells each having C channels. There can be G platform types in the system. New call arrivals occur according to a Poisson point process. The new call origination rate from a non-communicating g-type platform is $\Lambda(g)$. The number of non-communicating g-type platforms in any cell is $\nu(g,0)$ which is assumed to be much larger than C. Then the total new call origination rate of g-type calls in a cell is $\Lambda(g)\cdot\nu(g,0)$, and is independent of the number of calls in progress. The intended unencumbered call duration on a g-type platform is a random variable T(g), having a mean $\bar{T}(g)$ and a negative exponential distribution. The dwell time in a cell is a random variable $T_D(g)$, having a mean $\overline{T_D(g)}$. The dwell time, T_D is the sum of N statistically independent ned random variables $T_D(g,i)$, where i=1, 2, ..., N. N is the number of phases. A hand-off attempt will occur only if the call is not completed before the completion of the last phase.

Cut-off priority is used here. C_h channels in each cell are reserved for hand-offs. New calls will be blocked if the number of channels in use is C- C_h or greater. Hand-off attempts will fail if all the channels are occupied. We consider a loss type system. That is blocked (new) calls and hand-off calls that cannot be accommodated are cleared from the system.

3. Realization of Model

The simulation model was constructed in the simulation language SIMCRIPT II.5. Individual simulated calls were generated as show in Figure 1. A region with 121 cells arranged as shown in Figure 2 was considered. The "center" cell which is numbered 61 was the primary focus of simulated data collection. This was done to mitigate edge effects which occur on border cells such as cells 1, 2, 3, ..., 11, 22, 33, ..., 121. Some simulated mobile departures from border cells generate hand-off arrivals in neighboring cells that are in the coverage region. Some departures represent platforms leaving the coverage region.

The simulation consists of a collection of processes and routines including: *call handling* process, *hand-off judge* routine, *generator* process, *monitor* process, *report* routine and *initialize* routine. The details of the processes and routines are:

Call Handling Process

The most important entity of the simulation is the *call handling* process which will simulate the request of a channel upon a calls arrival to a cell and relinquishment of the channel upon its exiting the cell or completing. During the simulation time, new calls are generated according to a Poisson point process. Each call corresponds a *call handling* process with different ID number. At any specific time, there are many calls in progress, so there are many concurrent *call handling* processes, which implements all the calls in all the cells of the system. Without loss of generality, we explain only one *call handling* process in detail. Upon a new call's arrival, it will check whether there is channel available in the cell. If not available, it will be blocked. Otherwise, it will request a channel and start the service in ith dwell time phase randomly. If the "intend" call duration expires before it completes its last dwell time phase, the call is(satisfactorily)completed. Otherwise, a hand-off attempt will occur. The Hand-off judgment routine is invoked, whose function is to select a target cell for hand-off and determine whether the hand-off succeed or fail. If fail, the call is terminated. Otherwise, it will renew its service in the target cell and repeat all the steps above until it is completed or terminated. The flowchart of call handling process is shown in Fig. 1.

There are several points to note: 1), When the mobile transits from one phase to another phase the "intended" call duration must be refreshed because it is a memoryless process; 2), When a new call is admitted to a cell, the probability of the supporting platform being in any phase is random[1]; and 3), All calls that are successfully handed off, renew service(in the target cell) in the first dwell time phase.

Hand-off Judgment Routine

If the call is not completed in the last dwell time phase, the hand-off judgment routine will be invoked. It will determine a target cell for the hand-off and determine whether the platform is moving out of the coverage region. Then it checks the availability of channels in the target cell. If no channel is available, then the hand-off fails, otherwise, the hand-off succeeds. If hand-off succeeds, the routine will check whether the hand-off is to the center cell. Finally, the cell number of target cell is returned, all the counters for hand-off attempts, hand-off failures, hand-off arrivals and hand-off departures of center cell are properly updated.

Generator Processes

The function of the generator is to create calls according to the Poisson point process with a arrival rate given by user during the simulation time. Each call is given an ID to distinguish if from other calls.

