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Communications, IoT, and Resilient Networks for Wildfire-Prone and Remote Regions

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Abstract

Natural fires and the nature of isolated regions create considerable difficulties when it comes to communication and environment monitoring. Infrastructure based on cell towers and wired Internet may be destroyed or becomes inaccessible during natural fires due to destruction, lack of power supply, or difficult landscape. In this paper, a survey and architecture of reliable communication system are provided, which include IoT, LPWAN wireless communications, satellite communication, UAVs, mesh networks, edge computing, AI, and cloud computing for provision of communication in case of failure of infrastructure. We discuss the properties of fire-prone and isolated regions, communication and sensing devices that will allow detection of natural fires and develop a layered architecture of a reliable communication system, which includes layers of sensing, communication, edge computing, and cloud computing. Also, we analyze how to make such communication system more reliable, provide its cybersecurity and workflow of early natural fire warning using multisource data fusion. Some of the open problems are power limitations, interoperability problems, deployment costs, spectrum usage restrictions. Possible areas of further research are emergency 6G communication, swarm of drones, digital twin of forest, energy harvesting sensors.

Keywords: Internet of Things (IoT), wildfire detection, robust networks, LoRaWAN, satellite communications, unmanned aerial vehicle (UAV), mesh network, edge computing, artificial intelligence, disaster management.

1. Introduction

Wildfires are listed among the most devastating natural catastrophes that have ever affected forests, grasslands, mountains, and rural areas all over the world. The frequency of wildfire occurrences and intensity of their occurrence has been rising in recent times due to high temperatures and drought conditions prevailing in such areas. Moreover, the areas which are highly susceptible to being affected by wildfires are those which lack any communications network at all. Such areas include dense forests, national parks, and mountains. Thus, the wireless communications infrastructure is scarce or completely non-existent in such areas and can get easily damaged by wildfires. Effective communication is very crucial at all levels of fire management from the initial detection of fires up to the evacuation level and beyond to communication among firefighters, resource management and medical emergencies or post disaster. In case the communication breaks down in such an emergency, the delay in communication will certainly lead to an increased threat to the safety of lives, properties, and even ecological system. There is a great need for a self-healing and resilient communication system that does not have any point of failure. The purpose of this research paper is to explore various methods by which various technologies may be integrated into a communication system referred to as the Internet of Things (IoT), wireless communication, satellite communication, UAVs, mesh networks, edge computing, Artificial Intelligence (AI), and cloud computing.

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A figure depicting the kind of deployment scenario discussed in this paper is illustrated in Figure 1. The sensors are deployed on the ground inside the forest, solar-powered gateway, a UAV for relaying data from aerial images and finally a satellite connection that ensures cloud connectivity should the ground towers be destroyed.

GW → SAT → Cloud

Figure 1: Diagrammatic illustration of forest fire detection system: IoT sensor nodes communicate with a solar-powered gateway and a satellite link provides cloud connectivity.

The structure of the paper is presented below. Section 2 will focus on wildland fire prone and isolated regions along with the problems in these regions and the contribution of communication networks to disaster management. Section 3 will provide an overview of the Internet of Things (IoT), wildfire sensing using IoT, suitable wireless communication technologies for such regions, satellite communications, UAVs, mesh networking, edge computing, artificial intelligence, cloud computing, early warning system process flow, network resilience, cybersecurity, and proposed architecture of the system. Section 4 will focus on the challenges and future directions.[1][2]

2. Literature Survey

2.1 Fire Prone and Remote Regions

2.1.1 Fire Prone Zones

These zones can be termed as geographic zones that experience forest fires regularly due to climatic conditions and environmental factors. Some examples of such fire prone zones can be forests, national parks, mountain zones, grasslands, and dry shrub lands. Some of the features of these zones are as follows: high density of vegetation providing fuel for fires, high temperatures, low humidity, wind making it easier for the fire to spread, and most importantly, poor communication facilities.

2.1.2 Remote Zones

It is that place where communication infrastructure is lacking. The regions which suffer from lack of infrastructure include mountainous, deserts, polar and island regions. Some of the challenges faced in such regions include lack of constant power supply, lack of cell phone networks, hard to reach such regions, low population density and thus less economic benefit to invest in infrastructure and extreme climatic conditions resulting in frequent break downs. Fire prone regions largely overlap with remote regions. Forests and mountains which are fire prone are also remote regions.

