Research and Application of Self-Organizing Communication Networks in Onsite Power Grid Rescue

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Abstract—Emergency communication and information technology has been an important research field in power emergency disposal industry. The existing onsite power emergency communication is based on satellite communication technology, which is expensive and lack of flexibility. In this paper, we propose to incorporate the technology of broadband wireless self-organizing networks into onsite power emergency communication systems. By analyzing the network architecture that can realize self-healing and high flexibility of onsite coverage, we develop a lightly hybrid networking protocol with the advantages of proactive and on-demand routing. Furthermore, we also design an interactive application software for mobile sharing of multimedia information. Software testing shows that the proposed emergency communication scheme can improve the performance in information submission, command scheduling, and rescue decision-making.

Index Terms—Emergency communication, power grid rescue, self-organizing networks, networking protocol, mobile applications

I. Introduction

In recent years, sudden natural disasters such as earthquake, landslide, debris flow, freezing rain and snow have occurred frequently, which has serious impact on the power grid and brings great challenges to safe and reliable power supply. In the domestic construction of the ultra-high voltage interconnected power grid of China, more and more power transformations facilities have to be deployed in those areas with intolerable natural and geographical conditions. On the other hand, most power transformation facilities lies in high altitude area with extreme climate or even unpopulated zone.

To deal with these challenges and ensure emergency rescue when sudden natural disasters or accidents occur, State Grid Corporation of China (SGCC) has promoted the construction of emergency response system [1]. As a result, an emergency communication system is initially built based on satellite communication and information sharing internet of level four emergency command centers so that SGCC is equipped with the emergency command and dispatch ability for handling with disasters.

However, although the existing mobile emergency communications system has provided effective technical support for the rapid and reliable onsite information transmission [2], there still exist several problems in practical applications [3]. For instance, relying on satellite communication vehicles, the satellite communication links still lack the ability to access to information service and suffer from small-scale single point communication coverage of satellite vehicle [4]. This limits the rescue performance based on satellite communications in the scenario of large-scale disaster area. Moreover, as current emergency satellite communication vehicles are disconnected, they cannot cooperate to satisfy the service requirements of all emergency responses and hence greatly affect the efficiency of disaster rescue.

To solve the small-scale coverage problems of existing emergency satellite vehicles, the access and coverage technologies of onsite communication need be reformed and upgraded urgently [5]. This necessitates the establishment of specialized onsite communication networks in outdoors or unpopulated area, where public telecommunication networks cannot provide instant coverage [6]. In this paper, we propose a backbone network covering scheme for onsite emergency rescue based on the technology of self-organizing networks [7]-[9]. The proposed scheme can effectively overcome the shortcoming of onsite satellite communications by providing sufficiently wide range of communication coverage, large communication capacity and mobile flexibility and hence promote the efficiency of power emergency rescue communication systems.

The remainder of this paper is organized as follows. Section II first analysis the demands and features of onsite emergency communications, Section III illustrates the system architecture design and the networking protocol, as well as an emergency communication application is depicted in Section IV. We summarize our contribution in Section V.

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II. Analysis of Demands and Features of Onsite Emergency Communications

A. Demands of Onsite Emergency Communication Services

In general, onsite emergency communications include disasters discovering, information reporting, orders delivery, and environment monitoring. Below summarize the detailed requirements of onsite emergency communications:

- Capability of audio and video transmission. The onsite emergency staff can send pictures and videos of onsite disasters to command center and directly talk to the latter.
- Capability of data transmission. The onsite emergency staff can transmit onsite files to command center.
- Ability of positioning and monitoring. The command center can monitor real-time onsite situation.

In order to meet the above requirements and guarantee the compatibility with existing communication systems, onsite emergency communication networks should be IP-based and can support broadband communication [10]. Via broadband IP networks and satellite communications, all services data transmitted from portable terminals can finally be delivered to the command center. To transmit 1 high definition video signal, 8 voice signals and other discrete data packages subject to the limitation of satellite communication bandwidth, a typical bandwidth for onsite emergency communication is 2-4 Mbps.

