Performance Study on Cooperative Dynamic Resource Control in the Satellite/Terrestrial Integrated Mobile Communication System

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This paper presents an overall performance study on cooperative dynamic resource control between satellite and terrestrial mobile phone system, in the Satellite/Terrestrial Integrated mobile Communication System (STICS), using the simulator developed in the STICS project, with the real situation of call demands and non-functional base stations in the Great East Japan Earthquake. It showed, although forced call terminations of general calls are needed, the STICS can satisfy almost all of priority call demands.

1 Introduction

The importance of the roles of mobile communication services in modern society has been steadily increasing. Especially, handling of mission critical use cases such as disaster prevention/disaster mitigation/safety measures is extremely important. When large-scale disasters such as an earthquake occur, the terrestrial mobile phone system often stops working because base stations stop functioning, the phone system gets congested as people want to make calls to check the safety of their family and friends, etc. On the other hand, communication satellites are less susceptible to terrestrial disasters, so they will be useful in ensuring important communications during large-scale disasters. In Term A of the research and development project of the Satellite/Terrestrial Integrated mobile Communication System (STICS)[1], the aim is to establish a dynamic integrated platform technology for frequency resources through coordinated control of the terrestrial mobile phone system and satellite mobile phone system, such as selecting a satellite channel when a terrestrial channel is not available, handing over to satellite channel if channel is not available when a terminal is handing over between terrestrial cells, etc. We are hopeful that STICS, which uses this technology, will play a role as communication infrastructure to ensure important communications even during large-scale disasters. Thus, as the overall evaluation of the coordinated control of in Term A in the STICS project, this paper contains the results of the evaluation of dynamic resource control, priority control and call admission control operations, which we obtained through the simulations conducted by modeling the communication traffic and base station non-functional state at the time of an actual large-scale disaster. We used actual communications traffic and the non-functional state of the base stations at the time of the Great East Japan Earthquake of March 11, 2011, which occurred due to the Tohoku Offshore Earthquake (9.0 moment magnitude (Mw)). The epicenter was on the ocean floor off the coast of Tohoku near Sendai City. The Great East Japan Earthquake had an extensive epicenter, and was the strongest measured earthquake to ever hit Japan or its surrounding areas. The focal region of the earthquake was wide (100,000 km^2), about 500 km long (north-south) and 200 km wide (east-west), stretching from off the coast of Iwate Prefecture to Ibaraki Prefecture. Also, the maximum seismic intensity was recorded at 7 in Kurihara City in Miyagi Prefecture.

In order to conduct a full-fledged performance evaluation of STICS during coordinated control operations, a “terrestrial/satellite coordinated control comprehensive simulator” with the functions of “simulating traffic” and “simulating dynamic control” was developed for the first time in this project. “Satellite/terrestrial integrated mobile terminal,” “terrestrial base station,” “base station control station,” “STICS satellite,” “satellite gateway station,” and “network dynamic control device” were the components of this simulator. However, since the simulations are done on a single computer, there were limits on the processing speed and settings scale of the simulation model, due to computer hardware and other reasons. Also, the transmission of the actual control signals between components was not simulated. Hence, it was not possible to evaluate the characteristics in case STICS is put to practical use.

Therefore, as a simulation system that can simulate closer to the actual conditions, the “terrestrial/satellite comprehensive network monitoring management device” was developed with functions for decentralizing function-wise, traffic processing based on actual usage, and transmitting control signals and communication signals etc. for implementing call control such as handover control between cells. This device contains functions that can simulate the characteristic evaluation of coordinated control of the comprehensive resources of dynamic resource control, priority control, and call admission control including the seamless migration from a normal situation to situations of large-scale disasters. Moreover, since during large-scale disasters such as earthquakes there is massive traffic, in the simulation of traffic it was possible to scale up the execution of the simulation by having a process for reducing the discretization errors of time interval in simulations and a process for consolidating the terminal calls. This paper describes a comprehensive evaluation of a STICS based on coordinated control technology, conducted by using this device and a simulation model that simulated the environment of the Great East Japan Earthquake that occurred on March 11, 2011, and clarifies its usefulness and issues.

The subsequent contents of this paper are as follows. Section **2** outlines the “terrestrial/satellite coordinated control comprehensive simulator” and evaluations done using this simulator, and also a summary of the functions of the “terrestrial/satellite comprehensive network monitoring management device” which is the simulation system used in the comprehensive evaluation. It also describes the processes that enable scaling up of simulation, i.e. the process for reducing the discretization errors of time interval in simulations, and consolidation of terminal call processes. Section **3** describes the model that simulated the Great East Japan Earthquake. Section **4** describes the simulation evaluation results. Section **5** is the conclusion.

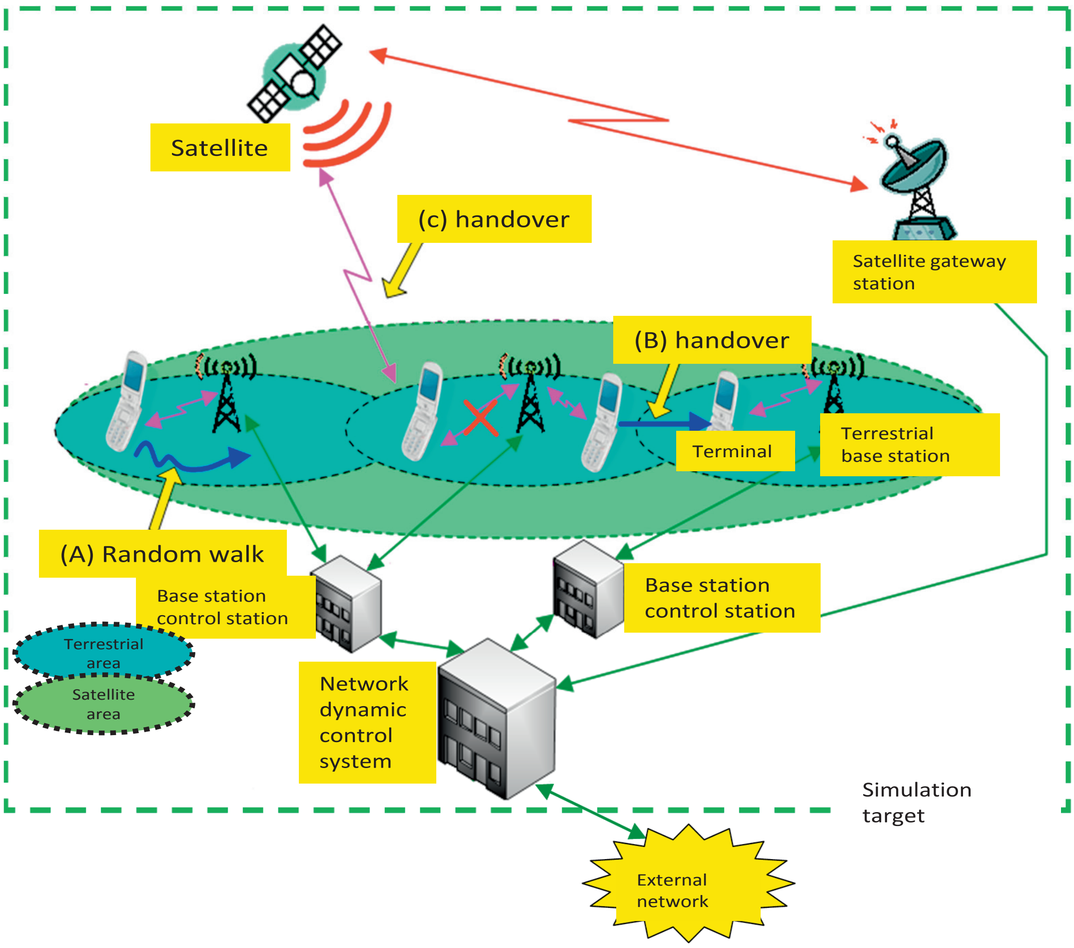


Fig. 1 Terrestrial/satellite coordinated control comprehensive simulator model

2 Terrestrial/satellite comprehensive network monitoring management device

2.1 Summary of terrestrial/satellite coordinated control comprehensive simulator and its evaluation

Here, we describe the terrestrial/satellite coordinated control comprehensive simulator developed for the first time in the STICS project, and the summary of results of the evaluation of coordinated control which were conducted using this simulator. This simulator has the functions of “simulating traffic” and “simulating dynamic control.” As shown in Fig. 1, “satellite/terrestrial integrated mobile terminal”, “terrestrial base station”, “base station control station”, “STICS satellite”, “satellite gateway station”, and “network dynamic control device” are the components of this simulator. This terrestrial/satellite coordinated control comprehensive simulator has mainly three functions for simulating controls. The three functions are: a random walk traffic generation control function that manages the movement control of user terminals, a dynamic control function that manages the dynamic traffic fluctuations, and a priority terminals control function that manages the priority control of calls.

First, in the random walk traffic generation control function, the simulator generates traffic that may be generated when the terminal moves in accordance with the random walk mobility model while using the communication service. Random walk is a fundamental model which is widely used in many fields, such as modeling of physical phenomenon like Brownian motion, in the finance domain for mathematical modeling for fluctuations in share prices, and also in mobile modeling of mobile communications users.

Using this model, user movements were simulated and traffic generated. The results confirmed that the traffic at the time of an actual earthquake can be roughly simulated.

Next, in the dynamic control function, for the traffic fluctuations generated by the abovementioned random walk traffic generation function, the simulator provides functions that simulate the frequency sharing between the terrestrial system and satellite system, by dynamically allocating and controlling the resources. To handle sudden fluctuations in traffic during disasters, an efficient communication resource control including prediction is required, so as to maximize the communication opportunities and minimize the communication quality deterioration. In STICS, as elements for expressing the dynamic characteristics of traffic, three indices are defined: information of the channel usage status (usage ratio), time series information of the used channel (channel usage changing rate), as well as information on global difference between frequency allocation and actual traffic (detection of abnormal channel allocation). Based on these indices, we studied conducting optimizing control of communication resources[2][3]. Then, using this stimulator, we did coordinated control of the abovementioned frequency resources based on the usage ratio and change rate. Dynamic control of satellite channels was done, and it was confirmed that compared to the case when it was not done, the number of calls lost improved by approximately 5%.

Moreover, in the priority terminals control function, the simulator provides simulation functions that enable call processing of terminals with high priority, such as emergency calls, in accordance with specific policies. In general, mobile phone systems have developed commercial services globally in accordance with the standard specifications of the 3rd Generation Partnership Project (3GPP), which is an international standardization body. An overview of the standardization status for priority call handling and call admission controls in 3GPP shows that until now, priority calls such as emergency calls were basically not under any restrictions. The restrictions were broadly divided into 3 categories: all calls restrictions, international call admission controls, and call admission controls not including home networks. Restricted services were vendor dependent[4]. But recently, as an important topic, there has been renewed awareness about ensuring important communications, and as a new priority control service for calls, the enhanced Multi-Level Precedence and Preemption service (eMLPP) is being studied and standardized[5]. This eMLPP stipulates allocating priority for calls, and also preempting high priority order calls and services for connecting forcibly. This service also includes mandatory controls, but it has still not reached the stage where it can be put to practical use. However, taking into consideration the importance of prioritizing and ensuring emergency calls, especially during disasters, we thought that we should also consider incorporating mandatory control in STICS. In the terrestrial/satellite coordinated control comprehensive simulator, by defining the priority order control policy to conduct priority control of calls, and performing simulations, we confirmed that the priority control function can also be implemented in STICS.

