4-5 Limiting the Holding Time in Mobile Cellular Phone Systems During Disasters

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Call demand suddenly and greatly increases during major disasters, because people want to check on their families and friends in the stricken area. Many call attempts in mobile cellular systems are blocked due to the limited radio frequency resources. In this paper, as a solution to this problem, limiting the holding time of calls is investigated and a dynamic holding time limit (DHTL) method, which varies the holding time limit dynamically based on the number of call attempts, is proposed. The effect of limiting the holding time is investigated first using a computer simulation with a constant and heavy traffic load model. This simulation shows that the average holding time of calls is decreased as the holding time limit is reduced. But it also shows limiting the holding time decreases the number of calls blocked and forced call terminations at handover considerably. Next, a simple estimation method for the holding time limit, which reduces the blocking rate to the normal rate for increasing call demand, is described. Finally, results are given of a simulation, which show that the DHTL method keeps good performance for a sudden and great traffic load fluctuation condition.

Keywords
Holding time limit, Cellular phone, Emergency communications, Traffic congestion, Call blocking

1 Introduction

When a massive disaster occurs, people want to check on their families and friends in the stricken area. So, the traffic on communication systems increases suddenly and dramatically. In this situation, mobile cellular phones are very useful communication tools because of their portability. However, many calls are blocked because increasing the capacity of mobile systems is difficult due to limited radio-frequency resources.

There was a great earthquake in the Hanshin and Awaji areas of Japan on the early morning hours of January 17, 1995 (Magnitude 7.2)[1]. In this case, the desire for information regarding the earthquake sufferers was strong, and the call demand to the affected areas from the outside increased to about twenty times normal (regarding the peak call demand, fifty times normal)[2]. At that time, there were only about 4.3 million mobile subscribers in Japan, so the primary communication tool for most people was the fixed telephone. However, in the Japan of today, the number of mobile subscribers has reached about 86.14 million (Feb. 2005). In light of this, the mobile phone is expected to become the primary communication tool used by the general public, even in the event of a disaster. In fact, when an earthquake struck the offshore Miyagi prefecture on the evening of May 26, 2003 (magnitude 7.0), mobile cellular phone call demand in the three following hours was about thirty times greater than usual in and around the Miyagi prefecture[3], although its damage was not so large.

When call demand rises because of a

major disaster and many call blockings occur, a priority-number control method is often used. In this method, only terminals designated with priority numbers can have access to the system and the many other terminals cannot. By using this method, most terminals will be rendered unusable and mobile cellular service will be denied to the majority of affected users in the event of a disaster.

Therefore, in this paper, limiting the holding time of calls during a disaster is investigated. This action does not limit call access but it does limit the holding time of calls. When the holding time of a call reaches a limit, the call is forcibly terminated. Warning announcements before the forced termination is performed are included in this action. Such limiting by the system produces forced call terminations. However, it also allows many more people to have access to mobile services during a period of increased demand. A dynamic holding time limit (DHTL) method is proposed for sudden and great traffic load fluctuation situations that occur during disasters. This method varies the holding time limit dynamically based on the number of call attempts. Moreover, a simple estimation method for the holding time limit, which reduces the call blocking rate to the normal rate for increasing call demand, is presented.

In Sec. **2**, the DHTL method is proposed. In Sec. **3**, a simple estimation method for the holding time limit, which reduces the call blocking rate to the normal rate for increasing call demand, is described. In Sec. **4**, the basic effect of limiting the holding time is estimated through a simulation with a constant and heavy traffic model. In Sec. **5** the DHTL method performance is estimated through a simulation of a sudden and great traffic load fluctuation situation. Finally, the conclusion is given in Sec. **6**.

This paper focuses on traffic-channel capacity. The signal-channel capacity and the call switch's capacity to make call connections are assumed to be sufficient.

2 Dynamic holding time limit

This section explains the proposed DHTL method for limiting the holding time. Fig.1 shows an outline of the method. In this method, a call is forcibly terminated by the system when the holding time of a call reaches the holding time limit. Sudden forced terminations annoy the user. The DHTL method thus includes warnings of forced termination (for example, two announcements, one ten seconds and the other five seconds before the forced termination). The warnings also induce the user to summarize what they want to communicate and to keep the holding time short.

