Use Case Analysis and Architecture Design for 5G Emergency Communications

Hongbiao Jiao[1(✉)], Jijiang Hou[1], and Chengli Mei[2]

[1] China Telecom Corporation Limited, Beijing, China
jiaohb@chinatelecom.cn
[2] China Telecom Research Institute, Beijing, China
meichl@chinatelecom.cn

Abstract. 5G has significant advantages in emergency communications. If it is directly deployed in the disaster area, there are still some disadvantages such as large data traffic and long service delays. This paper analyzes the needs of public safety network (PSA), and studies the application of dynamic messaging delivery, network slicing, C-RAN, and D2D in 5G PSA. Then, this paper puts forward two 5G emergency rescue solutions, one is the portable 5G private network and 5G public network collaboration, and the other is the public network UPF sinking. Finally, we compare these two solutions according to the needs of the emergency management department. The conclusion is that the portable 5G private network and 5G public network collaboration solution can be independently deployed locally. It does not have the limitations of the 5G public network UPF sinking solution but has the same network functions, which is more in line with the requirements of the emergency management department.

Keywords: Emergency communications · Public safety network (PSA) · Lightweight 5GC · 5G private network · UPF sinking

1 Introduction

Emergency communication is generally used in scenarios such as floods, earthquakes, forest protection, urban fire rescue, emergencies, and major security. In order to get timely and scientific rescue of emergency events and protect people's lives and properties from losses, it is necessary to quickly establish an emergency communication dispatching and command system to help scientific decision-making, multi-party consultation and visual command of emergency events.

5G has a broad application prospect in the field of emergency communications with its larger bandwidth, lower latency, and more stable and reliable network capability. The high bandwidth of 5G network can be used to transmit high-definition video from the emergency site to the command center in real time, and to realize multiparty video of high-definition video through 5G communication network. It is also possible to use the 5G slicing capability to directly download the service stream locally, and the on-site emergency video interaction does not need to interact through the remote core

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network, which can make the on-site command more efficient. Using 5G network low latency features to provide end-to-end data transmission services, 5G low latency is conducive to real-time control of rescue robots and rescue UAVs during emergency rescue, and remote control of rescue equipment in the command center through the 5G communication network.

Many departments that need to make emergency calls have high requirements for the security of mobile communication network architecture and prefer to use a separate dedicated emergency communication network than the congested and delayed public network. According to the needs of emergency communication, by cutting out unnecessary network elements in the 5G core network of the public network, and connecting their interfaces to the 5G network elements required for emergency communication through direct connection or co-location, a customized 5G lightweight core network for emergency communications can be formed. The ease of deployment and low consumption of the 5G lightweight core network will play a critical role in emergency communications. The customized 5G lightweight core network can quickly build an emergency communication system at the communication site to cover the entire disaster area, thereby ensuring on-site communication scheduling and helping the affected people communicate with the outside world.

Emergency communication vehicles play an important role in traditional rescue and disaster relief and emergency handling. It is currently the most typical and most extensive emergency communication system platform. It has the characteristics of quick deployment and opening, long working hours, convenient scheduling, and convenient access to existing communication networks. Emergency communication vehicles will still be a key means of emergency communication guarantee in the future.

UAV communication systems have gradually emerged in the process of continuous development of UAV technology. UAVs equipped with "air base stations" have become an important guarantee for emergency communications. When disasters occur, a new communication system can be quickly created through UAV communication systems, so as to quickly contact the disaster area, so that the disaster relief work can be carried out smoothly. In view of the high speed, high reliability, low latency and low power consumption of 5G communication network and the rapid development of drone cluster technology, the intelligent networking technology of drones and 5G communication technology are integrated to achieve rapid air-to-ground Communication to solve the problems of the existing emergency communication system becomes possible.

However, the emergency communication vehicle cannot enter the disaster area in time to provide communication services on the spot when the road is interrupted. UAVs can quickly gain access to the network in areas where emergency communication vehicles cannot reach. They are one of the most powerful communications guarantee tools in disaster scenarios with large areas affected by earthquakes, floods, and mudslides and severe road damage. Although UAV communication has the characteristics of rapid deployment and flexible mobility, it also has obvious disadvantages, such as short battery life, small coverage area, and high flight cost. Moreover, UAV communication is also vulnerable to extreme weather such as severe convective weather, icy plateaus, and marine environments. In addition, UAVs can also be used to airdrop 5G base station equipment. By dispatching UAVs to fly to the target area and accurately throw base

station equipment, the emergency communication support capability is significantly improved. Even if the airdrop target area is severely affected, UAVs can also operate at ultra-low altitude and throw base station equipment.