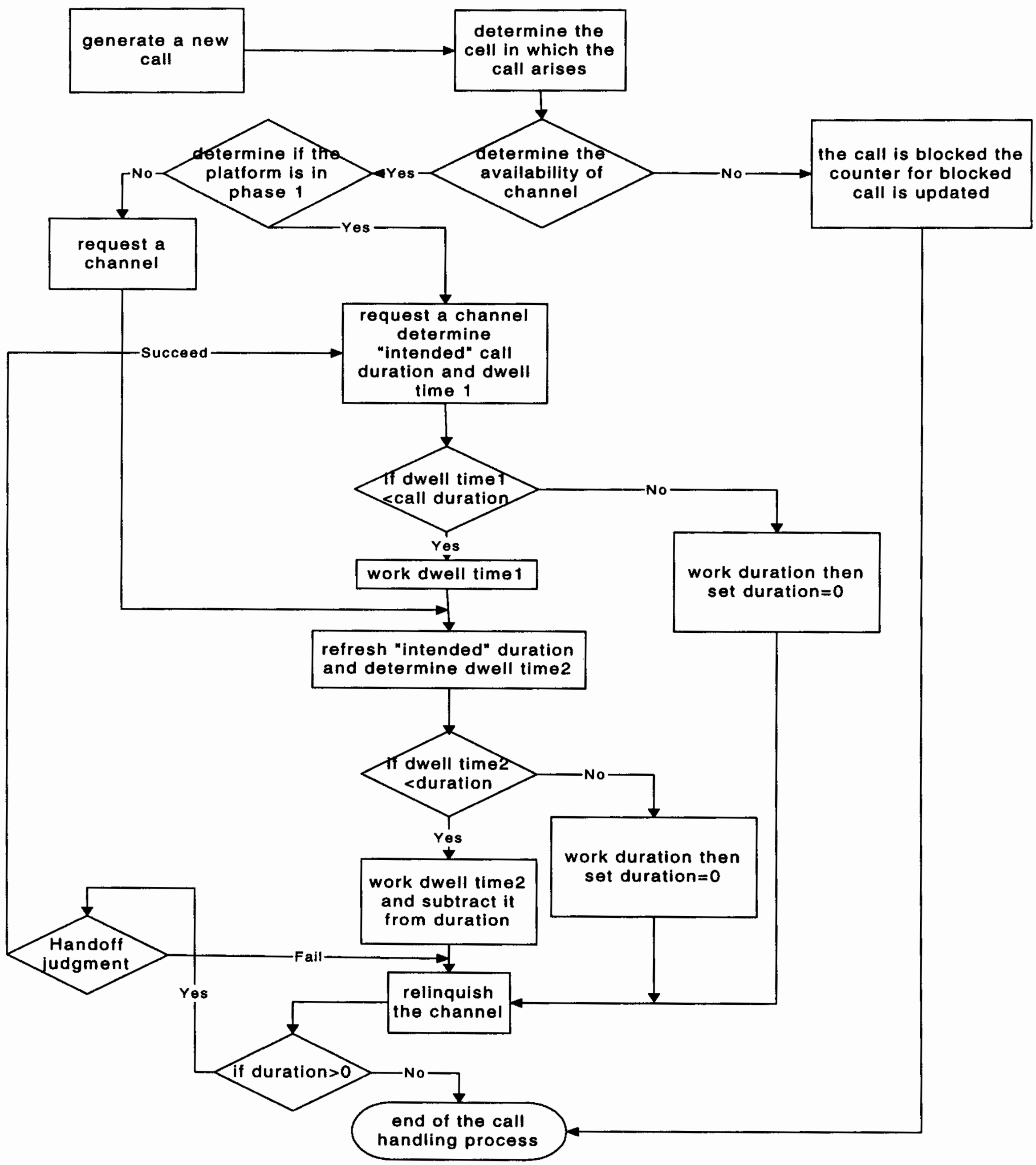

Fig. 1. Flowchart of Call Handling Process

Monitor Process

In this process, we get the instantaneous hand-off rate to the center cell by using the formula:

$$\Lambda_h(t) = (1/6) \sum_{i=1}^{6} U_i(t) \ / \ \overline{T_D} \qquad (1)$$

where $U_i(t)$ is the number of channels being used in neighboring cell i. Then Λ_h (t) is the instantaneous hand-off rate to the center cell. All Λ_h (t) are output to a data file. Then this data file is loaded into MATLAB, in which the curves of results are plotted and average of instantaneous values is calculated. We also record the inter-arrival time between hand-off events to the center cell.

Initialize Routine

This routine reads in the simulation parameters, such as arrival rate, C, N, C_h, initializes the counters, such as for hand-off attempts, hand-off failures, number of calls, to zero, sets up the table keeping the information of neighboring cells, sets up the *channels* according to the number of cells and C, and activates process *generator* and process *monitor.*

Report Routine

In this routine, we get the final result of simulation. The following results are obtained: number of calls initiated in the whole system during the simulation time, call blocking probability and forced termination probability of the whole system, long term hand-off arrival rate and departure rate of the center cell.

4. Parameters and layout of the simulation system

A. Parameters of the simulation system.

Number of cells in simulation system: M=121.

Number of channels in each cell: C=15 (G=1) or C=36 (G=2).

No quotas for platform are considered.

Number of platform type: G=1, 2.

Number of channels reserved for hand-off: C_h=0, 2, 4 (G=1) or 0, 3, 6 (G=2).

Number of non-communicating platforms in a cell: $v(1,0)=v(2,0)=300\sim350$.

New call arrival rate of a non-communicating platform: $\Lambda=2\times10^{-4}\sim4\times10^{-4}$ calls/sec.

The mean of unencumbered session duration: $\overline{T}(1)=\overline{T}(2)=100$sec.

The mean of dwell time in phase1 and phase 2: 20~500sec.

The simulation time: 10000~20000 seconds.

