2 Technologies for Emergency Communication Networks

2-1 For High Availability of Mobile Phone —Researches on Network Control Technologies in Disasters—

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Mobile phones come into wide use now and many people usually carry about and are familiar with using them. So, mobile phone becomes a very useful communication tool in large scale disasters. But it often cannot use, because congestion occurs owing to large demand of calls by which people wants to know their family with accidents or without accidents, non-functional base stations occur owing to cable cutting or long time power failure. As countermeasures to these issues, we study the holding time limitation and the emergency multi-system access, in the project of researches on network control technologies in disasters. This paper describes the outline of our studies.

Keywords
Mobile phone, Congestion control, Non-functional base station, Holding time limitation, Multi-system access

1 Introduction

Cell phones are now widely used and many people usually carry them about and are familiar with using them. Therefore, the cell phone has become a very useful communication tool in the event of large-scale disasters, such as earthquakes. If the power goes down, communication devices, including multifunctional telephones, personal computers and routers, cannot be used in ordinary households that do not have an uninterruptible power supply. In these circumstances, the cell phone is likely to be the only means of communication. However, most cell phone terminals often become unusable due to congestion caused by the large increase in demand as people calls their friends and family to confirm that they are safe. In addition, cell phones may become unusable in an area covered by a base station that goes down due to severed cables or an extended power failure. Considering communication networks when a disaster occurs, it is very important to ensure that communication networks are available for general calls, and more importantly, emergency calls in disasters including 110, 118, and 119 number calls, to prevent damage and to ensure security.

This paper focuses on problems such as congestion and non-functioning base stations when a disaster occurs and outlines the current measures, including ensuring the availability of emergency calls, and our studies concerning the holding time limitation and emergency multi-system access in relation to the research project on network control technologies in disasters.

Chapter **2** describes the congestion that occurs during a disaster and the call admission control, which is the current measure for handling congestion. Chapter **3** outlines our studies on the holding time limitation. Chapter **4** describes the non-functional base station and the current measure, Chapter **5** gives an outline of the studies on emergency multi-system access, and Chapter **6** is the conclusion.

2 Congestion and call admission control

In the Great Hanshin earthquake, fixed-line phones experienced congestion due to a load of up to fifty times that in normal time[1]. However, the number of cell phone subscriptions was approximately four million at that time, and congestion was not a major problem. It was even said that cell phones are disaster-proof[2]. Cell phones became generally available after this disaster and many people wanted to use it to confirm the safety of their family and friends in the event of a disaster. In the Miyagi-ken Oki earthquake in May, 2003, total traffic volume made from cell phones in Tohoku region from right after the earthquake to three hours later ballooned to approximately thirty times as much as that in normal time, causing congestion that prevented many calls from getting through[3]. Moreover, in the Niigata-ken Chuetsu earthquake in October, 2004, communication into and out of Niigata prefecture increased dramatically when the disaster occurred and lasted for about for about six hours. At its peak, the level of call demand was approximately 45 times greater than that in normal time[4]. Congestion has also occurred in subsequent major earthquakes.

Call admission control is currently used as a measure against congestion to ensure the availability of emergency communication. Call admission control involves disabling a percentage of call demand from general terminals, other than priority terminals, based on restriction information broadcast signal from the base stations. With regard to securing the availability of emergency communication, Article 8 of the Telecommunications Business Act (TBA) stipulates: “When an emergency such as natural disaster or incident occurs or is liable to occur, emergency communication that is necessary for preventing disaster, or ensuring rescue operations, traffic flow, communication, electricity supply and the maintenance of order shall be treated as a priority.” In addition, when necessary, telecommunication carriers are supposed to be able to stop part of the telecommunication service in accordance with criteria provided by ministerial order of the Ministry of Internal Affairs and Communications (MIC). Also, the organizations specified in Article 56 of the Ordinance for Enforcement of TBA may have priority terminals. Specifically, MIC public notice No. 584 identifies a wide range of organizations, including government departments such as the meteorological bureau, the Fire and Disaster Management Agency (FDMA), the National Police Agency (NPA), prefectural and city governments, municipal governments, electric power companies, gas companies, telecommunication carriers, educational institutions from preschools to universities, and financial institutions from credit unions to the Bank of Japan[5]. If each of these institutions possesses many priority terminals, it is highly anticipated that congestion will become a problem for priority terminals in the future.

