2-2 Ad Hoc Based Emergency Communications Models for Wide-Scale Disaster Management

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In case of disasters, telecommunication infrastructure might be destroyed rising the demand of fast-deployment emergency wireless communication systems in order to provide communication services to victims and rescue teams. Recently, mobile ad hoc communications is considered as an efficient solution for emergency communications in disaster areas. Beside the advantages in terms of fast deployment and self-configuration capability, ad hoc communications networks show less performance in large scale networks. In this paper, we first discuss some proposed ad hoc based emergency communications models for wide scale disaster management. Then we present a hybrid system model of wireless data networks for emergency communications in disaster areas. Due to limited radio resource, resource management plays an important role to system performance and provide user's QoS. We propose a resource management scheme for the hybrid wireless networks in which selected powerful end users operate as temporary relay hosts (TRH) in order to utilize the system resource efficiently. The scheme combines network controlled handover, resource allocation and admission control and takes advantages of adaptive transmission rates and multi-hop/relay communication mode. Performance results obtained by computer simulation show that using the proposed resource management scheme can reduce the connection blocking probability i.e. increase the quantity of simultaneous connections.

Keywords
Emergency communications, Ad hoc networks, Resource management

1 Introduction

As severe disasters e.g. earthquake, hurricanes might destroy telecommunication infrastructure, an efficient communication system is needed in disaster areas in order to exchange information between rescues teams, between victims and rescue staffs etc. Victims use the system to access emergency information and communication services e.g. victim information database[1]. Because the deployment of emergency communication systems has to be fast and flexible, wired communication technologies are not suitable because they require many days to establish communication infrastructure. Communication systems for emergency and disaster management should base on wireless technologies such as 3G cellular[2][3], WiMAX[4].

Mobile ad hoc communications is considered as an efficient method for emergency communications in disaster areas because of its self-organizing and fast deployment capabilities. Mobile ad hoc networks (MANET) face the problem of scalability in terms of throughput when the network size increases. In wide scale disaster areas, the number of mobile nodes might be very high thus that would cause the degradation of network throughput. Another problem is the connection availability i.e. not all mobile nodes can be reached in the area of low user density. In order to solve the problems, hybrid ad hoc based emergency communications models have been proposed recently.

As shown in [5], an ad hoc based disaster area wireless network (DAWN) consisting of communications nodes of helium filled balloons with fixed locations, helicopters, trucks and humans has been proposed. Connections between nodes exploits Free Space Optical (FSO) or Radio Frequency (RF) links where RF links are used as backup paths in case FSO links have bad quality. A multipath routing protocol has been designed for the network that is able to minimize packet loss, delay while maximizing packet delivery ratio. This network architecture is efficient for providing emergency communications in wide areas and can be deployed to other applications such as military missions, on-the-fly conference.

Another similar research known as SKYMESH has been presented in [6]. SKYMESH is an ad hoc communication system which is as an urgent communication network backbone and built at 50–100 meters over the ground by using balloons. SKYMESH is used as an emergency communication network for large-scale natural disasters and for collecting information on disaster areas in order to support rescue, recovery and surveillance. Using balloons as transceiver stations is more appropriate than using helicopters or airships because maintaining balloons at fixed locations for many days is much easier at lower cost. Ad hoc communication is provided by using 802.11 WLAN and Optimized Link State Routing (OLSR) protocol. Experiment results show the efficiency of SKYMESH for emergency communications in large disaster areas.

Combinations of satellite and ad hoc communications for wide scale disaster areas have been investigated in many researches. As described in [7], a multi-tier Wi-Fi/WiMAX/Satellite network has been proposed for emergency communications. Each rescue team forms a MANET which provide communications between team's members. The gateway of each MANET is equipped with a WiMAX subscriber unit connected with a WiMAX base stations. The WiMAX base station connects to the outside headquarter via a satellite link. Inter-team communications is carried out via the WiMAX station instead of using satellite link so that inter-team communications delay is reduced. System simulation has shown the architecture can support VoIP and data services in terms of low end-to-end delay and high capacity.