The structure of this article is as follows. We introduce the basics of 5G for public safety networks and emergency communications in Sect. 2. In Sect. 3, we focus on China Telecom's 5G on-site emergency solutions, including two major categories: public network mode and private network mode. We will give specific solutions for each type of mode, and in-depth analysis of the corresponding system capabilities and resource requirements. Finally, we conclude the full text in Sect. 4.

2 Basics of 5G Public Safety Network

Emergency communications are an important communication method to ensure emergency relief and essential communications, mainly for major natural disasters and sudden emergencies, and there is a surge in the demand for communications at certain specific times. These networks that function in special times are formally called public safety networks (PSN). In modern society, with the changing emergency emergencies and the rapid development of mobile communication devices, PSNs will provide not only voice services, but also instant video services. In specific emergency situations, it is difficult for the communication devices of rescue teams to meet the communication needs, so continuous and stable communication becomes an important factor limiting the emergency response, and heterogeneous cloud radio access network (HCRAN) has been considered as an important area to facilitate the rapid development of the 5th Generation Mobile Communication Technology (5G). In HCRAN is no longer bounded by the traditional cellular network technology, the introduction of high-power node (HPN) technology allows massive coverage of signals. Also, Radio Remote Units (RRU) will support emergency communications, which allows a much higher local signal coverage and network transmission rate. At the same time, all centralized management units control the allocation of resources centrally. In case of emergency, the H-CRAN can dynamically allocate resources to the required units. This allows a more efficient and flexible use of limited network resources.

The stability of emergency communications depends on the communications infrastructure, and natural disasters of varying magnitude will disrupt the infrastructure, causing communications outages and rendering emergency services inoperable. And cyber-attacks launched by some malicious actors can also disrupt critical functions or reduce the efficiency of response operations.

In emergency situations, first responder teams may rely on the Public Safety Network (PSN). Also, to ensure the stability and reliability of information transmission, different methods can be used such as widening the signal coverage of base stations (BSs), changing the deployment of BSs equipment, and using coordinated multipoint (CoMP) to improve signal quality. These schemes achieve increased coverage area at the expense of energy consumption, at the expense of flexibility, and with limited compensation. There are many other methods to improve communication quality and network coverage, and relaying is often used to extend the coverage of BS, such as airborne base stations (ABS) that can be deployed in large post-disaster scenarios, but it leads to long

deployment times and high network costs. In addition, there is no effective method to meet the needs of the increasingly demanding emergency communication field.

Building on existing PSNs, many other types of PSNs have been established to provide first responders with sufficient information and resources to better accomplish rescue missions. In this case, a successful PSN management can provide fast communication services to first responders. Figure 1 depicts a specific example of a PSN where the connectivity of these devices is general in day-to-day situations (see Fig. 1a). while Fig. 1b depicts a PSN deployment in the event of a disaster. The PSN in special times (see Fig. 1b) utilizes the existing communication infrastructure of the PSN (see Fig. 1a), such as vehicles, drones, sensors, existing base stations, etc. In this way, all the communication devices required for the emergency scenario will function in the PSN.