Since the call admission control reduces the traffic volume that represents the communication volume, it serves not only to ensure emergency communication, but also to avoid system failure due to overload.

In terms of the rate of call admission restriction, in the Chuetsu Earthquake for example, up to 75% of call demand was restricted in the base stations of a cell phone operator in the Kanto and Koshinetsu districts, and up to 87.5% were restricted in base stations in Niigata prefecture[4]. With such restriction rates, it is almost impossible to use general cell phones. Therefore, each cell phone operator provides a message board service during disasters that uses the web function on cell phones. The message board ser-

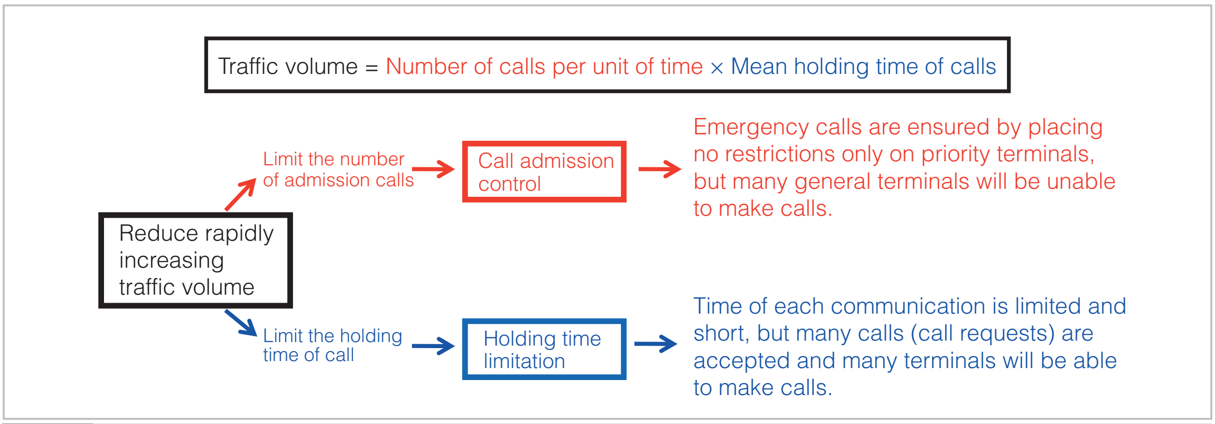

Fig.1 *Call admission control and holding time limitation*

vice enables members of the public to confirm the safety of their family members and friends[6]-[9]. In addition, an emergency messaging service[10][11] to store voice messages is also provided, which was developed in response to the Great Hanshin earthquake.

3 Holding time limitation

With regard to the key points in confirming safety, the results of a questionnaire show that 76.2% of respondents attach importance on immediate and direct connection to the other party, even for a short time (30 seconds or so), 15.8% want certain direct connection to the other party even if it is not immediate, and 6.2% want confirmation via a recording medium, such as a message board, even if it is not possible to make have an immediate connection to the other party[12]. These results prove that there is a strong demand for direct connection, i.e., a phone call. It is important, therefore, that many phone calls can be made in times of disaster, and for this reason, the holding time limitation was proposed[13][14]. Various studies have been made for practical use in this research project.

The traffic volume is the total holding time of calls per unit of time. It can be expressed by multiplying the number of calls per unit of time by the mean holding time of calls, as shown in Fig. 1. While call admission control limits the number of calls to reduce the traffic volume, holding time limitation limits the communication time to reduce the mean holding time and to lower the traffic volume. With call admission control, emergency communication is ensured by placing no restriction on priority terminals, but communication with many general terminals becomes unavailable. On the other hand, with holding time limitation, many calls (call requests) can be accepted although the time of each communication is limited and short.