Another research effort described in [8] is to design a mobile ad hoc satellite and wireless mesh networking for emergency communications scenarios. In this system, ad hoc mesh networking plays an important role and mobile IPv6 is deployed for mobility management in order to support transparent and seamless movement of end terminals between local coverage areas. Satellite communications is used for providing Internet connectivity to the disaster site. Vehicles which are equipped with Satellite Universal Mobile Telecommunications System (S-UMTS) devices become connecting points of ground ad hoc mesh networks with outside areas. Connectivity between vehicles is provided through mobile ad hoc mesh networking. A vehicle can act as mobile router in critical areas where mobile terminals form Wi-Fi 802.11 and ad hoc networks. Mobile routers connect local Wi-Fi 802.11 networks with the core mobile ad hoc mesh networks. IEEE 802.11s is assumed as the relevant standard for mesh and ad hoc networking in this architecture. In order to provide seamless mobility to Public Safety units, proxy mobile IP version 6 (PMIPv6) has been exploited. Authors have shown that PMIPv6 can support efficient use of wireless resource and reduce handoff latency.

Another testbed of emergency communications systems denoted as DUMBONET[9] based on a combination of mobile ad hoc networks, a satellite IP network and terrestrial Internet has been implemented. The disaster stricken field might include several sites. Each rescuer uses a Wi-Fi capable mobile device such as a laptop or a personal digital assistant (PDA). Rescuers residing in a disaster site connect with each other via ad hoc communications mode. One or several rescuers might be equipped with satellite communications supported devices to maintain the connectivity between disaster sites or between disaster sites and the command headquarter center. A virtual private network (VPN) is deployed in order to hide the network heterogeneity caused by different networking technologies including satellite, ad hoc communications and terrestrial Internet. DUMBONET also implements multimedia communications, sensor applications and human identification by face recognition.

The combination of terrestrial cellular and ad hoc communications is also considered as a candidate solution for wide scale disaster areas. In disaster areas, users can locate in locations where users cannot connect to the nearest base station due to bad signal quality[10]. To provide services to users who are not able to connect directly to base stations, multi-hop/relay communication is proposed as an additional connection mode into cellular networks forming hybrid emergency mobile communication networks[10][11]. Using relay stations for enlarging cell coverage of cellular mobile networks has been introduced in [12]-[14] where relay stations can be either fixed or mobile stations to enhance the system capacity.

In our research, we proposed a hybrid system model of wireless data networks for emergency communications where particular end users can operate as relay stations temporarily. Differed with solutions proposed in [10][11], we take the importance of exploiting adaptive transmission rates and efficient resource management into account. We proposed a resource management scheme which combines network controlled handover, resource allocation and admission control. This scheme exploits advantages of adaptive transmission rates and multi-hop communications in order to provide a high quantity of simultaneous connections and satisfy user's minimum required throughput. We evaluated the performance of the proposed system and compare with those of conventional systems under different simulation scenarios.

In the next chapter, we describe the hybrid wireless system model for emergency communication networks. The proposed resource management scheme is presented in Chapter **3**. In Chapter **4**, a connection admission control algorithm is presented. Chapter **5** includes the performance results obtained by computer simulation. Finally, conclusion remarks are given in the last section.

2 System model

A wireless data network for emergency communications can consist of several fixed/mobile access point (AP) as shown in Fig. 1. Each AP broadcasts radio signal to users locating in a large coverage area with the radius R. The APs connect with a service and control gateway (SCG) which is connected to a backbone network, a network control center (NCC) and a disaster evacuation headquarter (DEH). The NCC performs functionalities of network and security management. The DEH's roles are to update information of disaster victims, coordinate and carry out evacuation activities[15]. User terminals (UT) e.g. cell phones, laptops, power PC belonging to victims and rescue staffs. They use emergency services, access to external information database and communicate with each other. UTs might be the facilities provided by the network provider as aggregated service access stations (e.g. UT3 in Fig. 1) for victims who are not equipped with communication devices. The number of APs depends on the size of the disaster area and the user density. Because the wireless resource is limited in terms of radio spectrum, even in the case many APs are provided, maximizing the system performance while consuming efficiently limited radio resource is still an important task.