B. The layout of the simulation system

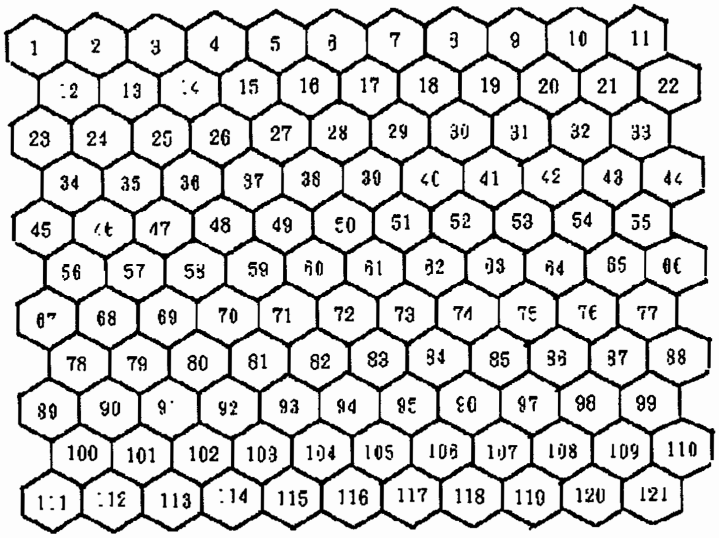

Fig. 2. The layout of the simulation system, cell 61 is the perfect center

5. Simulation results

The simulation determines the long-term hand-off rate Λ_l to the center cell , which is the number of hand-offs to the center cell divided by simulation time. The mean of the instantaneous hand-off rate to the center cell is denoted by $\overline{\Lambda_h}$. We plot the curves of the instantaneous hand-off rate to compare them with the long-term hand-off rate.

In following figures, we used: the number of channels in a cell, C; the number of reserved channels, C_h ; the number of non-communicating platforms, $v(1,0)$ and $v(2,0)$; the mean unencumbered session time, $\overline{T}(1)$ and $\overline{T}(2)$; the number of phases, N(1) and N(2) ; new call arrival rate of a non-communicating platform $\Lambda(1)$ and $\Lambda(2)$, and a fixed simulation time. Specific parameters choice are shown in the figure captions. The simulation time was long enough to assume that the system is in statistical equilibrium.

Fig. 3 is for a single platform type (G=1). It shows the instantaneous hand-off rate to the center cell as a function of time. The long term hand-off rate to the center cell obtained from simulation , Λ_l, is 0.04113 calls/s; While the average of instantaneous hand-off rate to the center cell got from theoretical prediction in formula (1), $\overline{\Lambda_h}$, is 0.04110 calls/s. Then it verifies the theoretical prediction in formula (1).

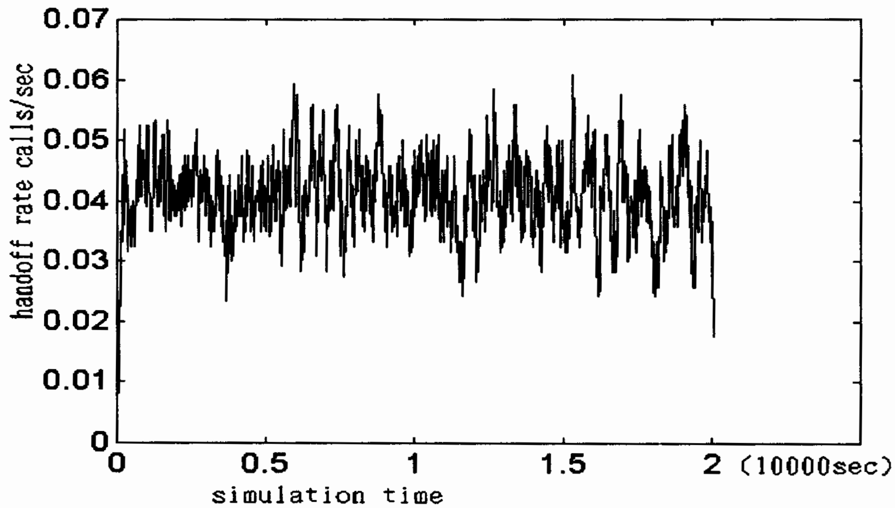

Fig. 3. C=15, C_h=0, G=1, $\overline{T}$ =100s, $\overline{T_D(1)} = \overline{T_D(2)}$ = 100s, $v(0)$=300, N=2, Λ =2.75×10^{-4} calls/sec

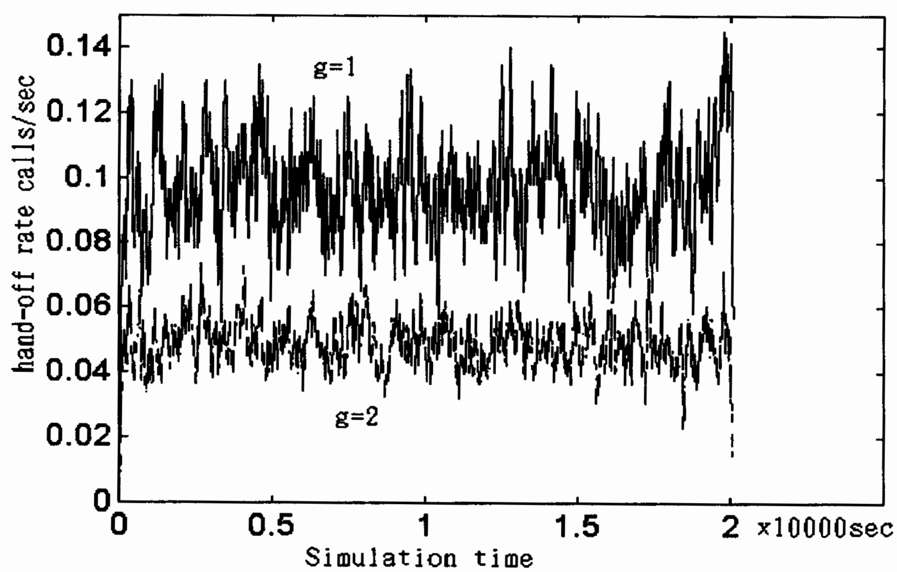

Fig. 4. C=36, C_h=0, G=2, N(1) = N(2) = 2 , $v(1,0) = v(2,0)$ = 350, $\overline{T(1)} = \overline{T(2)}$ =100s, $\overline{T_D(1,1)} = \overline{T_D(1,2)}$ =50s, $\overline{T_D(2,1)} = \overline{T_D(2,2)}$ =100s, Λ =2.75×10^{-4} calls/sec, Λ_{l1}=0.0951 calls/s, $\overline{\Lambda_{h1}}$ =0.0964 calls/s, Λ_{l2}=0.0475 calls/s, $\overline{\Lambda_{h2}}$ =0.0487 calls/s