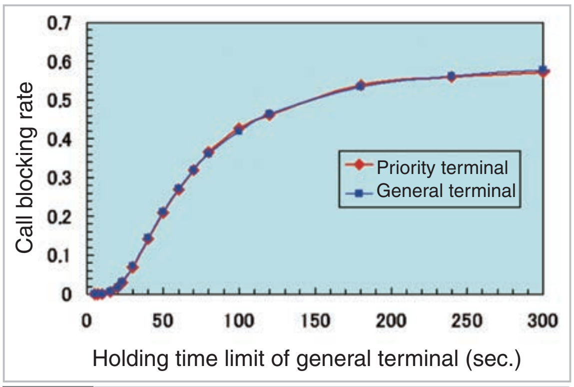

Fig.2 *Characteristics of call blocking rate in holding time limitation*

It is inappropriate to limit the holding time of priority terminals. The results of simulation[15] limiting the holding time of general terminals only is shown in Fig. 2. With a call volume five times greater than that in normal time and a mean holding time of 120 seconds in the case where no holding time limitation is placed, the incidence ratio of priority terminals to general terminals is 0.03:0.97. The shorter holding time limit, the shorter the communication time. Therefore, more channels become available and are allocated to other calls. Then the call blocking rate is reduced and more calls are accepted. Moreover, since the channel is evenly allocated to priority terminals and general terminals, the call blocking rate of both is the same, satisfying both requirements of ensuring emergency calls with priority control and calls with general terminals, even for a short time.

Figure 3 shows the result of considering the main characteristics of holding time limitation and call admission control, listing the advantages and disadvantages of both. The mean holding time limitation include the fact that many general terminals can perform communication and that emergency communication is ensured with a reduction of call blocking rate. Even in important organizations for preventing disaster, rescue operations and so on, not every terminal is specified as a priority terminal, and calls made from general terminals in such organizations to priority terminals are also important. Since such calls from general terminals can be made with a higher success rate, it is thought to be beneficial to those organizations.

Moreover, since the demand for communication in times of disaster is strong, call origination is often repeated when communication is unavailable, and the demand for communication takes a long time to die down. Achieving as much communication as possible with holding time limitation will reduce the communication demand itself as well as congestion. In particular, since it is difficult to make a call during a disaster, some people stay on the line for a long time once their call is successful[16]. It is assumed to be important that users requiring communication, including the users of general terminals, have more opportunity to use the lines of communication by using the holding time limitation to prevent people from staying on the channel for extended periods.

However, holding time limitation has the disadvantage that the holding time is shortened. To handle this, setting a limit on the holding time limitation is necessary so that the communication becomes meaningful. Sudden disconnection is inconvenient for the users and it also motivates them to retry. Therefore, it is important to motivate the user to make a brief call by informing the user at the start of the call with a display or sound that the hold-

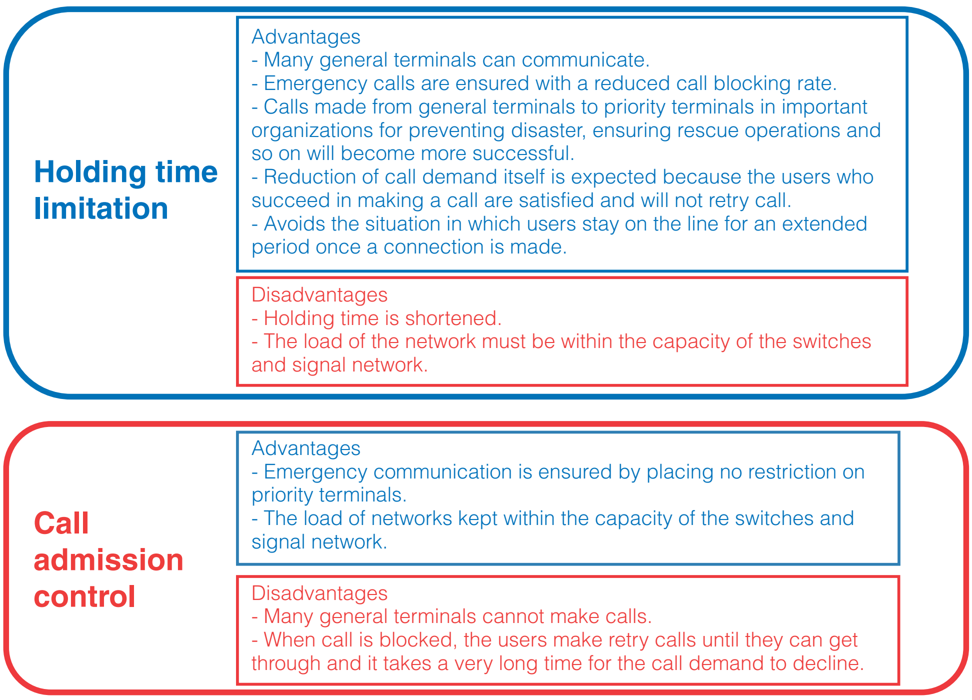

Fig.3 *Main characteristics of holding time limitation and call admission control*

ing time is limited and its time limit, as shown in Fig. 4. It is also important to warn of the disconnection by vibrating the terminal, for example, before disconnection.

