Studies on System Architecture and Dynamic Control for Traffic Fluctuation during Large Scale Disaster in Satellite/Terrestrial Integrated Mobile Communication System

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In this paper, we propose the system architecture of the Satellite/Terrestrial Integrated mobile Communication System (STICS). Also, dynamic control is needed in the STICS to meet to traffic fluctuation during disasters. So, in this paper, dynamic control to traffic fluctuation, rapid handover procedure and admission control of the STICS are studied. Finally, this paper presents a simulation study with a simple model. It showed the STICS makes call blocking rate and forced call termination rate at handover lower.

1 Introduction

People are used to always carrying and using terrestrial mobile phones, so when there is a large disaster due to earthquake etc., they become extremely effective communication tools. However, due to congestion resulting from surges in traffic to check safety, and due to long term transmission cuts and power outages that result in base station shutdowns etc., terrestrial mobile communication systems often become unavailable. Even at such times, it is important to meet social needs for providing reliable communications. Satellite mobile communications systems are unlikely to be affected by earthquakes, so there are hopes that a Satellite/Terrestrial Integrated mobile Communication System (STICS)[1] can serve as communications infrastructure during large disasters. A STICS feature is that it shares the frequency resources of terrestrial mobile communications systems and satellite mobile communications systems, thereby boosting usage efficiency; it is important to study how to coordinate and control the shared resources between both systems. To do this, first, one must study the overall architecture of a system equipped with functions for coordinated control of both systems. Also, to handle sudden traffic changes hypothesized during a disaster, one needs to configure a system that can continue operating even if sudden traffic changes occur, with dynamic control against traffic changes, such as system control to minimize effects due to sudden traffic changes, and system control to prevent effects due to sudden traffic changes, etc.

Thus this paper describes the results from study of STICS system architecture[2], study of dynamic control of traffic changes[2], study of high speed handover processes[2], and study of call admission control. And by computer simulation using a simple model, we show the benefits of sharing frequencies in STICS[2], and show the effectiveness of STICS.

From the viewpoint of STICS implementation and actual operation, detailed protocol study, interface definition, or system implementation study etc. are required. This paper describes our study of the technology platform that will serve as the core, as system study before implementation.

2 3GPP standards compliant STICS architecture proposal

A STICS feature is that it shares the frequency resources of terrestrial mobile communications systems and satellite mobile communications systems, thereby boosting usage efficiency; it is important to study how to coordinate and control the shared resources between both systems. To do this, first, one must study the overall architecture of a system equipped with functions for coordinated control of both systems. Thus this section describes the results of our study on the overall system architecture of STICS, which considers both terrestrial and satellite mobile communication systems.

The final targets of STICS are actual implementation and commercialization. In the field of information and communications, for actual implementation and commercialization, the standardization process is important. Therefore, for the overall system architecture of STICS, our study was done with the aim of compliance with international standards.

ITU Recommendations created by the International Telecommunication Union (ITU) are representative international standard specifications. Also, as standardization bodies that do international standardization for commercial mobile communication systems that have now spread all over the world, including the EU, North America and Asia, there are the 3rd Generation Partnership Project (3GPP) and 3GPP2. The specifications established by 3GPP and 3GPP2 are being studied under global scale partnerships, so they are reliable, and in accordance with the IMT-2000 family concept approved by the ITU, they are formed into recommendations as international standardization specifications of the ITU.

The Internet Engineering Task Force (IETF) is a voluntary body that promotes standardization of internet technology. The IETF developed from a group that discussed common technology specification creation, for interconnections of computer systems. A Request for Comments (RFC) is a standardized specification by the IETF. An RFC is becoming an important standardization specification, along with the progress in all-IP conversion of mobile communication systems. In third generation mobile communication systems, there were clear differences between wireless transmission systems: 3GPP is W-CDMA, 3GPP2 is cdma2000; but in fourth generation mobile communication systems, 3GPP is integrated, incorporating the 3GPP2 specifications. Also, an all-IP network base by the core network by IP is being studied, so in this chapter, the overall STICS system architecture is proposed, based on 3GPP standardization architecture.

Figure 1 shows an all-IP mobile communication system architecture of 3GPP[3], considering extensibility with non-3GPP networks which is being studied. This architecture is broadly divided into Home Public Land Mobile Network (HPLMN) which is a 3GPP IP home network, and non-3GPP networks which are external IP networks not being studied in 3GPP. The former accommodates the group of functions required on the side of terrestrial mobile communication systems, and the latter pertains to other networks. Figure 1 shows that non-3GPP networks are further divided into trusted non-3GPP IP access, and untrusted non-3GPP IP access, from the viewpoint of whether or not that network is protected by a secure scheme. In this paper, a satellite communication system is regarded as one of these non-3GPP networks in STICS, and we propose to build a terrestrial/satellite integrated system architecture compliant with standardized architecture, as shown in Fig. 1. In a STICS satellite communication system, it is