Figs. 4 to 6 are for C=36, two platform types (G=2) and different number of channels reserved for hand-off (C_h=0, 3, 6). These figures show the instantaneous hand-off rates to the center cell as the functions of time. The same basic simulation model can simulate all the scenarios with mixed platforms(G=2 or more) and with different values of C_h.

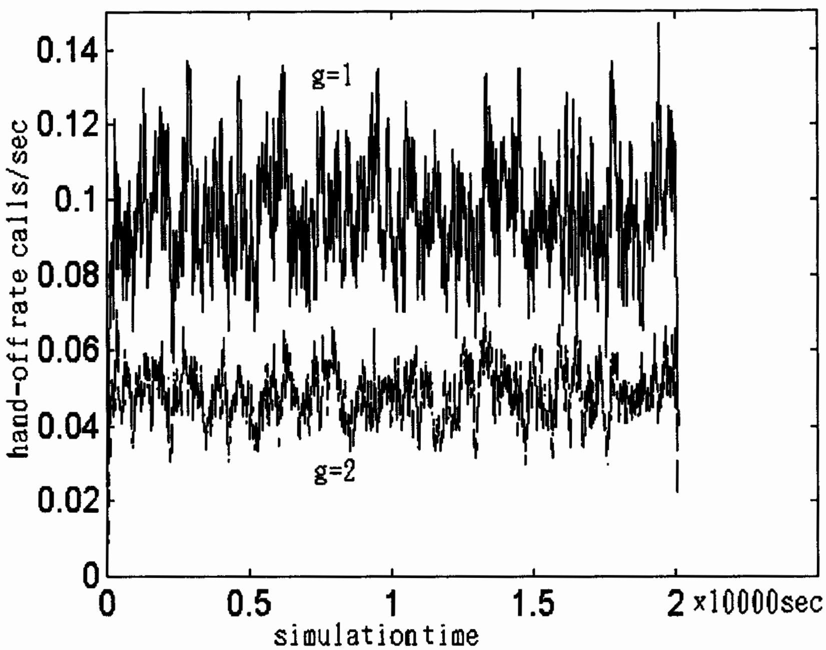

Fig. 5. C=36, C_h=3, G=2, N(1) = N(2) = 2 , $\nu(1,0) = \nu(2,0) = 350$, $\overline{T(1)} = \overline{T(2)}$ =100s

$\overline{T_D(1,1)} = \overline{T_D(1,2)}$ =50s, $\overline{T_D(2,1)} = \overline{T_D(2,2)}$=100s, Λ =2.75$\times 10^{-4}$ calls/sec,

Λ_{l1}=0.0951 calls/s, $\overline{\Lambda_{h1}}$ =0.0961 calls/s, Λ_{l2}=0.0485 calls/s, $\overline{\Lambda_{h2}}$ =0.0484 calls/s

Fig. 7 is for C=36, G=2, C_h=0 and Λ =3.75$\times 10^{-4}$ calls/sec. In comparison with Figs. 4 to 6, we found that the hand-off rates are insensitive to the number of channels reserved for hand-offs and depend on the new call arrival rate. The errors between $\overline{\Lambda_h}$ and the long-term hand-off rate Λ_l were very small, ranging from 0.073% to 2.7%. We also compared the long term hand-off arrival rate of the center cell with the long term hand-off departure rate of center cell. The error was less than 1%.

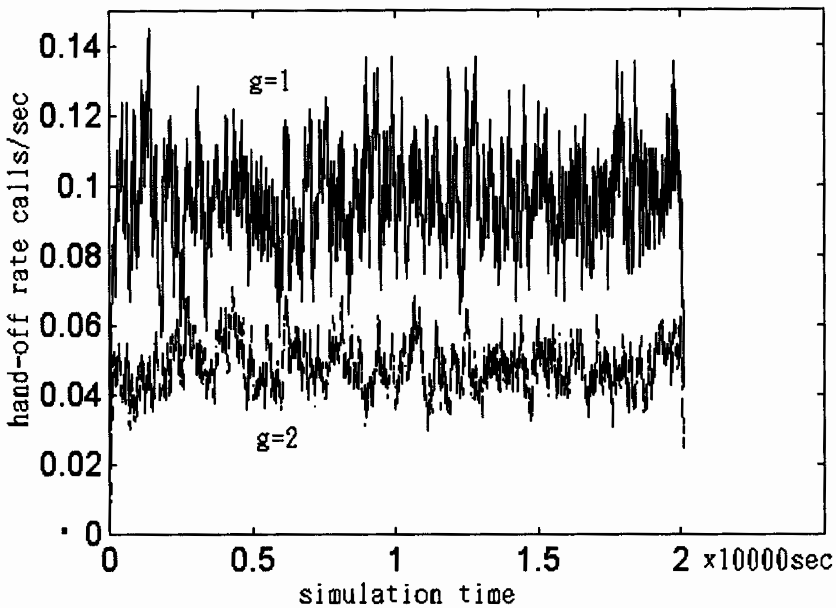

Fig. 6. C=36, C_h=6, G=2, N(1) = N(2) = 2 ,$\nu(1,0) = \nu(2,0) = 350$, $\overline{T(1)} = \overline{T(2)}$=100s,