In a cellular wireless model, there is only connectivity between an AP and UTs located in its coverage area. Because UTs might use different radio interface technologies with that of APs, there might be UTs who cannot get access via the AP. Fortunately, nowadays,

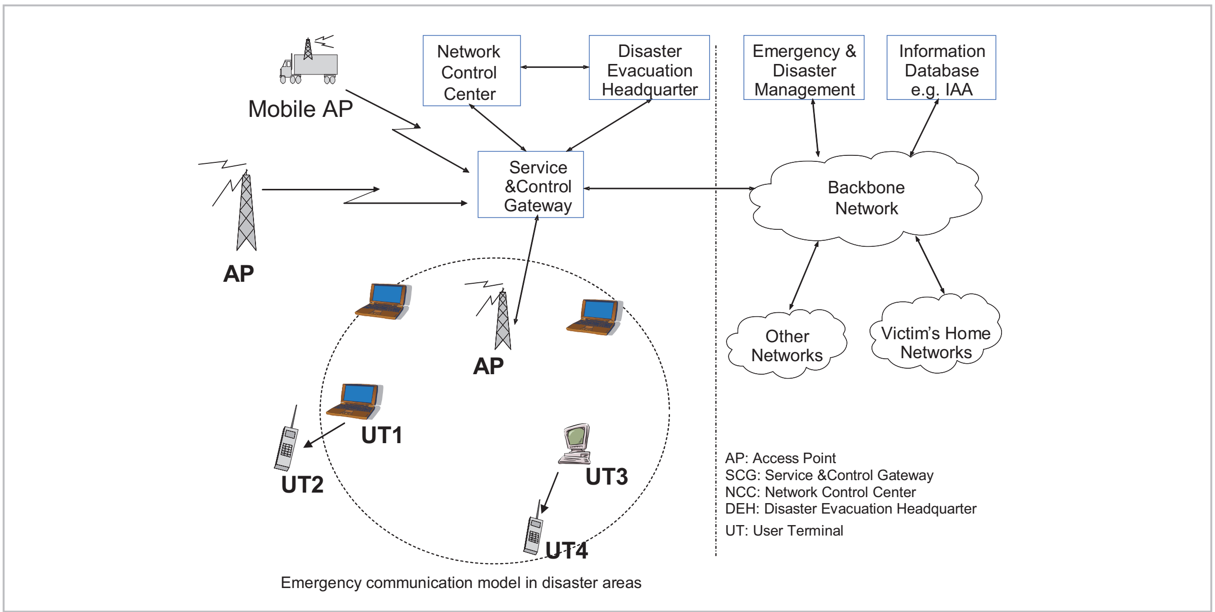

Fig. 1 System model for emergency communications

many communication devices can be embedded a second additional commodity standardized air interface such as IEEE 802.11b[16]. Also, there are many research efforts for IP-based ad hoc networking protocols, which have been carried out and standardized by the IETF[17]. Those advanced technologies will bring more opportunities to establish multi-hop/relay connectivity between UTs.

The multi-hop/relay connection mode is used in following scenarios:

- When a UT is located outside the transmission range of the AP (e.g. UT2 in Fig. 1), it will try to establish an ad hoc connection with other UTs e.g. UT1 if it is possible.
- When a UT is located inside the coverage area of the AP but it has not the common air interface with the AP (e.g. UT4 in Fig. 1), it will find a route to the AP via other UTs e.g. UT3.

In cellular ad hoc network models proposed in previous studies[10][11], all UTs are able to become relays or ad hoc nodes. In emergency situations, because most of UTs has limited battery lifetime, it is not relevant to apply such approaches. In our proposed hybrid system exploiting in emergency situations, we consider that only particular UTs equipped for rescue vehicles (e.g. UT1) or UTs which are aggregated service access stations (e.g. UT3) can have enough battery energy and processing capabilities. Such UTs are denoted as powerful end users. The AP can select them to operate as relay stations temporarily for establishing the multi-hop/relay connections with other UTs. The TRHs exploit adaptive transmission rates and adopt relay connectivity in order to provide better system performance and utilize the radio resource more efficiently. There are many research challenges such as suitable wireless technology for the multi-hop/relay air interface, networking protocols, signaling issues, auto-configuration, authentication etc. We consider issues of resource management for this hybrid network as described in the next chapter.