Table 1: Comparison of wildfire-prone and remote region characteristics

Parameter	Wildfire Area	Remote Region
Typical Terrain	Forests, grasslands, shrublands	Mountains, islands, deserts
Key Risk Factor	Dense vegetation, dry conditions	Isolation, sparse population
Infrastructure	Sparse, fire-vulnerable	Absent or minimal
Power Supply	Grid present but vulnerable	Frequently unavailable
Communication	Cellular with fire-risk outages	Limited to no cellular coverage

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2.2 Importance of Communication Networks in Disaster Management

The communication networks are meant to facilitate all the processes that are necessary for the effective management of the wildfires and disaster. The processes involved are early detection of the wildfires, warnings to the residents and authorities concerned, evacuation process, communication amongst the firefighting teams, resource management which entails management of manpower and equipment, medical cases, disaster recovery process, and environmental monitoring. In the event that the communication networks are interrupted, the response time is increased thereby putting lives and property at risk.[3][4]

3. Proposed Method/Model

3.1 Basic Principles of Internet of Things

The definition of Internet of Things (IoT) is the connectivity of physical objects or things that are provided with sensors and have the ability to communicate with each other and automatically collect and send data. The IoT process in wildfire and environmental surveillance application consists of four major components explained below.

3.1.1 Sensors

Sensors sense environmental parameters that influence the occurrence and spread of fire and include temperature, smoke density, humidity, carbon monoxide, carbon dioxide, wind speed, moisture in the soil, and atmospheric pressure.

3.1.2 Communication Module

This module transmits the data collected by sensors through various modes of communication including LoRaWAN, Zigbee, NB-IoT, Wi-Fi, Bluetooth, cellular (4G/5G), and satellite communication.

3.1.3 Processor

Embedded processors and controllers including Arduino boards, ESP32, Raspberry Pi, and STM32 microcontrollers carry out data processing and transmission to minimize bandwidth usage.

3.1.4 Cloud Platform

This platform enables storage and analysis of data and executes tasks such as data visualization and analytics.

Table 2: Core components of an IoT system for wildfire monitoring

Component	Representative Examples
Sensors	Temperature, smoke, humidity, CO, CO2, wind speed, soil moisture
Communication	LoRaWAN, Zigbee, NB-IoT, Wi-Fi, Bluetooth, cellular, satellite
Processing	Arduino, ESP32, Raspberry Pi, STM32
Cloud Platform	AWS IoT, Microsoft Azure IoT, Google Cloud IoT

Sensors → Comm. Module → Processing Unit → Cloud Platform

Figure 2: Basic data flow within an IoT system for wildfire monitoring.

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3.2 IoT for Monitoring Wildfires

IoT sensors may help monitor the fire situation in its initial stages without the visual presence of flames or smoke. Different types of sensors are used for this purpose.

Table 3: Sensor types used for wildfire monitoring

Sensor Type	Examples	Function
Temperature	LM35, DS18B20	Detect abnormal temperature rise
Smoke	MQ-2, MQ-135	Identify smoke particles pre-flame
Gas	CO, CO2, methane sensors	Detect combustion byproduct gases
Infrared	IR thermal sensors	Detect heat emitted by flames
Optical	Cameras with vision processing	Visual fire/smoke recognition

Temperature sensors, including LM35 and DS18B20, detect any increase in the temperature in the surroundings. Smoke sensors, which include MQ-2 and MQ-135, detect smoke particles. Gas sensors detect gases such as carbon monoxide (CO), carbon dioxide (CO2), and methane gas emitted from the burning process. Infrared sensors detect the heat released by fire, whereas optical sensors detect fire through cameras.[5][6]

3.3 Wireless Communication Technologies

The choice of an appropriate wireless communication technology becomes very critical when considering wildfire monitoring in distant locations where power supply availability, range of coverage, and cost of deployment are challenges.

3.3.1 A. LoRaWAN

LoRaWAN stands for Long Range Wide Area Network, an IoT communication technology that uses low power and provides long-range connectivity. Its features include long-range coverage up to 15 km or more, low power usage, long battery life, suitability for rural areas, and low deployment cost.