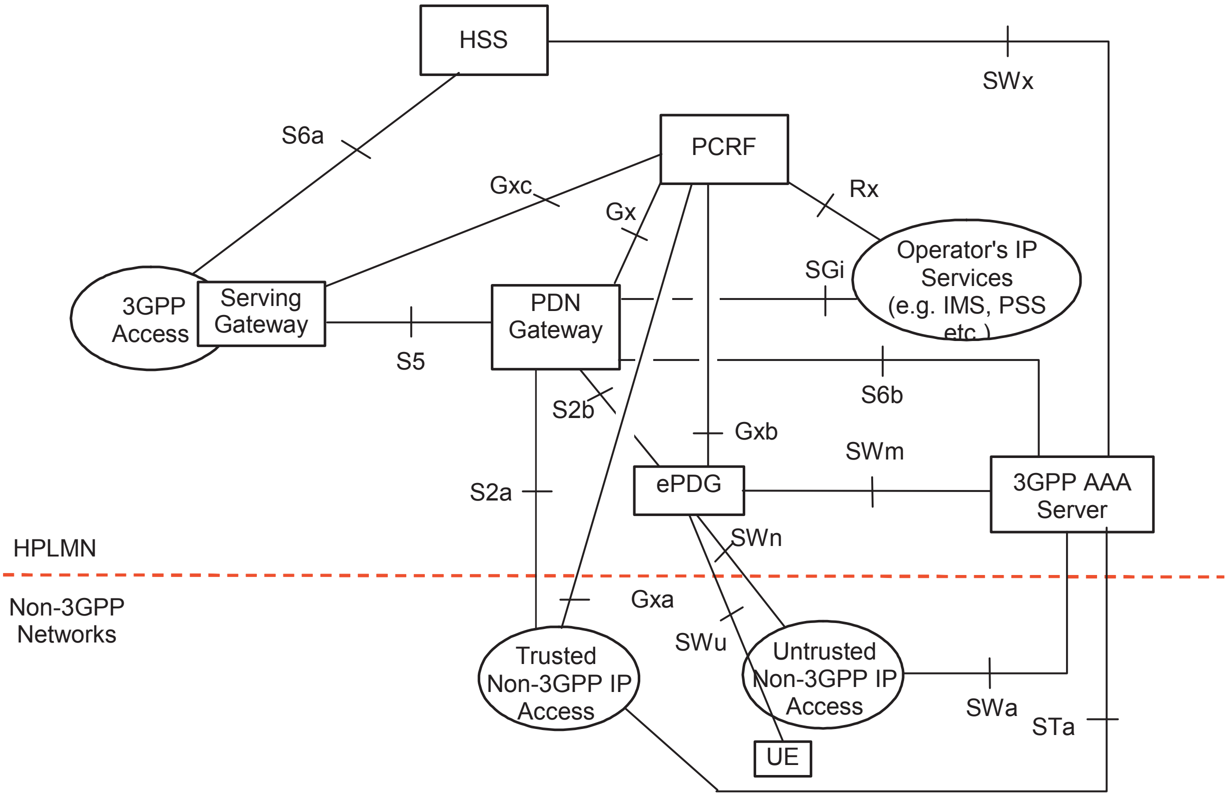

Fig. 1 3GPP all-IP system architecture[3]

desirable to build a network that maintains sufficient security, by equipping it with functions for user authentication etc. in providing communication access, and by building a system with a communications transmission path by a modulation scheme for wireless transmission sections. In this case, a satellite communication network by STICS is regarded as a trusted non-3GPP IP access network, and it is possible to build an overall STICS architecture based on 3GPP standardization.

On the other hand, in cases where a STICS satellite communication system cannot maintain sufficient security, an overall architecture is built in which the satellite communication network is regarded as an untrusted non-3GPP IP access network. In this case, it must be equipped with additional functions which ensure communications which maintain security between the Evolved Packet Data Network Gateway (ePDG) and terminals, or, invoke a user authentication mechanism utilizing a 3GPP Authentication Authorization Accounting (AAA)* server.

In STICS, it is not enough to simply maintain network mutual connectivity; it requires efficient mutual control of the terrestrial mobile communication system and satellite mobile communication system. Therefore, we need an architecture that deploys a management node that mediates between the terrestrial mobile communication system and satellite mobile communication system, and that achieves efficient coordinated control of jointly used frequency resources.

Figure 2 shows the overall STICS system architecture proposed in this paper. The management node in Fig. 2 has an interface, for the terrestrial communication network, with function blocks of gateway (PDN gateway or ePDG;) for centralized control of a secure or insecure access network, Policy and Charging Rules Function (PCRF; for control of access policy and charging information), and AAA server (control of authentication information), and performs coordinated control of these across systems. Therefore, the function block that corresponds to this management node does not directly exist in the all-IP system architecture of 3GPP in Fig. 1; it is deployed inside (in edge part of HPLMN side) the trusted/untrusted non-3GPP IP access network, or, a new node must be introduced as a function block that covers all the points where the lines extending between reference points intersect with the red dashed line in Fig. 1. Also, to achieve the goal of governing the functions such as optimized control of frequency allocation that follows traffic changes and considers

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* AAA: Abbreviation for Authentication (confirm who the user is), Authorization (confirm whether the user has rights), and Accounting (collect usage information of user). We comprehensively look at these three different security functions, and study security.