Then, finally by using the terrestrial/satellite coordinated control comprehensive simulator, we confirmed that when terrestrial systems are congested during disasters, etc., in order to handle users' emergency call requests, STICS can smoothly hand over from terrestrial systems to satellite systems, and reduce congestion during disasters, etc.

2.2 Configuration of terrestrial/satellite comprehensive network monitoring management device

The terrestrial/satellite coordinated control comprehensive simulator performs the simulation using a single computer, so large-scale simulations are not possible, and the areas to be simulated are limited. Also, it could not simulate transmission of control signal/communication signals, etc. for implementing handover control, etc. Accordingly, we made improvements to make it more similar to the actual traffic at the time of a disaster, by consolidating the terminal call processes, and by having a process for reducing the discretization errors of time interval in simulations in the simulation of traffic.

Moreover, as a simulation system more similar to actual conditions, the terrestrial/satellite comprehensive network monitoring management system was developed, with functions for distributing components by each function, traffic processing based on actual usage, and actually transmitting control signal/communication signals, etc. for implementing call control such as handover control between cells. This system also has coordinated control functions such as dynamic control, priority control, and call admission control, including seamless migration from a normal situation to situations of large-scale disasters.

Figure 2 shows the configuration of the terrestrial/satellite comprehensive network monitoring management system. By distributing the respective functions to the "comprehensive monitoring management simulator" that simulates network dynamic control systems, base station control stations and terrestrial base stations, and the "terrestrial/satellite feeder link station simulator" that simulates satellite stations and satellite gateway stations, and the "actual communication terminal devices" that simulates the terminals, each equipment conducts cooperative operations depending on the status of the terrestrial station and the

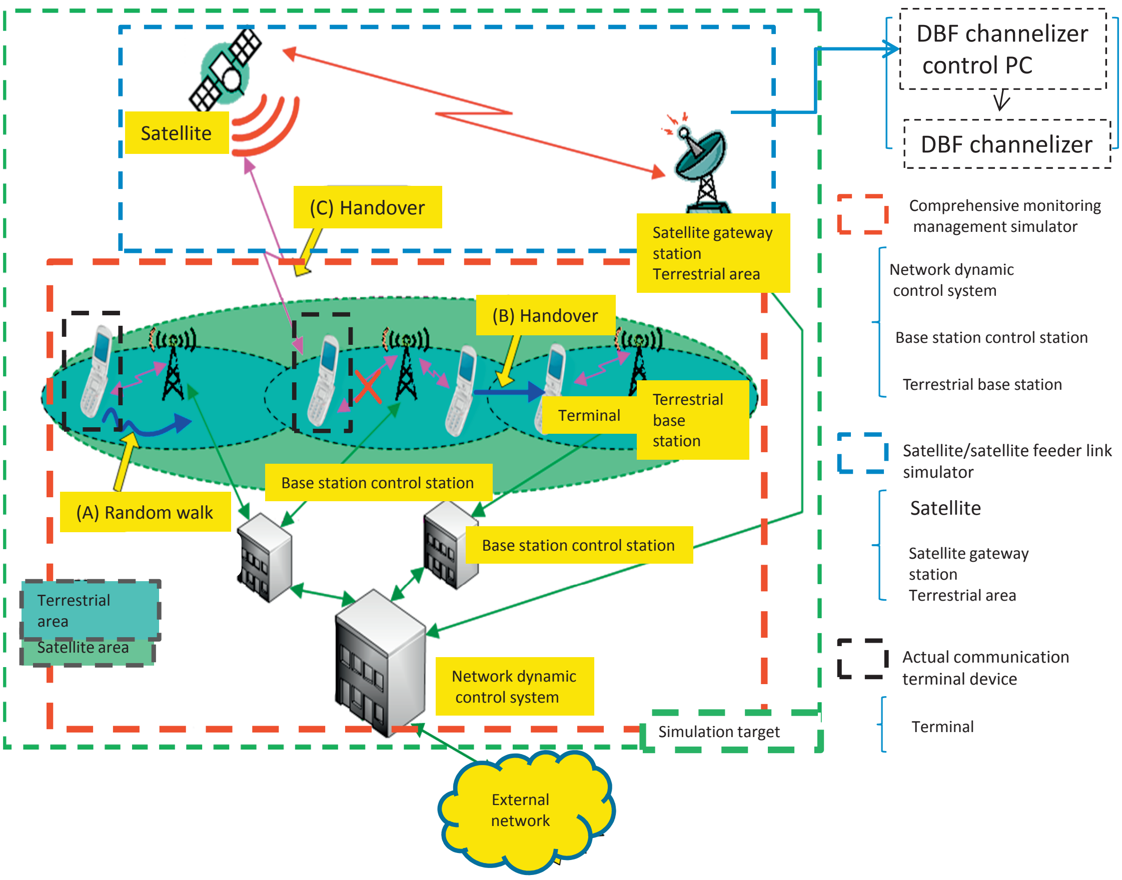


Fig. 2 Configuration of terrestrial/satellite link comprehensive network monitoring management device

satellite station, for attending to the calls from the terminals. Thus, a system was built where the call control operations could actually be processed. As a satellite mounting technology for implementing optimum resource allocation by frequency sharing, satellite channelizer/digital beam forming (DBF) was developed, composed of super multibeam formation (100 or more beams) with feeder unit of 16 or more elements. We decided to have the satellite/satellite feeder link station simulator play the role of the interface with the DBF channelizer. Then, depending on the status of traffic, the resource settings commands are sent for the DBF channelizer, in accordance with the satellite resource dynamic control algorithm.

2.3 Function summary

This section outlines the call control cooperative operation functions of the terrestrial/satellite comprehensive network monitoring management system, satellite resource dynamic control functions by the DBF channelizer, and processing functions for large-scale simulations.

2.3.1 Call control and priority call control operation functions

For calls from the actual communication terminal device, based on the results of the traffic simulations, dynamic call control is done depending on the channels usage status of the terrestrial base stations/satellite stations.

The call process flow is shown below.

(1) When the actual communication terminal device is within the terrestrial base station area, the actual communication terminal will make the call request to the terrestrial base station. The call will be successful if a channel of the terrestrial base station is available.

(2) When a channel is not available to that terrestrial base station, the terrestrial base station will reject the connection of the call.

(3) When the connection is rejected or the actual communication device is not within a terrestrial base station area, the actual communication terminal will make the call request to a satellite station. The call will be successful if a channel to the satellite station is available.

(4) When a channel is not available to the satellite station and if the actual communication terminal is a general terminal, it will reject the connection and the call will be unsuccessful. If the actual communication terminal is a priority terminal, a general terminal's call is disconnected and the call will be successful.

(5) After the call connection is established, the terrestrial base station/satellite station achieves voice communication by transferring the voice signals from the actual communication terminal through the path of the call connection.

(6) When an actual communication terminal is currently in a call via a terrestrial base station, then is moved outside the terrestrial base station area, the call connection is to be maintained by handover to the satellite station.

These processes make it possible to dynamically switch the path of the actual voice communication.

The priority terminals are used for emergency communications during disasters in government organizations and in public agencies such as fire stations, etc. The priority terminals do not come under the admission restrictions by each carrier, and probably, priority terminals were also used for emergency communications during the Great East Japan Earthquake. In simulating the traffic conditions during a disaster, we thought that priority terminals must also be simulated, and decided to add priority terminal functions to the simulator.

In the priority control operations of the simulator, the following operations can be selected at the time of simulation.

(1) To connect the call of a priority terminal, the terrestrial station forcibly disconnects a connected general terminal when the capacity limit is reached, and receives the call from the priority terminal.

(2) To connect the call of a priority terminal, when the capacity of the terrestrial system has reached the upper limit, the terrestrial station forcibly hands over a connected general terminal to the satellite station, and connects the priority terminal to the terrestrial station.

(3) Try to connect the call of a priority terminal to the satellite station. At this time, when the satellite station has reached the capacity limit, the call of the priority terminal will be rejected (call loss).

(4) Try to connect the call of a priority terminal to the satellite station. At this time, when the satellite station has reached the capacity limit, a general terminal which is connected to the satellite station will be forcibly disconnected, and the call from the priority terminal will be received.

2.3.2 Satellite resource dynamic control functions by DBF channelizer

Figure 3 shows the algorithm of satellite resource dynamic control. The usage ratio and the change rate (increased volume of satellite calls in unit of time) of the satellite station are monitored, and the usage ratio of the satellite station in several minutes is predicted. Satellite system capacity is controlled (increased/decreased) by determining the predicted value threshold. The satellite resource control is carried out in the simulation in accordance with this algorithm. It can be demonstrated that resource settings commands are sent for the actual DBF channelizer in the satellite resource control (increase/decrease) timing via the DBF channelizer control PC from the satellite gateway station, and operating the DBF channelizer, dynamic control is actually possible.

2.3.3 Processing functions for large-scale simulations

During disasters, there is a sudden increase in call traffic as people want to make calls to confirm the safety of family and friends. In order to implement a large-scale simulation which can handle such traffic, we implemented a process for reducing the discretization errors of time interval in simulations, and a process for consolidating terminal calls.

2.3.3.1 Process for reducing the discretization errors of time interval in simulations

The time interval in simulation is in unit of minutes, and the minimum time interval is one minute. The call holding time is usually in accordance with the exponential distribution of 120 seconds on average. Whereas, if the minimum time interval is one minute, 120 seconds is 2 minutes, so the simulation's resolution will be coarse. The call holding time calculated from the exponential distribution is rounded up in unit of time interval in simulation, resulting in the red line in Fig. 4 that shows the distribution of the call holding time of the stimulator, and only in the parts protruding from the exponential distribution graph, excess call volume is recorded.

Very precise resolution is achieved with a time interval in simulation of one second. However, it becomes difficult to simulate over a long period of time due to constraints (data amount, memory usage, calculation time, etc.) of the computer.

The protruding parts in the index distribution graph represent the error factor, so, in order to offset the errors, after calculating the call holding time of each terminal on the basis of the exponential distribution, the process for reducing half of the time of the time interval in simulation from the call holding time was added.