3 Resource management scheme

For the clear presentation, we will discuss our resource management scheme based on downlink transmission because downlink traffic is much higher than uplink traffic. For uplink transmission, the resource management scheme can be exploited with minor modifications. We consider a network scenario in case of disasters with fixed or moveable users where most of victims and many rescue staffs are in stationary situations for long period.

In order to utilize radio resource efficiently and increase downlink transmission rates, adaptive transmission rates based on user's signal quality have been proposed for 3G[2][3] and WiMAX networks[4]. An user receives data at an appropriate transmission rate which corresponds to a modulation and coding scheme depending on its signal quality, as illustrated in Fig. 2a.

Consider that there are M different transmission rates $\{Tr_1, Tr_2, \ldots, Tr_M\}$ sorted in ascending order corresponding to M transmission modes. As an example shown in Table 1, the minimum data transmission rate is Tr_1 which is corresponding to QPSK modulation with coding rate (R_C) of 1/2, denoted as QPSK-1/2. With fixed UTs, the AP can exploit power control to keep stable link quality of UTs.

When connecting directly to the AP, UTs download data by using a shared channel which carries data information in time slots (TS). Following parameters are used for analyzing performance of conventional systems where the multi-hop/relay communication mode is not exploited (Fig. 2a):

- Th^i_{req} : the minimum required throughput for user i
- t_{TS} : the duration of a time slot
- Tr^i_j : the transmission rate j of user i
- n^i_{TS} : the number of time slots per second is needed for user i in order to provide Th^i_{req}
- N_{TS} : AP's total number of time slots per second
- n_{TS} : total allocated time slots per second
- C_{TS} : time slot consuming ratio

