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High-Speed Networks for Information Communication Technologies for Disaster Recovery Operations

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Abstract: This work delves into the design of high-speed networks for information and communication technologies (ICTs) during natural disaster recovery operations, thoroughly examining the current design strategies, as well as the challenges and limitations of existing approaches. One of the key findings is that low earth orbit (LEO) satellite technology presents a promising option for delivering high-speed internet connectivity to remote and underserved areas, particularly in disaster recovery operations. The advantages of LEO satellites, such as low-latency and global coverage, as well as the challenges and potential risks associated with the technology are highlighted. The work concludes that continued innovation and investment in LEO satellite technology can lead to increased adoption for internet connectivity in disaster recovery operations.
Keywords: Natural Disaster Recovery, High-speed Networks, LEO Satellites, UAV, ICT

I. INTRODUCTION

Natural disasters, such as earthquakes, hurricanes, floods, and wildfires, can cause extensive damage to infrastructure, disrupt communication networks, and result in loss of life and property. Disaster recovery operations are essential to restore normalcy in affected areas and ensure the safety and well-being of affected populations. Information and communication technologies (ICTs) can play a crucial role in disaster recovery operations by providing real-time information, coordinating emergency responses, and facilitating communication between responders and affected populations.

During a disaster, communication networks can become overloaded or disrupted, making it difficult to coordinate response efforts and aid affected populations. In such situations, high-speed networks for ICTs are essential to ensure that emergency responders can communicate effectively and provide timely assistance. High-speed networks can facilitate real-time data collection and analysis, enable remote monitoring of affected areas, and provide a platform for delivering critical information to affected populations.

Given the critical role of ICTs in disaster recovery operations, it is important to survey the existing literature on the design of high-speed networks for ICTs for services during disaster recovery operations. This survey will explore the current state of high-speed network design and ICTs in disaster recovery operations, and provide insights into how to design more resilient and effective networks that can support emergency response efforts in the face of natural disasters.

By surveying the existing literature on the design of high-speed networks for ICTs during disaster recovery operations, this research will provide a comprehensive overview of the current state of the field and identify areas where further research is needed.

II. RELATED WORK

Gurkan et al [1] proposes the use of a team of unmanned aerial vehicles (UAVs) to establish an emergency communications system during natural disasters. Each UAV has an onboard computer running three main subsystems responsible for end-to-end communication, formation control, and autonomous navigation. The study proposes the use of unmanned aerial vehicles (UAVs) for two scenarios: as communication relays to connect ground stations and as part of a mesh network to maintain connectivity between a ground station and an UAV over a long distance.

In the first scenario as depicted in Fig. 1, the radios on the ground are placed at fixed locations, implementing a mesh network. Intermediate nodes relay traffic if two nodes are not in direct communication range. However, this setup can experience decreased throughput and increased latency with more hops. The proposed solution is to use UAVs as communication relays to connect disconnected ground stations/nodes. Ground nodes that are not in direct communication range with other ground nodes can communicate through the UAV, achieving wider connectivity ranges using low-cost UAVs.

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Fig. 1 Using UAV to relay between ground stations [1]

In the second scenario as depicted in Fig. 2, the objective is to maintain connectivity between a ground station and an UAV over a long distance. A mesh network of UAVs is used due to the constraints limiting communication ranges, such as power. To extend the communication range while considering the weight and volume limitations of micro-UAVs, intermediate UAVs are used. A wireless communications network of UAVs and a ground station node acting as the control center constitute the network architecture as shown in Fig. 3 of the proposed system.