As seen in Fig. 5, for the call holding time, the distribution is centered on the exponential distribution graph, and hence errors of time interval in simulation discretization can be absorbed. But for terminals with call holding time

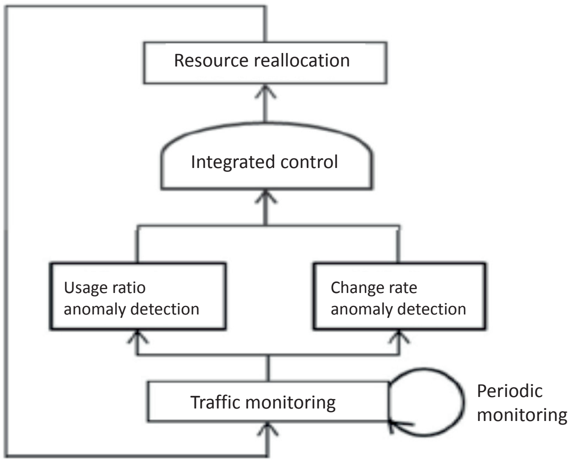


Fig. 3 Satellite resource dynamic control algorithm

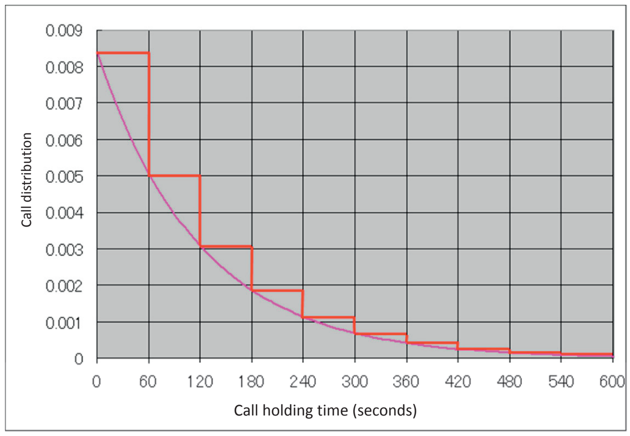


Fig. 4 Distribution of call holding time and discretization errors

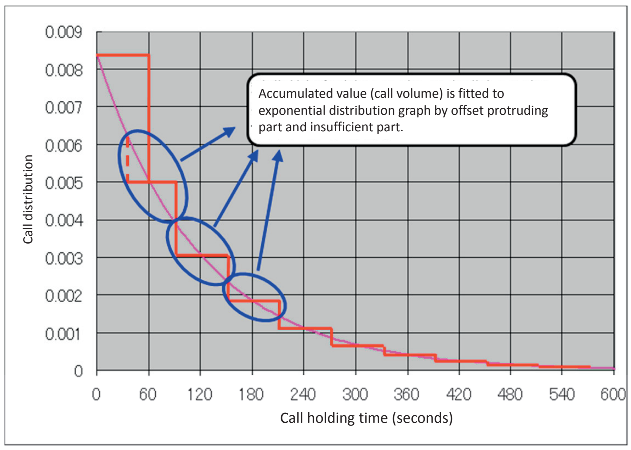


Fig. 5 Simulator call holding time distribution

less than the time interval in simulation, the call holding time becomes 0 or less seconds which cannot be simply corrected and errors will occur. Consequently, we verified the validity of this process for scaling up simulations.

Figure 6 shows the model used for verifying validity. Simulation is done by deploying the terminals in 1 terrestrial cell, and the call loss ratio is calculated from the actual number of terminals calling and terminals making unsuccessful calls, and what is obtained by multiplying 120 seconds which is the average call holding time by the actual number of terminals calling is taken as the call volume, and is compared with the call loss ratio which was obtained using the Erlang B formula. At the beginning of a simulation, there would be special conditions such as a small number of calls, and mostly free channels, and hence simulation observations must be done excluding these conditions. And so, in this verification, the simulation is done for 3,600 seconds, starting 120 seconds after the first failed call (call loss).

Table 1 shows the results of the verification. When the time interval in simulation is 60 seconds, the call loss ratio increased by approximately 2% to 5% compared to the call loss ratio obtained by the Erlang B formula. It was confirmed that the call loss ratio almost matches the call loss ratio obtained by the Erlang B formula in the case of other simulation intervals. Therefore, if the time interval in simulation is 30 seconds or less, it seems that valid simulation results can be obtained. In the simulation model described in the next section, for better precision the time interval in simulation is taken as 10 seconds instead of 30 seconds.

2.3.3.2 Consolidation of terminal call process

Scaling up the simulation leads to an enormous increase in the number of terminals in the area. As a result, it becomes difficult to simulate over a long period of time due to the constraints (data amount, memory usage, calculation time, etc.) of the computer. And so, we decided to lighten the simulation by regarding multiple terminals as one terminal. In calculating the number of terminals calling by Poisson distribution, fractions are generated because the number of calls is determined in units of 1 terminal. If the fractions are rounded down, the number of calls falls and the call volume decreases more than expected. If the fractions are rounded up, the number of calls increases. So we decided to equally retain the overall call volume by adjusting the average call holding time.

An example is shown below.

Assuming the average call holding time is T seconds, and the number of terminals calling is 55, then the call volume will be

$55 \times T = 55T$

When the number of consolidated terminals is 10, if the fraction is rounded up, and the number of terminals becomes 60

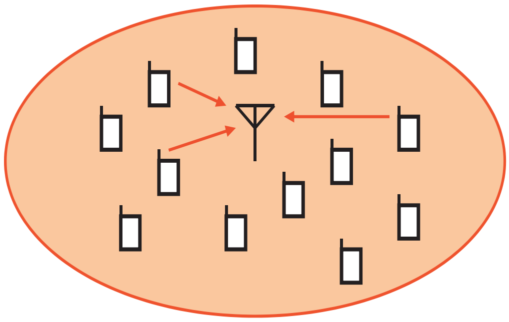
$60 \times T = 60T$

The call volume is maintained by shortening the average call holding time, depending on the (actual number of terminals calling)/(number of terminals calling after consolidation).

$60 \times T \times 55/60 = 55T$

As a result of this process, calls and call terminations occur in unit of the consolidation number, so as shown in the graph after consolidation in Fig. 7, the number of communicating terminals is observed in lumps. Therefore, assuming that the data of consolidation number 1 is correct, the percentage of data included in the range of number of communication terminals ± X% was evaluated, and its validity was confirmed.

Figure 8 shows the verification evaluation model of the consolidation of the terminal call process. Simulation is done by deploying the terminals in 1 terrestrial cell, and each consolidation number is changed and the confidence interval of the data of the number of communicating terminals is evaluated. (Assuming that the data of consolidation number 1 is correct, the percentage of data included in the range of the number of calls accepted ± X%, shall



Terrestrial cell	1 Cell (all terminals are in the cell)
Base station volume	3 ways: 100, 200, 300 channels
No. of terminals	3,000
Average number of terminals calling	2 ways: 180,300 terminals per 60 seconds
Average call holding time	120 seconds
Simulation period	3,600 seconds
Time interval in simulation	5 ways: 60, 30, 10, 5, 1 seconds

Fig. 6 Evaluation model of process for reducing the discretization errors of time interval in simulation

Table 1 Verification results of the evaluation of the process for reducing discretization errors of time interval in simulation

Base station volume	Average no. of terminals calling (stationary)	Time interval in simulation	No. of terminals calling (stationary)	No. of terminals call losses (stationary)	Call loss ratio	Erlang B call loss ratio
100	180	60	10334	7642	73.95007	72.53
		30	10092	7235	71.69045	71.87
		10	10256	7347	71.63612	72.16
		5	9890	6993	70.70779	71.26
		1	10027	7180	71.60666	71.53
	300	60	17235	14621	84.83319	83.5
		30	17079	14242	83.38896	83.2
		10	16770	13838	82.5164	82.89
		5	16823	14016	83.31451	82.9
		1	16839	13947	82.82558	82.93
200	180	60	9917	4711	47.50429	43.89
		30	9664	4092	42.34272	42.44
		10	9569	3806	39.77427	41.71
		5	9396	3749	39.89996	40.65
		1	9682	3978	41.08655	42.29
	300	60	16630	11338	68.17799	65.81
		30	16498	10909	66.12317	65.54
		10	15982	10198	63.80929	64.43
		5	16088	10226	63.5629	64.61
		1	15859	10219	64.4366	64.07
300	180	60	9400	1893	20.1383	15.28
		30	8859	1008	11.37826	11.43
		10	8814	871	9.882006	11.04
		5	8881	921	10.37045	11.27
		1	8590	786	9.150175	9.02
	300	60	16127	8190	50.7844	48.1
		30	16015	7604	47.48049	47.28
		10	15355	6826	44.45458	45.19
		5	15220	6602	43.37714	44.63
		1	15116	6656	44.03281	44.31

be evaluated.)

Figures 9 and 10 show examples of the consolidation verification evaluation result of terminal calls. Figures 11 and 12 show the confidence interval calculation results. In Figures 11 and 12, the horizontal axis shows the error range from the true value, and the vertical axis shows the proportion of the data included in that range.

It can be confirmed that if the consolidation number is less than half of the average number of terminals calling, then approximately 90% of the data is included in the ± 10% range. Therefore, by taking a rough estimate of the average number of terminals calling, if its consolidation number is less than half of that estimate, then it seems that valid simulation results can be obtained to a certain extent. Based on this result, settings of the simulation model were configured.

3 Simulation scenario that simulated the Great East Japan Earthquake

With the process for reducing the discretization errors of time interval in simulations, and the process for consolidating terminal calls, which are mentioned in the previous section, it has become possible to execute large-scale simulations. And so, in order to ascertain the usefulness and issues of STICS, an environment more similar to the Great East Japan Earthquake is simulated. Also, in congested situations such as this simulated version of a large-scale disaster, we confirm the ability to operate the call control of actual communication terminals and also that voice communication can be performed by dynamically switching between terrestrial and satellite.

3.1 Summary of simulation scenario

Table 2 shows the various types of reference data which served as the basis for the parameters of the settings for the simulation scenario in which the Great East Japan Earthquake was simulated. Also, unclear parameters were assumed and settings were configured. Table 3 shows the summary of the scenario settings parameters.