B. Coverage Features of Onsite Emergency Communication

Given the strong uncertainty of sudden natural disasters, the coverage requirements of onsite emergency communications vary from categories of natural disasters. For example, when an earthquake happens, rescue and emergency power supply requires wide flat coverage, which is different from the linear coverage along the transmission line of electricity during ice and snow disasters. As it is impossible to enter the disaster site in a short time period, we need long-distance transmission for connecting the point coverage of power station and tower. Accompanying with the proceeding of emergency disposal, both the emergency disposal mission and the demand of network coverage may change [11]. Below summarize several requirements of onsite emergency communication coverage during a power emergency rescue:

- Transmission distance. The transmission distance is normally at the order of kilometers or tens of kilometers.
- Network coverage. In point, linear and planar coverage of onsite emergency communications, it is necessary to provide flexible coverage location and automatic optimization of network routing.
- Network capacity. The network capacity should be large enough to support video, voice and data transmission.
- Routing protocols. The routing protocols for onsite emergency communication should be robust enough to automatically handle with the communication failures of individual nodes.
- Terminal access capacity. The communication network should simultaneously support tens to hundreds of terminals for access and communication.
- Operation and setup. The onsite emergency communications should be convenient for operation and simple for automatic setup.

While the existing combination of satellite communications, WiFi and wireless image transmission system cannot meet the requirements of emergency rescue, broadband self-organizing networks with robustness of networking protocol can be incorporated to support high data rate communications [12], provide multi-point relay coverage and flexibility of network structure. Following this clue, one promising solution is broadband self-organizing wireless mesh networks (WMNs), a special class of self-organizing networks, with optimized networking protocols. Compared to traditional self-organizing network, the backbone nodes in WMNs is relatively static and has sufficient bandwidth and capacity for providing stable and efficient broadband access services. Moreover, as a new broadband multi-hop network with high capacity and transmission rate, WMNs enjoy the advantages of quasi static backbone mesh nodes and unconstrained energy consumption for increasing network capacity, enlarging the coverage, supporting wireless devices of multiple frequency bandwidth, and improving network reliability and robustness.

WMNs have been applied for meter-based remote sensing [13] and transmission line monitoring [14] of transmission lines. As these applications only deploy unmoved communication nodes and do not require much communication bandwidth, they are greatly different from onsite emergency communications. Therefore, we need to optimize and redesign network architectures, routing protocols, and hardware/software models.

III. System Architecture

A. Network Architecture Design

According to different organizational structure and node deployment methods, existing multi-hop mesh structures are divided into three types: backbone, client and hybrid structures. Considering relatively static backbone nodes and dynamic terminals during onsite emergency rescue, the backbone structure is chosen for mesh networks to provide stable and efficient broadband access services.

Fig. 1 exemplifies a backbone mesh structure, where each dotted line represents wireless link and Mesh routers forms the network backbone through broadband wireless links. Once backbone nodes are set up, the access service of onsite broadband communications can be provided and each terminal can use WiFi links to access the mesh routers. When direct communication between mesh terminals cannot be supported, all data must be relayed by backbone mesh routers. As each mesh node can be used as backbone router or access point of mobile terminals, the flexibility of onsite emergency communication can be guaranteed. According to practical experience, deploying only 20 backbone nodes with the communication coverage of 10 square kilometers can meet the demands of most typical onsite emergency rescue communication.

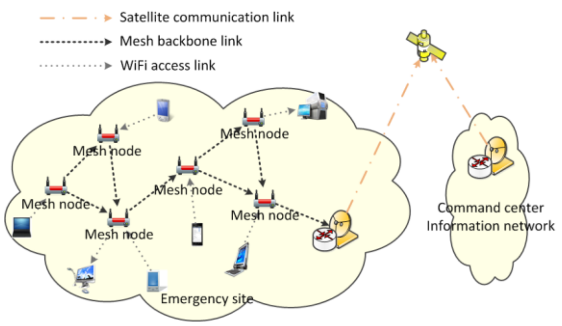

Fig. 1. Network architecture of emergency communication.