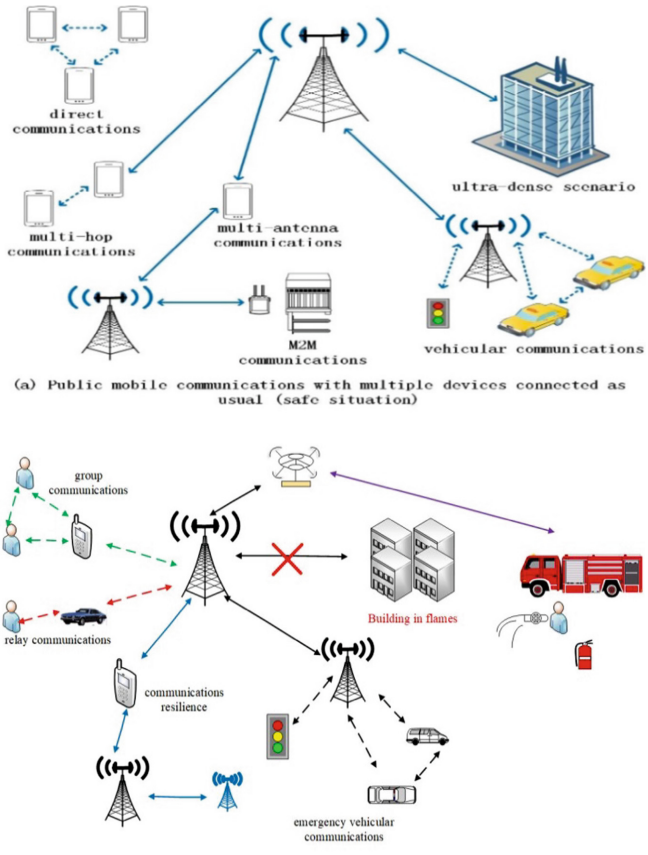

Fig. 1. Using public mobile communications to support emergency management in a Public Safety Network (PSN)

Most of the previously proposed contingency scenarios will be based on already existing network communication protocols for wired or wireless networks, the latter

mainly focusing on Wi-Fi, 4G or LTE technologies. In order to better achieve scenario efficiency, all the above proposals will be based on LTE, a broadband communication technology considered as a 5G pioneer [1], reevaluated in terms of integration. Based on this, this paper proposes a base station deployment scheme based on UAS [2].

From the development of the technology, the heterogeneous system will provide security for the public network, including an LTE core network with multiple subnetworks and layered services [3]. The following uses and requirements will be the main considerations for the authorities in the concrete implementation of building PS-LTE networks [4]. (1) smart device terminals to ensure network security for users and operators; (2) quality of service (QoS) assurance and signal transmission quality; (3) convergence of commercial and private networks; (4) combination of fixed and mobile to ensure service continuity and efficiency; (5) development of a dedicated LTE network construction policy, taking into account the limited budget, to guide the extension of coverage from economically developed cities to economically less developed areas.

2.1 Application of Dynamic Message Provision in 5G Public Safety Network

It is well known that effective communication is a key issue for successful management of PSNs. The joint application of Network Function Virtualization (NFV) and Software Defined Networking (SDN) technologies can effectively solve this problem by providing an effective communication capability for managing PSN services [5]. And related fields propose a TCP/IP network based on the converged application of NFV and SDN for resilient operation of 5G networks and protection against malicious network attacks, respectively, as in [6, 7].

In emergency situations, PSNs with strong autonomous capabilities allow the deployment of communication resources as VNF services in case of base station collapse. For example, in [8], an emerging cognitive intelligence engine is proposed to enable real-time adaptation of communication resources through VNF services. In the case of damaged base stations, where virtualization is not possible, this scheme allows sending unmanned aircraft, such as drones (UAVs) to areas in emergency situations to provide deciphering operations [9]. In addition, it is possible to establish device-to-device (D2D) communication between the user's devices and to restore basic communication by establishing a mobile Ad hoc network (MANET) through a multi-hop connection. This has been extensively discussed in the literature [10] to enable real-time data transmission and feedback with the help of D2D communication and the mobility of UAVs.

Security and privacy protection issues must also be considered when deploying PSNs, such as personal information used by search and rescue teams, which cannot be accessed by other unrelated personnel. This point is highlighted in the related agenda [11], which emphasizes that the relevant authorities should further strengthen the regulation to ensure the reliability of data in emergency situations.

2.2 Application of Network Slicing in 5G Public Safety Network

Network slicing is a technology specifically designed to customize scenarios with heterogeneous and complex requirements. This technology enables on-demand management of network resources and services to enhance SDN/NFV environments, which allows

operators to create multiple virtual networks as overlay networks from a single communications infrastructure. That is, NFV and SDN-based technologies allow the application of virtual resources to specific networks, and network slicing technology, a new 5G technology, will address potential challenges in 5G networks through the architecture of existing technologies, as detailed in.

In addition, enabling and maintaining secure communication between two parties by defining specific network slices is an important application of network slicing in the security domain, for example, using IPsec to protect user-to-user connections, while another network interface will be used to maintain interface connections for mobile devices. Table 1 summarizes the advances and opportunities for PSNs.