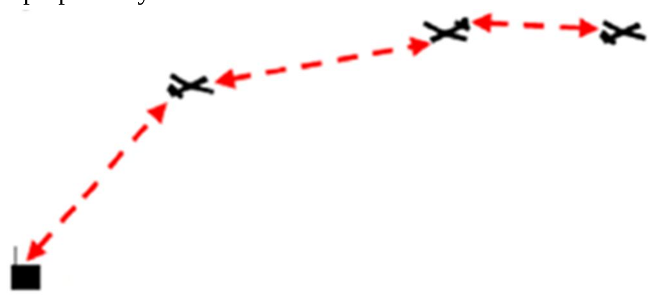

Fig. 2 Using Multiple UAVs to relay between a ground station and an UAV [1]

The proposed system was evaluated through simulation studies and field tests using an autonomous helicopter, and the results showed that it can be successfully used to establish an emergency communications system. Future work includes the realization of field tests with a group of autonomous helicopters to verify the success of the proposed communications system.

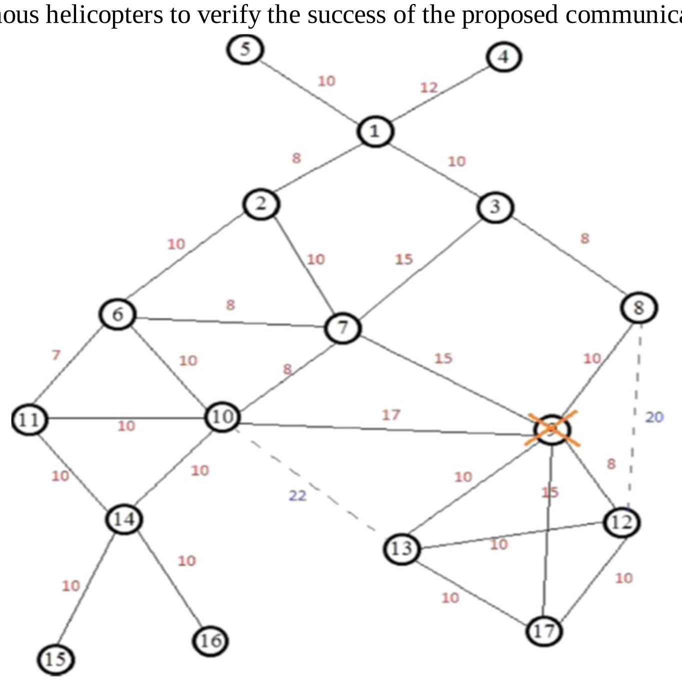

Fig. 3 Simulated graph of nodes [1]

Saha et al in their paper [2] on using disaster management using Internet of Things (IoT) discusses the importance of disaster management and the processes involved in it, including risk identification, preparedness, response, resource allocation, reaction planning, and recovery. The paper highlights the potential obstacles and challenges in deploying a Wireless Sensing Network (WSN) in an IoT situation for disaster management. The use of Compressed Sensing (CS) in IoT framework can reduce the amount of data transmitted and lower power consumption for battery-operated nodes. The paper also discusses the revolutionary technology of detecting people in a disaster situation who are not in possession of a tracking device. The conclusion emphasizes the need to improve disaster management abilities, especially in developing countries that are disproportionately exposed to the risks of natural disasters. The interconnection of devices to the internet offers a massive potential for recognizing and assessing risks and launching preventive measures.

Erdelj et al [3] discusses the role of Wireless Sensor Networks (WSN) and Unmanned Aerial Vehicles (UAV) in natural disaster management. The authors classify the main applications of WSN and UAV systems according to the disaster management phase and provide a review of relevant research activities. Fig. 4 shows the disaster management cycle as depicted in the paper. They also present the challenges that remain unsolved in disaster management systems.