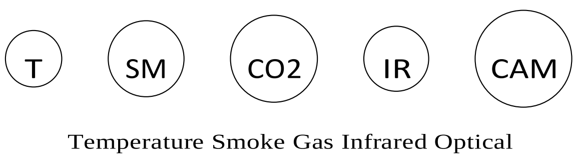

Figure 3: Diagram showing the arrangement of multi-sensor systems placed on a single monitoring pole.

3.3.2 B. NB-IoT

NB-IoT is narrowband IoT, a mobile network technology using cellular infrastructure. It offers good coverage, low power usage, high dependability, and supports multiple devices.

3.3.3 C. Zigbee

Zigbee is a short-range wireless network technology used in sensor networks, home automation, and industrial monitoring. Its key features include low power usage, mesh networking, and low deployment cost.

3.3.4 D. Wi-Fi

Wi-Fi uses Internet infrastructure to provide high bandwidth connectivity but has a lower range and higher power consumption.

3.3.5 E. Bluetooth Low Energy (BLE)

Bluetooth Low Energy is best suited for short-range sensor communication and is commonly used in wearable devices.

Table 4: Comparison of wireless communication technologies

Tech.	Range	Power	Best Use
LoRaWAN	Up to 15 km+	Very low	Forest/rural sensing
NB-IoT	Cellular range	Low	Agriculture, metering
Zigbee	Short range	Low	Mesh sensor networks
Wi-Fi	Short range	High	High-bandwidth links
BLE	Very short	Very low	Wearables, local links

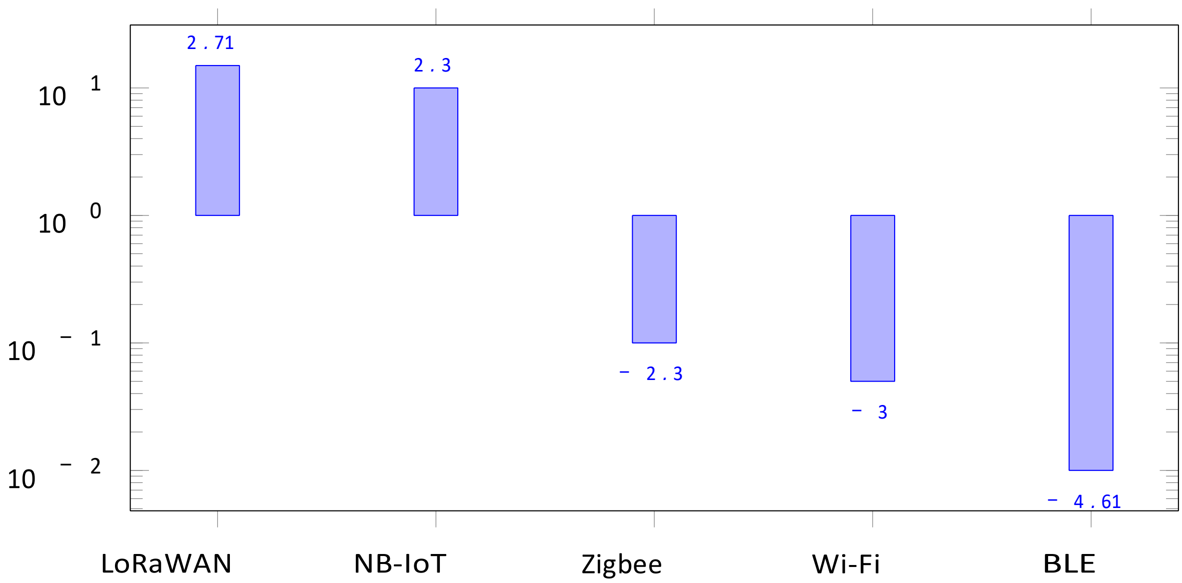

Figure 4: Typical maximum communication range of wireless technologies used in wildfire and remotearea IoT sensing.