2.3 Application of C-RAN in 5G Public Safety Network

The architecture of a cloud radio access network (C-RAN) applied to a PSN is shown in Fig. 2. The architecture specifically consists of a radio remote unit (RRU), a baseband unit (BBU) and a central management unit (CMU). The BBU pool centralizes all the network resources and the CMU is responsible for managing them. the CMU directly manages and assigns them to the RRU regardless of the link between the user and the RRU, which can make the network operation more efficient and flexible. However, if an e-NB loses service in an LTE or LTE-A network, the resources there will be lost. However, in a C-RAN-based PSN, there are links between BBUs and RRUs are responsible for sharing. Even if the RRU is out of service, other network nodes can continue to use these resources.

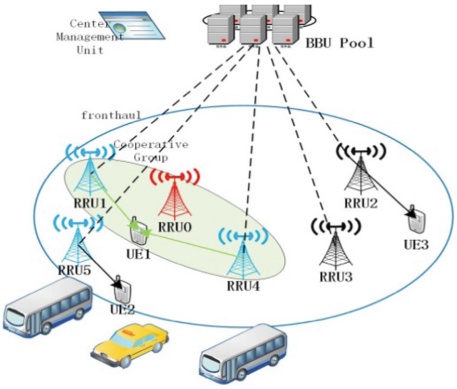

Fig. 2. Outage compensation in C-RAN based PSN

As shown in Fig. 2, RRU0 stops working due to various reasons. RRU1, RRU4 and RRU5 are selected to participate in the compensation. RRU1 and RRU4 transmit the same resource to UE1 at the same time and UE will be responsible for receiving the signal. Then the transmitted signals from RRU1, RRU4 and RRU5 will be reinforced to cover other areas.

2.4 Application of D2D in 5G Public Safety Network

In the event of a disaster, network communication may be difficult to maintain due to various complex reasons, and using other devices to compensate power usage for this can effectively relieve communication pressure, which will fully utilize the function of the PSN [12], and D2D technology, a common communication enhancement technique, has long been proven in related fields [13–15], and various compensation mechanisms will make D2D communication even better.

D2D communication will use area resources to satisfy the terminal communication.D2D technology can implement different types of communication in 5G PSNs: resource communication between HPNs, resource reuse in a single HPN, extended communication between PN overlay and external [16], and self-organized communication without HPNs. The H-CRAN architecture will consist of HPNs, baseband units, central management units, etc., and the specific structure is shown in Fig. 3 错误!未找到引用源. The CMU manages various resources in the BBU pool in a unified manner. The CMU enables efficient resource allocation. The advantages of D2D are: high speed, low latency, low load, efficient resource utilization, and extended coverage. Since HCRAN has the advantage of efficient resource allocation, the expanded coverage of D2D signal will effectively meet the user network demand. And D2D is used to realize efficient emergency communication scenarios.

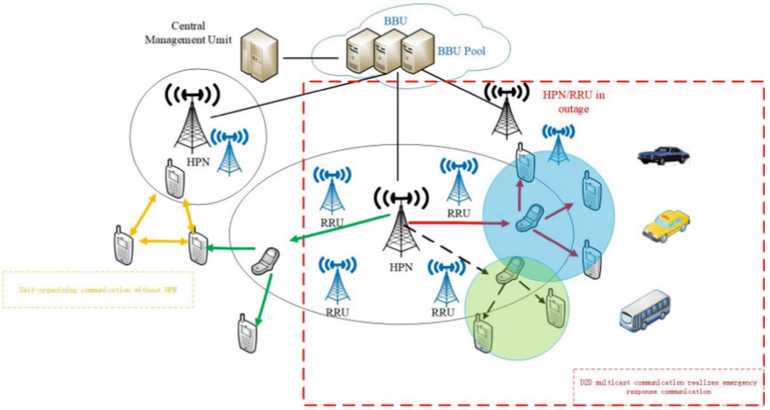

Fig. 3. Device-to-Device (D2D) technology and the application in PSN

In the first hour after the disaster, rescue teams and equipment vehicles will arrive at the scene, these equipment and personnel are called User Equipment (UE), after the completion of information collection, these information about the terrain, weather, damage and other information will be fed back to the PSN command and dispatch center, with D2D technology, the signal coverage further expanded, the network load is reduced, signal quality and transmission rate greatly improved thus This helps the command center to complete the initial judgment of the disaster situation. In Fig. 3, the user's communication service will not only rely on HPN technology, but also D2D technology

will provide emergency services in emergency situations and achieve continuous and stable communication service through related technologies.