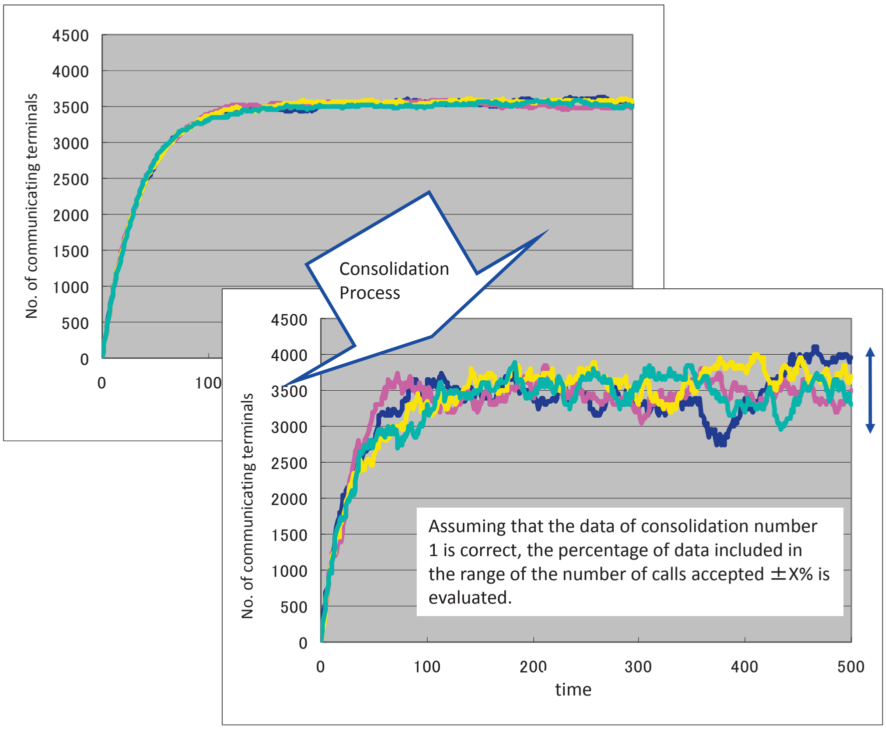


Fig. 7 Effect of consolidation process

3.2 Simulation area

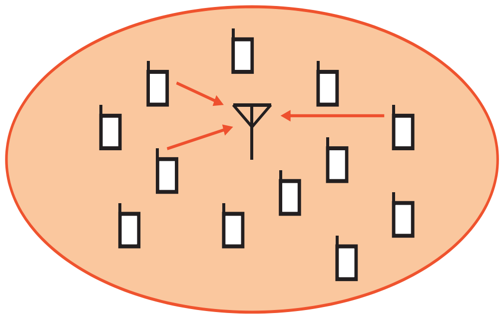
Figure 13 shows the simulation area, using a simulator screen.

In order for the simulation area to be proportional to the population density, and for reducing the calculation load, the population of nearby neighborhoods is distributed on four 2D meshes and is considered as a single area. Then, assuming that the Great East Japan Earthquake covered a total of 28 areas, we ran simulations of Kurihara City which recorded the maximum seismic intensity as well as its surrounding areas and of the coastline which was heavy damaged by the tsunami.

3.3 Call status, simulation period, call admission controls

In order to simulate the calling situation during the Great East Japan Earthquake, calls were made by referring to “Voice traffic conditions in the Tohoku region” from data ③. There is a sudden increase in the number of calls after large-scale disasters such as earthquakes. Typically, call admission controls are applied to protect the system, and after the passing of peak time, the calls reduce. The traffic conditions from data ③ are also like this. The earthquake struck at 14:46, and the number of calls peaked between roughly 15:00 and 16:00. Even though 80% call admission controls were applied, the number of calls was 12.6 times the calls made normally. Later, the number of calls reduced, and were even less than normal day time calls. Also, the next day at 02:00, all call admission controls were released.

Hence, this simulation period was set from 14:00 March 11 (before the earthquake hit) until 02:00 March 12 (when call admission controls were released). We decided to start the call admission controls on March 11 at 15:00, and set the call admission control ratio at 80%, and the time interval in simulation at 10 seconds.



Terrestrial cell	**1 cell (All terminals are in the cell)**
Base station capacity	5,000 channels
No. of terminals	5,000
Average number of terminals calling	2 ways: 100 or 10.5 terminals per second
Average call time	120 seconds
Simulation period	500 seconds
Time interval in simulation	1 second
Consolidation number	6 ways: 100, 50, 20, 10, 5, 1

Fig. 8 Consolidation verification evaluation model of terminal calls

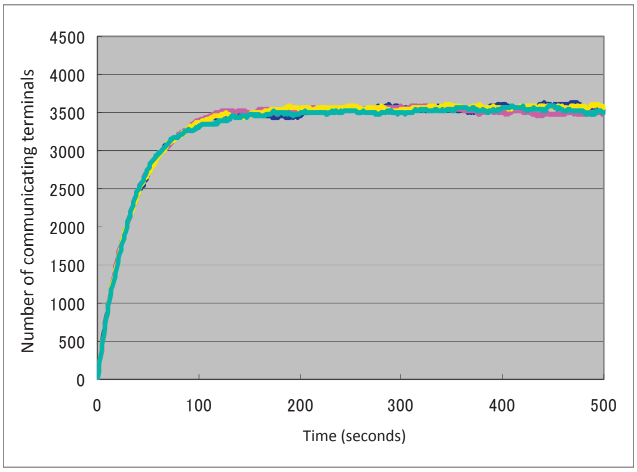


Fig. 9 Accepted call number (average of calling terminals/second is 100, aggregating number of terminals is 1)

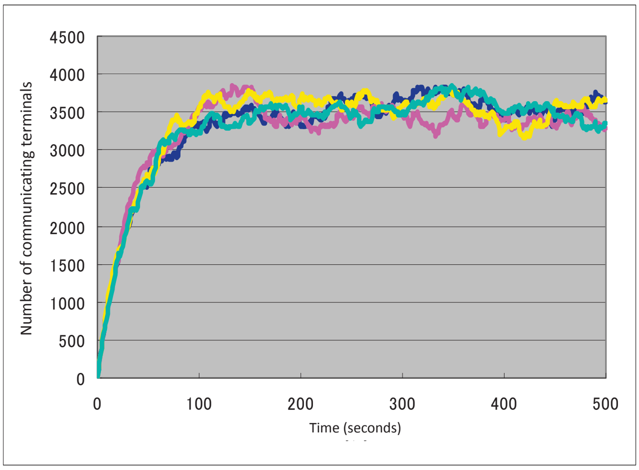


Fig. 10 Accepted call number (average of calling terminals/second is 100, aggregating number of terminals is 20)

Table 2 List of reference data for simulation scenario settings

Data No.	Data name	Created by	Basic items used
Data ①	Region-wise statistical database (Municipality-wise population distribution) From the general access point for e-stat government statistics	Ministry of Internal Affairs and Communication	• Terminals deployment • Average number of terminals calling during normal times • Terrestrial base station 1
	http://www.e-stat.go.jp/SG1/chiiki/CommunityProfileTopDispatchAction.do?code=2		
Data ②	"Research Group on How to Make Important Communications More Advanced" (First meeting), Document 1-3, p.21	Ministry of Internal Affairs and Communications	• No. of priority terminals
	http://www.soumu.go.jp/main_sosiki/joho_tsusin/policyreports/chousa/jyuyou-t/pdf/071122 _1 _si1 -3.pdf		
Data ③	Working group on methods for ensuring communication during emergency situations such as large-scale disasters (Network Infrastructure WG) (Second meeting), Document 2-1, p.3	NTT DoCoMo	• Simulation period • Call admission controls ratio • Average number of terminals calling after an earthquake
	http://www.soumu.go.jp/main_content/000117676.pdf		
Data ④	Japan's communication usage status based on traffic (2008) pp.50	Ministry of Internal Affairs and Communications, Telecommunications Bureau	• Average number of terminals calling during normal times
	http://www.soumu.go.jp/main_content/000052399.pdf		
Data ⑤	Study group on how communications were affected during the Great East Japan Earthquake, current status of recovery work, and ensuring the capital city's core functions if an earthquake were to hit it (Second meeting), Document 1, p.7	Ministry of Internal Affairs and Communications	• How much each factor contributed to making a base station non-functional • Percentage of base stations that were non-functional when the simulation ended
	http://www.bousai.go.jp/kaigirep/kentokai/kinoukakuho/2 /pdf/1.pdf		
Data ⑥	Status of Response to the Great East Japan Earthquake (Recovery Plan) (2011/3/30)	NTT DoCoMo	• Proportion of base stations that were non-functional on March 2013
	http://www.nttdocomo.co.jp/corporate/ir/binary/pdf/library/presentation/110330 /notice_110330 -2.pdf		
Data ⑦	IP Network Facilities Committee/Task Force for Ensuring Communications, Additional explanation on the first meeting (October 19, 2011), Information & Communications Council, Information & Communications Technical Subcommittee, IP Network Facilities Committee (18th meeting), Task Force for Ensuring Communications (Second meeting), Joint Meeting, Document 18-1-3, pp.1-7	NTT DoCoMo	• System capacity of terrestrial base stations
	http://www.soumu.go.jp/main_content/000136724.pdf		

3.4 Terrestrial base station deployment

Figure 14 shows the deployment of the terrestrial base stations. In order to reduce the calculation load, we decided to deploy for each area one base station which will cover the entire area, and process the statistics of the terrestrial base station of that area. By adjusting the volume of each terrestrial base station according to the population distribution of the area, the effectiveness of the simulations does not seem to change.

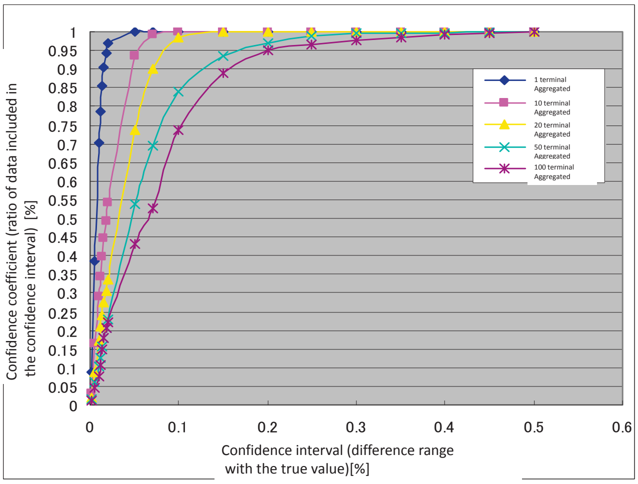


Fig. 11 Confidence interval of calculation results (average of calling terminals/second is 100)

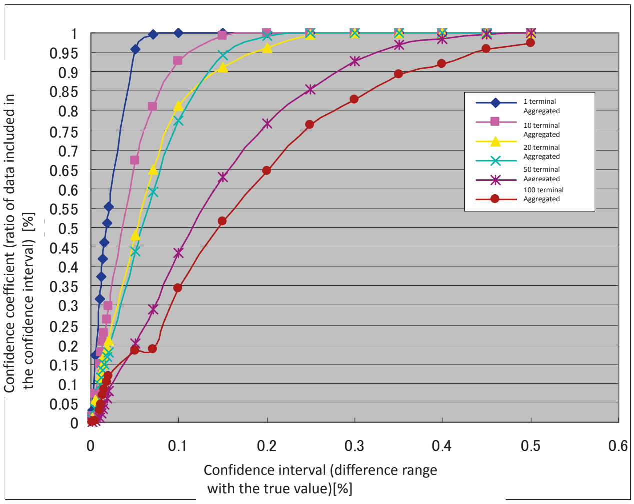


Fig. 12 Confidence interval of calculation results (average of 10.5 calling terminals/second)

