4 Network Technologies for Safety Life with Feeling Relief

4-1 States and Trends of Technologies in the Ad Hoc Networks Applicable to Emergency Communications

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Research on the ad hoc networks, which belongs to the type of autonomous distributed network, has been done actively in recent years. The ad hoc networks have the feature that they only consist of user terminals and has no infrastructures. So, it is possible to use as a communication means in the emergencies at the time of disaster, etc. where usual telecommunication infrastructures are damaged.

In this paper, the outline of the ad hoc networks is introduced. The present states and the trends of key technologies in the ad hoc networks are also presented. The researches for using an ad hoc network in the emergency communications are also described.

Keywords
Ad hoc networks

1 Introduction

Conventional communication networks, which is mainly focused on telephone, have been developed to realize and optimize real time interactive telecommunication. In contrast, the development of networks using TCP/IP (a representative set of Internet communication protocols) has provided not only those communication services optimized by conventional communication networks (instantaneous, bidirectional, long-distance communication) but also services for non-instantaneous, unidirectional, and short-range communication. As a method of transmission, wireless communication had been used in the same manner as conventional wired communications in backbone networks to reach more distant sites. However, in recent years wireless communication has been in greater demand as a transmission method in access networks; this method is expressed by the phrase “last one hop”. This shift reflects a desire to take advantage of the distinctive features of wireless communication, including quick and temporary setup and portability/ mobility of terminals. Services now widely popular, such as those for mobile phones, wireless LANs, etc. all take advantage of wireless communication’s usefulness in an access network environment.

Networks consisting of wireless access networks and interconnecting backbone networks are thus prevailing. However, there are drawbacks to these systems: if the base stations or other elements of the infrastructure comprising these networks are damaged by large-scale disasters such as earthquakes, communications may become impossible. Even if the infrastructure is not damaged, spikes in traffic and congestion may render communication virtually impossible. It is essential to restore communication networks in such emergencies as the event of large-scale disasters by repairing the infrastructure as quickly as possible and taking appropriate measures to control congestion. On the other hand, communications and sharing of information in emergencies are also possible via ad hoc networks. These take full advantage of the features of wireless communication, including rapid and temporary setup as well as outstanding terminal portability and mobility. Without the need to rely on the conventional communication infrastructure, ad hoc networks can allow for communication among temporarily assembled user terminals.

In this paper, in which we address ad hoc networks for use in emergencies, we provide an overview of these networks and discuss the current status and trends of key technologies. We then describe future ad hoc network research for emergency communications which we should advance.

2 Overview of ad hoc networks

2.1 Definition of ad hoc networks

The phrase “ad hoc” has become more popular recently in Japan in a variety of contexts. Originally from the Latin (ad höc, ad huc), meaning “for this [specific purpose]”, or “toward this [matter]”, this phrase has come to mean “temporary”, “concerned with a particular issue”, “impromptu”, “special”, and so on. Thus ad hoc networks can be defined as temporary networks created on the specific area for a specific purpose. In practice, as mentioned above, applications are already taking advantage of the features of wireless technology, including those involving temporary deployment of mobile terminals. Thus, ad hoc networks are often referred to as “wireless ad hoc networks” or “mobile ad hoc networks”.

The distinctive features of wireless ad hoc networks can be summarized as follows[1]:

- They do not require conventional infrastructural elements, such as base stations.
- They can be used anytime, anywhere.
- They can be created and deleted as needed.
- Terminals in these networks have router functions.
- They support peer-to-peer communication (with terminals directly connected to other terminals).
- They support peer-to-remote communication (multi-hop communication using terminal relay functions).

In addition, support for the following features is considered mandatory in these networks[2].

(a) Zeroconf: technologies that free users from tedious configuration tasks and enable users to join networks simply by bringing the terminal in range

(b) High scalability: the ability of networks to support more or fewer terminals

(c) Highly efficient use of resources, including bandwidth and power

Creating these systems poses a range of challenges, necessitating the combination of different types of technologies. Section **2.2** of this paper presents the background of the relevant research in Japan and overseas, and also describes current research trends. Trends and challenges in key technological research are discussed in Section **3**.

2.2 Background and trends in research of ad hoc networks

Packet radio networks (PRNs) were developed under the auspices of a project undertaken by the Advanced Research Projects Agency (ARPA). Originally intended for military applications, the technology is now viewed as the predecessor to wireless ad hoc networks. These networks are expected to be developed over the coming years for commercial, non-military applications. We can imagine a wide range of applications—routine communications (beyond emergency communications, the main purpose envisioned in this paper) within communities, Internet access, and other services for user-established networks—all enabled simply by bringing portable wireless terminals to conference halls, sports stadiums, or event venues, or even in trains or other transit environments. Wireless ad hoc networks are also a promising basis for sensor networks, robot networks, or inter-vehicle/road-vehicle networks in intelligent transport systems (ITS). Furthermore, these networks are expected to form a next-generation platform for Internet access and to promote development of ubiquitous networking[3][4].