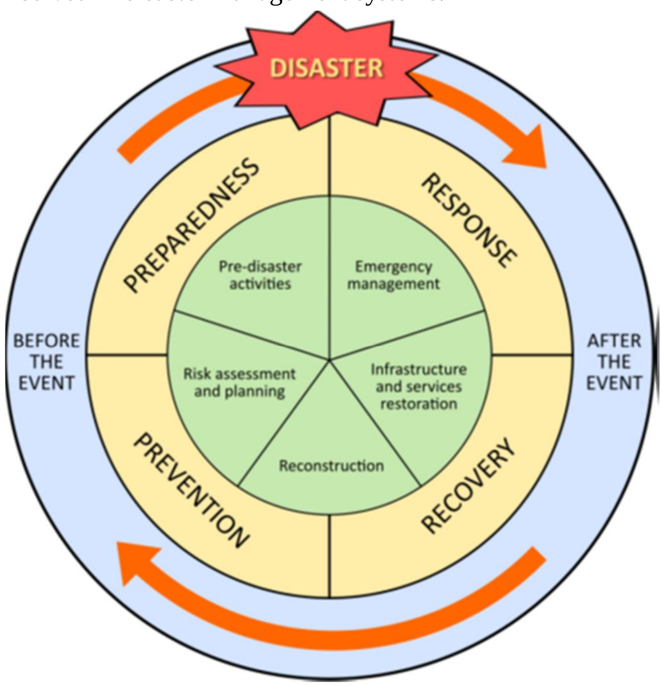

Fig. 4 Disaster management cycle [3]

The paper highlights the joint role that WSN and multi-UAV systems can play in disaster management and presents a roadmap for research activities in this field. The authors identify open issues in disaster management, including coverage, mobility, connectivity, robustness, reliability, security, privacy, safety, inter-operability, and quality of service. The paper aims to push the state of the art one step forward in the definition of a complete disaster management system. The authors identify open issues in disaster management, including coverage, mobility, connectivity, robustness, reliability, security, privacy, safety, inter-operability, and quality of service. The paper aims to push the state of the art one step forward in the definition of a complete disaster management system.

Paper about emergency networks by Kumar et al [4] discusses the challenges of dealing with natural disasters and proposes various mechanisms to tackle the situation, including MANET and WSN. The paper provides a comparison between different tools used to help in disaster management and proposes an alert mechanism using these tools. The technologies studied include WSN, MANET, and IoT, with WSN and MANET being useful for a natural disaster or post-disaster scene, while IoT is considered to sense the situation before the event or disaster. The paper proposes a hybrid Adhoc network architecture that combines IoT, WSN, and MANET to help victims and rescuers with different devices. The performance of the Alert network architecture will depend on the nodes deployed in this network to sense, including sensing node or mote, smartphone, or other devices, and on the algorithm used by its applications. The success of the alert network depends on the devices used in it and the standard used for communication.

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The paper concludes that sensor networks hold a lot of promise in applications where gathering information of remote locations is required while IoT is a powerful mechanism to sense and visualize.

The increase in natural disasters has led to a need for Disaster Response Organizations (DROs) to adopt novel technologies to improve efficiency. The paper by Stute et al [5] analyses International Disaster Response (IDR) operations and derives principles and system requirements for ICT designers to consider. The paper suggests three areas of research to enhance IDR operations: decentralized means of communication, USAR-supporting cyber-physical systems, and automating reporting. The goal of this paper is to serve as a reference for future ICT research endeavours to support and increase the efficiency of IDR operations.

Pirzada et al [6] proposes the use of a Space-Air-Ground Integrated Network (SAGIN) shown in Fig. 5 for disaster management, which utilizes devices in space, air, and ground for communication during disasters. The SAGIN framework uses devices in space (satellites in different orbits), in air (UAVs, airplanes, etc.), and on the ground (mobile networks, internet communication, etc.) for disaster management.

Fig. 5 Depiction of operation of SAGIN [6]

Communication is facilitated between these devices using different frequencies and through satellite to satellite and UAV to UAV communication. The framework utilizes GEO and MEO satellites, UAVs, and quadcopters for detection and communication of disasters, and the information received is communicated through terrestrial networks to disaster management centres. Different disaster detection centres are integrated for early warning and detection of disasters, and all devices are connected using IP for communication.