$\overline{T_D(1,1)} = \overline{T_D(1,2)}$=50s, $\overline{T_D(2,1)} = \overline{T_D(2,2)}$=100s, Λ =2.75×10^{-4} calls/sec,

Λ_{l1}=0.0951 calls/s, $\overline{\Lambda_{h1}}$ =0.0960 calls/s, Λ_{l2}=0.0493 calls/s, $\overline{\Lambda_{h2}}$ =0.0482 calls/s

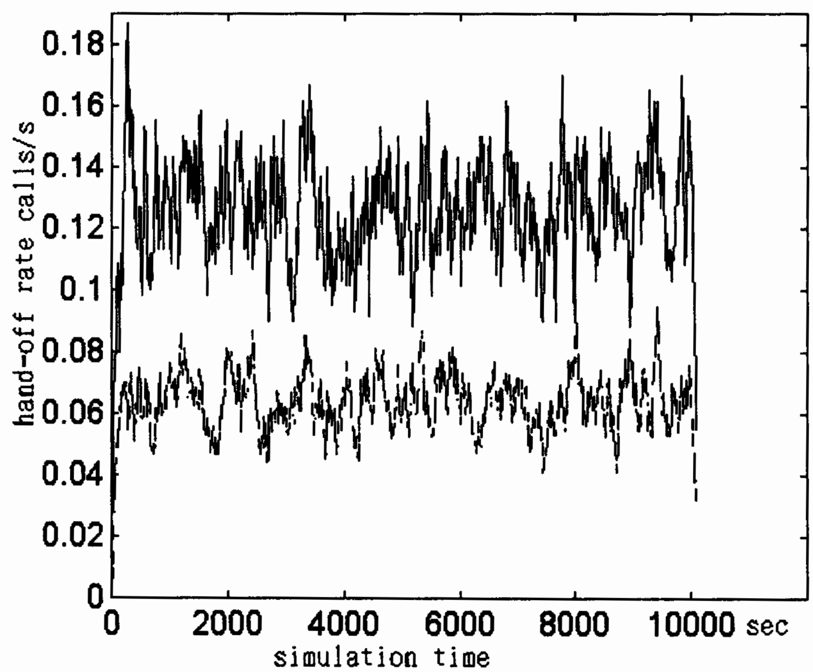

Fig. 7. C=36, C_h=0, G=2, N(1) = N(2) = 2 , $\nu(1,0) = \nu(2,0) = 350$, $\overline{T(1)} = \overline{T(2)}$=100s,

$\overline{T_D(1,1)} = \overline{T_D(1,2)}$=50s, $\overline{T_D(2,1)} = \overline{T_D(2,2)}$=100s, Λ =3.75×10^{-4} calls/sec,

Λ_{l1}=0.1256 calls/s, $\overline{\Lambda_{h1}}$ =0.1268 calls/s, Λ_{l2}=0.0640 calls/s, $\overline{\Lambda_{h2}}$ =0.0643 calls/s

Parameter choices in Figs. 8 and 9 are the same as the scenario in Fig. 7. The blocking probabilities of both platforms are about 1%. We calculated the standard deviations of the instantaneous hand-off rates for each platform. We use the following formula to calculate the instantaneous coefficient of variation of hand-off rate:

$$E(t)=\sqrt{(\Lambda_h(t)-\overline{\Lambda_h})^2}\,/\,\overline{\Lambda_h} \qquad (2)$$

$\overline{\Lambda_h}$ is the mean of instantaneous hand-off rates. This ratio represents the instantaneous dispersion of hand-off rate relative to the mean. We found that standard deviations of different scenarios didn't vary a lot and were insensitive to the means of instantaneous hand-off rates. Because of this, the mean of instantaneous coefficient of variations depends on the mean of instantaneous hand-off rate.

Figs. 8 and 9 show the coefficients of variation as functions of time. From these two figures, the mean of coefficients of variation of hand-off rates were less than 0.1154 while maintaining a blocking probability of 1×10^{-2}. This small coefficient value helps validate the analytical model's assumption of a fixed hand-off arrival rate.