Accordingly, research and development on ad hoc networks has become extremely active in recent years, both in Japan and all over the world. In Japan, related reports are issued throughout the various technical groups of the Communications Society of the Institute of Electronics, Information and Communication Engineers (IEICE). The Society's Technical Committee on Ad Hoc Networks was established in 2004, and the group holds workshops on related topics of interest[5]. Research is also underway at the Mobile Computing and Ubiquitous Communications working group of the Information Processing Society of Japan (IPSJ), which is active in publicizing its results. Overseas, Mobile Ad Hoc Networks (MANET) working group of the Internet Engineering Task Force is focused on routing within ad hoc networks. The IEEE Communication Society (ComSoc) sponsors several international conference including the Globecom conference, the Wireless Communications & Networking Conference (WCNC), and the International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC). Additionally, ad hoc network research is presented at the ACM Sigmobile International Conference on Mobile Computing and Networking (MobiCom) and the International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc). Further, the international Conference on Sensor and Ad Hoc Communications and Networks (SECON) has been sponsored by IEEE ComSoc since 2004.

3 Key technologies of ad hoc networks

3.1 Low power consumption and high efficiency

As discussed above, ad hoc networks do not rely on a network infrastructure, thus reducing network processing costs. The only such cost incurred is limited to the user terminal itself. Practical implementation of ad hoc networks thus requires user terminals that are smaller, lighter, and more affordable. Among the technologies enabling more compact, lighter, and low-cost terminals, efforts to make batteries smaller and lighter are particularly significant, as batteries comprise relatively heavy constituent elements. Low power consumption is especially critical in ad hoc networks, for which it is assumed that terminals will be kept on in order to allow for voluntary relay of other users' packets. Thus, technology is required for smaller yet more powerful batteries, as well as terminals that consume less power.

In terms of smaller, lighter, and higher-output batteries, the highly efficientized technology of a lithium ion battery, which is now commercialized, is required. In addition, the fuel-cell technology, cited as a potential next-generation energy source and partially commercialized, will be needed. Meanwhile, to reduce the power demands of terminals, means must be introduced to reduce terminal energy consumption on many levels, not only through OS-based energy management in the processor and display, but also through technologies for wireless devices, media access control, routing, and so on. A great deal of recent research has focused on these issues. Specific details on advances in lower power consumption and higher efficiency in these technologies are discussed individually in Section **3.2** and thereafter.

3.2 Smart antennas

In wireless devices, higher carrier frequencies degrades the energy efficiency of the transmitting device, and it also worsen propagation loss and noise figures in the receiver considerably. So, RF power takes a relatively significant part in power consumption. Methods are currently under study for improving the efficiency of RF power amplifiers in high frequency bands, for radical improvement in the efficiency of user terminals. One way to improve the efficiency of wireless devices in such terminals is to replace conventional omni directional antennas with directional antennas. Ideally, user terminals would be equipped with adaptive antennas (also called “smart antennas”) that can be controlled to adapt to the signal environment. This would enable a much greater reduction in the required power. Compared to omni directional antennas, adaptive antennas offer higher gain and can transmit more efficiently to other terminals while consuming less high-frequency power. They offer better reception as well, so the positive effects are multiplied. Adaptive antennas can also suppress interference, a feature that can significantly increase the capacity of network subject to predominant interference in a single channel. Research on improving performance in media access control through the use of directional antennas is described in Section **3.3** and thereafter.

Previously developed adaptive antennas were based on digital beam-forming (DBF) technology. Because it needs the number of RF circuits and high-speed AD converter as much as the number of antenna elements, these antennas have been viewed as impractical for implementing in user terminals due to high cost and power consumption. In a different approach from DBF to provide adaptive antenna functionality, espar (electronically steerable passive array radiator) antennas (Fig.1)[7] based on a concept known as spatial beam forming had been developed. Research on the commercialization of this concept through user-terminal adaptive antennas is currently underway.