The holding time limit should be adjusted according to fluctuations in call demand (offered load). The offered load is the product of the number of call attempts during a unit of time and the mean of their holding time. The holding time of a blocked call cannot be measured. In a heavy traffic situation, there are many call blockings. So, the mean holding time is difficult to compute accurately and

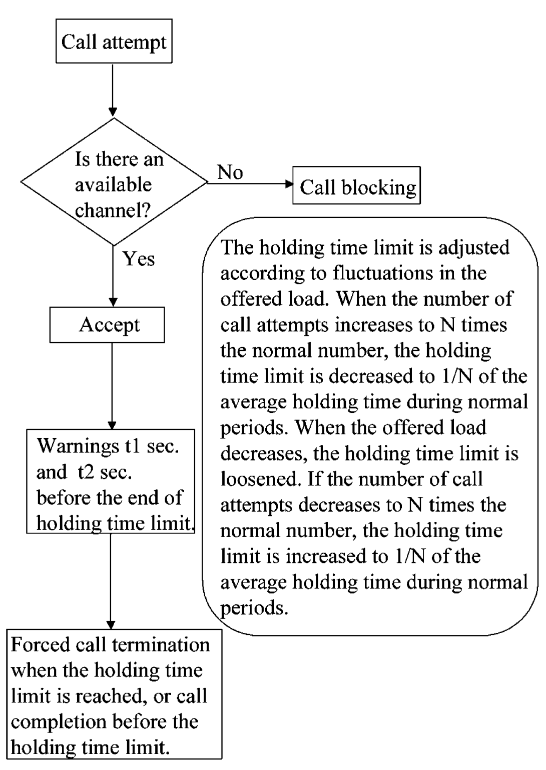

Fig.1 Outline of dynamic holding time limit method.

quickly. Thus, the proposed method uses the number of call attempts to estimate the volume of an offered load.

The number of call attempts is counted at a fixed interval. The result is used to determine the holding time limit in the next interval. The interval for counting should be adequate to the system in question. If this interval is too long, the DHTL method will not pursue offered load fluctuation well. On the other hand, if this interval is short, many counting processes are needed and some errors of the decision on traffic congestion will occur because of random call attempt.

When the number of call attempts reaches N times the normal number, the holding time limit is decreased to 1/N of the mean holding time for a normal offered load. N is a natural number. For example, if the number of call attempts triples, the holding time limit is decreased to 1/3 of the mean holding time for a normal offered load. Generally, the number of call attempts, the mean holding time, and the offered load vary according to the time of day, even on ordinary days. The DHTL method uses a particular case as a normal, which is used for the designing capacity of the system in question.

When a major disaster occurs, the increase in call demand is sudden and drastic. However, this call demand generally decreases gradually as time passes. For example, in the great Hanshin and Awaji earthquake, the call demand was about twenty times normal on January 17, 1995, the day the massive earthquake struck. The next day, however, the call demand decreased to about seven times normal[2]. Therefore, this method is designed to loosen the holding time limit as call demand decreases. If the number of call attempts decreases to double that of the normal call attempt situation, the holding time limit is increased to 1/2 of the mean holding time in the normal offered load condition.

3 Estimation method for holding time limit

This section describes a simple estimation method for holding time limit that reduces the call blocking rate to the normal rate when call demand is increased.

Assumptions are as follows.

- Call attempts are generated as a Poisson process.
- Call holding time is assumed to have an exponential distribution
- Mobile station does not move during the call.
- Increase of offered load means increase of the number of call attempts. Namely, holding time of each call does not vary.

Let α denote holding time limit and $1/\lambda$ denote the mean of the holding time in a normal call demand situation. As call holding time is assumed to have an exponential distribution, the mean of holding time h at α holding time limit is as follows,

$$h = \int_0^{\alpha} x\lambda e^{-\lambda x}dx + \int_{\alpha}^{\infty} \alpha\lambda e^{-\lambda x}dx$$
$$h = 1/\lambda\,(1 - e^{-\lambda\alpha}) \qquad (1)$$

From this, α holding time limit is calculated,

$$\alpha = -1/\lambda \log_e(1 - \lambda h) \qquad (2)$$

The offered load is the product of the number of call attempts during a unit of time and the mean of their holding time. If the number of call attempts increases to N times normal, the offered load becomes N times normal and the blocking rate is increased greatly. However, if the mean holding time is reduced to 1/N, the offered load is reduced to a normal volume and the blocking rate is returned to normal. Hence, when the number of call attempts is increased to N times normal during a disaster, we can restore the normal blocking rate by reducing the holding time limit α, which turns the mean holding time h to 1/N. The equation (2) can be used for the calculation of α.

If a mobile station moves and crosses a cell boundary, there is the possibility of a forced call termination at handover owing to the lack of an available channel in the new cell. Forced call termination at handover reduces the holding time of a call without limiting the holding time. This yields an error in the estimation of α by using equation (2). Thus, this estimation method is inaccurate in the case where many forced call terminations at handover occur.

4 Effect of limiting the holding time

In this section, the basic effect of limiting the holding time is estimated using a simulation with a constant and heavy traffic load situation.

4.1 Simulation model

The simulation model is as follows. The service area is modeled as a structure of square cells (Fig.2). The service area has 144 (12×12) cells and the ends of the service area are connected to each other in order to avoid edge effects[4]. The cells are all the same size and the length of a cell side is 1 km. Call attempts are generated as a Poisson process.