The article highlights the limitations of current disaster management networks, including terrestrial, air-ground, and space-ground networks. The proposed framework uses Internet Protocol (IP) for communication and provides a comparison of services offered by different networks. The article concludes that the proposed protocol on SAGIN is effective for disaster detection and communication, and offers a range of services for disaster management. Article concludes with the comparison of the proposed solution with other technologies as depicted in Table I.

Table I Comparison of services for disaster management [6]

Abilities	Terrestrial Network	Air Ground Network	Space-Ground Network	SAGIN
Coverage	Terrestrial	Terrestrial	Global	Global
Communication	Terrestrial	Terrestrial	Global	Global
Navigation	NO	NO	YES	YES
Imaging	YES	YES	YES	YES
Effected by disasters	YES	NO	NO	NO
Security	YES	YES	YES	YES
Weather Information	NO	NO	YES	YES

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Kota et al [7] discusses the challenges and possible solutions towards satellite 5G networks and beyond as a part of the roadmap study addressed by the Satellite Working Group of IEEE Future Networks Initiative. The paper highlights the potential of Non-Terrestrial Networks (NTN), including satellite systems, Unmanned Aerial Vehicles (UAVs) and High-Altitude Platforms (HAPs) to connect the unconnected, unserved and underserved areas on the earth, thus complementing terrestrial 5G networks as depicted in Fig. 6.

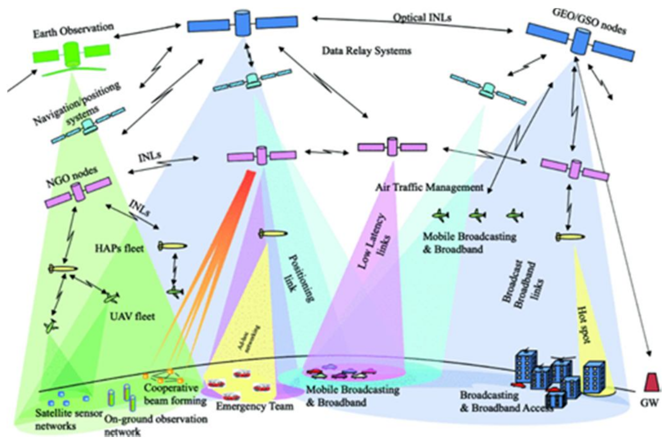

Fig. 6 Satellite 5G services [7]

The paper also discusses the potential of Beyond 5G (B5G) and future 6G systems, capable of implementing new technologies for mmWave frequency bands, space IoT, pervasive use of Machine Learning/Artificial Intelligence (ML/AI) paradigms, tactile Internet, and advanced security schemes based on quantum satellites. The paper concludes that additional work is needed to define new interfaces and address multi-layer NTN, specifying the role of UAVs and HAPs.

Khan et al [8] proposes a methodology for disaster data classification using urgency levels and priority index assignment to efficiently transmit high and low priority packets with minimum delays in transmission queue. The authors also propose a bio-inspired mechanism using behavioural study of bird flocking for cluster formation and maintenance to handle N number of UAVs for disaster management. A priority-based route selection methodology for data communication in FANET cluster is also proposed. Simulation results show that the proposed mechanism performs better than single-level and multi-level queuing, making FANETs efficient for disaster management. The article discusses four disaster management scenarios that require different communication aspects for UAVs based networks. The first scenario depicted in Fig. 7 is standalone UAV scenario involves using a UAV that communicates with a distant control center via satellite. The satellite serves as a relay for transmitting information between the UAV and the control center. This approach allows for efficient and effective communication between the UAV and the control center, enabling important information to be transmitted back and forth in a timely manner.