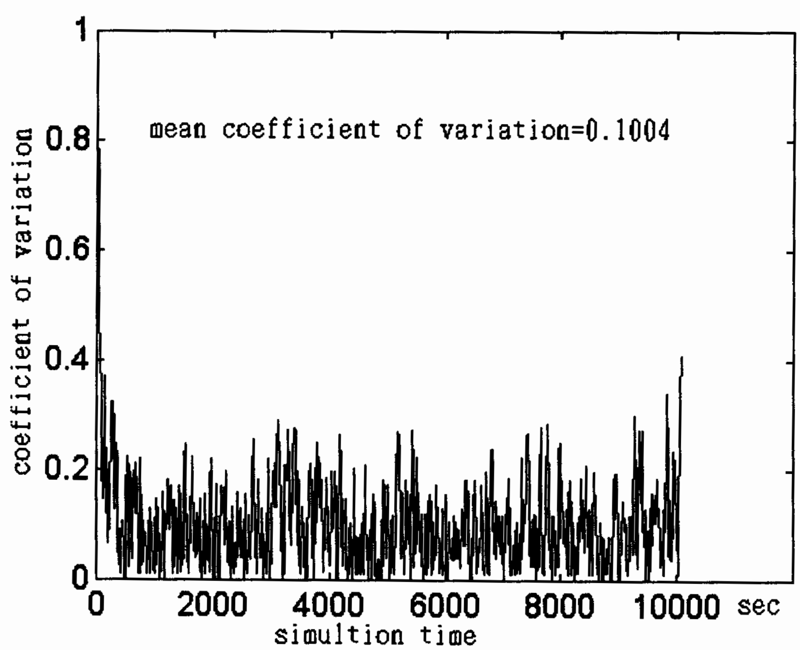

Fig. 8. Coefficient of variation for platform 1.

C=36, C_h=0, G=2, N(1) = N(2) = 2, $v(1,0) = v(2,0) = 350$, P_{B1}=1.06%,

$\overline{T(1)}=\overline{T(2)}$=100s, $\overline{T_D(1,1)}=\overline{T_D(1,2)}$=50s, $\overline{T_D(2,1)}=\overline{T_D(2,2)}$=100s, Λ =3.75$\times10^{-4}$ calls/sec.

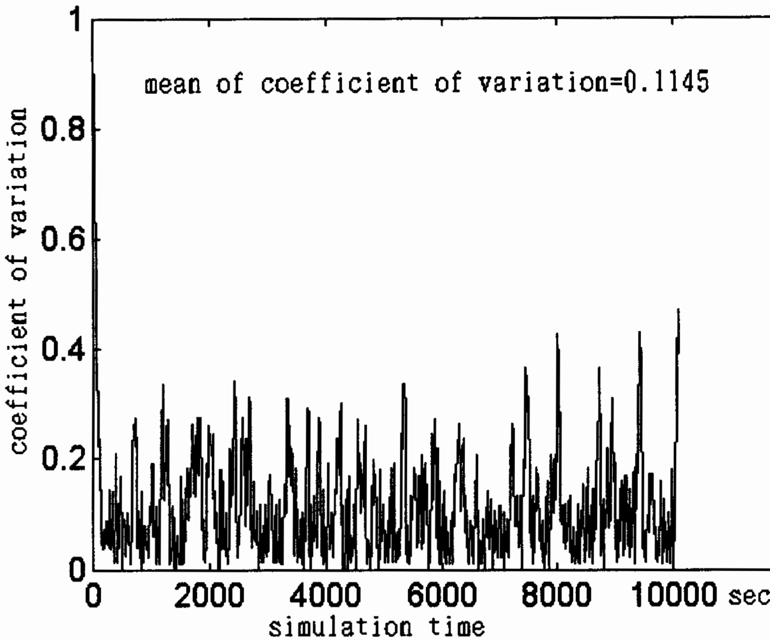

Fig. 9. Coefficient of variation of platform 2.

C=36, C_h=0, G=2, N(1) = N(2) = 2 , $\nu(1,0) = \nu(2,0) = 350$, P_{B2}=1.04%

$\overline{T(1)} = \overline{T(2)}$ =100s, $\overline{T_D(1,1)} = \overline{T_D(1,2)}$ =50s, $\overline{T_D(2,1)} = \overline{T_D(2,2)}$ =100s, Λ =3.75×10^{-4} calls/sec

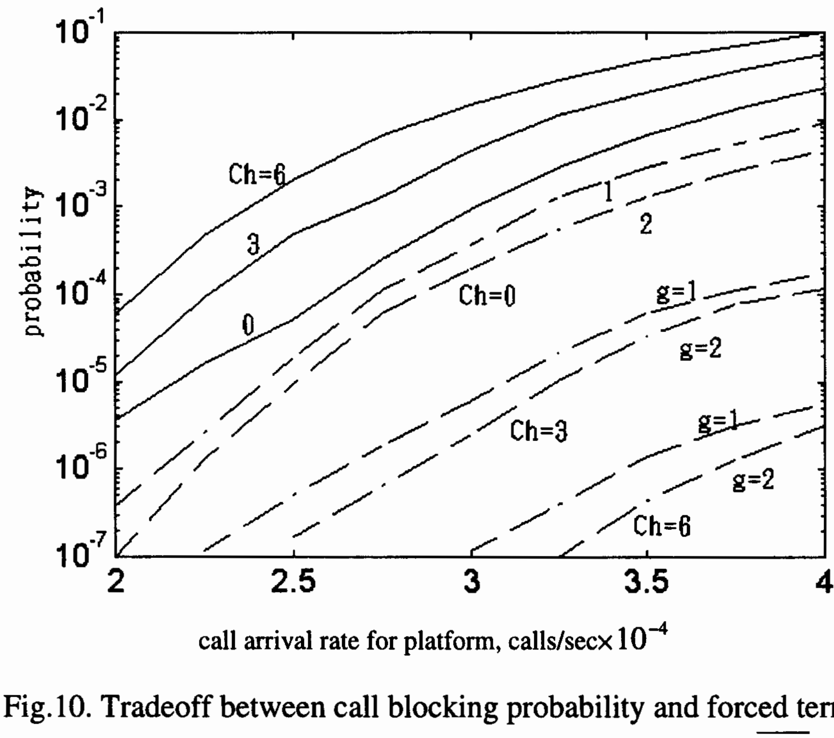

Fig.10. Tradeoff between call blocking probability and forced termination probability