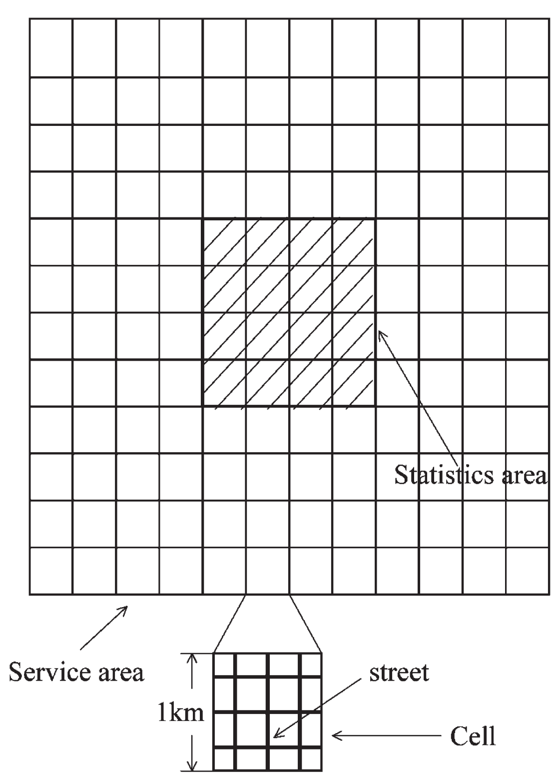

Fig.2 Service area model.

The number of a reuse cluster is 16 cells and the whole service area has 160 channels. There are various channel assignment strategies for call attempts in cellular systems[5]. For convenience, the fixed channel assignment strategy is adopted here. Thus, ten channels are assigned to each cell permanently. Every cell has six streets laid out in a lattice and mobile terminals only exist on these streets. The mobile terminals with calls move at speeds which are uniformly distributed between 0 and 20 km/h. The directions of the mobile terminals are set at random. The speeds and directions of mobile terminals do not change during their calls. Statistics are gathered from the 16 (4×4) cells at the center of the service area.

Call holding time is assumed to have an exponential distribution, with a mean of 120 seconds, when there is no holding time limitation. The basic offered load is assumed to be 5.6 erl/cell. This yields a blocking rate of about 3%. This value is often used for system capacity designing. Offered loads of 28 erl/cell (five times the basic offered load) and 56 erl/cell (ten times the basic offered load) are used for estimation.

Call blocking rate means the rate of new call attempts blocked because no free channel is available. This does not include forced call termination at handover. Forced call termination at handover occurs when a mobile terminal crosses a cell boundary and no channels are free in the new cell. In order to estimate the number of forced call termination at handover in the system, the forced call termination rate (FCTR) at handover is defined here. FCTR=NFCT/(NCA-NB), where NFCT is the number of forced call terminations at handover, NCA is the number of call attempts and NB is the number of blockings for call attempts. The FCTR at handover for the basic offered load was 0.9%.

As a first step of the estimation, it is needed to investigate the basic performance of limiting the holding time for a heavy traffic load situation during a large disaster. Therefore, in this simulation model, no fluctuation in call demand occurs, and offered load of each cell is even. It is also assumed that no call re-attempt is yielded by limiting the holding time.

4.2 Results and discussions

This section describes the results of the simulation and presents discussions.

4.2.1 Blocking rate

Figure 3 shows the relationship between the blocking rate for call attempts and the holding time limit. The blocking rate was very high because of a heavy offered load without the holding time being limited. The blocking rate was 59% for five times the basic offered load and 77% for ten times the basic offered load. However, the blocking rate decreased as the holding time limit was shortened. In particular, it decreased greatly as the holding time limit decreased below the mean holding time in normal offered load situation, 120 seconds in this simulation. A short holding time limit eliminates the long channel occupation and creates many free channels. Call attempts can use them. This is the reason for the decrease in the blocking rate. The blocking rate was 3% when the holding time limit for five times the basic offered load was 26.5 seconds, and for ten times the basic offered load it was 12.5 seconds.