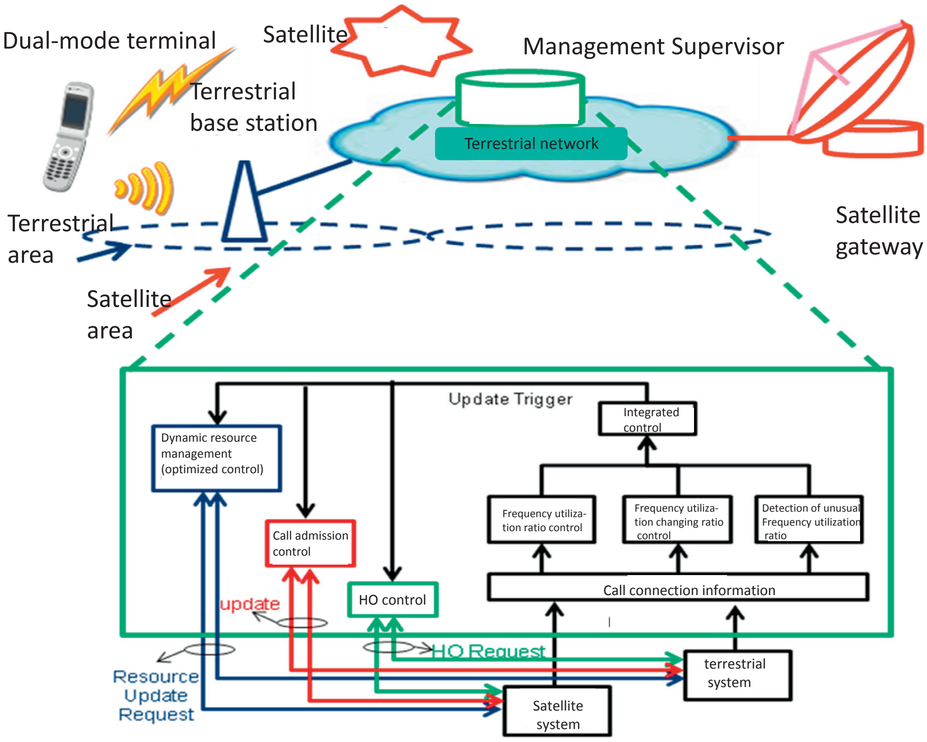


Fig. 2 STICS overall system architecture

interference between own stations and other stations, and handover control between terrestrial and satellite systems, we conducted additional study and created a unique composition of the internal functions of this management node. Also, in a system like STICS that does satellite communication, the satellite's electric power is an unshared resource used by the satellite alone, but it is a limited precious resource, so efficient control of the satellite's electric power is required. In short, when doing optimized frequency allocation control, we must consider the limitation of the satellite's electric power.

The all-IP system architecture of 3GPP in Fig. 1 is an architecture for the most reliable mobile communication networks internationally. Being in compliance with this most effective architecture and highly compatible with it in terms of mutual connectivity is a very advantageous condition for aiming to be the best in the world in the information and communication platform research field, and for aiming to achieve international deployment of communication systems, etc. Also, if it has the feature of being in compliance with international standards for terrestrial mobile communication systems, then control of switching between terrestrial and satellite becomes very achievable, and it could be a very practical system architecture. Moreover, in the proposed architecture, management nodes are deployed between terrestrial and satellite, so it has the benefits of being relatively easy for both systems to evolve independently, and easy to expand their functions. Especially for STICS, if the satellite mobile communication system that mutually connects with the terrestrial mobile communication system is configured as a trusted system, then there is great isolation between the systems and nodes. However, if the satellite communication system is configured to as an untrusted system, then one must separately provide the system with functions of user authentication and secure transmission path construction, so the architecture's isolation is reduced. In this way, trusted/untrusted configuration of a satellite mobile system brings about slight differences in functional deployment. However, the proposed STICS overall system architecture, which is compliant with 3GPP system architecture, is expected to play an important role in the study of achievability and practicality of the STICS system.

3 Study of dynamic control for traffic changes

In this section, we study dynamic control for frequency allocation optimization control, for sudden traffic changes during disasters. We use three indices as factors that show traffic change qualities: usage status of user traffic channels (usage ratio control), time series of usage channels (change ratio control), and large differences between frequency allocation status and actual traffic (error detection). These three indices are used for dynamic control, by frequency utilization ratio control, frequency utilization changing ratio control, and control on the detection of unusual frequency utilization ratio. Threshold control is done for utilization ratio and change ratio, and the error detection process is controlled based on centrality. The basic control function composition is as shown in the system architecture proposed in the previous section, Fig. 2. The three control indices mentioned above are explained below.

Periodic monitoring management of these control indices could help to achieve efficient system control, and to reduce communication quality deterioration by enabling efficient frequency resource control that predicts sudden traffic changes, and traffic restrictions that accompany traffic changes.

(1) Frequency utilization ratio control function

The frequency utilization ratio x_t indicates the frequencies used by users, divided by the frequency resources available in time *t*. For that value, control by the threshold U_{opt}, and control the optimized update trigger value *f*(*x*).

$$f(x,t)=\begin{cases}0 & : \; x_t < U_{opt}\\ 1 & : \; x_t \geq U_{opt}\end{cases}$$

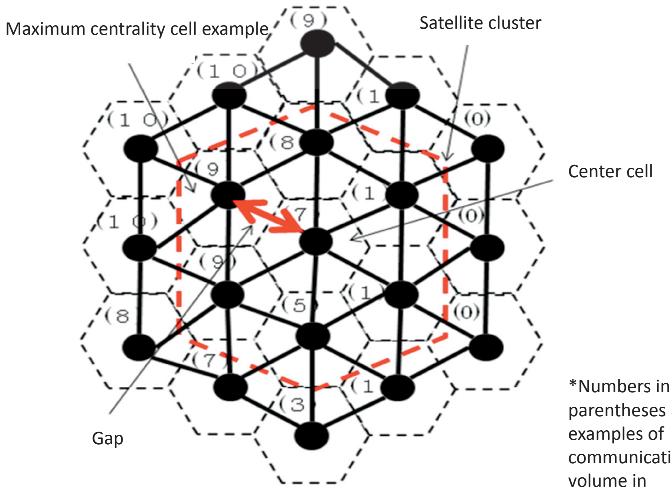
(2) Frequency utilization changing ratio control function