C=15, C_h=0, 3, 6, G=2, N(1)=N(2)=2, $\nu(1,0)=\nu(2,0)=350$, $\overline{T(1)} = \overline{T(2)}$ =100s,

$\overline{T_D(1,1)} = \overline{T_D(1,2)}$ =50s, $\overline{T_D(2,1)} = \overline{T_D(2,2)}$ =100s,

---- P_{FT}

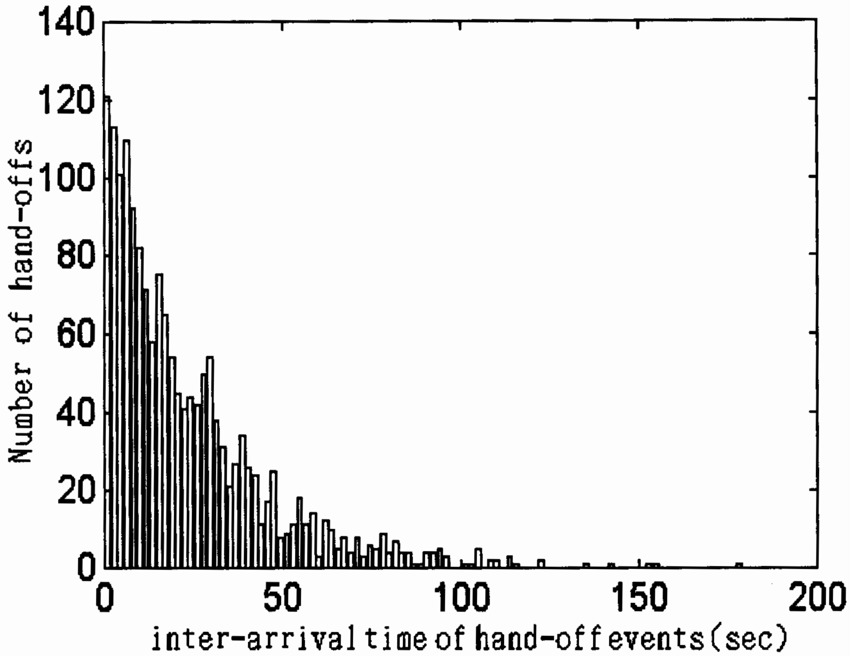

Fig. 11. Histogram of the interval of hand-off events

C=15, C_h=0, G=1, $\overline{T}$=100s, $\overline{T_D(1)}=\overline{T_D(2)}$=100s, $v(0)$=300, N(1)=N(2)=2,

Λ =3.0×10^{-4} calls/sec, Λ_l =0.0425 calls/sec.

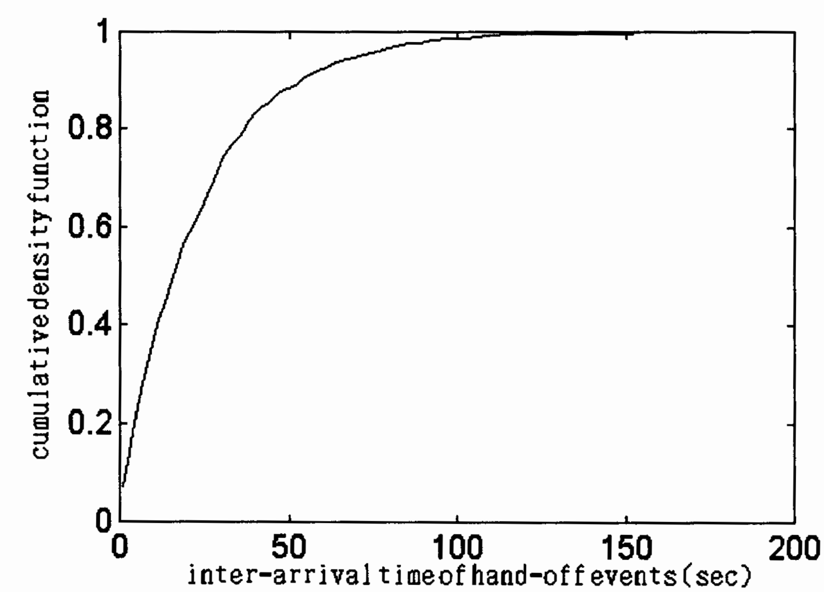

Fig. 12. The cumulative density function of the hand-off interval time to center cell.

Fig. 10 shows blocking and forced termination probabilities as functions of new call arrival rate. Since there is no channel quotas, the blocking probability is the same for each platform type. But because mean dwell times (mobility parameters) are different, there are differences in forced termination probabilities. We found that as C_h increases, forced termination probability decreases dramatically while blocking probability increases relatively slowly. This trade-off between blocking probability and forced termination probability matches the theoretical calculation results in [1] very well.

Fig. 11 shows the histogram of the inter-arrival time of hand-off events. In the simulation, the new call arrival is generated by input. Other processes such as hand-off arrival, hand-off departure, call blocking are generated from the dynamics of the simulation. We obtained the empirical probability density function of hand-off inter-arrival time from the histogram. Fig. 12 shows the cumulative density function of the hand-off interval time to the center cell, which is the integration of the probability density function.