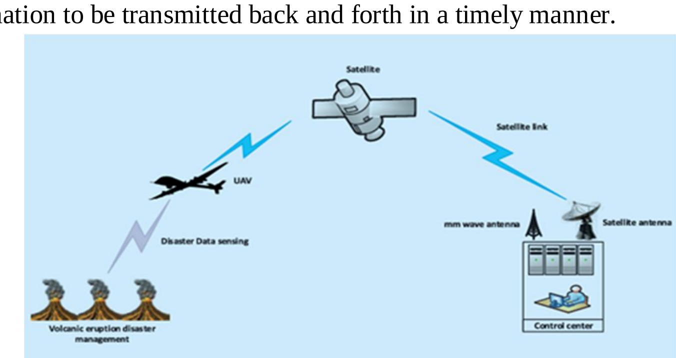

Fig. 7 Disaster management using standalone UAV [8]

The UAV-to-UAV communication scenario shown in Fig. 8 involves using mm-wave communication between two UAVs, where one UAV acts as a relay between the other UAV and the control center. The first UAV monitors the disaster situation and sends the information to the second UAV via mm-wave communication. The second UAV then relays the information to the control center, where it is processed and appropriate action is taken. Mm-wave communication is preferred in this scenario due to its high data rate and long-range communication capabilities.

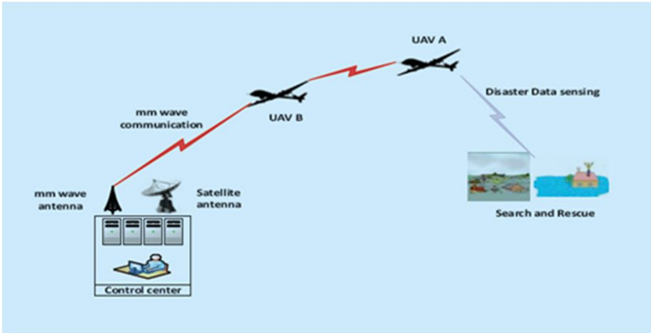

Fig. 8 Disaster management using UAV to UAV communication [8]

The disaster management using N number of UAVs scenario shown in Fig. 9 involves using multiple UAVs for sensing, transmitting disaster information, and monitoring disasters. In situations where the UAVs are not in range of the control center and satellite, N UAVs can be used to send disaster information to the control center by relaying information through other intermediate UAVs connected via mm-wave link. To efficiently manage N number of UAVs, the concept of clustering can be utilized to organize the networking environment effectively. The UAV near the control center transmits the information received from the clustered UAVs to the control center via mm-wave communication. This approach enables efficient transmission of disaster information from source to destination.

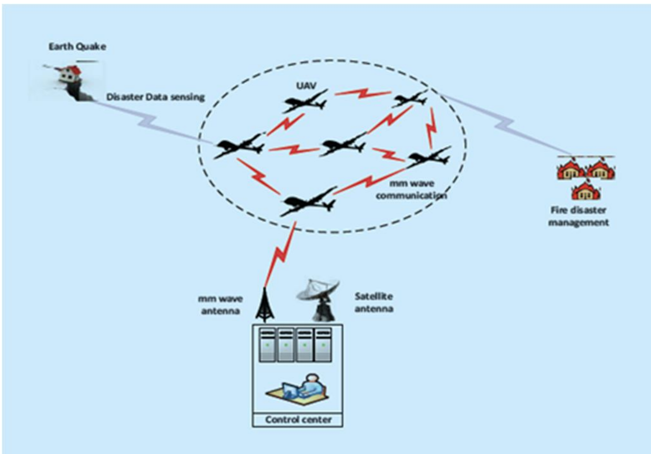

Fig. 9 Disaster management using N numbers of UAVs [8]

The disaster management using multi-network communication between UAVs scenario as shown in Fig. 10 combines all three previous scenarios. The UAVs identify different disasters and transmit the sensed information to the control center directly if they have a direct connection. If a UAV does not have direct connectivity, N number of UAVs can be used as a relay to transmit the information to the control center. Clustering can be utilized to efficiently organize the N number of UAVs, and a CH (cluster head) can be elected to act as a relay for all the UAVs in the cluster for transmission of data toward the control center. This approach ensures effective disaster management and communication between UAVs and the control center.