B. Hardware Design for Mesh Network Nodes

As the core of onsite emergency communication, backbone mesh routers should be equipped with the abilities of both the short-distance WiFi access and the long-distance relay communication. Moreover, it should high integrate intelligent routing protocols.

Fig. 2 depicts the function of a backbone mesh router, which is equipped with two wireless transmitting and receiving physical interfaces, one being based on WiFi for providing wireless access function for mobile terminals and the other being mesh backbone network interface for implementing the broadband backbone communication with other mesh routers.

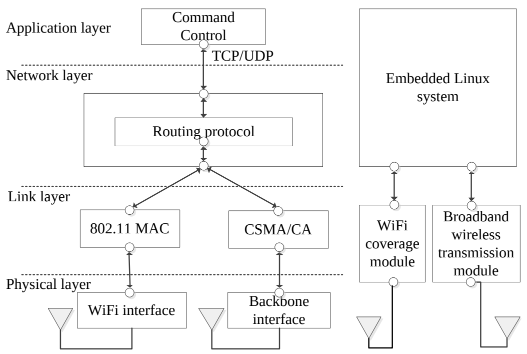

Fig. 2. Hardware design of backbone mesh node.

Since onsite power emergency rescue faces with a great deal of uncertainty, e.g., complex multipath effect, especially in urban areas and mountainous areas, it is difficult to directly achieved communication between any two network nodes. In view of this, we choose the ultra-short wave under 800 MHz to improve the ability for avoiding signal diffraction. In terms of channel modulation, using adaptive dynamic modulation of COFDM technology can effectively resist the multipath effect of fading communication links. With MIMO and OFDM technologies, WiFi access points supporting the IEEE 802.11 series standard at 2.4 GHz frequency band are chosen to improve capacity and reliability of terminal access. The detail parameters of communication modules are depicted in Table Ⅰ.

TABLE I: PARAMETERS OF COMMUNICATION MODULES

Module Type	Backbone	WiFi
Frequency	600-780 MHz	2.412-2.485 GHz
Supported protocol	Private protocol based on 802.11g and COFDM	802.11a/b/g/n MIMO-OFDM
Data rate	6/9/12/24/36/48/54Mbps	6~300Mbps
Communication distance	>500 meter (indoor), >50 kilo meter (outdoor)	100-500meter
Maximum power consumption	6000mW	500mW

To ensure that the network capacity of onsite emergency communications can allow no less than 20 mobile terminals for simultaneous access, the data throughput rate of mesh backbone communication link to be as large as possible. Thus we select high-order modulation mode of 54 Mbps to validate the coverage requirement of 0.5-1 square kilometers per single point though this selection may sacrifice part of the transmission distance.

C. Protocol Optimization and Implement

Networking protocol is the key technology to realize flexible wide-area onsite emergency communication, and it will ensure the self-healing ability of network communication when network topology changes. Fig. 3 shows one implementation scheme of networking protocols. According to the characteristics of terminal mobility and the transmission requirements in different networking modes, we have to redesign the networking function for supporting the self-organizing networking ability and dynamic reconfiguration ability. Following this scheme, we implement the corresponding networking protocol in embedded Linux system for running in kernel space, where routing protocols can store and calculate the routing information and maintain the routing table.