$$n^i_{TS} = \frac{Th^i_{req}}{Tr^i_j * t_{TS}} \tag{1}$$

$$n_{TS} = \sum_{i=1}^{N_{user}} n^i_{TS} \tag{2}$$

$$C_{TS} = \frac{n_{TS}}{N_{TS}} \tag{3}$$

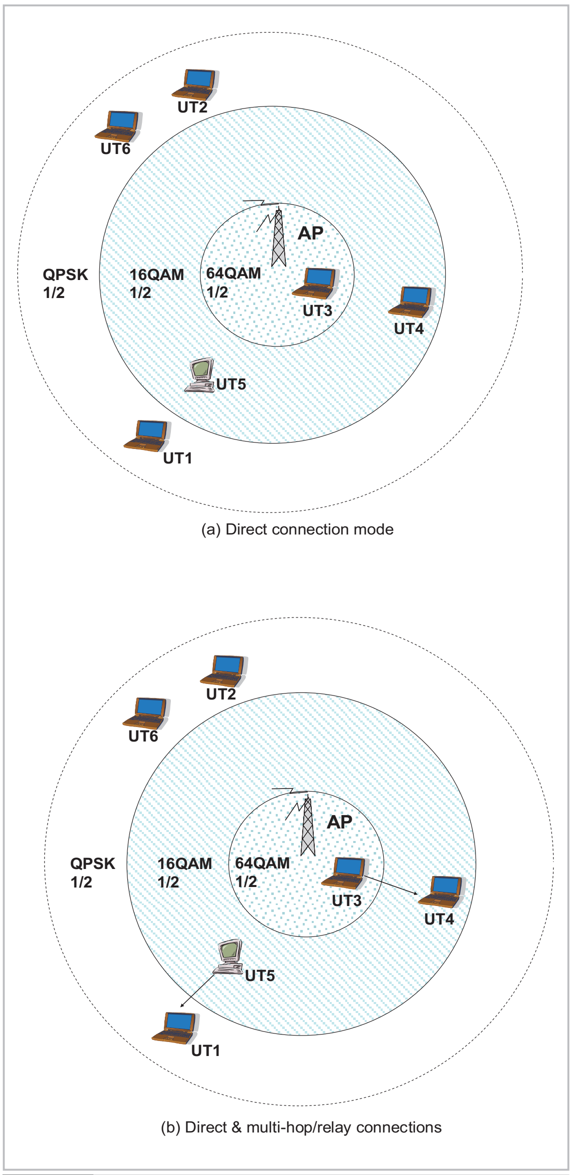

Fig.2 *Transmission properties and multi-hop/relay connection mode*

Table 1 *Multiple transmission modes*

Modes	1	2	3	4
Modulation	QPSK	QPSK	16QAM	64QAM
R_C	1/2	3/4	1/2	1/2
Tr_i	Tr_1	$1.5Tr_1$	$2Tr_1$	$3Tr_1$

The system is saturated i.e. all TSs (system resource) are consumed when C_{TS} = 1. An efficient resource management scheme has to be able to provide a high quantity of simultaneous ongoing connections (N_{user}) as well as guarantee the minimum required throughput to users.

We propose a resource management scheme which combines network controlled handover, resource allocation and admission control. Powerful UTs have strong processing capabilities and long battery lifetime. Fixed powerful UTs, who download data at high transmission rates, can operate as temporary relay hosts (TRHs) e.g. shown in Fig. 2b. As mentioned in Chapter **2**, TRHs can be UTs of rescue teams and PCs at aggregated service access stations provided by the network provider. By exploiting fixed TRHs, the APs is able to always maintain stable links between the AP and TRHs. UTs prefer to access the network directly via the AP in order to reduce the end-to-end delay.

An example of resource allocation is illustrated in Fig. 3. As shown in Fig. 2a, there are five active mobile hosts UT1, UT2, UT3, UT4, and UT5 who are connected directly to the AP, denoted as direct-mode UTs. Assume UT3 and UT5 are powerful UTs. Each user requires downloading data with a minimum guaranteed throughput. As an example, they need to consume 6 TS/s, 3 TS/s, and 2 TS/s, corresponding to QPSK-1/2, 16QAM-1/2, and 64QAM-1/2, respectively. Assume that there are two free TS/s currently (Fig. 3A). When the UT6 requests a connection, as UT6 has low link quality, 6 TS/s should be allocated to UT6. In the conventional system, the request will be rejected because there are only 2 free TS/s. As UT3 and UT5 have high transmission rates, they consume fewer TSs. UT1 has a lowest transmission rate than UT5 where as UT4 has lower transmission rate than that of UT3. In our proposed system, because UT1 can establish a relay connection with UT5, the network asks the UT1 to take a handover to UT5 (shown in Fig. 2b), thus there are five free TS/s (Fig. 3B). The network can force UT4 to handover to UT3 in order to save more TSs for UT6 (Fig. 3C). After these network controlled handovers are performed as illustrated in Fig. 2b, there are 6 free TS/s for allocating to UT6 and thus the connection request of UT6 is accepted. The UT3 and UT5 now are operating as TRHs. The UT1 and UT4 are denoted as relay-mode UTs (Fig. 3D).

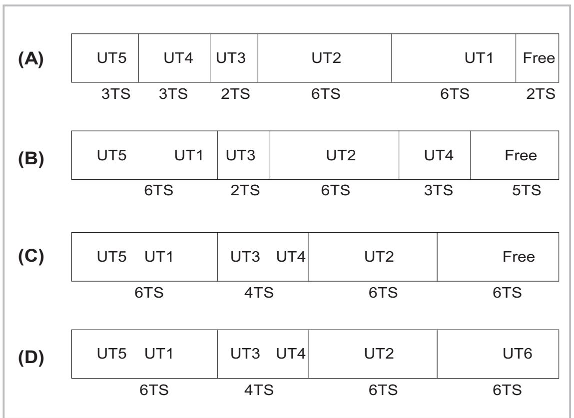

Fig.3 Resource management example

The resource allocation strategy is appropriate to the considered network scenario of fixed and moveable users because such users do not often change their locations i.e. their signal quality are stable. In the network scenario of mobile users, user's signal quality can be degraded resulting in unstable resource allocation. That can cause system saturation. Therefore, in the network scenario of mobile users, an amount of resource should be reserved in order to avoid the system overload. On other hand, due to frequent user mobility, relay-mode UTs can move out of range of its TRHs during its session duration. The UTs need to take intra-AP handover to either another TRH or the AP.