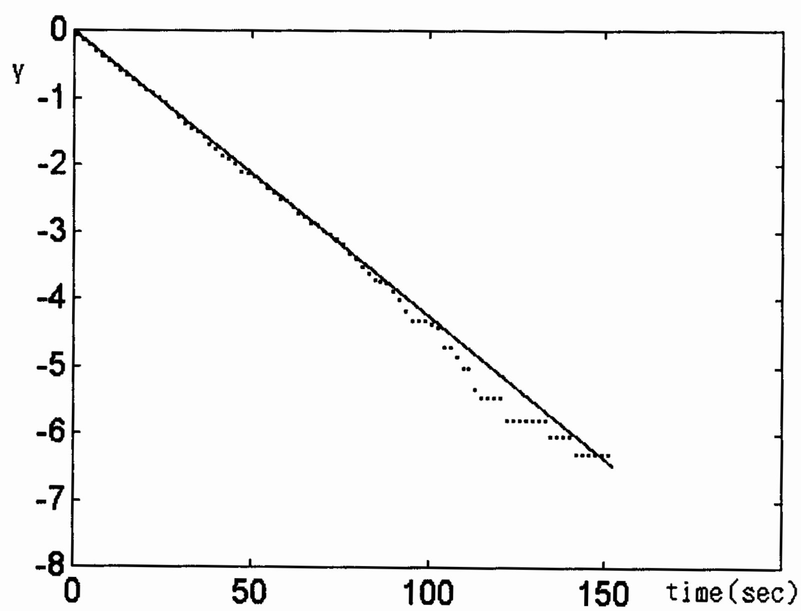

Fig. 13. Comparison of curve of $Y = -\Lambda_l t$ with the curve with the survival function of hand-off inter-arrival times in the center cell. Λ_l is the long term hand-off arrival rate to the center cell.

In [1] the hand-off arrival rate was assumed to be a Poisson process. For this process the survival function, i.e. the (1-cdf), is a negative exponential distribution having a parameter which is the hand-off arrival rate. So if we plot the survival function using a logarithmic ordinate, the result should be a straight line whose slope is the hand-off arrival rate. In Fig. 13 we plot both the curve of $Y = -\Lambda_l t$ and the logarithm of the survival function to compare them. Λ_l is the long term hand-off arrival rate to the center cell that was obtained from the simulation. We can see from Fig.13 that the logarithm of the survival function of inter-arrival time hand-off to the center cell is approximately a straight line, which validates the Poisson assumption. For abscissa values greater than 90 seconds there is some departure from the straight line, because such large inter-arrival time are rare events and the simulation time is limited (2×10^4 sec). If the simulation time is very large tending to infinity, then this part will also be approximately a straight line. We can infer that the analytical model put forth in [1] is applicable in this range of parameters and very useful in traffic performance analysis in this field.

6. Conclusion

In this paper, we consider the model presented in [1]. The simulation model is developed and a powerful discrete-time simulation tool SIMSCRIPT II.5 is used as the programming language to realize the simulation model. We discussed and summarized the simulation results to verify the model. The simulation results are in substantial agreement with theoretical predictions. We conclude that the analytical model in [1] is verified applicable in traffic performance analysis in the cellular system.

References

1. S. S. Rappaport, "Blocking, hand-off and traffic performance for cellular communication systems with mixed platforms", *IEE Proc-I,* Vol.140, No.5, pp.389-401, October 1993.
2. Edward C. Russell, "Building simulation models with SIMSCRIPT II.5", *CACI Product Company*, 1989.
3. D. Hong and S. S. Rappaport, "Traffic model and performance analysis for cellular mobile radiotelephone systems with prioritized and non-prioritized hand-off procedures," *IEEE Trans. Veh. Technol.*, vol. VT-35, pp. 77-92, Aug. 1986.

4. D. Hong and S. S. Rappaport, " Priority oriented channel access for cellular systems serving vehicular and portable radio telephones," *Proc. Inst. Elec. Eng.*, vol. 136, pt. I, no. 5, pp. 339-346, Oct. 1989.
5. S. S. Rappaport, "The multiple-call hand-off problem in high-capacity cellular communications systems," *IEEE Trans. Veh. Technol.*, vol. 40, no. 3, pp. 546-557, Aug. 1991.
6. S. S. Rappaport, " Models for call hand-off schemes in cellular communication networks," in *Third Generation Wireless Information Networks*, S. Nanda and D. J. Goodman, Eds. Boston: Kluwer, 1992, pp. 163-185.
7. S. S. Rappaport, "Modeling the hand-off problem in personal communications networks," in *Proc. IEEE Vehicular Technology Conf., VTC '91*, St. Louis, MO, May 1991, pp. 517-523.
8. C. Purzynski and S. S. Rappaport, "Traffic performance analysis for cellular communication systems with mixed platforms and queued hand-offs," in *Proc. IEEE Vehicular Technology Conf., VTC '93*, Secaucus, NJ, May 18-20, 1993, pp. 172-175.
9. S. S. Rappaport and L-R. Hu, "Microcellular communiction systems with hierarchical macrocell overlays: Traffic performance models and analysis," Proc. IEEE. Vol. 82, no. 9, pp. 1383-1397, Sept. 1994.
10. S. S. Rappaport and C. Purzynski, "Prioritized resource assignment for mobile cellular Communication systems with mixed services and platform types," *IEEE Trans. Veh. Technol.*, vol. 45, no. 3., Aug, 1996.