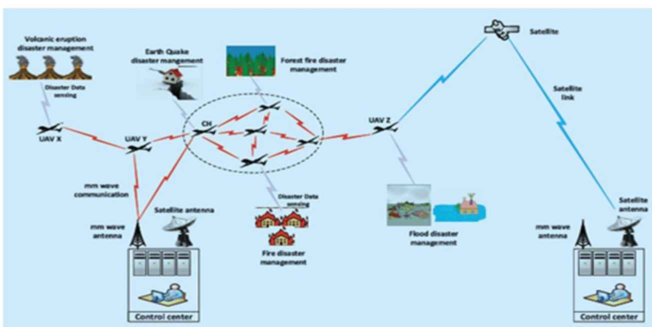

Fig. 10 Multi network communication between UAVs [8]

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Franchi et al [9] discusses the potential benefits of using fifth generation mobile networks for disaster management systems, particularly in the areas of structural health monitoring and earthquake early warning. The integration of IoT hardware, network infrastructure, and software platforms can achieve unprecedented reliability levels and low latency. The paper presents a vertically integrated 5G-based disaster management system developed in the Italian city of L'Aquila, which focuses on monitoring the status of buildings in a seismic area and providing earthquake early warning. The system shown in Fig. 11 involves design aspects of several domains, including IoT board design, 5G network management, and disaster management software platform.

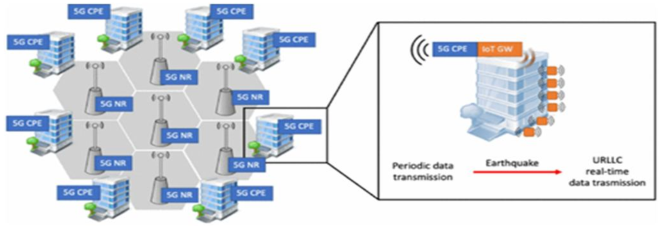

Fig. 11 Permanent SHM using 5G network [9]

The paper concludes by presenting a practical example of how the proposed system can be applied to a real monitoring problem and how it can be integrated into a Disaster Management control center or an automatic Decision Support System.

Osoro et al [16] presents an open-source modelling framework for assessing the techno-economics of satellite broadband connectivity, with a focus on Low Earth Orbit (LEO) satellite systems. The approach is applied to assess the three main competing LEO constellations, including Starlink, OneWeb, and Kuiper, and simulates the impact on coverage, capacity, and cost as the number of satellites and quantity of subscribers increases. The results depicted in Fig. 12 reveal that LEO broadband will be an essential part of the connectivity toolkit, but these mega-constellations will most likely have to operate below 0.1 users per km2 to provide a service that out-competes other broadband connectivity options.

Parameter	Starlink	Kuiper	OneWeb	Unit
Simulated Satellites	5,040	720	3,240	-
Satellite Mass	260	147.5	260	kg
Downlink Frequency	13.5	13.5	17.7	GHz
Bandwidth	0.25	0.25	0.25	GHz
Channels	8	8	8	-
Aggregate Bandwidth	2	2	2	GHz
System Temperature	290	290	290	K
EIRP	67.7	68.3	73.1	dBm
Receiver Antenna Gain	37.7	38.3	43.1	dBi
Altitude	550	610	1,200	km
Minimum Elevation Angle	40	35.2	55	Deg
Antenna Diameter	0.7	0.75	1	m
Modulation Scheme	16	16	16	APSK
Frequency Reuse Factor	2	2	2	-
Satellite Lifespan	5	5	5	-

Fig. 12 Comparison of parameters by LEO constellation [16]

The paper also highlights the importance of engineering innovative supply-side technologies for connecting hard-to-reach users, particularly if they can overcome many of the economic barriers facing deployments in rural and remote areas. It also compares the cost of various constellations in Fig. 13.