Table 3 Summary of the scenario settings parameters

Item	Settings summary	Settings basis
Simulation area	• Kurihara City and its surrounding areas and coastline • Four 2D meshes per area	The maximum seismic intensity area at the time of the Great East Japan Earthquake is assumed, and the size in which the population distribution can be simulated is taken as the size of a single area.
Simulation period	• From 14:00 on March 11 to 02:00 on March 12 (Earthquake struck at 14:46), 10 seconds time interval in simulation	The call admission controls release time from data ③ is used as the simulation end time.
Terrestrial base station deployment	• Each simulation area is represented by one base station.	Specific information on the actual deployment of the base stations is unclear, so it was decided to deploy one base station for each area, and process the statistics of the base station of that area.
Terminal deployment	• Terminal deployment is based on population distribution. • 0.072% of general terminals are priority terminals. • 10 terminals are the unit of consolidation of terminal calls.	Population distribution is from data ①. The percentage of priority terminals is from data ②.
Average number of calls	• During normal times, this is based on population distribution. • Tracing of data ③ after a disaster	The average number of terminals calling during normal times is from data ④. The average number of calls after a disaster is from data ③.
System capacity of terrestrial base stations	• For the average number of terminals calling during peak normal times, 1.5 times the system capacity that results in a 3% call loss ratio	The system capacity that amount to a 3% call loss ratio is calculated by the Erlang B formula, and it was presumed that approximately 50% greater capacity is possible (data ⑦).
Changes in system capacity of terrestrial base stations	• Simulate the destruction immediately after an earthquake, disconnection of transmission lines, washed away by tsunami, and shutdowns due to dead batteries because of prolonged power outages.	The percentages of non-functional base stations by each factor is from data ⑤. The proportion of non-functional base stations was assumed based on the area ratio mentioned in attachment 3-2 of data ⑥. The changes over time were assumed for each factor.

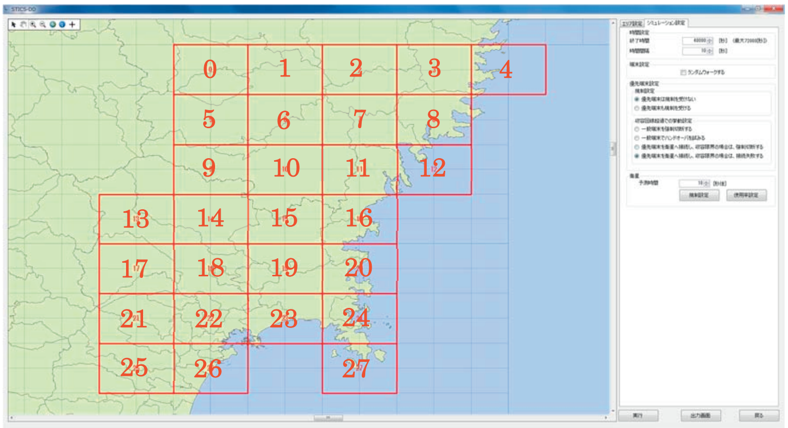


Fig. 13 Simulation area (No. 14 corresponds to the central part of Kurihara City)

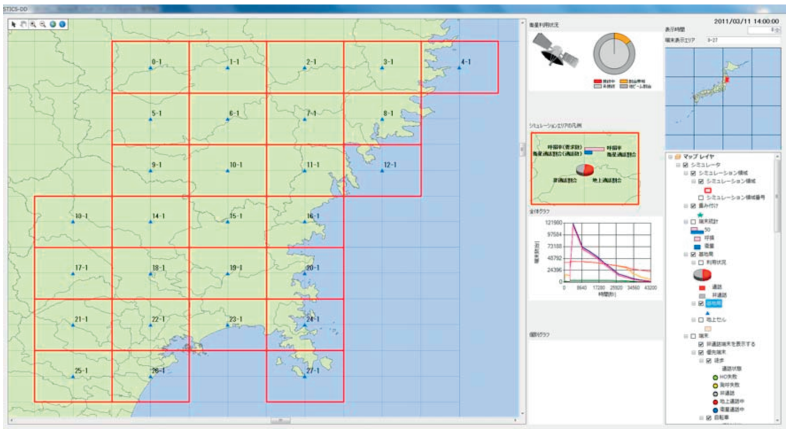


Fig. 14 Terrestrial base station deployment

3.5 Terminal deployment

The terminals are deployed in each area based on the population distribution given by the Ministry of Internal Affairs and Communications for fiscal year 2010 (data ①). The consolidation number of terminals was set at 10, and based on the population distribution of the simulation area, the equivalent of a total 2,532,670 general terminals (10 × 253,267) were deployed.

The average number of terminals calling per time interval in simulation differs depending on the population distribution; however, in most areas it is from 20 to several thousand. Also, after an earthquake hits, the average number of terminals calling increases by tens of times, so based on the result in Subusubsection 2.3.3.2, "if the consolidation number is less than half of the average number of terminals calling, then approximately 90% of the data is included in the ± 10% range," it seems that valid results can be obtained even with the consolidation number of being 10. Therefore, we set this number at 10, to reduce the calculation load. The number of terminals deployed in each simulation area is shown in Table 4.

Also, based on data ②, approximately 1,800 priority terminals which is 0.072% of the general terminals were deployed in each area.

3.6 Average number of terminals calling

If we assume that in normal times, approximately 1.1% of the terminals deployed are being used for making calls during peak hours (17:30–18:00), it means that the system carries the call volume of the number of terminals calling. The average call holding time is 120 seconds, so if we divide this call volume by 120, the average number of terminals calling per second during peak times is obtained. Based on the average number of terminals calling during peak times, the average number of terminals calling in each area before an earthquake (normal times) was set according to the ratio of the number of calls for each time period in the day, from data ④. In data ④, the communication frequency ratio is 8.8% for the period from 17:00 to 18:00 which includes the peak time, and the communication frequency ratio is 6.3%

for the period from 14:00 to 15:00 during which the earthquake occurred (14:46). Therefore, we take the average number of terminals calling during the normal time immediately before an earthquake as 6.3/8.8 times the average number of terminals calling during the time period that includes the peak.

After an earthquake strikes, the average number of terminals calling will be changed based on the results of tracing the ratio of calls by referring to "Voice traffic conditions in the Tohoku region" from data ③. Using the same data, it is assumed that the number of terminals calling during a peak is approximately 60 times the average number before the earthquake, and also the call admission controls are assumed to be 80%. Table 5 shows the average number of terminals calling during peak normal times in each area, and the maximum time taken by the average number of terminals calling after the earthquake.

Table 4 Number of terminals deployed in each simulation area

Area No.	No. of terminals deployed (Equivalent number of terminals)	Area No.	No. of terminals deployed (Equivalent number of terminals)
0	86420	15	65340
1	46320	16	27530
2	16620	17	36770
3	23430	18	143420
4	14860	19	62020
5	32250	20	12550
6	74470	21	65300
7	14600	22	131930
8	48340	23	167620
9	36600	24	16190
10	70790	25	427930
11	65920	26	760040
12	14120	27	2730
13	11380	total	2532670
14	57180		

3.7 Changes due to the system capacity and non-functioning of terrestrial base stations in the simulation area

The system capacity of terrestrial base stations in each simulation area is based on the population distribution. Using data ⑦, it was assumed that approximately 1.5 times the normally used system capacity is possible. The average number of terminals calling during the peak time zone in normal times is multiplied by the average call holding time of 120 seconds to obtain the call volume. The system capacity that results in a 3% call loss ratio is calculated using an Erlang B formula. Then, this system capacity number is multiplied by 1.5, and that value is taken as the system capacity of the terrestrial base stations of each simulation area. Table 6 shows the system capacity of terrestrial base stations in each simulation area calculated by this method.

After an earthquake, base stations become non-functional due to reasons such as prolonged power outage. In this simulation, we decided to simulate the non-functioning

Table 5 Average number of terminals calling in each simulation area

Area No.	Average number of terminals calling (Peak normal time) (Terminals/10s)	No. of terminals deployed (Equivalent number of terminals)	Area No.	Average number of terminals calling (Peak normal time) (Terminals/10s)	No. of terminals deployed (Equivalent number of terminals)
0	79	3262	15	60	2466
1	42	1748	16	25	1043
2	15	627	17	34	1388
3	22	887	18	131	5413
4	13	534	19	57	2341
5	30	1217	20	11	462
6	68	2811	21	60	2465
7	13	551	22	121	4981
8	45	1843	23	153	6286
9	34	1382	24	15	619
10	65	2672	25	392	16152
11	60	2487	26	699	28767
12	13	552	27	3	118
13	10	430			
14	52	2158			

of base stations by reducing the system capacity of the terrestrial base stations. The areas where service was interrupted is traced as against the service areas from the map (attachment 3-1 (Iwate Prefecture) and 3-2 (Miyagi Prefecture)) which shows the areas where mobile phones were available and not available at 18:00 on March 13 (Sunday), which is taken from data ⑥. The size of other areas is calculated, and then the ratio of the size of areas where service was interrupted vs. the size of other areas is calculated. We decided to reduce the system capacity by only that much ratio. Table 7 shows the calculated size ratio of the areas where service was interrupted.

Moreover, this simulation is until 02:00 March 12 (Saturday), so how much of the system capacity is to be reduced at that time is calculated as follows. The changes in the number of non-functional base stations are shown in "Changes in the number of non-functional mobile phone base stations" on page 7 of data ⑤. It is assumed that this can also be applied to all simulation areas. Accordingly, the number of non-functional base stations was approximately 6,700 on March 13 and approximately 4,000 on March 12, so the system capacity of terrestrial base stations at the end of the simulation is to be reduced by 4,000/6,700 as given in Table 7.

Also, based on data ⑤, we give the reasons for the non-functioning of terrestrial base stations. Each simulation area is divided into 3 sections: maximum seismic intensity area, coastal area, and other inland areas. Depending on the reason for non-functioning, we assumed how the system capacity will reduce as follows.

① Earthquake: In the maximum seismic intensity area, the system capacity will be lost immediately after the earthquake hits.

② Tsunami: In the coastal area, a tsunami will hit the coast 2 hours after an earthquake, and the system capacity will be lost at that time.

③ Disconnection of transmission lines: In the entire area, the system capacity will be gradually lost due to the aftershocks immediately following an earthquake.

④ Power outage: In the entire area, starting 3 hours after an earthquake hits, the system capacity will be gradually lost over time, due to the differences in the battery capacity of each base station.

Figure 15 shows the division of a simulation area, according to the reasons for non-functioning of base stations. Also, Figures 16 to 18 show the settings examples of the number of terrestrial base station system capacity in each section. Finally, Figure 19 shows the settings for the fall in the total system capacity of base stations in the entire area.