The holding time limitation concerns use of user traffic channel, and the load on the switches and signal network must be considered in the real communication network so that the limitation is controlled within the range of their capacity. Therefore, with the current system, it would be appropriate to combine the call admission control and holding time limitation, as shown in Fig. 5, to fully restrict the call admission within the range of the capacity of switches and signal network before implementing holding time limitation on general terminals. This combination will also be able to utilize the advantages of both methods.

In addition, during the research project for network control technologies in disasters, we also performed theoretical analysis on traffic in the case when holding time limitation is applied[17].

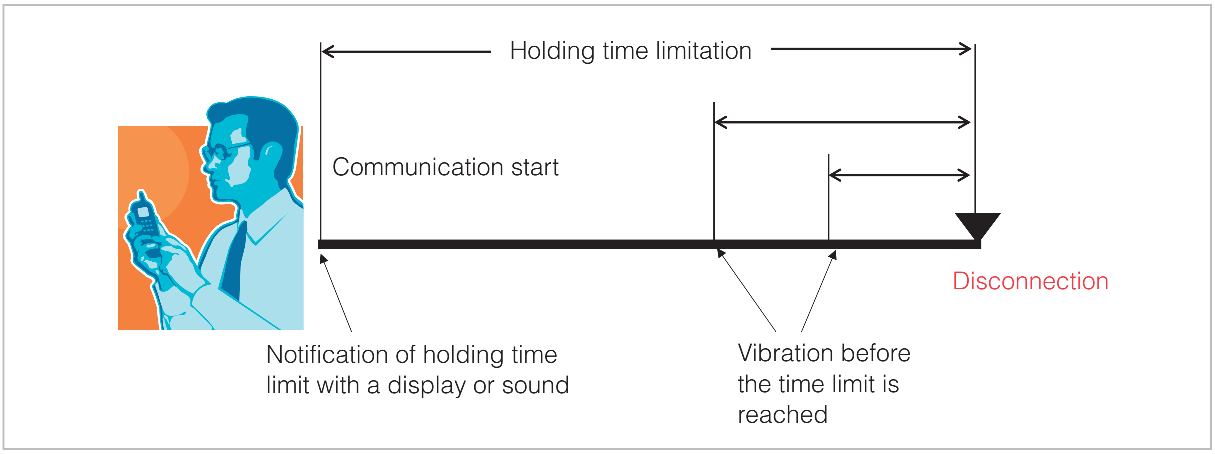

Fig.4 *Example of notification of holding time limitation and disconnection warning*