The frequency utilization changing ratio α_t indicates the temporal change ratio of the frequency utilization ratio. Against that value, it controls by the threshold V_{opt}, and controls the optimized update trigger value *g*(*a*). Here, *T* indicates the time interval in which after T seconds pass, it is likely that communication restrictions occur.

$$g(a,t)=a_t \times T + x_t = \begin{cases}0 & : g(a,t) < V_{opt}\\ 1 & : g(a,t) \geq V_{opt}\end{cases}$$

(3) Control on the detection of unusual frequency utilization ratio

The unusual frequency utilization ratio indicates the degree of gap between the frequency use status and the actual frequency allocation status. Here, we use structural centrality to measure the gap between the use status and allocation status. To calculate the centrality value (for example between centrality) for cell *k*, it can be expressed by



*Numbers in parentheses are examples of communications volume in terrestrial cells

Fig. 3 Cell composition diagram and example of cell that has maximum centrality value

the equation below.

$$b_k = \sum_{i,k} \frac{g_i k_j}{g_{ij}}$$

Here, g_{ij} indicates the number of the shortest paths from cell i to cell *j*, and within these paths, $g_i k_j$ indicates the number of paths that pass through cell *k*. Figure 3 shows a composition diagram and an example of a cell that has the maximum centrality value used in the process for control on the detection of unusual frequency utilization ratio. This example shows a situation in which that communication volume's distribution is biased to the left side of the diagram; by doing threshold control according to the Euclidean distance that indicates the gap between the cell that has the maximum centrality value in a satellite cluster, and the central cell of the satellite cluster, optimize frequency allocation in accordance with traffic change qualities.

4 Handover control algorithm study

In this section, we propose an algorithm for handovers between the terrestrial mobile communication system and the satellite mobile communication system. This algorithm takes into account the propagation delay of the satellite mobile communication system, and effectively utilizes the feature of terminals that can use both terrestrial and satellite circuits, so in cases where a low propagation delay terrestrial system is in an active status, use a handover control process to actively use that terrestrial system, and thereby reduce handover switching time between terrestrial and satellite mobile communication systems.

Figure 4 shows an example of a process sequence for handover from a terrestrial mobile communication system to a satellite mobile communication system. Figure 5 shows a process sequence for handover from a satellite mobile communication system to a terrestrial mobile communication system.

As shown in Fig. 4, while a dual-mode terminal uses a terrestrial mobile communication system and is doing data communications, for example, if a disaster was predicted, it did frequency optimization control, so that situation makes it desirable to switch from the terrestrial mobile communication system to a satellite mobile communication system, and it does the process for handover from the terrestrial mobile communication system to a satellite mobile communication system. When doing that, while maintaining the session of the terrestrial mobile communication system that is communicating, newly connect a session of the satellite mobile communication system, and create a situation in which the dual-mode terminal simultaneously has sessions of both the terrestrial mobile communication system and the satellite mobile communication system. After that, conventional systems generally use the satellite line to which it is handed over, and exchange handover control messages between the terminal and control node, but in this proposed system, the dual-mode terminal uses the terrestrial channel, and exchanges control messages with the management node. In short, a feature of this proposed process sequence is that handover control message exchange uses a faster channel (for example, a terrestrial channel); by this process, compared to the conventional case of using a satellite channel, we can dramatically reduce the effects of propagation delay time

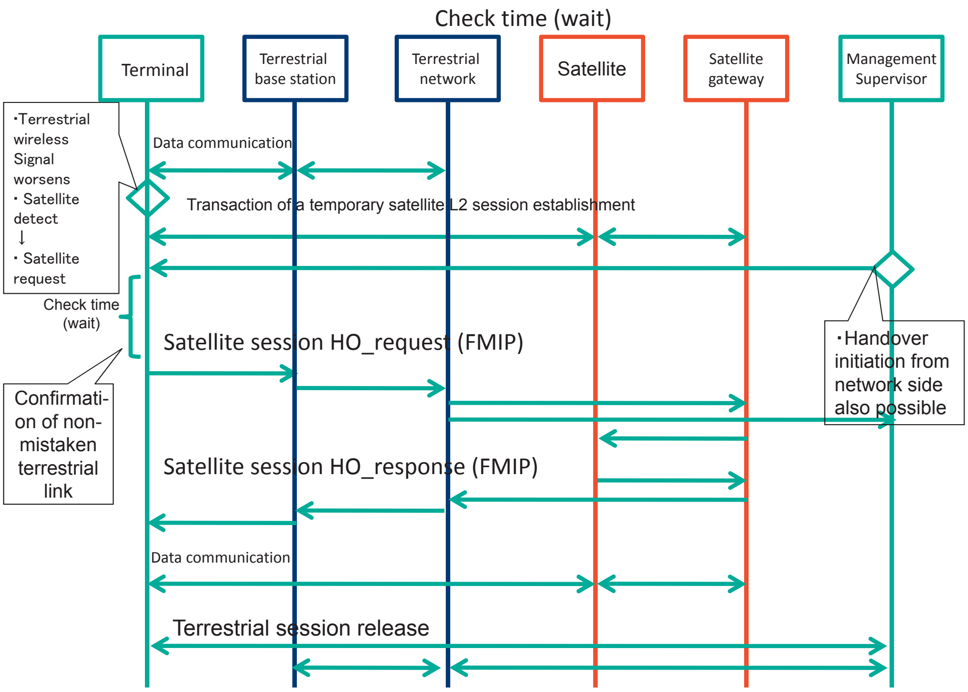


Fig. 4 Example of terrestrial system ⇒ satellite system handover process sequence