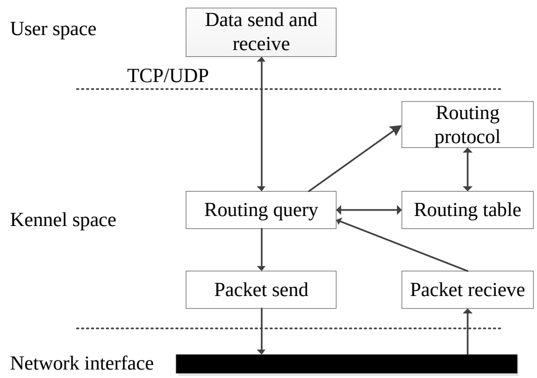

Fig. 3. Implementation scheme of networking protocol.

Routing protocols are divided into two categories, proactive routing protocols and on-demand routing protocols [15]. In proactive routing protocols, nodes will periodically broadcast announcement frames, perceive the topology changes, and maintain the shortest routing path. Enjoying the advantages of shorter path finding delay and fewer path hops, these protocols face with the problems of large protocol overhead and increasing node power consumption, which may restrict the efficiency of emergency communications. In on-demand routing protocols, routing path needs to be calculated only when data packets need to send. While it may save a lot of topology maintaining overhead, on-demand routing model has low efficiency and large delay because of recalculation of path cannot meet the real-time requirements of onsite emergency communications.

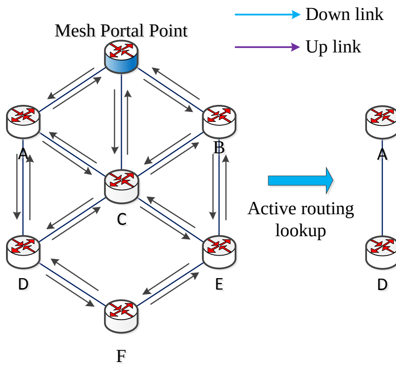

Fig. 4. Active routing lookup.

To solve this problem, we propose a hybrid routing protocol to concurrently improve routing efficiency and reduce the network topology management overhead [16]. As the key of hybrid routing protocol, we reconfigure mesh portal point such that, in proactive mode shown in Fig. 4, portal point will first work as root node to generate routing tree and store the two-way distance vector tree as the initial network routing. In particular, the portal point in the system is connected to the satellite station.

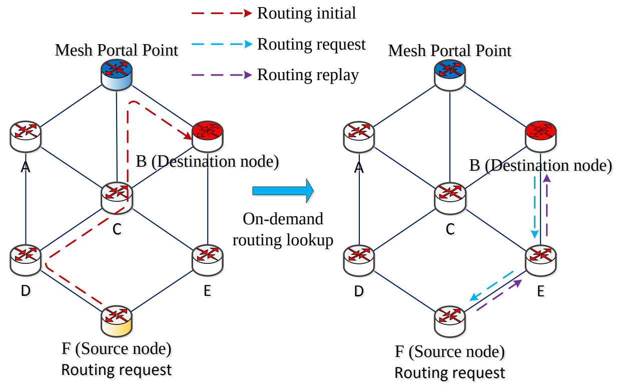

Fig. 5. On-demand routing lookup.

When mesh node has data to send, as shown in Fig. 5 (a), it will send data to the mesh portal point according to vector tree. If the data is sent to the external network, the mesh portal point will directly send the packet through the satellite link; else, if the data is sent to other mesh nodes within the network, as shown in Fig. 5 (b), the mesh portal point will send the data packet to corresponding mesh node according to the initial routing table. When the destination mesh node receive the data packet, it will start on-demand route discovery mechanism and send corresponding routing request packets back to the source mesh node, which will then directly add the multi-hop routing path to the routing table according to the routing request packets. If the new routing path is more efficient, the ensuing data packets will be transmitted through this path as shown in Fig. 5.

To optimize network routing, a parameter field of air link metric measurement is defined in routing decision. As the decisive parameter of link choice, the metric fields of routing request message will be updated by intermediate nodes in the transmission of routing request. In this updation, the metrics of last and current nodes are added and the sum of metric value will be forwarded to the next node. After the destination node of routing request receives many routing request messages from different paths, the best path choice is determined based on metric values of different paths. More specifically, if multiple routing requests have the same serial number, the destination node can choose the path with the smallest metric value as the best optimal path for updating the routing table.