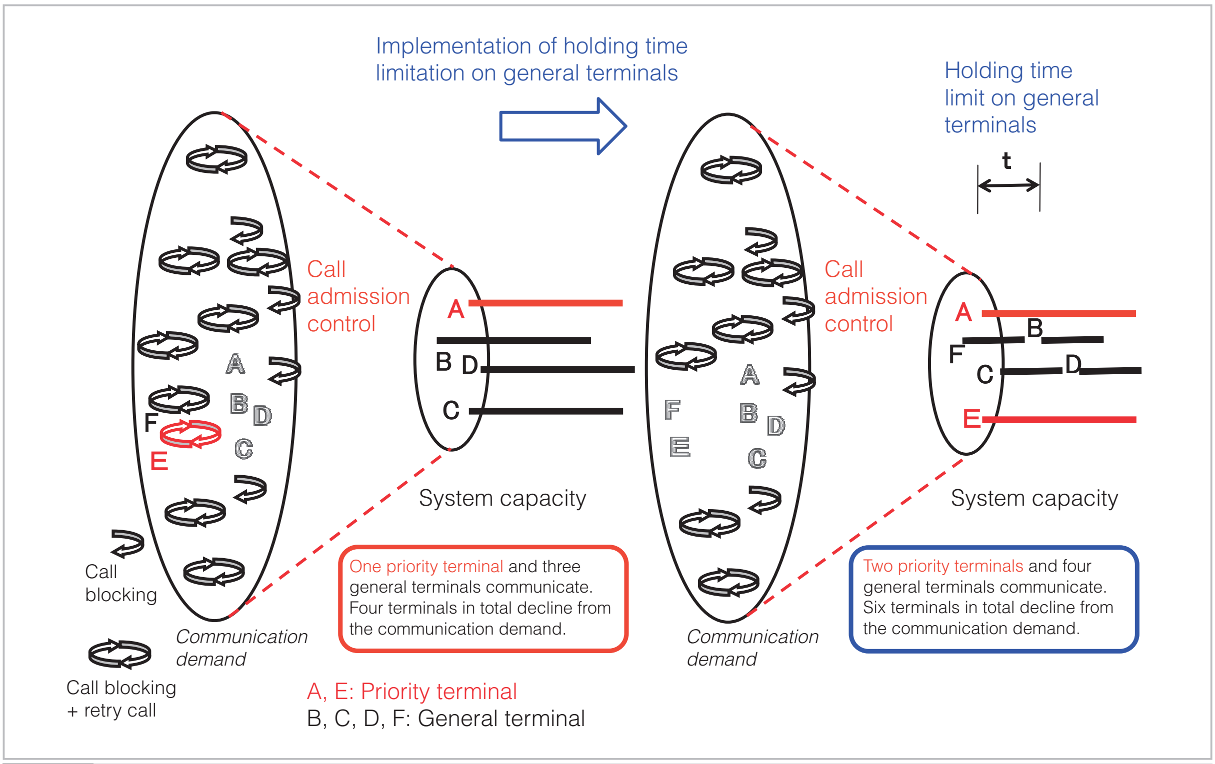

Fig.5 *Control combining call admission control and holding time limitation*

4 Problem of non-functioning base station and countermeasures

In the Chuetsu earthquake, the base stations ceased functioning due to power failure and the disconnection of transmission lines to the base stations, which presented a problem. When a power failure occurs, the base stations operate using the backup power supplied by batteries. However, the batteries ran down because of the extended duration of the power failure and because vehicles that provide power were unable to gain access because the roads were cut. In one cell phone operator, a total of 61 base stations went down[4].

Cell phone operators take various measures to prevent base stations from going down. When deciding where to locate the base stations, they consider the resilience of the ground and whether it is adjacent to facilities that handle dangerous materials, and they use earthquake-proof and fire-resistant buildings. Multiple routes are provided for the relay lines. Each base station is equipped with batteries, and switching centers are equipped with emergency power generators as well as batteries. Vehicles that supply power are deployed when the batteries go flat or when the emergency power generators fail, and portable motor generators are deployed in case the roads are cut[18][19].

If base stations go down despite these precautions, adjacent base stations step in to temporarily cover the areas where the base stations have failed by controlling the reception angle of the antennas. Alternatively, mobile base stations are deployed or cars equipped with radio facilities for satellite communication are put in action to respond to disconnected transmission lines[18][19].

5 Emergency multi-system access

The rates at which base stations fail in a disaster differ depending on the system that the cell phone operators use. For example, in the case of the Chuetsu earthquake, a total of 61 base stations failed, as indicated above, but 37 base stations failed in other cell phone systems, which is 40% lower than these figures. In addition, as many as 91 base stations failed in another cell[4].

The increase in communication also differs depending on the system that the cell phone operators use. In the Chuetsu earthquake, as indicated above, communication increased significantly for about six hours after the disaster, and at one point, it reached approximately 45 times the level during normal times. However, in the case of another cell phone operator, it was approximately 17 times greater than normal, while in another, it was three to four times greater than normal[4].

Considering these conditions, which differ depending on the cell phone system, it is thought that measures across the frames of the cell phone system of each operator are effective in securing communication from terminals in areas covered by non-functioning or congested base stations, with efficient usage of frequency and high reliability. Therefore, we propose the emergency multi-system access shown in Fig. 6, which enables access and communication to the base stations of other cell phone systems when it is impossible to communicate with the base stations of the subscribing cell phone system to which connection is usually made, due to congestions or a failure. The measures in which the linkage of cell phone systems are especially required to ensure important communication and emergency calls relate to human life and the reduction of damage.