Table 6 System capacity in each simulation area

Area No.	System capacity (Channels)	Area No.	System capacity (Channels)
0	1410	15	1080
1	760	16	460
2	280	17	620
3	410	18	2300
4	250	19	1030
5	550	20	210
6	1220	21	1080
7	250	22	2130
8	810	23	2670
9	620	24	280
10	1160	25	6640
11	1080	26	11630
12	250	27	70
13	190	total	40380
14	940		

Table 7 Percentage of each simulation area where service is not provided

Area No.	Percentage of area where service is not provided (At 18:00 March 13) (%)	Area No.	Percentage of area where service is not provided (At 18:00 March 13) (%)
0	19.6	15	96.0
1	21.7	16	91.0
2	86.3	17	98.6
3	87.8	18	80.6
4	97.1	19	95.6
5	42.1	20	97.1
6	55.8	21	95.8
7	86.5	22	97.7
8	98.4	23	99.8
9	51.8	24	99.8
10	66.3	25	91.6
11	93.4	26	28.7
12	100.0	27	100.0
13	83.1	total	67.0
14	82.8		

3.8 Settings of satellite resource dynamic control

Regarding the satellite system capacity, we assume that 4 MHz × 7 beams will be repeated during normal times by using the DBF channelizer developed in Term B of the

STICS project. When using dynamic control to increase the resource allocation for the beams damaged during a disaster, we considered that a minimum (500 kHz) of resources must be retained for 6 beams, excluding the beams in the disaster stricken areas. Thus, we decided to allocate up to a maximum 25 MHz for the beams in the disaster stricken areas.

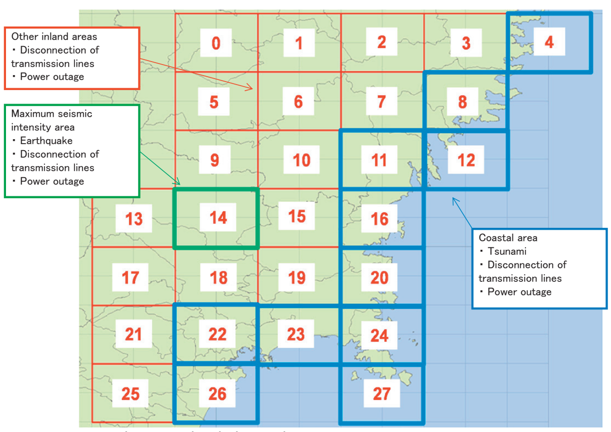
As satellite resource dynamic control, the usage status of the satellite circuits 100 seconds in the future is forecast from the present usage status, and resources are expanded beforehand. Table 8 shows settings of dynamic control. Assuming 2,500 circuits are 100%, we decided to ensure that when the forecasted number of required circuits exceeds the resource expansion threshold, the number of circuits will be set at the corresponding satellite system capacity.

4 Comprehensive evaluation of coordinated control and simulation results

This section describes the simulation evaluation results of STICS when coordinated control is done by using the simulation model, assuming the Great East Japan Earthquake described in Section **3**, and by using the terrestrial/satellite comprehensive network monitoring management system.

4.1 Outline of the results

Figure 20 shows the situation after the earthquake, on a simulator screen. The terrestrial base station of each area is in red color, which indicates that they are being used,



Maximum seismic intensity area: 14
Coastal area: 4,8,11,12,16,20,22,23,24,26,27
Other inland areas: 0,1,2,3,5,6,7,9,10,13,15,17,18,19,21,25

Fig. 15 Division of a simulation area, according to reasons for non-functioning of base stations

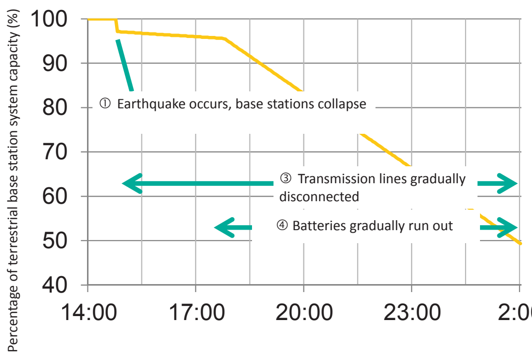


Fig. 16 Settings example of terrestrial base station system capacity (Maximum seismic intensity area: Area 14)

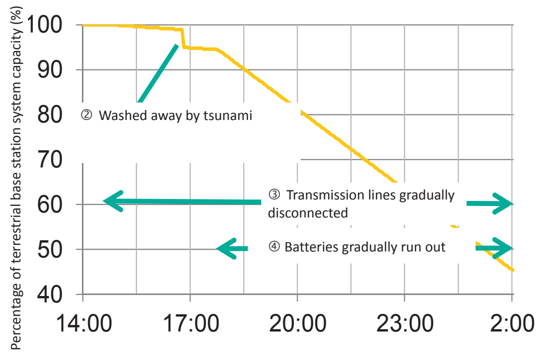


Fig. 17 Settings example of terrestrial base station system capacity (Coastal area: Area 16)

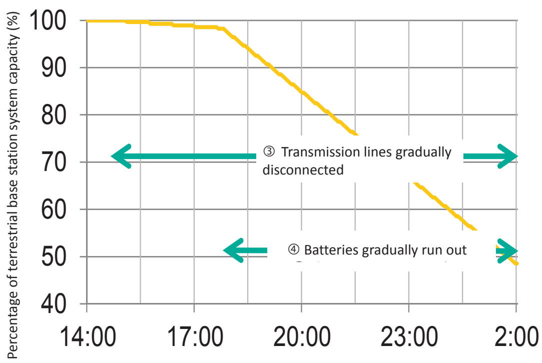


Fig. 18 Settings example of terrestrial base station system capacity (Other inland areas: Area 2)

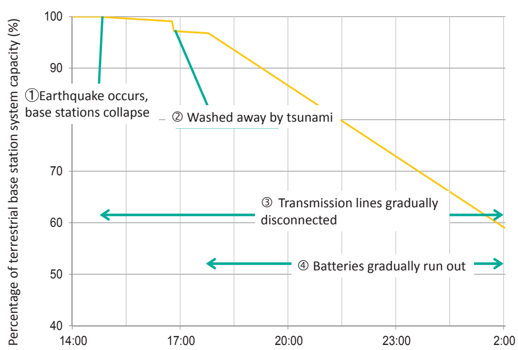


Fig. 19 Settings example of terrestrial base station system capacity (Total of all areas)

and it shows that with all the base stations being used at 100%, the pink colored graph bars showing the call loss ratio are also long, showing congestion. The blue colored graph bars show the percentage of terminals in calls that were calling by using the satellite stations; these are small percentages in most areas, showing that some calls were being rescued with the help of the satellite stations. However, it can be seen that even though the satellite resources were concentrated in the simulation area, the utilization of satellite stations is 100%, and it was not possible to rescue all the overflow calls from the terrestrial base stations.

The following subsections present simulation results and the discussion, step by step, starting from the situation of terrestrial base stations.

4.2 Situation of terrestrial base stations

Figure 21 shows the change over time in the number of call requests from the terrestrial base stations, the number of calls accepted, etc. when call admission controls were applied to about 80% of the call requests from general terminals, at the time of sudden increase in the number of call requests after the earthquake.

From after the earthquake to 21:00, the number of terminals calling is over 99% of the system capacity of terrestrial base stations, so these are almost the same. And even in the state where the call admission controls were applied to about 80% of the call requests on the general terminals, it was observed that the terrestrial base stations continued to be in a congested state.

Figure 22 shows the change over time in the channel usage ratio, as well as the call loss ratio which is the number of lost calls divided by the number of call requests to terrestrial base stations. Notwithstanding restrictions of call requests due to call admission controls on the general terminals, for a few hours after the earthquake (14:46 to 18:30), the congestion was from 70% to over 80%, leading to calls lost. The terminals that face such call loss make call requests to satellites. Decrease in the system capacity due to non-functioning base stations did not occur often in those few hours.

However, at around 02:00 the next day (approximately 11 hours after the earthquake hit), the system capacity fell from around 40,000 to 24,000 terminals. As the number of call requests greatly shrank because it was the middle of the night, call loss was not seen. However, if the earthquake had occurred 6 hours earlier, at around 08:00, then 11 hours after the occurrence of the earthquake would be 19:00, and thus there would have been many call requests. Moreover, in the state where the system capacity declines, the congestion would be much worse.

Table 8 Settings of satellite resource dynamic control

Satellite system capacity (10 kHz converted to one channel) (Channels)	Resource expansion threshold (%)
400	–
800	30
1600	60
2500	100

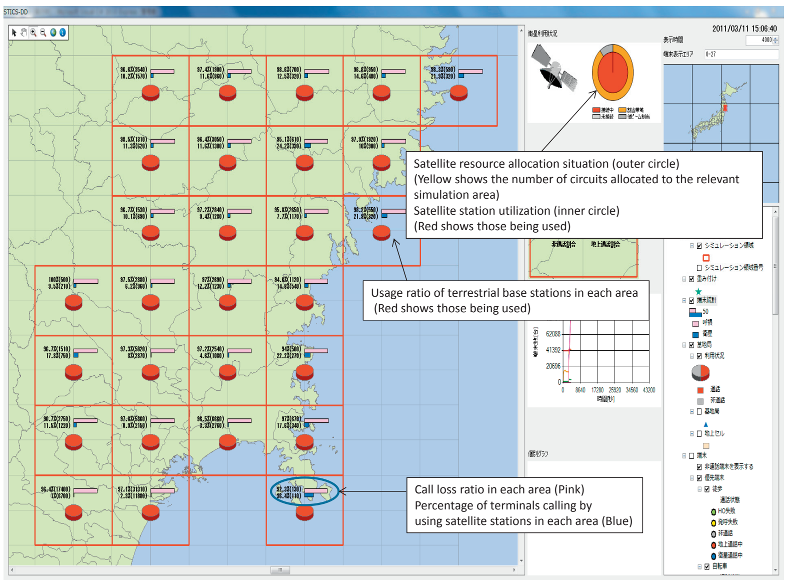


Fig. 20 Situation after earthquake

4.3 Situation of satellite stations

Figure 23 shows the change over time in the number of calls lost and number of calls accepted from priority terminals, for the satellite stations. If terminals that lost calls at terrestrial base stations as indicated in Fig. 21 try to make call requests to the satellite stations, even when call admission controls are applied to about 80% of the call requests from the general terminals, more than 10,000 call requests occur every 10 seconds to the satellite stations. The result being, even when the resources of the disaster site beams in the satellite resource dynamic control were set to the maximum value of 2,500, the satellite channels became occupied immediately, which also caused call losses to priority terminals.

Figure 24 shows the call loss ratio and channel usage ratio in the priority terminals of the satellite station. It shows that the channel usage ratio of the satellite station is used up at 100%, and the call loss ratio of the priority terminals continued to be high until close to midnight. Especially until around 20:00 after the earthquake hit, from among the calls from the priority terminals, more than 90% were call losses. A problem is that it is not possible to provide communications for important priority terminals related to disaster prevention and life and property. To rescue call requests of priority terminals, one can consider the need to use call admission controls to further decrease call requests of general terminals, or classify the calls from priority terminals at the satellite and force ending of calls of general terminals, to connect calls of the priority terminals.