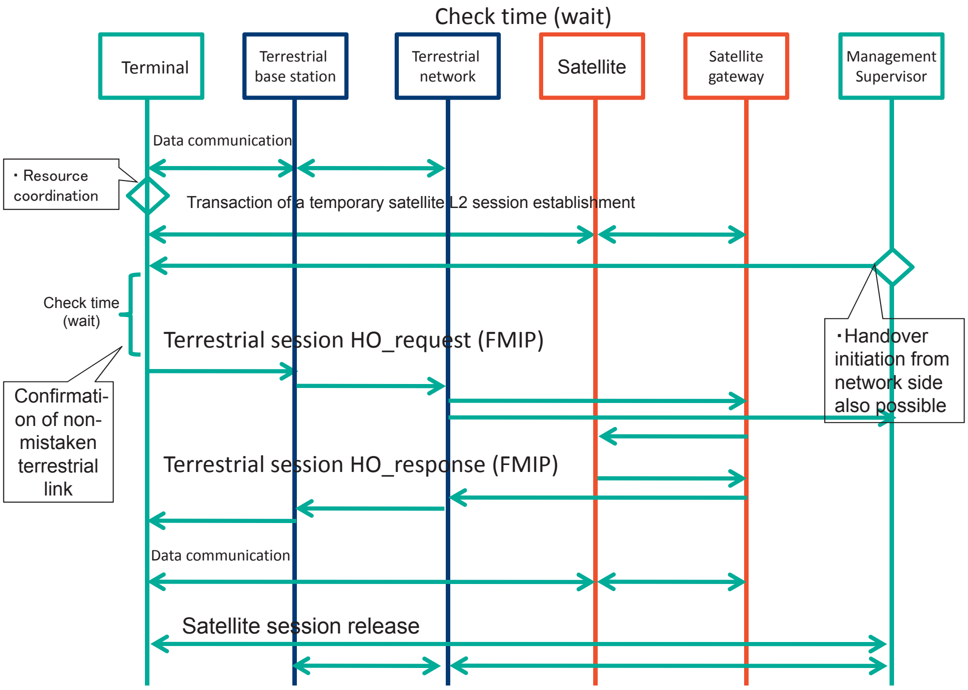


Fig. 5 Satellite system ⇒ terrestrial system handover process sequence

that accompanies use of satellite channels. Figure 5 is an example of the process sequence for handover from a satellite mobile communication system to a terrestrial mobile communication system; its process is the opposite of Fig. 4. Here, this proposed sequence assumes an environment that enables simultaneous use of both terrestrial and satellite channels. Along with the occurrence of a terminal distribution environment change such as when a special event occurs, if a sudden increase in the presence density of terminals occurs, then by doing the resource control through the dynamic control described in Section **3** in advance, one can expect to ensure a certain number of terrestrial channels.

However, for example during a disaster emergency, if predictive controls cannot be effectively executed, and base stations suddenly stop transmitting, then the terrestrial mobile communication system's channels cannot be used any longer, and thus this paper's handover controls cannot be used any more. For such a situation, one can consider utilizing the feature of a control node deployed between the terrestrial mobile communication system and satellite mobile communication system, allowing various types of media-independent communication requests, and implementing channel capacity restrictions and handover controls based on reliability of communication channels, but this is an issue for future study.

5 Study of call admission control

As shown in Table 1, in the 3GPP international standardization body, mobile communication system traffic restrictions are roughly categorized into all call restrictions, international call restrictions, and home network vs. other calls; for the three types of outgoing call restrictions, regulations are defined by call type: outgoing calls vs. incoming calls[3]. Emergency calls are not subject to the above, and are not restricted.

On the other hand, specific call admission controls during disasters currently rely on communications companies. Call admission control of mobile communication systems is now generally as follows. Restriction types can be broadly classified into two types: restrictions from the network side and from the user side. One can think of two types of restrictions from the network side: restriction caused mainly by congestion in the exchange equipment network of the network upper layer, and restriction from the base station side accompanying a shortage of wireless channels. During a disaster, there is a sudden increase in demand for voice traffic to check the safety of their families and friends. On the one hand, data traffic such as email does not increase as much as voice traffic, so at some communication companies, depending on whether the call subject to those restrictions is a packet switched data call (PS) or a channel switched (CS) voice call, it can independently restrict each. On the other hand, regarding restrictions from the user side, for mobile terminals other than priority communications during disasters, outgoing call regulations are applied to all calls except for emergency messages, in a restriction method consistent with the standard described above.

In contrast to this situation of traffic restriction controls, we studied what kinds of restriction controls should be in a STICS system. As a result, we reached the conclusion that the three points below are important.