Parameter	Type	Starlink Cost (US$ Millions)	Starlink Source	OneWeb Cost (US$ Millions)	OneWeb Source	Kuiper Cost (US$ Millions)	Kuiper Source
Ground Station	Capex	81.2	Author calculations from SES (2019)	47	Author calculations from SES (2019)	33	Author calculations from SES (2019)
Digital Infrastructure	Capex	6.2	Author calculations from Oughton et al.,(2019)	2.5	Author calculations from Oughton et al.,(2019)	3.6	Author calculations from Oughton et al.,(2019)
Spectrum Cost	Capex	125	Assumption	125	Assumption	125	Assumption
Regulation Fees	Capex	0.7	Calculations from FCC (2021)	0.7	Calculations from FCC (2021)	0.7	Calculations from FCC (2021)
Cost of Operational Staff	Opex	60	Calculations from SES (2019)	7.5	Calculations from SES (2019)	60	Calculations from SES (2019)
Cost Overhead per R&D	Opex	7.5	Calculations from SES (2019)	7.5	Calculations from SES (2019)	7.5	Calculations from SES (2019)
Marketing and Customer Acquisition Cost	Opex	50	Assumption	50	Assumption	50	Assumption
Launch Cost Per Satellite	Opex	0.5	Author calculations from Jones (2018)	2.0	Author calculations from Jones (2018)	1.5	Author calculations from Jones (2018)
Cost of each Satellite	Opex	0.25	Assumption	0.25	Assumption	0.25	Assumption

Fig. 13 Cost comparison of LEO constellations [16]

The results of the model reveal that mean aggregate capacity speeds of 11.72 ± 0.04 Gbps, 3.43 ± 0.01 Gbps, and 7.53 ± 0.03 Gbps are achievable for Starlink, OneWeb, and Kuiper, respectively. The paper concludes that success will depend on maintaining relatively low spatial subscriber densities, preferably below 0.1 users per km2, otherwise the services provided may offer little benefit against other terrestrial options.

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III. LEO SATELLITES FOR DISASTER RECOVERY

Low earth orbit (LEO) satellites are a type of satellite technology that orbit the Earth at an altitude of approximately 1,200 km to 2,000 km, which is much lower than traditional geostationary satellites that orbit at an altitude of 36,000 km. LEO satellites are used for a variety of applications, including earth observation, global positioning systems (GPS), and internet connectivity.

One of the major advantages of LEO satellites for internet connectivity is their ability to provide low-latency, high-speed broadband connectivity to remote and underserved areas of the world. This is particularly important in disaster recovery operations, where traditional terrestrial infrastructure may be damaged or destroyed, leaving affected communities without internet connectivity.

LEO satellites can provide global coverage, making them a viable option for delivering internet connectivity to even the most remote areas of the world. Furthermore, the low altitude of LEO satellites allows for faster data transfer rates and lower latency, making them ideal for applications that require real-time data transfer, such as telemedicine and disaster response.

One of the key players in the development of LEO satellite internet connectivity is SpaceX, with their Starlink satellite constellation. The Starlink constellation consists of thousands of small, low-cost satellites that can provide high-speed, low-latency internet connectivity to users anywhere in the world. As of May 2023, SpaceX has launched over 4238 Starlink satellites, with plans to launch thousands more in the coming years.

