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Review Article

Space-Air-Ground Integrated Network for Disaster Management: Systematic Literature Review

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The occurrence of any kind of natural disaster will eventually lead to the loss of life and property. Countries where such disasters occur make every effort to monitor such disasters and aid as quickly as possible. However, in some cases, a rescue cannot be sent because no information is available to initiate any type of rescue operation. This is usually because common disaster management systems (DMS) use on board or ground networks to route information from the disaster scene to rescue headquarters (HQ), which in most cases cannot provide the information efficiently. One effective approach is to use satellites in conjunction with existing air-to-ground systems. This study provides a comprehensive and systematic overview of the complexities of the space-air-ground integrated network (SAGIN) in disaster management applications, including different architectures and protocols. The main rationale behind this review is to provide an extensive analysis of existing disaster management systems that are making use of SAGIN. This paper also presents the taxonomy for disaster management systems and challenges. Moreover, this research work also highlights open research issues and challenges for any type of disaster scenario. Our results indicate that several challenges are faced by disaster management systems such as hardware-based challenges, network-based characteristics and communication protocols related challenges, availability and accuracy of imagery data, and security and privacy issues.

1. Introduction

The mitigation of loss of human lives in any kind of disaster situation is one of the key aspects of any disaster management system. Whether a disaster occurs in the form of a traffic accident or in the form of a natural disaster, the major objective for rescuers is to lessen the loss of lives. To prevent lives in such situations, an effective disaster management system (DMS) is significantly important. A DMS can be made highly effective with the provision of high-quality imagery and data to conduct a successful rescue operation. This data can be fetched through the use of technological applications and devices. As per [1], monitoring technologies such as sensor networks and unmanned aerial vehicles (UAV) can be employed for the reduction of disaster scenarios.

Disasters and hazards can occur at any time, whether they be natural or human-made and can result in the loss of lives. However, using information technology (IT) infused preventive techniques, researchers believe that such loss of lives can be entirely negated. Several recent research covers different aspects of IT applications in disaster management systems [2–4]. Despite these advancements, there are still several challenges related to the assimilation of data pertaining to a disaster-struck area. One of the major issues in data accumulation during a disaster scenario is the timely communication of data to the DMS rescue team. Without such data communication the detection of disaster and prevention of loss is difficult. Therefore, the use of air-based networks is a substantial research area for any type of disaster scenario.

Using UAV [5], it is possible to take aerial photos and then communicate this data to the disaster management (DM) headquarters for further processing. Additionally, vehicle networks can be used to obtain data from disasters [6–8]. Though such systems are effective to a certain extent, however, the effectiveness can be increased with the use of satellites along with air and ground support.

1.1. Motivation. The use of space, air, and ground networks has led to the specific field of the space-air-ground integrated network (SAGIN). SAGIN can attain more data relevant to the rescue operation of a disaster scenario effectively and efficiently. Thus, the utmost importance is to accumulate, review, and classify all of the research that has been performed in the area of SAGIN, especially in the case of disaster management.

Research studies for the advancement of disaster management using state-of-the-art techniques are available. However, the number of research papers related to SAGIN was extremely limited and the literature review of SAGIN for disaster management systems has not been conducted yet. Coupled with the use of such technology in the application of disaster managementa major problem is the lack of existing literature. This is evident from Table1 where a majority of the high-scoring research is survey-based research, but there are only 4-5 survey research studies that have focused on making use of SAGIN in general for emergency situations or disaster relief.

The rationale behind this study is to motivate and help the researchers to know about SAGIN and its effectiveness in the disaster management system. Moreover, this study analyses the progress of SAGIN for disaster management systems.

1.2. Contribution. This research provides a comprehensive systematic review of the complexities of SAGIN in the application of disaster management including different architectures and protocols. The main contribution of this review is that it provides insight into existing disaster management systems that are making use of SAGIN. Moreover, this research work also highlights open research issues and challenges for any type of disaster scenario. Our results indicate that several challenges are faced by disaster management systems such as hardware-based challenges, network-based characteristics and communication protocols related challenges, availability and accuracy of imagery data, and security and privacy issues. Their solutions need to be further investigated for disaster management systems.

1.3. Organization of Article. The objective of this paper is to present a systematic literature review for the sake of providing a comprehensive review of all the research that has been conducted. The contribution in this paper is as follows:

Table 1: Quality assessment score.