- To avoid traffic controls as much as possible by performing by dynamic control and network guided handover control.
- As basic controls in situations where traffic restrictions are required, restrictions are preferentially placed on terrestrial systems, and satellite systems are preferentially used, in an effort to maximize the frequency utilization ratio during disasters, which is the number one advantage of a STICS system. Specific optimal control values and algorithms are a topic for future study.
- A STICS system is a terrestrial and satellite integrated system, so as a management unit applying unique traffic restrictions on the integrated system, we add a management unit for each shared frequency (for example, implement controls corresponding to whether active or inactive).

Table 1 Main types of restrictions in 3GPP

Call type	Restriction type
Outgoing call	Barring of all outgoing calls (BAOC)
	Barring of outgoing international calls (BOIC)
	Barring of outgoing international calls EXCEPT those directed to the home PLMN country (BOIC-exHC)
Incoming call	Barring of all incoming calls (BAIC)
	Barring of incoming calls when roaming outside the home PLMN country (BIC-Roam)
Emergency calls	Outside of restrictions

6 Computer simulation using a simple model

This section describes the results of verification on the benefits of frequency sharing in a satellite/terrestrial integrated mobile communication system, by computer simulation using a simple model.

The cell layout model in this simulation is a tetragonal lattice model, as shown in Fig. 6. This is one of the basic models, and it seems sufficient for this verification to check the benefits on frequency sharing. The entire area is comprised of 12 × 12 cells (each cell's size is 1 square km), and the center 4 × 4 = 16 cells are considered as satellite beam cluster; that area is a "statistical area" for which statistical data is collected in this simulation.

Table 2 summarizes the simulation conditions. In the terrestrial and satellite integrated system considered for STICS, we set the conditions so there are 80 terrestrial cell channels and 80 satellite cell channels for a total 160 frequency channels that can be used in a statistical area. Also, in a terrestrial-only system for comparison, we set the conditions so 160 terrestrial cell channels can be used in the statistical area. In both systems, the same total 160 channels can be used, so the two systems can be compared. Also, there are 2,000 nodes of dual-mode terminals, and while repeating random call connects and disconnects according to a Poisson distribution, we perform a random walk in 4 directions through the entire area. When a dual-mode terminal makes a call, if a terrestrial channel is free, then a terrestrial channel is given priority for connecting the call. If a terrestrial channel is not free, then if a satellite channel is free, the call is connected by a satellite channel, but if a satellite channel is not free, then the call is blocked.

Also, if the terminal is being handed over across a cell border, then it is connected according to the call connec-

Table 2 Simulation conditions

Item	Value
Service area	Tetragonal lattice model (12×12 model)
Number of channels	• Terrestrial-only system 160 terrestrial channels • Terrestrial and satellite integrated system 80 terrestrial + 80 satellite channels
Call attempt	Random (Poisson process) Average 30 (seconds)
Call duration time	Exponential distribution with an average 30/480 (seconds)
Number of terminals	2000 nodes
Movement speed	20(m/s) / 1(m/s)
Movement model	Random walk (4 directions)