4.2.2 Forced call termination at handover

Figure 4 shows the relationship between FCTR at handover and the holding time limit. The mobile velocity was assumed to be low. Therefore, handovers did not occur frequently. However, the FCTR at handover was very high, because of the heavy offered load. The FCTR at handover was 18% for five times the basic offered load and 23% for ten times the basic offered load. In the same way as the blocking rate, the FCTR at handover decreased as the holding time limit was shortened. One possible cause is that the short holding time limit makes many free channels available for handover calls as well as for call attempts. Another cause might be that the holding time limit reduces the holding time of calls and the number of handovers. For example, in the case of 56 erl/cell offered load, the number of handovers per cell decreased from about 570 to 415, when the holding time limit is reduced from 300 seconds to 26.5 seconds

If FCTR at handover is defined as NFCT/NH, where NH is the number of handovers, FCTR at handover is the same with

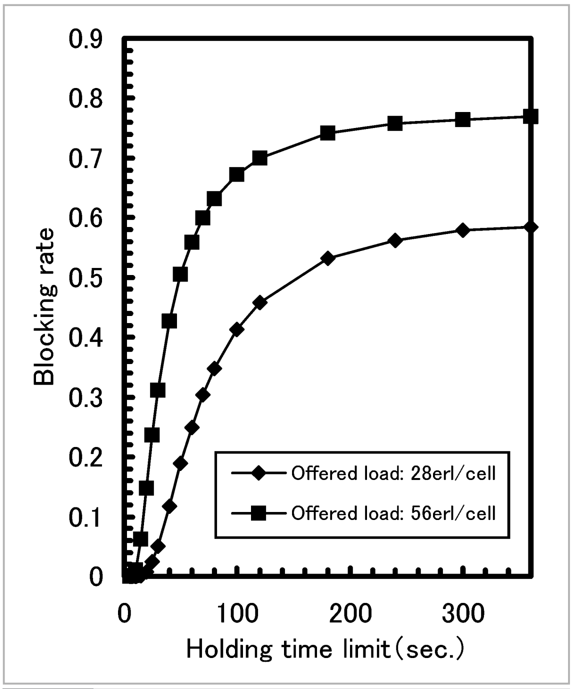

Fig.3 *Blocking rate vs. holding time limit.*

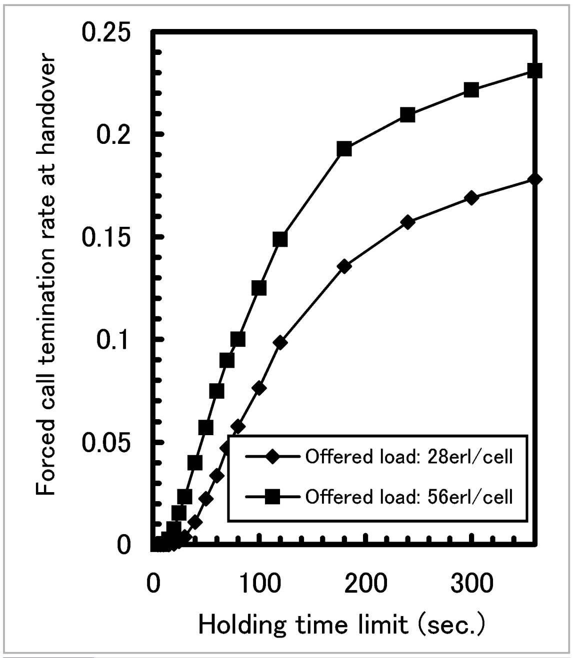

Fig.4 *Forced call termination rate at handover vs. holding time limit.*

the blocking rate for call attempts. This results from handover calls have not been given priority in this simulation. Handover calls are treated like new call attempts in the new cells.

4.2.3 Mean of holding time

The relationship between the mean holding time and the holding time limit is shown in Fig.5. The holding time of calls was decreased as the holding time limit was reduced. However, the mean holding time was 23.4 seconds for five times the basic offered load and 11.4 seconds for ten times the basic offered load, when the blocking rate was 3% and the normal holding time was 120 seconds.

A forced call termination at handover reduces the holding time of a call. The FCTR at handover for a 56erl/cell offered load was higher than that for a 28erl/cell offered load. Therefore, the mean holding time for a 56erl/cell offered load was a little shorter than that for a 28erl/cell offered load.