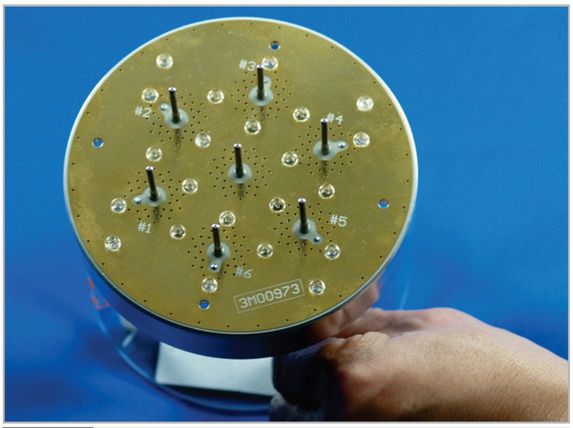

Fig.1 *Espar antenna (provided by ATR Wave Engineering Laboratories)*

3.3 Media access control

A great deal of research is now focusing on media access control (MAC) in autonomous distributed environments represented by ad hoc networks. In particular, researchers are investigating the distributed coordination function (DCF). DCF is based on CSMA/CA, which is used in IEEE 802.11 MAC, a wireless LAN standard[8]. As mentioned in Section **3.2**, smart antennas increase the number of communication channels that can be used simultaneously, resulting high throughput and high energy efficiency. Recent years have seen extensive research in MAC protocols using directional antennas and smart antennas[9]-[13], all of which have proven effective in simulation. However, smart antennas themselves pose new problems of their own.

First, unlike omni directional antennas, smart antennas feature a beam that must be directioned at the receiving terminal, raising the issue of how to determine terminal positions. We can assume that, at least on the simulation level, terminal position information could be provided via GPS or another mechanism, or from higher layer, but so-called cross-layer approaches such as these have some difficulties in implementation. Further, if we attempt to resolve the issue of positioning in the MAC layer, the protocol becomes complex and overhead increases, which would likely have a significant effect on performance.

Second, when omni directional antennas are used, hidden-terminal problems can be resolved by introducing RTS/CTS packets during the handshake process; however, with directional antennas, new hidden-terminal problems may arise. These problems arise because RTS/CTS packets can only be received from directions providing symmetrical antenna gain and toward which the antenna is directioned.

The third problem is referred to as "deafness". When an antenna beam is not directioned correctly, terminals that cannot receive communications already underway continue to send RTS packets to terminals that do not return CTS packets, wasting channels and impairing performance.

Although it is difficult to overcome these problems, it is expected that further R&D will resolve them and lead to practical implementation.

In addition to the use of smart antennas, another approach to lower power consumption and higher efficiency is seen in the treatment of battery status, including research on the battery-aware MAC protocol (BAMAC)[14].

MAC-related research is also underway from the standpoint of quality of service (QoS); this is discussed in Section **3.5**.

3.4 Routing

Routing, i.e., the determination of a communication route between sources and destinations is a key issue in ad hoc networks. User terminals not only send and receive packets in the user's own communication processes, they also relay the packets of other users. These functions enable packets from sources to be relayed in multiple hops, as needed, until they reach the destinations. However, all of the relay terminals that make up the route are mobile, so as they move, the wireless environments change to an enormous extent. Communication may be interrupted if a given terminal battery is out, or communication links might be cut. To deal with this type of dynamic environment, various schemes have been proposed to create and select the optimal route at any given time.

Based on the means of routing, routing protocols are broadly classified as reactive or proactive.

With reactive protocols, a routing request is issued before the actual communication, and the route created in response is then used. Proactive protocols, on the other hand, create or update routing tables on a predetermined cycle; these protocols form the basis for communication.

Three routing protocols for ad hoc networks are currently in the Experimental RFC stage in the IETF's MANET working group, as follows.

- Ad Hoc On-Demand Distance Vector (AODV) Routing Protocol (RFC3561)
- Optimized Link State Routing (OLSR) Protocol (RFC3626)
- Topology Dissemination Based on Reverse-Path Forwarding (TBRPF) (RFC3684)

The MANET working group revised its charter in 2005. Their results to date, including these protocols, will now be applied in standardizing the following two routing protocol specifications.

- Reactive MANET Protocol (RMP)
- Proactive MANET Protocol (PMP)

AODV, DSR, are reactive protocols, and OLSR and TBRPF are proactive protocols.

Meanwhile, at the simulation level, many new and improved versions of the above protocols have been proposed, and evaluated by comparing their performance between existing and new protocols. With reactive protocols, the process of "flooding" to transmit route requests and route maintenance information to terminals is one of a factor of routing overhead. Researches to improve efficiency in this regard have been done, and leading recently to the proposed dominating set[15] and gossiping[16] methods. A routing protocol applying gossiping has also been proposed[17]. Extensive researches have been done on these topics: to improve routing performance with smart antennas, as with MAC (described in Section

3.3)[18][19]; to establish routing methods that apply information from the MAC layer[20][21]; to establish multi-channel routing[19][22]; and to investigate the multicast routing protocol using positional information[23]. The approaches to these topics differ, but they are similar in their search for improved performance, lower power consumption, and higher efficiency. Problems remain in practical implementation, however, similar to those that undermine the viability of cross-layer approaches mentioned above. Additional routing research is conducted from the standpoint of QoS; this is described in the next section.