However, there are various areas of study that target creating highly reliable and efficient emergency multi-system access. The areas include the evaluating the characteristics of the emergency multi-system access, the method of approximating the volume of important communication and emergency calls, which differ depending on the type, scale and time of the disaster, and the affected area, which may be an urban center area or the suburbs. The areas of study also include evaluating the characteristics of the call accep-

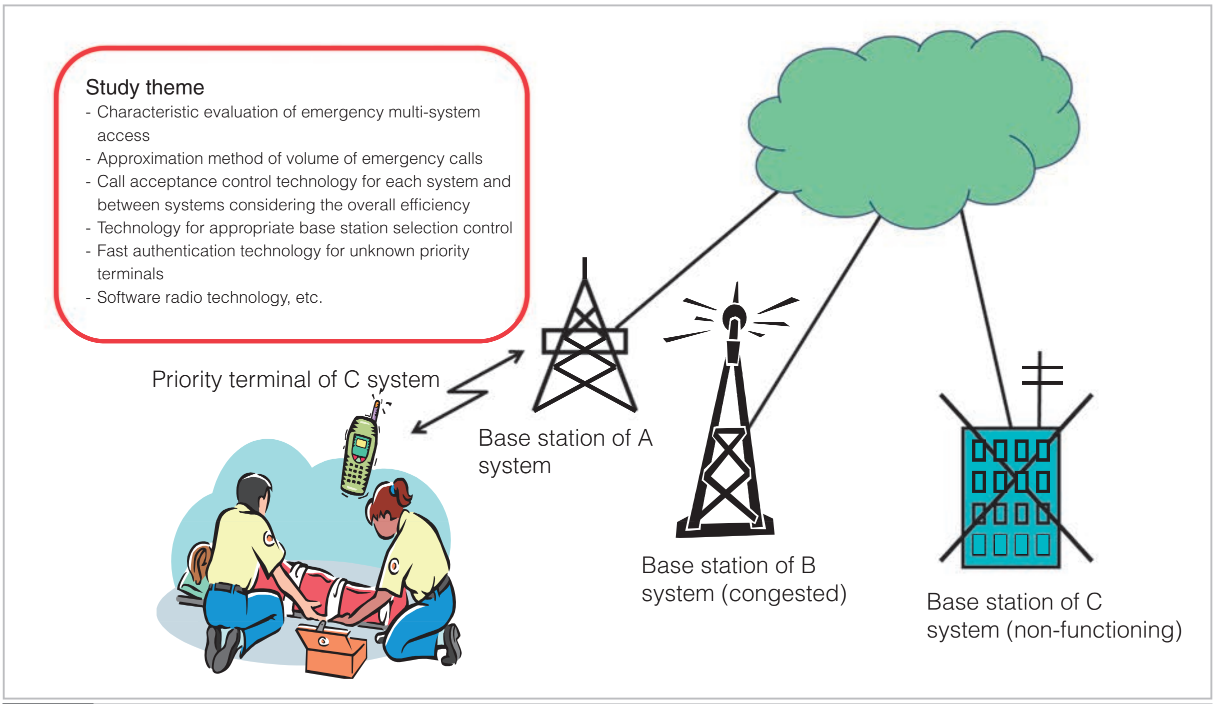

Fig.6 *Emergency multi-system access*

tance control technology for each system and between systems, considering the frequency usage efficiency in all cell phone systems beyond the border, technology for appropriate base station selection control considering the propagation conditions and congestion, fast authentication technology for unknown priority terminals, and the development technology of software radio[20] with fast and highly reliable download of software, which enables a terminal to access the base stations of various radio systems.

During a research project for network control technologies in disasters, we performed simulations to evaluate the network characteristics, such as call blocking rate when there are non-functioning base stations in the service area, forced call termination rate during communication and reception CIR. The simulations were conducted under the condition of high traffic load, using a model constructing the microcell networks shown in Fig. 7, which cover urban districts such as Manhattan as the service area, assuming cases when non-functioning base stations exist randomly and when they are concentrated in certain areas. The results show that the call blocking rate and