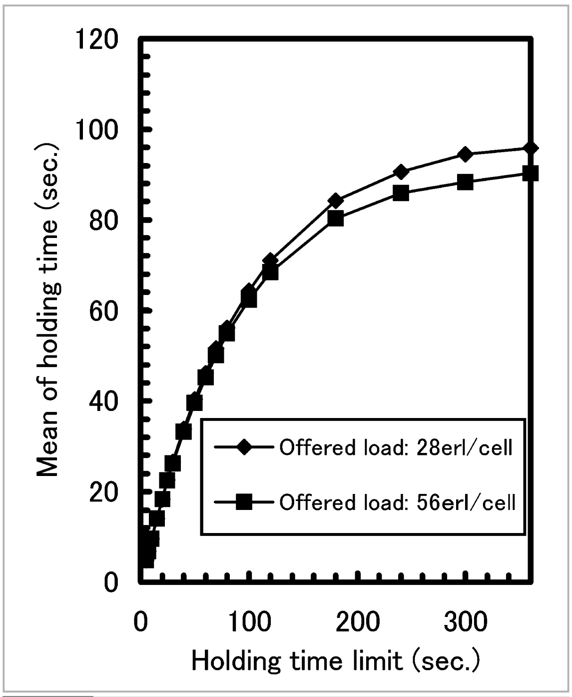

Fig.5 *Mean of holding time vs. holding time limit.*

4.2.4 Limited call rate

The limited call rate (LCR) is used here to estimate the performance for calls that are forcibly terminated by limiting the holding time. The LCR is defined as LCR = NLC / (NCA-NB), where NLC is the number of limited calls. Figure 6 shows the relationship between the LCR and the holding time limit. The LCR increases as the holding time limit is reduced. The LCR was about 30 and 80%, when the holding time limit was 120 and 25 seconds, respectively. Also, the LCR was 78% for five times the basic offered load and 88% for ten times the basic offered load, when the blocking rate was 3%.

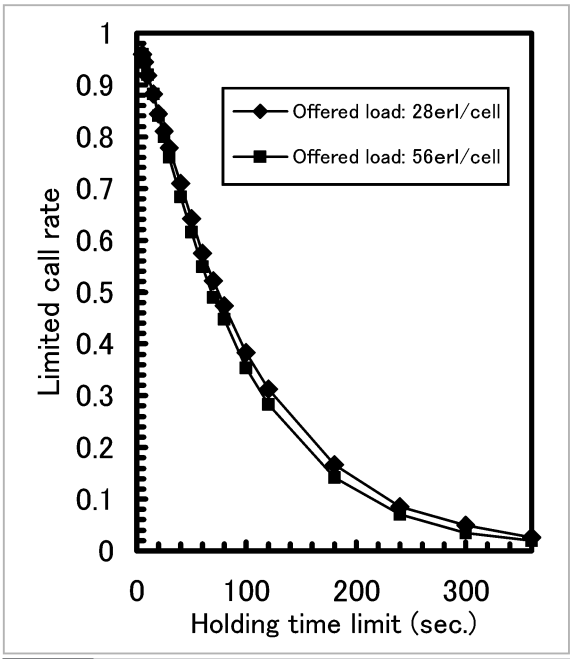

Fig.6 *Limited call rate vs. holding time limit.*

4.2.5 Characteristics with offered load

Figure 7 shows the relationship between the holding time limit and the offered load when the blocking rate was 3%. It also shows the relationship between the mean holding time and the offered load. As the offered load increases, the holding time limit must be reduced to keep the blocking rate at 3%. Thus, the mean of the holding time is reduced.

The mean of the holding time was a little shorter than the holding time limit when the offered load was low. It is considered that this resulted from some calls being voluntarily terminated before the holding time limit and forced call terminations at handover. When the offered load is high, the short holding time limit terminates almost all calls at the limit

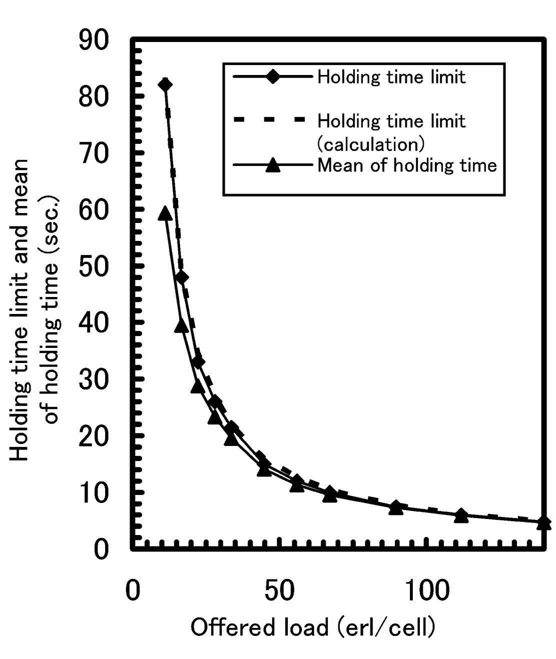

Fig.7 Holding time limit and mean of holding time vs. offered load. Blocking rate is 3%.

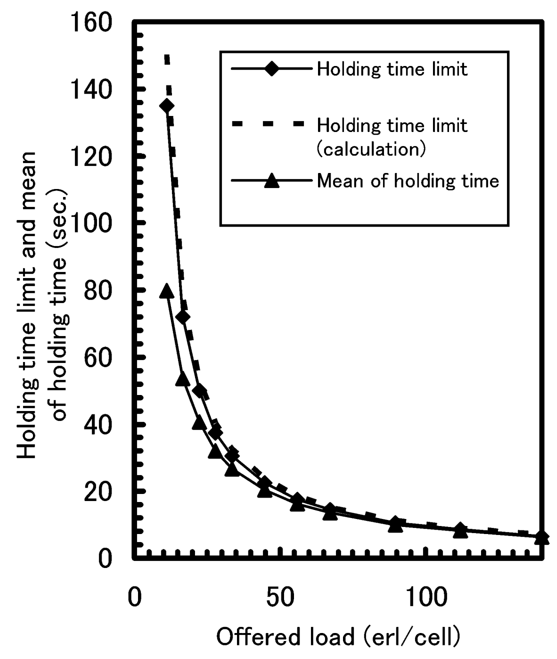

Fig.8 Holding time limit and mean of holding time vs. offered load. Blocking rate is 10%.

forcibly. Consequently, the mean of the holding time becomes almost the same with the holding time limit.