4 Admission control algorithm

We consider the single AP scenario i.e. there is no handover between APs (inter-AP handover). Assume that all UTs register their ID with the AP. In a practical system, the NCC might inform the AP a list of powerful UTs. The AP can select all powerful UTs as TRHs or only some of them depending on their signal quality. If a powerful UT is able to download data at very high transmission rate, it can operate as a TRH. Then, the TRH broadcasts a pilot signal periodically via its relay air interface. Other UTs can detect the signal and keep the address of the TRH to their tentative relay list. In the AP's interface, UTs update their signal quality to the AP. They update the AP their tentative relay list when a new TRH is added to or when a TRH is removed from the tentative relay list.

For an UT_m and one of its tentative relay stations e.g. UT_k, if the UT_k has available bandwidth in its relay air interface for the UT_m, the number of saving time slots (sTS_{mk}) which is gained when user m connects to the AP via user k is calculated:

$$sTS_{mk} = \frac{Th_{req}^{m}}{Tr_{i}^{m} * t_{TS}} - \frac{Th_{req}^{m}}{Tr_{j}^{k} * t_{TS}} \quad (4)$$

When a UT_i initiates a connection, UT_i sends a connection request to the AP including the minimum required throughput Th^i_{req}. As UT_i can download data at the transmission rate Tr^i_j, according to its link quality, the number of required time slots n_{TS}^{req} per second is estimated as below:

$$n_{TS}^{req} = \frac{Th_{req}^{i}}{Tr_{j}^{i} * t_{TS}} \quad (5)$$

An admission control algorithm for UT_i's connection request is proposed shown in Fig. 4. If the AP can immediately provide the amount of time slots, the AP will accept the connection request and UT_i is connected to the AP in the direct-mode. If not, the AP will perform a handover scanning procedure to find possible network controlled handovers in order to get more free TSs.

In the handover scanning procedure, first the AP will scan the list of direct-mode UTs to search for possible direct-to-relay handovers in order to get free time slots. The AP will find the relay k for UT_m if the relay provides the maximum value of saving-TS. Then the UT_m is added to the handover list. The AP will complete the scanning process when it finds enough available TS for the connection request. After performing the scanning procedure, if there is enough free TS, the AP accepts the request. Otherwise, it rejects the request. In any case, the connections of UTs who are saved in the handover list will be switched to their relays afterward.

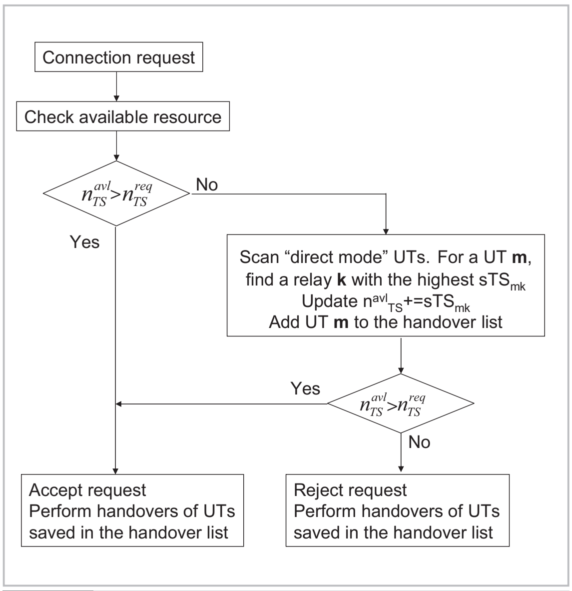

Fig.4 *Admission control algorithm*

In the next chapter, we compare performance of the proposed model with that of the conventional model. In the admission algorithm of the conventional model (exploiting adaptive transmission rates, no multi-hop/relay connections), if the AP can provide the required amount of TSs, the connection request is accepted. Otherwise, it is rejected.