3 Emergency Communication Solutions Based on 5G

3.1 Portable 5G Private Network and 5G Public Network Collaboration Solution

The basic hardware requirements of the program will include: local emergency configuration 5G RRU, BBU, lightweight core network, emergency service platform, satellite terminal and other equipment.

The portable 5G private network and 5G public network cooperation scheme has the following system capabilities: realize local 5G public network coverage; realize local high-speed command and dispatch and audio/video transmission; can connect to the Internet (or point to a private network address) via satellite link; and serve both public and private network users. When conducting emergency communications in the 5G lightweight core network, it is important to prevent the current communication network facilities from being damaged in order to achieve the normal application of special communications in the independent communication network in the temporary emergency communication network. The advantages of easy deployment and low consumption that portable 5G private and 5G public networks possess will play a key role in disaster relief efforts. In the initial moments, the original infrastructure in the disaster area including roads, power facilities, and communication base stations will be damaged to varying degrees, so emergency communication in the initial moments is the key to on-site command and control. The local public network in the disaster area should be restored as soon as conditions permit, and a one-time transmission network should be activated to ensure the transmission of information between the disaster area and the outside world. Due to the uncertainty of the situation in the disaster area, there is a chance that the local 5G public network core base stations in the disaster area will not be able to connect to the outside world, resulting in information interruption. At this time, professional equipment such as drones can be used to build a professional 5G emergency network to quickly restore the local public 5G mobile communication network.

The requirements for the portable 5G private network and 5G public network cooperation program are as follows: prototype product upgrade, custom R&D 5G equipment, emergency service platform, interference avoidance with local telecom, high-throughput satellite links, emergency ground dedicated line resources, telecom commercial core network, and technical service contracts with suppliers. In addition, the portable 5G private network and 5G public network synergistic solution can also quickly set up emergency communication system at the communication site. After a disaster, it is highly likely that the local public communication network in the disaster area will be directly paralyzed and cannot assume the role of remote emergency communication dispatch, and the public network facilities cannot communicate, so a temporary communication system that can quickly connect to the outside world is needed, and this communication network should have very high mobility, flexibility and stability. With the help of emergency communication transmission equipment, portable 5G network base stations and tethered drones, a lightweight 5G core network capable of covering the entire disaster area for emergency

information management can be built, thus ensuring on-site communication dispatch and helping the affected people to communicate with the outside world (Fig. 4).

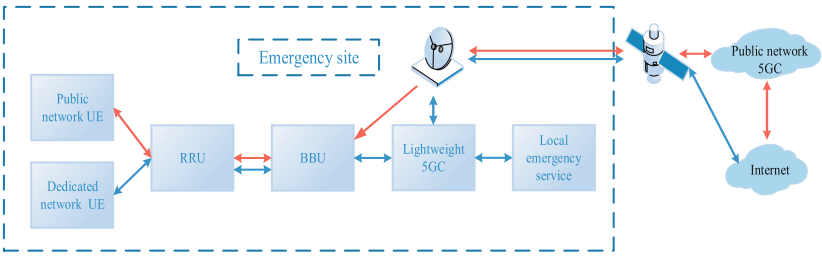

Fig. 4. Portable 5G private network and 5G public network cooperation

3.2 Public Network UPF Sinking Solution

The basic hardware requirements of the program will include: local emergency configuration 5G RRU, BBU, UPF, emergency service platform, etc.

The portable 5G private network and 5G public network cooperation has the following system functions: realizing local 5G public network coverage; realizing local high-speed command and dispatch, audio and video transmission, which can be connected to telecom commercial core network via satellite link to serve public network users and private network users. Emergency rescue teams should further integrate heterogeneous networks such as public networks, satellites, broadband self-assembling networks, cluster intercom and short-wave communications, etc., and conduct integrated dispatching of multi-source data such as voice, video, SMS, etc. Therefore, the solution is highly adaptable and flexible on site. In summary, the emergency communication and networking problem of large area "air, sky and ground" three-dimensional communication network integration is imminent.

Large area "air, sky and ground" three-dimensional communication network mainly refers to the use of space satellite systems, helicopters and UAVs, ground base stations for 5G emergency communications, helicopters can be used for communication relay, UAVs can be used to build 5G/ultra-short wave/self-assembling network communication relay, three-dimensional modeling, disaster assessment, expand the command and control network and search and rescue range, to open up the last mile of rescue. Finally, in the entire communication network, based on 5G communication technology, integrate drones, helicopters, satellites and other emergency rescue space resources, real-time convergence of meteorology, terrain and other types of important information, build interoperable, interoperable and complete emergency rescue command platform, and ultimately achieve a high degree of integration of command and dispatch and information interaction to improve the scientific and intelligent level of rescue.