As each link of air link metric mainly denotes the transmission time of a data packet of 8192 bits in the air link interface, the computation formula can be expressed by:

$$c_a = [O + \frac{B_t}{r}]\frac{1}{1-e_f} \tag{1}$$

where c_a means the airtime link metric of current link, O denotes packet head overhead, including preamble and PLCP head overhead, B_t = 8192, r denotes the transmission rate, and e_f denotes packet error rate. In general, the smaller the value of c_a, the shorter the transmission time in air link interface, and the better the corresponding routing path. Based on air link metrics, the routing protocol can ensure the quality of network optimization and improve the reliability of onsite emergency communications.

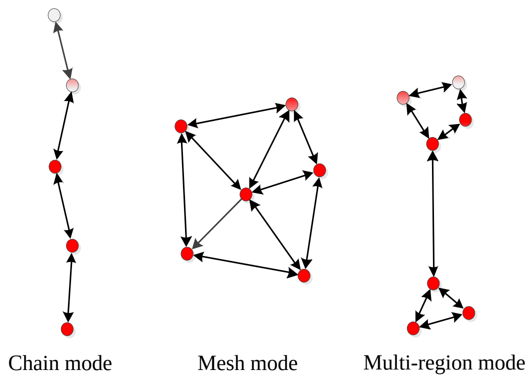

Fig. 6. Networking modes of emergency communication network.

IV. System Application

A. Application Scenario of the Self-Organizing Networks

The proposed onsite emergency self-organizing communication networks can adapt to different topologies, it can be put into use without any settings and its networking shape include chain networking, mesh networking and multi-region networking, which is shown in Fig. 6.

According to power emergency practice in recent years, the above networking modes each is suitable for different onsite emergency disposal respectively.

- Chain mode. The chain mode is used in emergency command communication along power transmission lines in rain and snow freeze disaster.
- Mesh mode. The mesh mode is suitable for emergency power supply and distribution network rescue in sudden large scale disasters such as earthquake.
- Multi-region mode. The multi-region mode is suitable for emergency command communication in different regions where geological hazard has hindered the traffic.

B. Development of the Emergency Communication Software

In order to efficiently use the onsite emergency communication networks, we develop an instant communication and positioning software based on private power information network. Emergency communication software is designed for android smart terminal to implement real-time interactive communication of location, video, images, voice, and text information between onsite staffs and command center or among onsite staffs.

With smart terminal, onsite staffs can share and manage voice, text, images, video and location information. The system server can be placed in any onsite communication nodes or rear command center, and the command center can communicate with onsite emergency network via the satellite links. Fig. 7 shows the user interface of emergency communication software.

Fig. 7. User interface of emergency communication software.

Emergency communication software based on onsite emergency self-organizing networks fully expanded the existing means of emergency communication. Mobile phone APPs can systematically meet the requirements of cluster intercom communication, individual figure system, BEIDOU positioning and document transmission, which not only improve efficiency of emergency command, but also lower the cost of emergency communication equipment.

V. Conclusions

In this paper, we have proposed a technical solution to onsite emergency communication based on wireless self-organizing networks. Through the research on the network structure and networking protocol optimization, we meet the onsite communication requirements of typical power emergency rescue. Mobile APPs can realize voice, text, video and other multimedia transmission and location monitoring, the efficiency of emergency command is improved.

The following work is to integrate power grid geographic information system and power management information system into mobile applications. Mobile APPs software effectively extend the existing emergency communication system, the emergency rescue will be shown in a more intuitive and clear way.

Emergency disposal and rescue is the most important ways to reduce the loss of disaster. The emergency communication and command systems are the fundamental guarantee of emergency disposal and rescue, which greatly improve the efficiency of disaster relief and reduce the disaster loss, thus means great economic benefit.

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