5 Numerical results

The simulation is performed in a connection-level discrete event simulation model to study impacts of the combination of adaptive transmission rates and relay connectivity to system performance. In order to observe the effectiveness of the proposed resource management scheme, connection blocking probability is evaluated. The low blocking probability means the high acceptance possibility of connection requests i.e. high quantity of simultaneous connections.

A single access point simulation model is simulated where the AP has the coverage area of radius R. The AP transmits downlink data in time slots of 6.7ms. A square area of size D, which is equal to 2R, is simulated. The user's relay transmission range (d) is an important factor impacting to the system performance. The inter-arrival time of connection requests is negative exponentially distributed. When there is a connection request, it is assigned to a UT who is uniformly distributed in the simulation area. Assume that if a connection request assigned to a UT is accepted, the UT maintains the communication during a certain session duration which is exponentially distributed. In relay air interface, TRHs can provide 1 Mbps data throughput. They are allocated frequency bands separately large enough thus TRHs do not cause interference to each other. The AP transmits downlink data with four transmission rates. For UTs located in the corner area of the simulation area (its distance to the AP is higher than the AP's radius), they can get the minimum transmission rate. Common simulation parameters are given in Table 2. For different simulation scenarios, additional parameters will be described later in each simulation scenario.

Figure 5 shows the performance comparison of connection blocking probability obtained by using conventional (non relay) and proposed resource management schemes. UTs use the same service which requires the minimum required throughput of 30 kbps with the mean session duration is 180s. There are 48 powerful UTs and the relay transmission range is 150m and 200m in different simulation experiments. Generally, the proposed scheme can provide lower blocking probability than that of the conventional scheme. When the transmission range of relays is 200m, the blocking probability of the proposed scheme is much lower than that of the conventional scheme. The reason is the longer transmission range of relays brings more possibilities for users to find neighbors who can become their relays. With long transmission range, users will be able to connect to relays which are located near the AP and have very high transmission rates. That makes more resource (TSs) to be saved for other users.

Figure 6 shows the handover ratio of the proposed scheme which is defined by the ratio of the number of network controlled handovers over the total number of accepted connections. This metric can show how much additional signaling traffic is needed for network controlled handover in order to gain a low connection blocking probability. Users use the same service which requires the minimum required throughput of 30 kbps with the

Table 2 Simulation input parameters

Parameters	Value
AP's coverage radius (R)	1000m
Time slot duration (t_{TS})	6.7ms
Tr_1	6 Mbps
Tr_2	12 Mbps
Tr_3	18 Mbps
Tr_4	24 Mbps
Relay's effective throughput	1 Mbps
Simulation time	3 hours

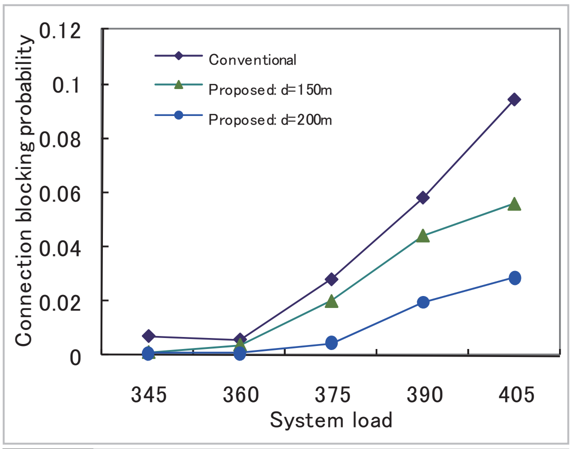

Fig.5 Blocking probability (different relay's transmission range)