3.5 Quality of service

Research on quality of service (QoS) in ad hoc networks has mainly focused on improved throughput in QoS parameters serving as evaluation standards, as well as on providing real-time traffic such as video audio through broadcast or multicast service. Research has also been conducted on MAC protocols for use in broadcast and multicast service[24][25], as well as on routing for these services[26]-[28]. Meanwhile, in terms of QoS guarantees and controls, IEEE 802.11e has been proposed as a means to guarantee and control QoS by extending IEEE 802.11 MAC on the MAC layer and introducing a framework for autonomous distributed control and priority control. Efforts are currently underway to promote standardization in these areas[29], through a range of related research projects[30].

Still more research focuses on routing as it is affected by physical-layer QoS parameters such as battery power, signal strength, bandwidth, and delay[31], as well as implementing QoS guarantees through cross-layer approaches[32]. Related studies address fairness among flows[33] and application-level QoS evaluations in the context of multi-channel streaming[34].

3.6 Security

Obviously, security technology is essential for the safe and secure use of networks. Ad hoc networks are autonomous and distributed, which poses a problem: typical authentication mechanisms used in ordinary networks are hard to deploy in ad hoc networks due to the difficulty in setting up centralized servers. To deal with this issue, research has focused on autonomous public key management for authentication in distributed environments[35][36], as well as on increasing the security of the routing protocol under these sorts of authentication schemes[37][38]. Additional research focuses on systems that use positional information in authentication[39], on detection of malicious intrusions in ad hoc networks[40], and on covert channels in the network layer[41].

3.7 Applications

In terms of R&D for applications that use ad hoc networks, studies have addressed the adoption of ad hoc networks for inter-vehicle communications in ITS[42], and approaches have included constructing experimental detection and warning systems for harmful wildlife[43]. Some of these efforts are geared toward the commercialization of groupware and applications for sensor networks[44]. However, the fact remains that no widely appealing applications (so-called “killer apps”) have yet emerged to trigger widespread popularization of ad hoc networks; further study of this point in particular is needed.

4 Adopting ad hoc networks for emergency communication

4.1 Trends in research on emergency communication using ad hoc networks

In research on the use of ad hoc networks for emergency communication during disasters, methods for selecting robust communication channels in an information support system during disasters were recently investigated by the Special Project for Earthquake Disaster Mitigation in Urban Areas (of the Ministry of Education, Culture, Sports, Science and Technology)[45]. Studies have also focused on networks enabling users to confirm that others are safe after disasters. These networks are formed by surviving base stations and terminals with relay functions[46].

4.2 Efforts of the National Institute of Information and Communications Technology

The National Institute of Information and Communications Technology (NICT) have been continued to research satellite-based systems and other means to establish emergency communications in the event of disaster. For emergency communications over ad hoc networks, NICT has conducted joint research with other organizations on autonomous, distributed multi-hop communication for private radio applications[48] and on multi-hop and ad hoc communication among micro-servers for rescue purposes; these micro-server communications in particular can serve as a platform to assess the status of the affected area[49]. NICT has also pursued collaborative research with Tohoku University and Osaka University to study the use of ad hoc networks for communications between robots, focusing on technologies to gather multimedia data during disasters using remote robots.

In terms of the direction of our ongoing research, we believe it is important to conduct R&D in the key technologies that will enable users to feel safe and secure when communicating in emergencies (just as they do as usual), when the parameters are dynamic and the environment may change dramatically. Users will be greatly reassured if they are able to communicate in emergencies as usual ways. Thus, we must continue to target technical R&D in the establishment of ad hoc networks (with the specific aim of putting the distinctive features described in Section **2.1** into practice: (a) Zeroconf, (b) high scalability, and (c) highly efficient use of resources); additional goals include alleviating congestion, QoS-guaranteed communication for wired and wireless devices alike, authentication in autonomous distributed networks, and the development of communication applications that are easy to use routinely as well as in emergencies.

5 Conclusion

We have presented an overview of ad hoc networks for use in emergencies, and have discussed the current status and trends of the key technologies involved. We have also described a range of future ad hoc network research for emergency communications which we should advamce.

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