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3.4 Satellite Communication

Satellite communication provides connectivity in locations where terrestrial connections are unavailable or destroyed. Its features include global coverage, disaster resistance, independence from local infrastructure, and emergency communication. Examples include Starlink, Iridium, and Inmarsat systems. Applications include connectivity to remote villages, forest monitoring, emergency rescue coordination, and weather monitoring.[7][8]

3.5 Unmanned Aerial Vehicles (UAVs)

Unmanned aerial vehicles (UAVs) or drones are used to gain immediate situational awareness during wildfires. They are employed for wildfire detection, thermal imaging, damage assessment, emergency communication relay, search and rescue operations, and supply delivery in remote locations. Equipment may include thermal cameras, RGB cameras, LiDAR, gas sensors, and GPS module.

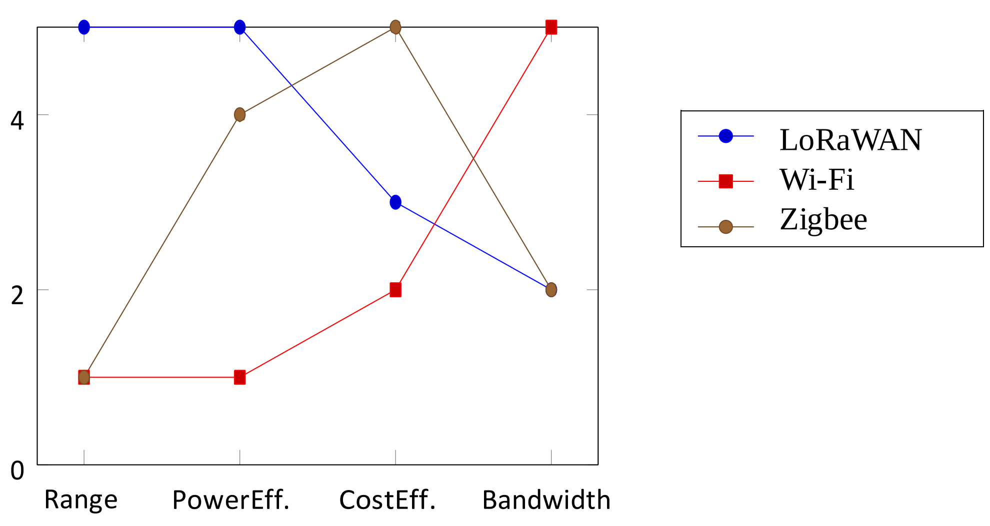

Figure 5: Qualitative multi-criteria analysis (relative scale 1-5) of wireless technologies for wildfire and remote-area IoT deployment.

3.6 Mesh Network

A mesh network connects devices to each other rather than relying on a single access point. Its advantages include self-healing capabilities, fault tolerance, reliability, easy deployment, wide coverage, and automatic rerouting of data when a node fails. Mesh networking is useful for disaster communication and forest surveillance.

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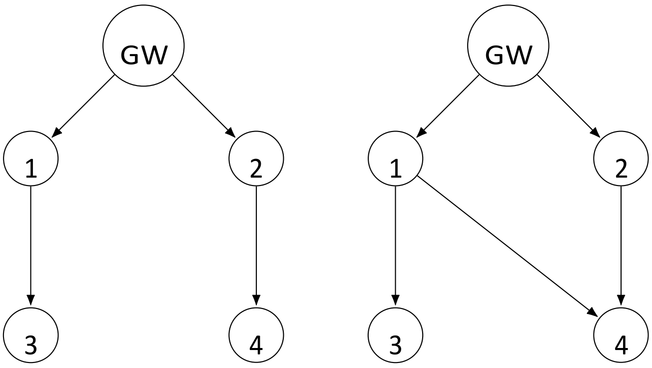

Figure 6: Star topology versus mesh topology under node or link failure.

3.7 Edge Computing

In edge computing, computations are performed closer to the source of the data rather than at distant cloud servers. Advantages include low latency, reduced bandwidth consumption, fast local decision making, enhanced privacy, and continued operation without Internet connectivity. Edge computing can be employed in fire detection, AI inference, and immediate emergency response.[9][10]

3.8 Artificial Intelligence Implementation in Wildfire Detection

Artificial intelligence improves wildfire detection in several ways. Computer vision identifies flames and smoke in images captured by cameras. Machine learning can predict wildfire movement using weather, vegetation, topography, and wind speed. Decision support systems can recommend resource allocation.