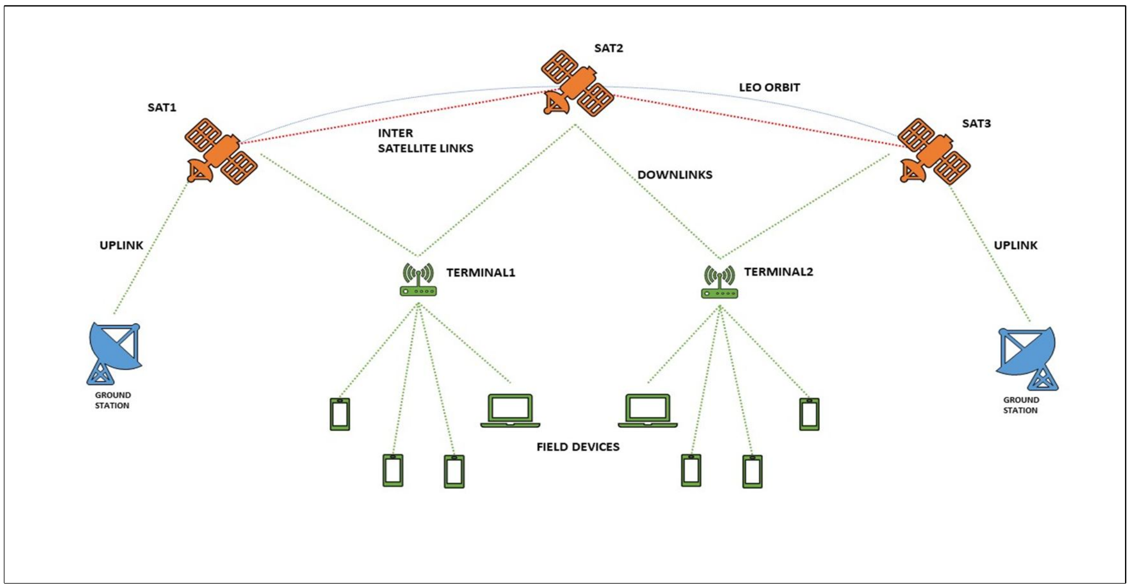

Fig. 14 Disaster Recovery using LEO Satellites

Fig. 14 displays the disaster recovery plan utilizing LEO satellites. The satellites will orbit in the LEO orbit, while the ground stations provide the uplink from the internet. The user terminals, which are mobile satellite dishes, will function as downlink devices and can be set up at the disaster sites. These terminals are designed to automatically track the satellites as they move across the sky, ensuring a steady and reliable connection. The link from the terminals to the user end devices, such as mobiles and laptops, is provided using a Wi-Fi connection.

While LEO satellite internet connectivity offers many advantages, there are also some challenges to consider. One of the major challenges is the cost of launching and maintaining the satellite constellation, which can be significant. Additionally, there is the potential for orbital debris and space junk, which can pose a risk to both the satellites themselves and other objects in orbit.

Overall, LEO satellite technology offers a promising option for delivering high-speed internet connectivity to remote and underserved areas, particularly in disaster recovery operations. With continued innovation and investment, we can expect to see increased adoption of LEO satellite technology for internet connectivity in the coming years.

IV. CONCLUSION

High-speed network designs for ICTs play a crucial role in disaster recovery operations by providing essential communication channels for search and rescue, medical care, emergency shelter, food and water distribution, power and communication monitoring and repair, debris removal and clean-up, transportation coordination, and counselling services.

However, existing high-speed network design strategies have some limitations, including power dependency, limited coverage, and scalability issues. These limitations can be mitigated by implementing best practices such as redundancy, scalability, prioritization, interoperability, flexibility, and security.

Moreover, advancements in low earth orbit (LEO) satellite technology offer an innovative solution to address some of the challenges faced by traditional high-speed network designs. LEO satellites can provide global coverage, low-latency connectivity, and faster data transfer rates compared to traditional communication systems. As a result, they offer a promising option for disaster recovery operations, particularly in areas where terrestrial infrastructure is destroyed or limited.

In the future, increased adoption of LEO satellites for disaster recovery operations is expected, as well as continued innovation in high-speed network design strategies. By leveraging these advancements, we can improve the resilience of communication networks during disasters, enabling faster and more effective response efforts to save lives and mitigate the impact of natural disasters.

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