A thirty second holding time limit yielded a 3% blocking rate when the offered load was about 25erl/cell (about 4.5 times the basic offered load). Moreover, when the offered load was about 45erl/cell (about 8 times the basic offered load) and about 67erl/cell (about 12 times the basic offered load), we achieved a 3% blocking rate with 15 and 10 second holding time limits, respectively.

Figure 8 shows the results of the holding time limit and the mean holding time when the blocking rate was 10%. Characteristics were almost the same with the 3% call blocking case. When the offered load was about 34erl/cell (about 6.1 times the basic offered load), we obtained a situation where the blocking rate was 10% with a 30 second holding limit. Moreover, 15 and 10 second holding time limits yielded a 10% blocking rate, when offered load was about 63erl/cell (about 11.3 times the basic offered load) and about 90erl/cell (about 16.1 times the basic offered load), respectively.

The dotted lines in Figs.7 and 8 express the results of calculation using equation (2) when the mean of holding time in a normal situation $1/\lambda$ was120 seconds. In Fig.8, 8erl/cell was used as the basic offered load for the calculation, because this offered load yielded a 10% blocking rate in this simulation model without limiting the holding time. These results agreed well with the simulation results.

5 Performance for fluctuation of traffic load

This section describes estimating the performance of the DHTL method for sudden and drastic traffic load fluctuation using a simulation.

5.1 Traffic fluctuation model

This simulation model is the same model used in section **4.1**, but without the offered load model. Figure 9 shows the offered load model. The basic offered load is assumed to be 5.6 erl/cell and the maximum offered load is assumed to be 84 erl/cell. The fluctuation

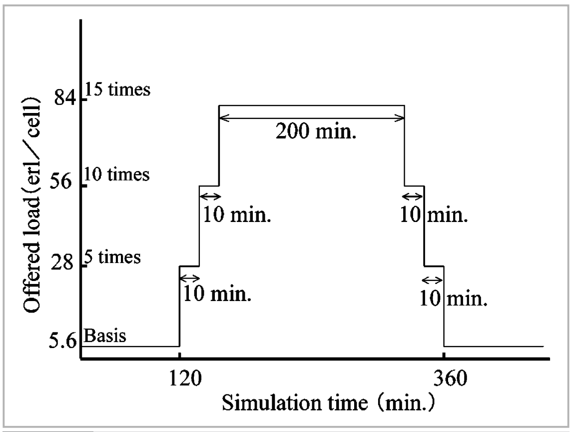

Fig.9 *Offered load fluctuation model.*

has three steps; 28, 56, and 84 erl/cell, which are 5, 10, and 15 times the basic offered load. It takes 20 minutes to fluctuate between the basic offered load and the maximum one. In this model, the offered load fluctuates, but the one each cell remains even. The interval for counting the number of call attempts, which is used for the DHTL method, is assumed to be 120 seconds.

A constant holding time limit (CHTL) method is used in order to express the flexibility of the DHTL method. The CHTL method uses the constant holding time limit, which is appropriate for a certain offered load, without considering traffic fluctuation. In this simulation, the appropriate blocking rate is set at 3%. The holding time limit of 26.5 and 12.5 seconds yielded a 3% call blocking rate, when the offered load was 28 and 56erl/cell. Thus, the CHTL method uses 26.5 and 12.5 seconds for the holding time limit from 120 minutes, when the offered load increased to 28 erl/cell, and 130 minutes, when the offered load increased to 56 erl/cell, to the end of simulation time, respectively.

5.2 Results and discussions

This section describes the results of the simulation and presents discussions.

Figure 10 shows the blocking rates in each time interval of the observation. When the offered load increased to 28 erl/cell (120-130 minutes) and 56 erl/cell (130-140 minutes), the CHTL method of 26.5 seconds and the CHTL method of 12.5 seconds had the lowest blocking rate. But the CHTL methods did not adapt to the offered load increase and yielded higher blocking rates for the increased offered load. When the offered load decreased, the CHTL methods did not loosen the holding time limit. Finally, the CHTL method of 12.5 second yielded no blocking, when the offered load was 28 erl/cell (350-360 minutes). This is an example of over limitation. On the contrary, the DHTL method adapted to the offered load fluctuation and adjusted the holding time limit appropriately. Therefore, the DHTL method had the lowest blocking rate for the entire simulation.