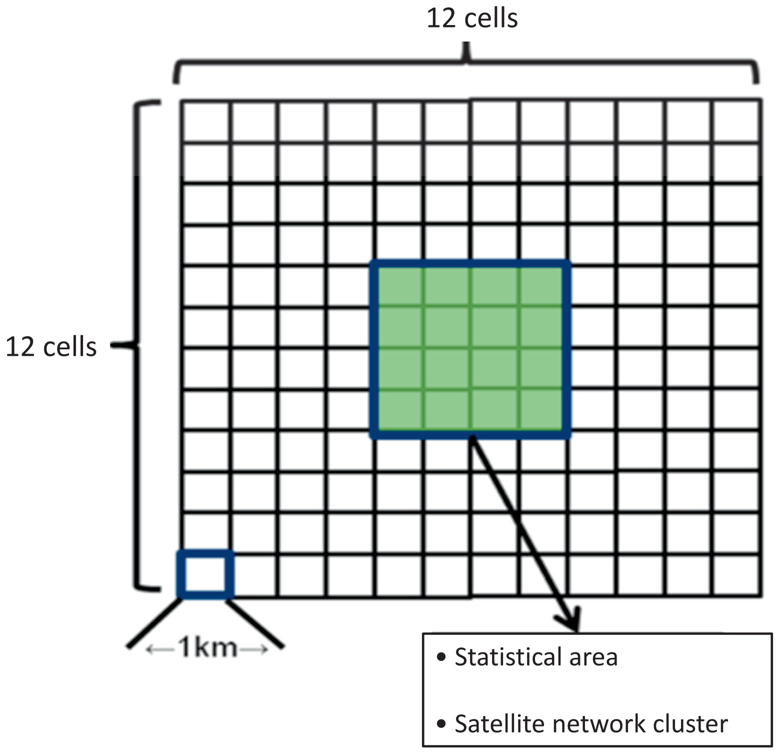


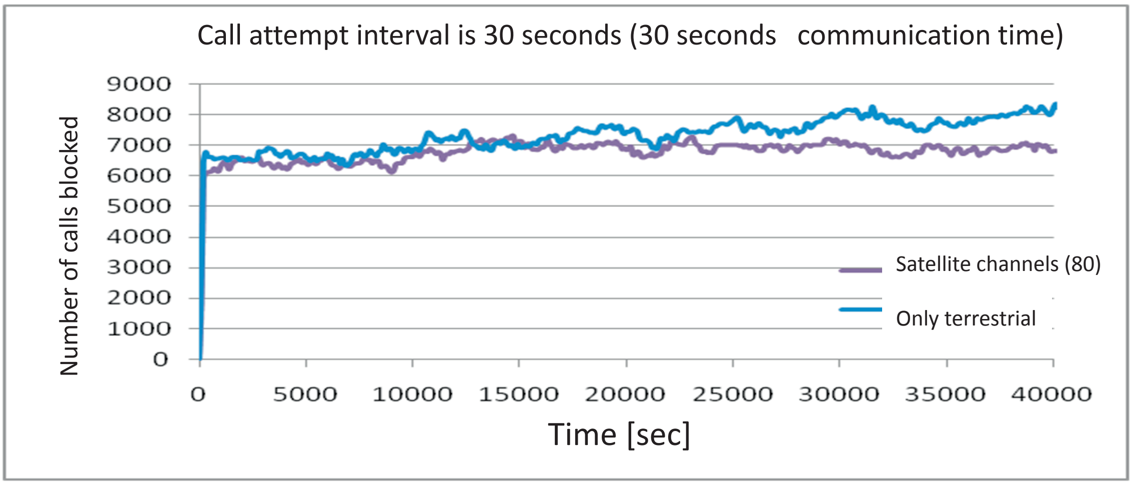
Fig. 6 Cell layout model

tion rules described above.

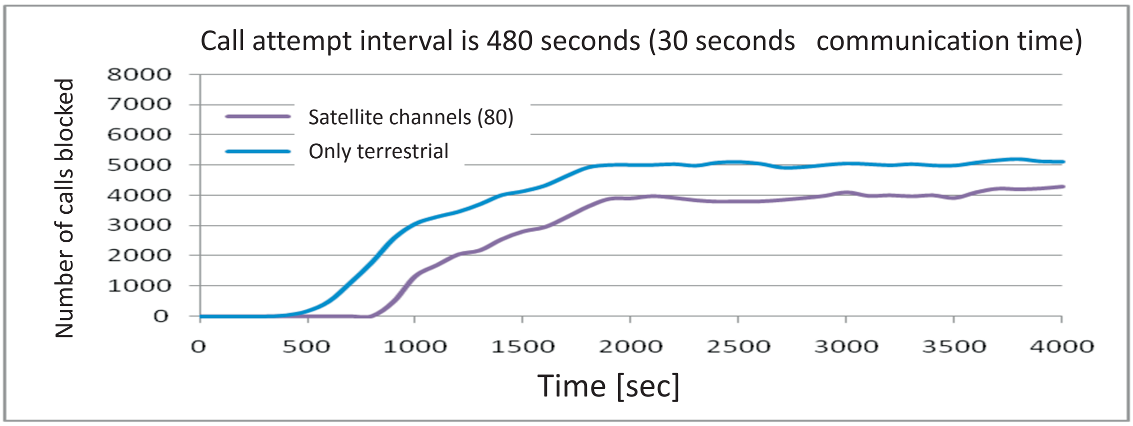
In the simulation conditions given in Table 2, we compared the effectiveness of two cases: frequency sharing is done (equivalent to STICS), and, frequency sharing is not done (equivalent to terrestrial only). Here, if the terminal is moving at low speed, then we assume handovers will occur infrequently, so we used the number of calls blocked as the evaluation index. On the other hand, if the terminal is moving at high speed, then we use the number of failed handovers as the evaluation index, and thereby evaluated the degree of effective utilization of the system's frequency resources.

Figure 7 shows the simulation results if the terminal is moving at low speed (1 m/sec.). Figure 7(a) shows the call attempt interval is relatively short (30 seconds), and Fig. 7 (b) shows results in the case when the call attempt interval is a relatively long (480 seconds). Immediately after the simulation starts, it is in an unstable state where few calls were blocked, but after some simulation time passes, the number of calls blocked converges on a certain value. If we compare when frequency sharing is done (80 satellite channels) vs. when frequency sharing is not done (only terrestrial), we see that frequency sharing has fewer blocked calls. That difference does not depend on the call attempt interval; it is about 1,000 calls/second.

Next, Figure 8 shows the simulation results if the terminal is moving at high speed. Figure 8 (a) is the case where frequency sharing is not done in a terrestrial-only system, and Fig. 8 (b) is the case where frequency sharing is done with a satellite system like STICS; call attempt interval and call duration time are both 30 seconds. If frequency sharing is not done in a terrestrial-only system, then for about 100 calls, there are no free channels at terminal handover time, so communication is not possible, resulting in forced termination at handover (HO failure). This is because the number of required channels of each cell changes due to handover, and bias occurs in the number of required geographical channels, but in the case of