Figures 25 and 26 show the call request situation and call loss ratio of the priority terminals for the

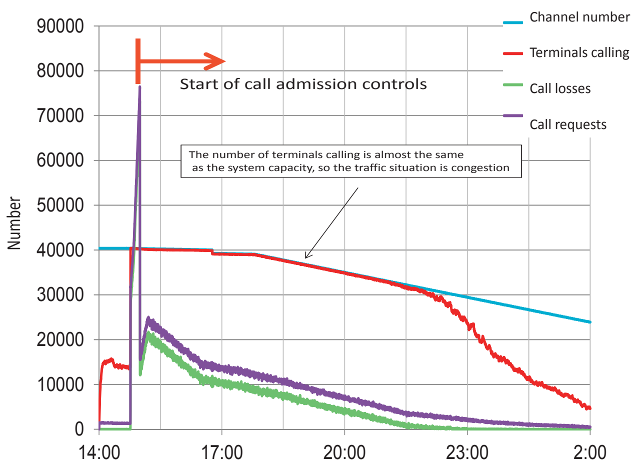


Fig. 21 Change over time in number of call requests and number of terminals calling by terrestrial base stations

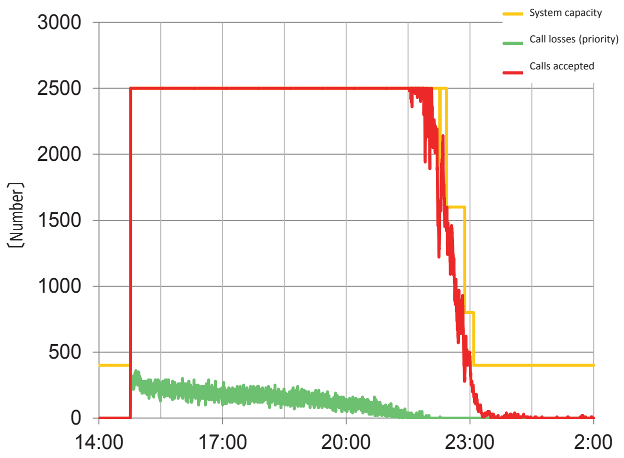


Fig. 23 Change over time in the number of call losses of priority terminals at satellite stations
(For general terminal call admission controls at 80%, with no differentiation of priority calls at the satellite station)

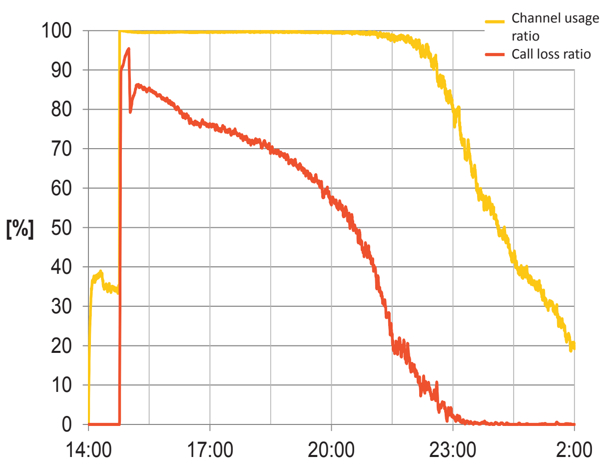


Fig. 22 Change over time of call loss ratio and channel usage ratio of terrestrial base stations

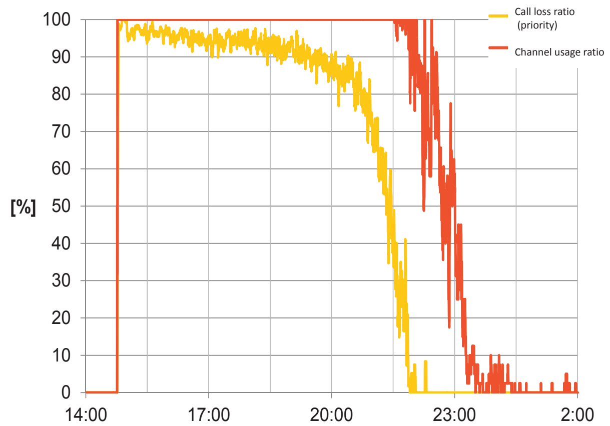


Fig. 24 Change over time in the call loss ratio and channel usage ratio of priority terminals at satellite stations
(For general terminal call admission controls at 80%, with no differentiation of priority calls at satellite stations)

satellite stations, when call admission controls on the general terminals are at 90%. The result is almost the same as when admission controls are at 80%, and while there is a slight decrease in the call loss ratio, the call loss ratio is around 90%, and for call admission controls at about 90%, it is seen that call requests at the priority terminals cannot be rescued.

4.4 Effects of forced ending of general terminal calls and its state of occurrence

The call admission controls ratio for general terminals is at 80%, where calls from priority terminals are differentiated at satellite stations. Thus, Figure 27 shows the change over time in the numbers of call losses and calls accepted of priority terminals, when there is forced call ending of general terminals that use satellite channels. From after the earthquake hit until about 20:00, the system capacity and the number of calls accepted were at 2,500, while the satellite channels of the disaster site beams were used almost 100%. For the problem of priority terminal calls, the number of call losses is 0, and thus all calls on priority terminals were able to communicate.

Moreover, Figure 28 shows the change in the number of priority terminals that use satellites to communicate. We see that the priority terminals that use satellites increase to more than 1,000 terminals. When dynamic control of satellite resources is not carried out, there are only 400 satellite channels in the disaster site beams, so usually, there are not enough channels for all priority terminals to communicate by satellite. It was confirmed that by using dynamic control to concentrate satellite resources, and increasing the system capacity, many priority calls can be rescued. Moreover, after 22:00, if the number of calls accepted falls, the system capacity of the satellites also falls. This may be because the satellite resource dynamic controls reduce the resources from the disaster site beam, and these are appropriately redistributed to the surrounding beams.

Next, we evaluated the effects on the general terminals in the case of priority calls causing forced ending of calls on general terminals. For satellite stations, in the case of priority calls causing forced ending of calls on general terminals, Fig. 29 shows the number of forcibly ended calls, and Fig. 30 shows the ratio of the number of forcibly ended calls divided by the number of priority terminals.

Around the time after 22:00, communication requests became few, so the forced ending of calls on general terminals, which occurs due to calls from priority terminals to the satellite, disappeared. But we see many forcibly

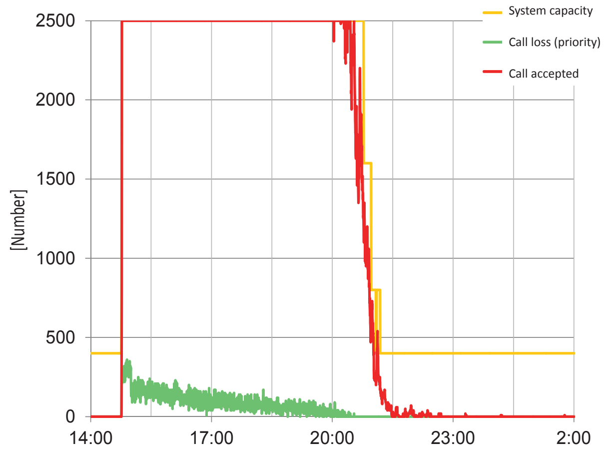


Fig. 25 Change over time in the number of call losses of priority terminals at satellite stations
(For general terminal call admission controls at 90%, with no differentiation of priority calls at satellite stations)

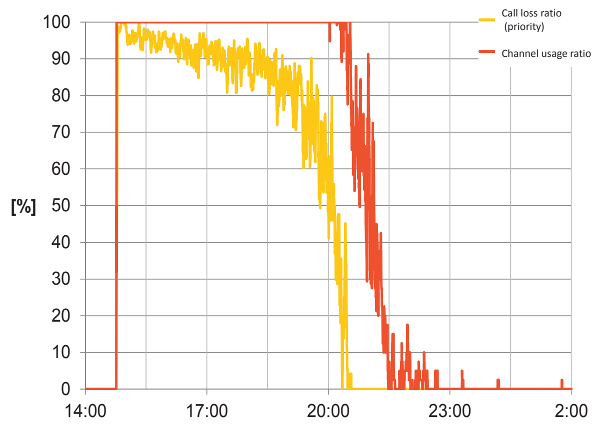


Fig. 26 Change over time in the call loss ratio and circuit usage ratio of priority terminals at satellite stations
(For general terminal call admission controls at 90%, with no differentiation of priority calls at satellite stations)

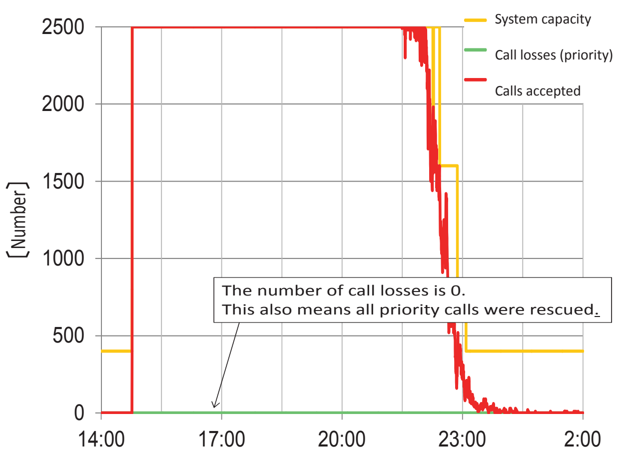


Fig. 27 Situation of call loss occurrence of priority terminals at satellite stations
(For general terminal call admission controls at 80%, with differentiating the priority calls at satellite stations, and force ending calls of general terminals)

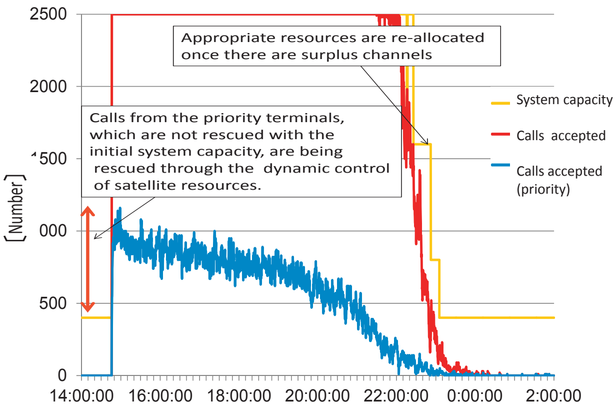


Fig. 28 Number of calls accepted from priority terminals in satellite stations
(For general terminal call admission controls at 80%, with differentiation of priority calls at the satellite stations, and forcibly ending calls on general terminals)

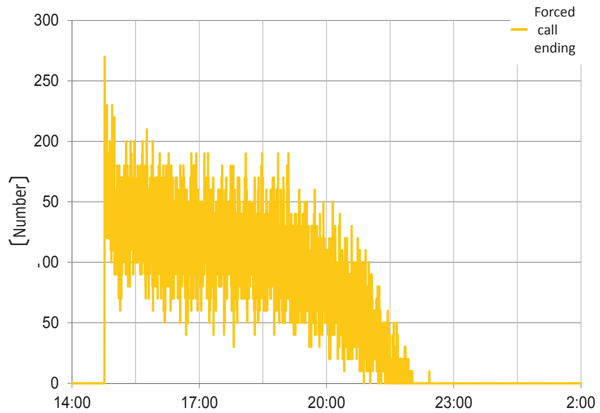


Fig. 29 Number of forced call endings when forcibly ended calls on general terminals at the satellite stations because of priority calls
(For general terminal call admission controls at 80%)

ended calls on general terminals between the earthquake occurrence time and 22:00. The forced ending of calls on general terminals that occurs due to calls on priority terminals to the satellite exceeds 100 calls in each 10 seconds. Also, we see that more than 90% of the priority calls get a free channel by forced ending of calls on general terminals. Conversely, one can also say that if there is not forced ending of calls on general terminals, more than 90% of the calls from priority terminals cannot communicate.