Figure 11 shows the FCTRs at handover in each time interval of the observation. The same characteristics for the blocking rate appeared. The DHTL method had the lowest FCTR at handover for the entire simulation.

Figure 12 shows the mean holding time in each time interval of the observation. The

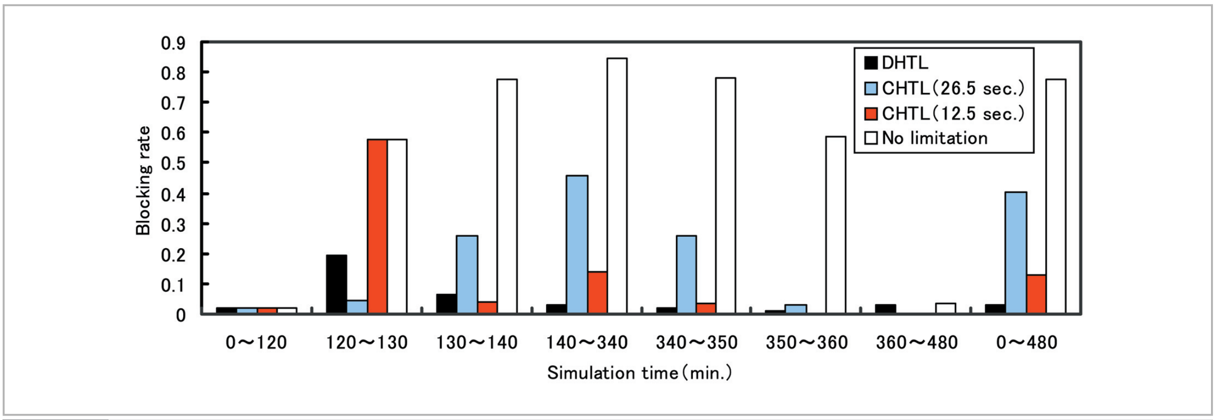

Fig.10 *Blocking rate vs. simulation time. Traffic fluctuation model.*

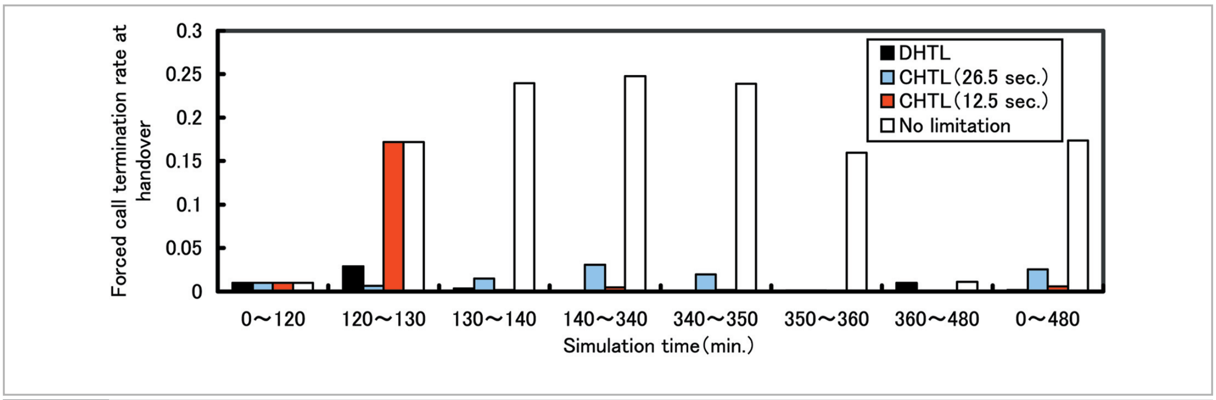

Fig.11 *Forced call termination rate at handover vs. simulation time. Traffic fluctuation model.*