The requirements of the 5G public network UPF sinking program for resources are as follows: prototype productization and upgrade, UPF equipment supporting with the core network.

Emergency service platform, interference avoidance with local telecom, high-throughput satellite links, emergency ground resources, telecom commercial core network, technical service contracts with suppliers, etc.

Based on the application of 5G communication technology and digital technology, analysis and research to achieve real-time monitoring of environmental parameters in the field. In the existing communication system, it is difficult to transmit the detection data effectively due to the limitation of bandwidth and speed. After entering the 5G era, the above limitations will be broken, and more detailed data will be transmitted in a timely and effective manner, such as monitoring real-time terrain changes in the disaster area, observing weather conditions at any time, and updating the location of rescue workers. In addition, with 5G communication technology, various types of real-time data at the scene can be transmitted back to the command terminal and form visual images, which can then be used to command and control rescue operations according to the actual situation (Fig. 5).

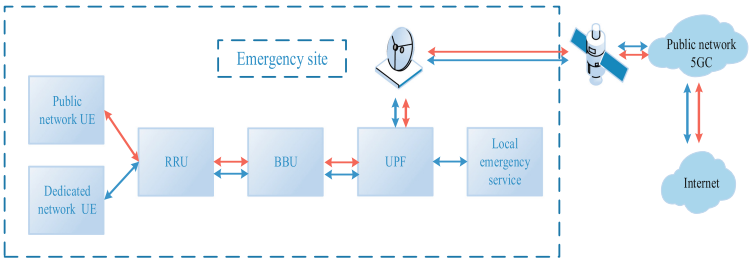

Fig. 5. Public network UPF sinking solution.

After R&D testing in 2019–2020, China Telecom completed the basic technology verification and principal function test. 2021–2022 is planned to evolve the basic technology to the portable 5G private network and 5G public network cooperation scheme and 5G public network UPF sinking solution. China Telecom's 5G emergency solution evolution is mainly divided into two directions, private network mode and public network mode. Since the internal application department of China Telecom is the mobile bureau, the 5G public network UPF sink solution is the main one, and the portable 5G private network and 5G public network cooperation solution is the backup.

The 5G public network UPF sink solution has the following problems compared with the demand of the Ministry of Emergency Management: the bandwidth and latency of the solution are limited by the satellite link, which cannot take advantage of the bandwidth and latency of 5G (slower than 4G). To solve this problem, the program improved UPF equipment with the supplier strong binding cannot be miniaturized, only vehicle. At the same time the general problem of the program is that as long as the satellite link does not work, the entire system cannot work. The main use scenario of the telecom mobile bureau is the vehicle scene, with the vehicle configuration satellite engineer, so the above problem does not affect the use of mobile bureau.

After in-depth communication between industry experts and scholars and relevant departments, it is concluded that the portable 5G private network and 5G public network cooperative solution is flexible, miniaturized, can be deployed and used locally and independently, and can be connected to the public network via satellite; after the solution is completed, it has the same network functions as the 5G public network UPF sinking solution and does not have the limitations of the 5G public network UPF sinking solution, which is more in line with the use requirements of the Ministry of Emergency Management.

4 Conclusions

With larger bandwidth, lower latency, and more stable and reliable network capabilities, 5G has broad application prospects in the field of emergency communications support. In order to enhance the role of 5G network in emergency communications, this paper proposes two emergency rescue solutions based on 5G. The portable 5G private network and 5G public network collaboration requires the development of a lightweight 5G core network for emergency communications, and access to the Internet and 5G public networks through satellite links. The 5G public network UPF sinking solution is to sink the UPF function in the core network to the edge, which can greatly reduce the data traffic transmitted through the satellite link and greatly reduce the end-to-end network delay. For emergency communications after major disasters, a single solution cannot meet multiple needs. A combination of multiple solutions may be required to meet the needs of rapid post-disaster relief and reconstruction.

As a cross-border combination of new technologies, emergency communication solutions based on 5G applications still have disadvantages and limitations at this stage. However, with the development of technology, such as new batteries and power supply technologies, emergency communication solutions based on 5G applications will surely become a universal solution for emergency communication, which can better serve the applications such as post-disaster rescue and post-disaster reconstruction.

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