4.5 Call control operations of actual communication terminals

In accordance with the call processing flow and the priority call control processing described in Subsubsection **2.3.1**, based on the simulation results for the call requests from the actual communication terminals, it could be confirmed that the call control operations were done according to the channel usage situation of terrestrial base stations/satellite stations. Figure 31 shows the connections via the terrestrial base station, when the terrestrial base station is available (red colored lines shows the connections for communication). Figure 32 shows the connection via satellite when the satellite station is available, but the terrestrial base station is congested. Figure 33 shows handover of the phone call by using the satellite station and maintaining the connection, when the actual communication terminal is moved outside the terrestrial base station area during the phone call.

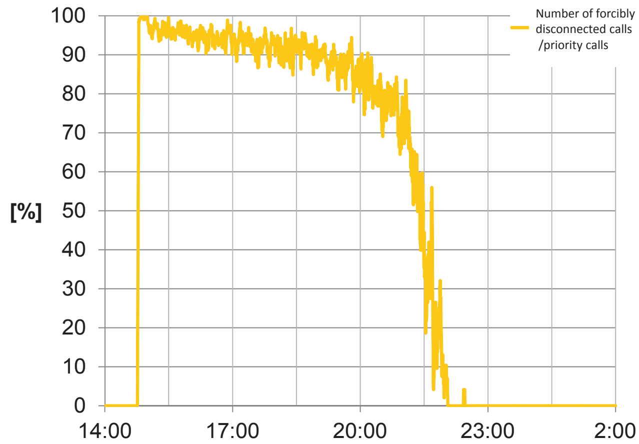


Fig. 30 Ratio of number of forced call endings when forcibly ending calls at general terminals because of priority calls via satellite stations
(For general terminal call admission controls at 80%)

5 Conclusion

This paper evaluates the performance of STICS when coordinated controls such as dynamic resource control, priority call control and call admission control were operated, as a comprehensive evaluation of coordinated control technology of the terrestrial system and satellite system under Term A of the research and development project of Satellite/Terrestrial Integrated mobile Communication System (STICS). This was done using simulation by modeling the situation of actual communications traffic and non-functional base stations in the Great East Japan Earthquake.

The result of this study was, when the earthquake took place (at 14:46 on 2011/03/11), even though 80% and 90% call admission controls were applied at the terrestrial base stations, in the few hours after the earthquake (14:46 to 18:30), there is congestion due to huge demand for communications such as verifying safety, and from 70% to more than 80% call losses, and these call loss terminals make call requests to the satellite, so with the number of satellite station channels assumed at this stage, even though the number of lines of the disaster area beams was changed to the maximum value of 2,500 using the resource dynamic control, it was found that the satellite channels become occupied immediately, and there are also call losses of priority terminals. However, when we especially focus on priority terminals that should establish the communication connections, with priority call control including forced ending of communications on general terminals, it was possible to receive most of them. In the sense of being able to rescue the priority terminals, STICS was extremely effective. Moreover, satellite resource dynamic control seems to be effective in rescuing more priority terminals.

However, in order to eliminate priority call loss, when the satellite channels were used up for communications on general terminals, it was necessary to forcibly end the calls for communications on general terminals. In view of the call request demand volume and the admission controls ratio, it may not have been possible to rescue the priority calls without doing forced call endings, but it is necessary to adjust the parameters and perform repeated simulations to obtain appropriate parameters. And an important issue for practical purposes is how to obtain and control appropriate parameters depending upon the situation. However, for example, when deciding which conditions are

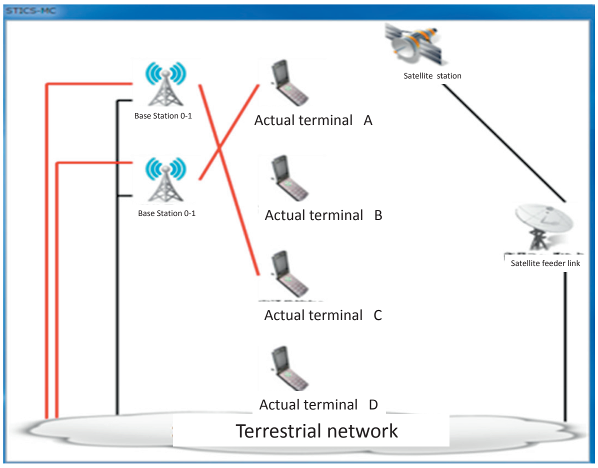


Fig. 31 When a terrestrial base station is available
(Connection via terrestrial base station (same for general and priority terminals))

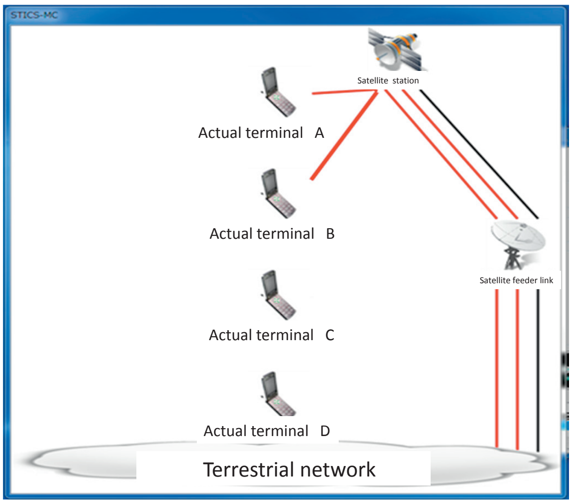


Fig. 32 When the terrestrial base stations are congested
(Connect via satellite when the satellite station is available (same for general and priority terminals))

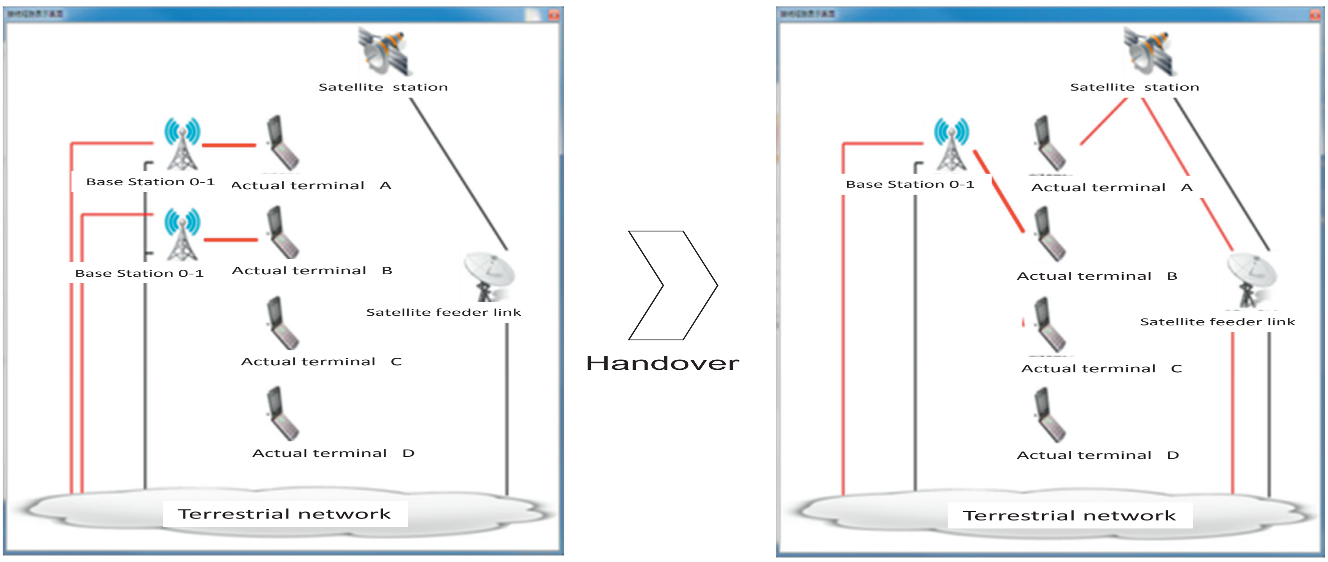


Fig. 33 When moving outside the terrestrial base station area during a phone call
(Handover from terrestrial connection to connection using a satellite station, to maintain the connection (same for general and priority terminals))

better (an extreme situation where the call admission controls ratio is 99%, vs. a situation where call requests are possible to some extent but can be forcibly ended), opinions were divided and we need to form a user consensus for these controls.

Moreover, it is also important to study what would be the ideal number of satellite channels in preparation for large-scale disasters such as the Great East Japan Earthquake. By setting more satellite channels, it could also be effective to perform simulations for estimating the number of channels required, for each type of situation sought, such as elimination of call losses at priority terminals, or elimination of forced call endings at general terminals, and further, suppressing of call loss ratios on general terminals to a particular value. Once the number of required lines is found, it could lead to the study of narrowing the bandwidth per channel of phone calls, reducing the radius of satellite beams through beam forming, and increasing the total number of channels by the frequency repetition.

Moreover, not just the priority terminal communications, emergency calls from general terminals to numbers such as 110 and 119 are also important communications. So if there is information available on how many such emergency calls are made in the event of a disaster, it is possible to easily simulate by configuring them as priority terminals, but in reality, there could be a difference in priority terminal call time and emergency number phone call time, so an improvement in the simulator would be required. Moreover, this time, just the call admission controls were enforced as restrictions for reducing congestion, but one can also expect reduction in congestion through separate restrictions on phone call time restrictions[6], and evaluating performance of STICS in such cases can also be raised as a future research topic.

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