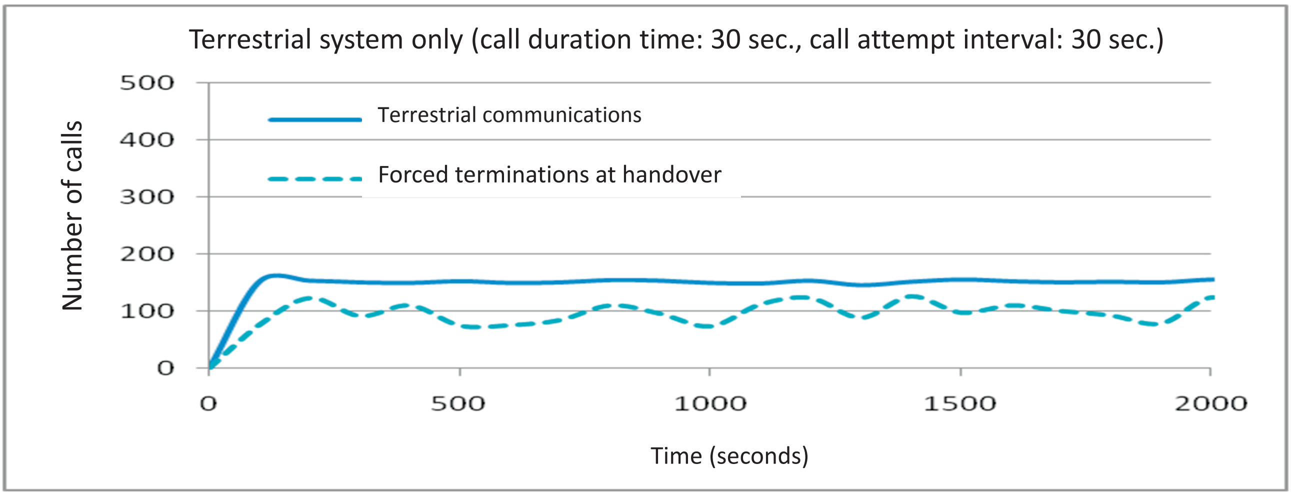


(a) Call attempt interval is 30 seconds

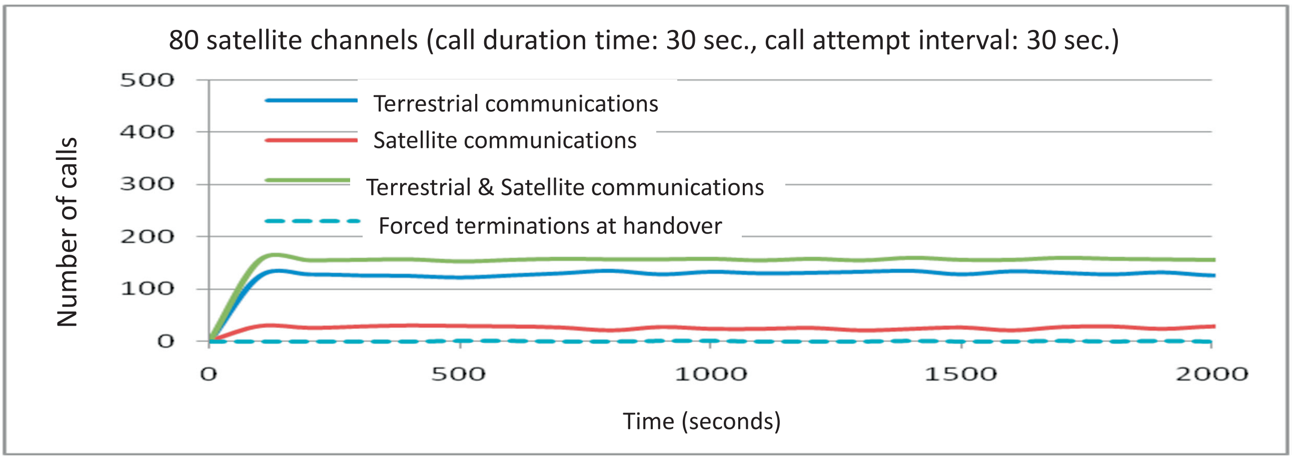


(b) Call attempt interval is 480 seconds

Fig. 7 Simulation results (with terminal moving at low speed (1 m/sec))



(a) No frequency sharing (terrestrial only)



(b) With frequency sharing (equivalent to STICS)

Fig. 8 Examples of simulation results (with terminal moving at high speed (20 m/s))

only terrestrial cells, each cell has a fixed number of 10 channels, so it cannot handle changes in the number of required channels, and forced termination at handover occurs easily. On the other hand, if frequency sharing is done with a satellite system, there are no forced terminations at handover. This could be because if there is frequency sharing with satellites, the satellite channel can be used at each terrestrial cell, so it can handle bias in the number of required geographical channels of each cell due to handover. In Figure 8 (b), forced termination at handover does not occur, and there are about 10 calls that communicate with the satellite system. Considering this, the terrestrial-only system had terrestrial forced terminations at handover in about 100 calls, but forced terminations at handover do not occur in STICS that does frequency sharing, so we can see a big improvement.

These results show that a system like STICS that does frequency sharing with a satellite system uses frequency resources more effectively than a system that does not share, so the number of blocked calls and number of forced terminations at handover can be reduced.

7 Conclusion

By frequency resource sharing between a terrestrial mobile communication system and a satellite mobile communication system, STICS features improved usage efficiency, and there is a need to study its overall system architecture, including providing functions for coordinated control of both systems.

Also, to handle hypothesized sudden traffic changes during a disaster, there is a need for dynamic controls for traffic changes. Thus, in this paper, first of all, an overall system architecture of STICS is proposed, which is compliant with a system architecture of 3GPP. Then, this paper described dynamic control for handling traffic changes during disasters, high speed handover process between the terrestrial mobile communication system and the satellite mobile communication system, and study of call admission control. Finally, we describe computer simulation results using a simple model, in order to show that STICS, which shares frequencies between terrestrial and satellite, uses frequency resources effectively, and can reduce blocked calls and forced terminations at handover.

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