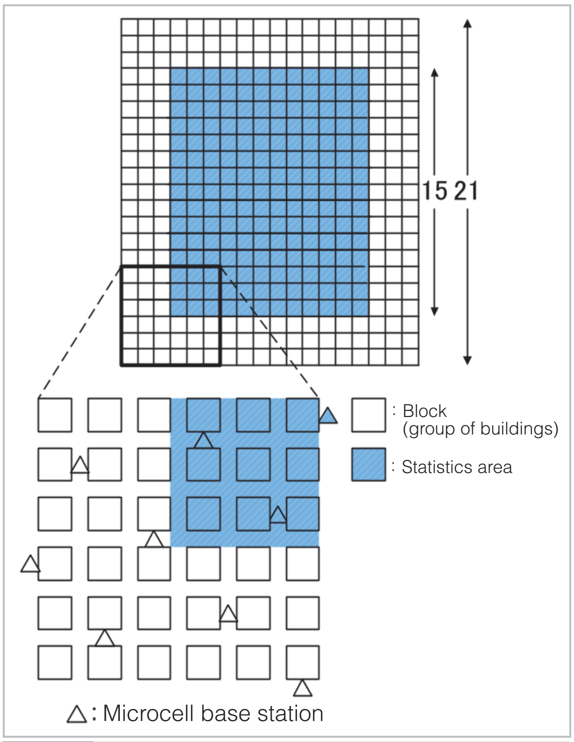

Fig.7 *Service area composition*

forced call termination rate increased because the distance between terminals and base stations increased and the whole capacity of the network decreased. However, the average reception CIR increased because the interference decreased due to the lower number of active calls[21]. It was also shown that the terminals in the area where non-functioning base stations were concentrated had a high call blocking rate, because such terminals frequently made connection requests to distant base stations that were adjacent to the area where non-functioning base stations were concentrated and connection requests were also concentrated[21][22].

With regard to the problem that the call blocking rate increases in the area where non-functional base stations are concentrated, we performed simulation evaluation on characteristics when emergency multi-system access is used, assuming the case when the system with concentrated non-functional base stations and normal system exist in the same area. The result showed that the communication blocking rate, which represents the rate that communication is eventually unavailable, of the system with the area where non-functional base stations were concentrated was greatly improved in the center of the most problematic area where non-functional base stations were concentrated[23]-[26]. In addition, we suggested selecting base stations with the highest received power in the base stations that can communicate. The result was a reduced communication blocking rate in the W-CDMA network[27][28]. Moreover, we suggested acceptance control between systems, which determines acceptance from another system, considering the conditions of the call blocking rate of our own system[29].

6 Conclusion

Cell phones are a very useful communication tool in the event of large-scale disasters, such as earthquakes, as they are widely used and many people usually carry them and are familiar with using them. With regard to cell phones, this paper focused on the problems of congestion and non-functioning base stations. The paper outlined the current measures that are used, including ensuring the availability of emergency communication and presented our study on the holding time limitation and emergency multi-system access, which we have proposed. In research other than that described above, it was also found that the QoS rapidly deteriorated when a high load is applied under the environment of IEEE802.11e, which is standardized in IEEE for the security of QoS of wireless LAN[30][31].

Although it is very difficult to ensure cell phone communication in situations where there is congestion or non-functioning base stations, there is strong demand for communication using cell phones in the event of a disaster, not only amongst people involved in important communication but also in the general public. It is important to satisfy more cell phone users by studying and combining various technologies.

Moreover, a disaster is a special situation but emergency calls (including 110, 118 and 119 number call) occur and a communications system is truly needed. When we think of the future cell phones, ensuring the availability of important communication and emergency calls using cell phones, even in the event of large-scale disasters, while satisfying general users, is one of the important requirements of cell phone networks. A study, starting with the fundamental architecture, is needed.

On March 11, 2011, a great earthquake with a magnitude of 9.0 occurred, focused on a broad area from the coast of Iwate prefecture to the coast of Ibaraki prefecture, extending for about 500 kilometers north and south and about 200 kilometers east and west. The earthquake triggered a massive, devastating tsunami, reaching heights of ten meters in some areas. In this East Japan Great earthquake and tsunami, up to 14,800 base stations of four cell phone operators failed and cell phones were not available in many areas. In the Tokyo metropolitan area, the trains stopped and many people could not go home. Communication with cell phones was not possible due to congestion. We keenly feel the importance of the subject of this research. We have the strong expectation that studies on the availability of cell phones in disasters will continue to be promoted.

Acknowledgements

We wish to express our deepest thanks to Dr. Osamu Takizawa, Group Leader of the Disaster Management and Mitigation Group, who helped us in many ways in conducting the research and who also gave us the opportunity to write this paper.

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(Accepted March 30, 2011)

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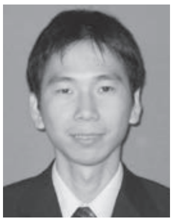

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