3.9 Cloud Computing Support

Cloud computing brings data gathered from large numbers of IoT sensors into one platform for storage, forecasting, monitoring dashboards, alerts, and data sharing with emergency services and government bodies. Examples include AWS IoT, Microsoft Azure IoT, and Google Cloud IoT.

3.10 Early Warning System

An effective early warning system integrates IoT sensors, weather stations, AI algorithms, satellite images, communication systems, and mobile alerts into one process. The process consists of six stages: sensing abnormal environmental conditions, data transmission, AI analysis, risk assessment, alert dissemination, and emergency response.

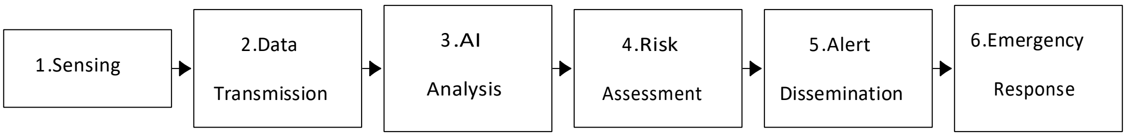

Figure 7: Six-stage early warning system workflow.

3.11 Resilient Network

A resilient network is capable of functioning despite failures. Its properties include redundancy of communication channels, backup energy supplies, diversity of communication methods, alternative routing, self-healing capabilities, and continuous fault detection and recovery. Such a network may use mesh networking, satellite backbones, rapidly deployable mobile towers, solar-powered sensors, and battery backups.[11][12]

3.12 Cybersecurity

Communication systems used for wildfire detection and mitigation must be protected from cyberattacks such as data sniffing, unauthorized access, malware, denial-of-service attacks, and physical or logical attacks against sensors. Security measures include encryption, strong authentication and authorization, secure boot, firmware updates, intrusion detection systems, and blockchain technologies.

3.13 Proposed Network Architecture

The paper proposes a four-layer resilient network architecture for wildfire-prone and remote regions.

3.13.1 Sensing Tier

The sensing tier comprises IoT nodes equipped with temperature, smoke, gas, infrared, and optical sensors distributed across the monitored forest or remote area, together with mobile sensing on UAVs.

3.13.2 Communication Tier

The communication tier uses LoRaWAN or Zigbee mesh networks from sensors to gateways, NB-IoT or cellular networks when available, and satellite communications as a robust backup solution.

3.13.3 Edge Layer

The edge layer performs local data aggregation and AI-based inference, enabling alert generation, reducing long-distance bandwidth requirements, and maintaining operation when upstream connectivity is unavailable.

3.13.4 Cloud and Application Layer

The cloud and application layer provides analytics, fire propagation prediction, dashboard-based visualization, and alerts to emergency services and civilians.

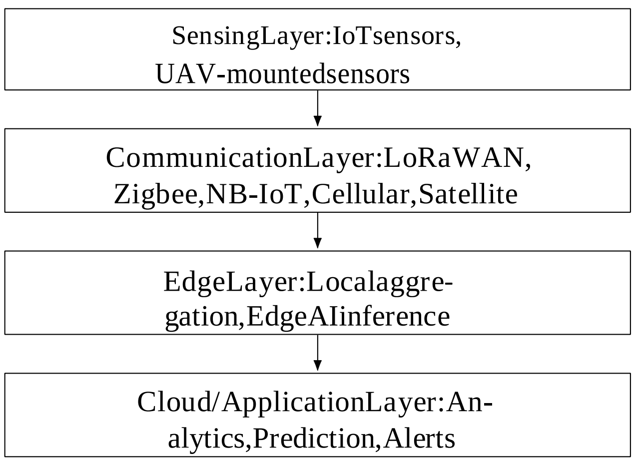

Figure 8: Proposed four-layer resilient network architecture for wildfire-prone and remote regions.

4. Result and Discussion

4.1 Challenges

Despite the promising concepts discussed above, there are still challenges associated with deployment. These include lack of communication infrastructure in regions where fires occur frequently, power required for continuous sensor operation, extreme weather causing hardware corrosion, difficulty of maintaining sensors in inaccessible regions, long-distance communication and link-budget limitations, expensive deployment of satellites and UAVs, data reliability and sensor accuracy, and interoperability problems among different devices and protocols.