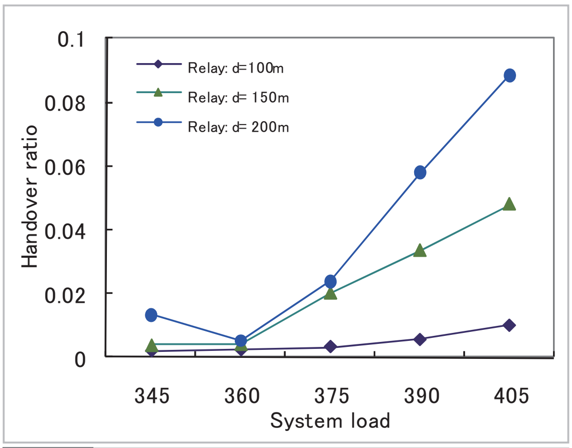

Fig.6 Handover ratio of the proposed scheme

mean session duration is 180s. There are also 48 powerful UTs and the relay transmission range is 100m, 150m, and 200m in different simulation experiments. The long relay transmission ranges cause the high handover ratio. The reason is that with longer relay transmission range, it gets high possibility to perform such handovers to get free TSs thus results in better system performance i.e. lower connection blocking probability. Consider the case with the relay transmission range of 200m, the handover ratio is less than 9% additional handovers should be performed in order to get more than 6% accepted connections (Fig. 5). The cost for handover is acceptable in emergency scenarios.

Figure 7 shows the connection blocking probability of different service classes in a multi-service simulation scenario. In the simulation scenario, the relay transmission range will be set to 200m. Two different service classes are simulated with different minimum guaranteed throughput and mean session duration. Assume that the minimum required throughput of the first service (class-1) is 30 kbps and its mean session duration is 180s. The second service (class-2) requires a guaranteed throughput of 10 kbps and its mean session duration is 240s. We take these assumptions based on the fact that end users normally consume the service with the lower QoS requirement for a longer period due to lower cost. The proposed scheme provides much lower blocking probability in this multi-service simulation scenario. The blocking probability of class-1 service is higher than that of class-2 service in both cases because the class-1 connections need more resource. When exploiting the proposed scheme, the difference of blocking probability of two services is much smaller than that of the conventional system i.e. the proposed scheme can provide better fairness for different service classes. In the conventional system, class-2 services require lower minimum required throughput thus more class-2 requests can be accepted. While they consume system resource, arriving class-1 connection requests might have not enough available TSs thus resulting in high blocking probability.

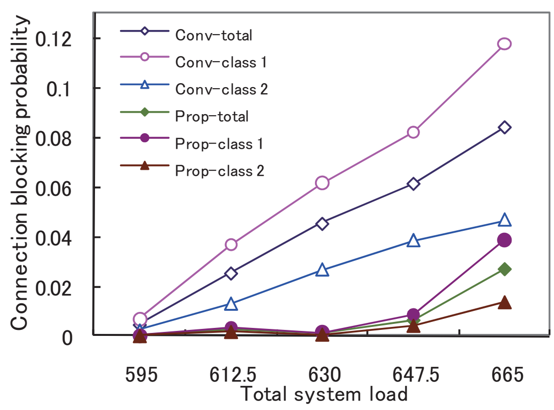

Fig.7 *Blocking probability of different service classes*

6 Conclusions

We have introduced a hybrid cellular relay model of wireless data networks for providing emergency communications where we consider a network scenario of disaster areas where users are assumed fixed or moveable. In order to enhance the system performance, we proposed a resource management scheme which is the combination of network controlled handover, resource allocation and connection admission. The proposed scheme performs direct-to-relay handovers in order to find free resource (here TSs) for new connection requests. Performance results obtained from computer simulation show that by deploying the proposed, the hybrid cellular relay wireless data network model is able to provide low connection blocking probability and satisfy QoS requirements of users. Particularly, the proposed scheme can provide fairness in the multi-service scenario.

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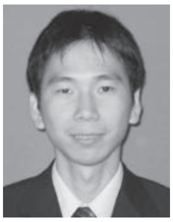

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