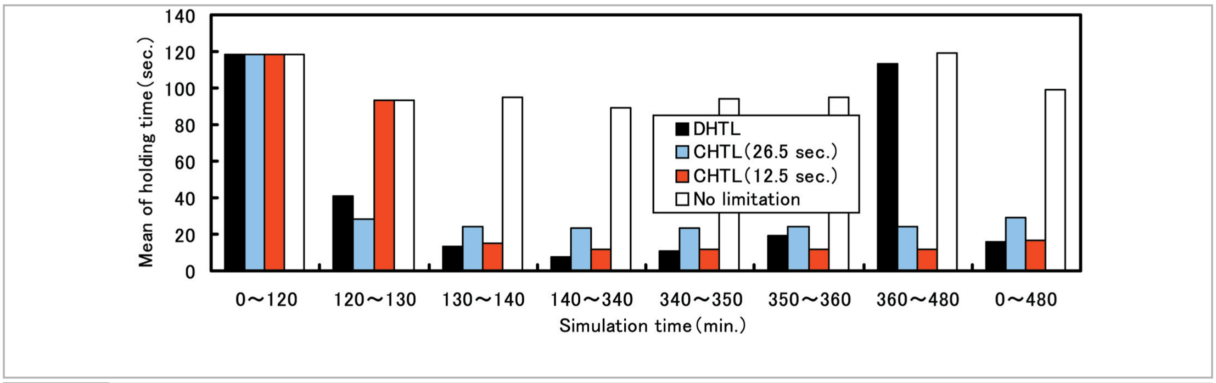

Fig.12 *Mean of holding time vs. simulation time. Traffic fluctuation model.*

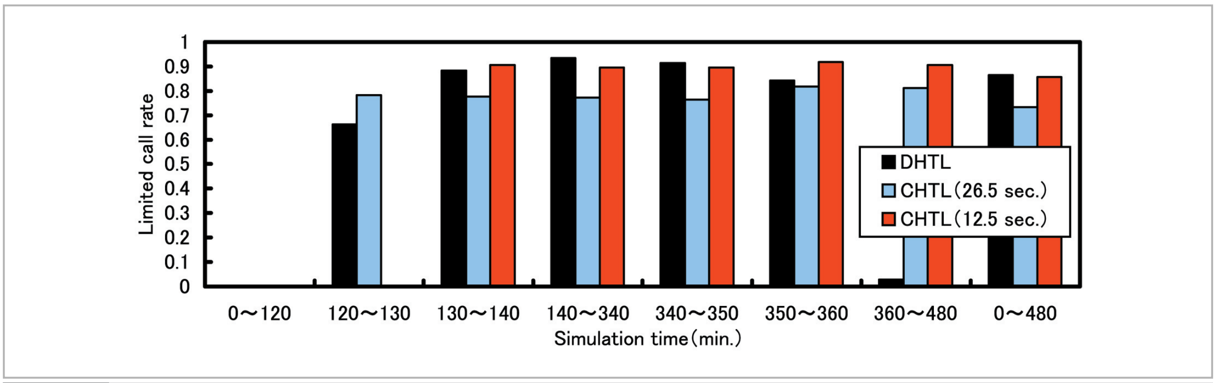

Fig.13 *Limited call rate vs. simulation time. Traffic fluctuation model.*

non-limited case had the longest time. However, it was reduced during a high offered load situation. This might have resulted from a lot of forced call terminations at handover. The mean holding time of the DHTL method became nearly the same as that of the CHTL method of 12.5 seconds for the entire simulation.

Figure 13 shows the limited call rates in each time interval of the observation. When the offered load decreased, the LCR of the CHTL method was not reduced because the holding time limit was constant. However, the LCR of the DHTL method was reduced. This resulted from the DHTL method adjusting the holding time limit in accordance with the offered load fluctuation. The LCR of the DHTL method became nearly the same as that of the CHTL method of 12.5 seconds for the entire simulation.

6 Conclusion

Limiting the holding time of calls to allow many people to have access to a mobile communication system during a period of increased call demand resulting from a major disaster, was investigated in this paper. A dynamic holding time limit (DHTL) method was proposed that varies the holding time limit dynamically based on the number of call attempts.

The effect of limiting the holding time was investigated using a computer simulation with a constant and heavy traffic model. Limiting the holding time can greatly reduce the call attempt blocking rate and the forced call termination rate at handover. The holding time was also reduced. However, even when limiting the holding time reduced the blocking rate to 3%, we gained 23.4 seconds of mean holding time at five times the basic offered load and 11.4 seconds of mean holding time at ten times the basic offered load, for the 120 seconds of the normal mean holding time.

A simple estimation method for the holding time limit, which reduces call blocking rate to the normal rate for increasing call demand, was also described. The calculation results obtained by using this method agreed well with the simulation results.

Finally, the performance of the proposed the DHTL method was estimated through a simulation with a sudden and great traffic fluctuation situation. The simulation showed that the DHTL method adapted to sudden and great traffic fluctuations and kept good performance.

The call demand during disasters is very strong. People will want to use some communication tools to ascertain the status of their families and friends or to let their condition or whereabouts be known to others. If mobile cellular terminals, which are usually on hand, could be used, it will be very useful, even if the holding time is short.

The following are future studies.

(1) Investigation of the signal-channel capacity and the call switch's capacity to make call connections and adaptation the DHTL method within those capacities.

(2) Influence of reattempted calls, which were terminated forcibly by limiting the holding time, and the effect of warnings of forced termination on system performance.

(3) Investigation of the appropriate interval for counting the number of call attempt in the DHTL method.

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Mobile communications, Emergency communications, Communications networks