4.2 Future Prospects

Future research directions include 6G-based communication systems that can provide ultrareliable low-latency services during emergencies, AI-based autonomous wildfire detection, swarm drones for extensive surveillance and communication relay, digital models of forests for anticipating wildfire behavior, Low Earth Orbit (LEO) satellite constellations with lower latency, energy-harvesting IoT devices, self-healing autonomous mesh networks, edge AI in IoT devices, multi-hazard monitoring systems for floods and landslides in addition to wildfires, and smart resilient communities with interconnected emergency infrastructure.

5. Result

The above-discussed areas of communication, IoT, and resilient networking have been covered alongside a four-layer framework consisting of sensing technology, communication technology, edge technology, and cloud technology. The combination of IoT sensors, LoRaWAN, NB-IoT, satellite communication, UAVs, mesh networking, edge computing, artificial intelligence, and cloud computing enables a resilient system capable of functioning in harsh conditions. Although limitations remain, including infrastructure, energy, cybersecurity, and implementation costs, advances in wireless communication, intelligent networking, and autonomous systems can improve community resilience against fires and natural disasters.

6. Conflict of Interest

The authors confirm that there is no conflict of interest in relation to the publication of this manuscript.

7. Acknowledgement

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References

1. M. A. Alkhalifah and M. A. Al-Turjman, "A survey on IoT-based wildfire detection systems," *IEEE Access*, vol. 9, pp. 45000–45015, 2021.

DOI:10.63252/JCBECA/3.2.2026.28
ISSN:3048-9695

2. S. Yao, X. Liu, and Y. Zhang, “LoRaWAN for large-scale environmental monitoring: A survey,” *IEEE Internet Things J.*, vol. 7, no. 6, pp. 4854–4869, Jun. 2020.
3. A. Bansal and R. Kumar, “NB-IoT: A survey on architecture, applications, and challenges,” *IEEE Commun. Surveys Tuts.*, vol. 22, no. 2, pp. 855–878, 2020.
4. J. Sanchez-Cubillo, J. Del Ser, and J. L. Martin, “Toward smart wildfire detection using wireless sensor networks,” *IEEE Sensors J.*, vol. 21, no. 3, pp. 2450–2463, Feb. 2021.
5. P. Barmpoutis, P. Papaioannou, K. Dimitropoulos, and N. Grammalidis, “A review on early forest fire detection systems using optical remote sensing,” *Sensors*, vol. 20, no. 22, p. 6442, 2020.
6. T. Toulouse, L. Rossi, A. Campana, T. Celik, and M. A. Akhloufi, “Computer vision for wildfire research: An evolving image dataset for processing and analysis,” *Fire Safety J.*, vol. 92, pp. 188–194, 2017.
7. H. Zhang, H. Wang, and Y. Zhou, “UAV-assisted communication for disaster recovery: Opportunities and challenges,” *IEEE Commun. Mag.*, vol. 57, no. 4, pp. 82–88, Apr. 2019.
8. M. Erdelj and E. Natalizio, “UAV-assisted disaster management: Applications and open issues,” in *Proc. Int. Conf. Comput., Netw. Commun. (ICNC)*, 2016, pp. 1–5.
9. O. Bekmezci, E. Sahingoz, and S. Temel, “Flying ad-hoc networks (FANETs): A survey,” *Ad Hoc Netw.*, vol. 11, no. 3, pp. 1254–1270, 2013.
10. A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, “Internet of Things: A survey on enabling technologies, protocols, and applications,” *IEEE Commun. Surveys Tuts.*, vol. 17, no. 4, pp. 2347–2376, 2015.
11. K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi, and M. Mustaqim, “Internet of Things (IoT) for next-generation smart systems: A review,” *IEEE Access*, vol. 8, pp. 23022–23040, 2020.
12. L. Wang, R. Wang, and Q. Xie, “Satellite communication for emergency and disaster relief: A survey,” *IEEE Wireless Commun.*, vol. 27, no. 6, pp. 30–37, Dec. 2020.

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