Classification			Quality assessment				
Ref	Year	Type	A	b	C	d	Score
[9]	2014	Proposed solution	0	0.5	1	2	3.5
[10]	2021	Survey	1	1	0	2	4
[11]	2016	Architecture	1	1	0.5	0	2.5
[12]	2013	Survey	0	1	0.5	0	1.5
[13]	2021	Survey	1	1	0.5	0	2.5
[14]	2020	Platform	0	0.5	1	2	3.5
[15]	2021	Survey	1	0.5	0	1	2.5
[16]	2015	Architecture	1	1	1	0	3
[17]	2014	Architecture	1	1	1	0	3
[18]	2021	Survey	1	0.5	0.5	2	4
[19]	2020	Model	1	1	0.5	0	2.5
[20]	2020	Architecture	1	0.5	0.5	0	2
[21]	2021	Survey	1	1	0.5	2	4.5
[22]	2021	Architecture	1	1	0.5	2	4.5
[23]	2020	Architecture	0	0	1	2	3
[24]	2021	Survey	1	1	0.5	2	4.5
[25]	2020	Framework	1	1	0.5	0.5	3
[26]	2021	Proposed solution	1	0	0	2	3
[27]	2021	Proposed solution	1	0	0	2	3
[28]	2021	Proposed solution	1	0.5	0	1	2.5
[29]	2017	Survey	1	1	1	1.5	4.5
[30]	2021	Proposed solution	1	1	0	1.5	3.5
[31]	2021	Proposed solution	0	0	0	1	1
[32]	2020	Proposed solution	1	0	1	2	4.5
[33]	2020	Survey	1	0	0.5	1	2.5
[34]	2019	Architecture	1	0	1	1	3
[35]	2019	Architecture	0	0.5	1	2	3.5
[36]	2019	Proposed solution	0	0	1	2	3
[37]	2021	Proposed solution	1	1	0.5	2	4.5
[38]	2020	Proposed solution	1	1	0.5	2	4.5
[39]	2018	Survey	1	1	0.5	0	2.5
[40]	2019	Proposed solution	1	1	0.5	1	3.5
[41]	2021	Survey	1	0.5	0	2	3.5
[42]	2021	Architecture	1	0.5	0	1	2.5
[43]	2015	Proposed solution	1	0	1	2	4
[44]	2021	Framework	1	1	0	2	4
[45]	2020	Framework	0	0	1	2	3
[46]	2017	Architecture	1	1	1	2	5
[47]	2019	Architecture	1	0	1	2	4
[48]	2020	Framework	1	1	0.5	0	2.5
[49]	2021	Framework	1	1	0.5	0	2.5
[50]	2019	Model	0	0.5	1	1	2.5
[51]	2021	Model	0	0	0.5	2	2.5
[52]	2018	Survey	1	1	1	2	5
[53]	2021	Survey	1	1	0	2	4
[54]	2020	Architecture	1	1	1	0	3
[55]	2021	Survey	0	1	0	0	1
[56]	2018	Survey	1	1	1	0	3
[57]	2019	Model	0	0.5	0.5	0	1
[58]	2016	Architecture	1	1	1	0	3
[59]	2019	Architecture	1	1	0.5	0	2.5
[60]	2022	Model	1	0	0.5	2	3.5
[61]	2021	Survey	1	1	0.5	2	4.5
[62]	2020	Architecture	1	0.5	0	0	1.5
[63]	2015	Architecture	1	0.5	1	2	4.5
[64]	2021	Proposed solution	0	0.5	0.5	2	3
[65]	2022	Proposed solution	0	0.5	0	2	2.5
[66]	2020	Survey	1	1	1	2	5
[67]	2018	Survey	1	1	1	2	5
[68]	2021	Platform	1	1	0	0.5	2.5

Table 1: Continued.

Classification			Quality assessment				
Ref	Year	Type	A	b	C	d	Score
[69]	2022	Framework	1	1	1	2	5
[70]	2021	Platform	1	1	0	0	2
[71]	2022	Model	1	1	0.5	2	4.5
[72]	2021	Proposed solution	1	1	0	0	2
[73]	2019	Proposed solution	1	1	1	1	4
[74]	2022	Framework	1	1	0.5	2	4.5
[75]	2022	Proposed solution	0	0.5	0	1.5	2
[76]	2019	Proposed solution	1	0.5	1	0	2.5
[77]	2020	Survey	1	0.5	1	2	4.5
[78]	2021	Model	1	0.5	1	2	4.5
[79]	2019	Framework	0	0.5	1	2	3.5
[80]	2021	Model	0	0.5	0.5	1	2
[81]	2020	Proposed solution	1	1	1	1	4
[82]	2022	Framework	1	1	0	2	4
[83]	2021	Architecture	1	1	0.5	2	4.5
[84]	2022	Framework	0	0.5	0	2	2.5
[85]	2020	Architecture	1	1	1	2	5
[86]	2020	Architecture	1	1	0.5	0	2.5
[87]	2019	Model	1	1	1	2	5
[88]	2022	Survey	1	1	0	2	4
[89]	2021	Proposed solution	1	1	0.5	2	4.5
[90]	2018	Framework	0	0.5	1	2	3.5
[91]	2022	Survey	1	1	0.5	2	4.5
[92]	2021	Survey	1	0.5	1	2	4.5
[93]	2021	Proposed solution	1	0.5	0	2	3.5
[30]	2021	Proposed solution	1	1	0.5	1.5	4
[94]	2017	Survey	1	0.5	0.5	0	2
[95]	2017	Framework	1	0.5	0	0	1.5
[96]	2020	Proposed solution	1	0.5	1	1	3.5
[97]	2022	Model	1	1	0	1.5	3.5
[98]	2020	Survey	1	1	1	2	5
[99]	2021	Proposed solution	1	1	0	0	2
[100]	2019	Survey	1	0.5	1	2	4.5
[101]	2021	Proposed solution	0	0.5	0	0	0.5
[102]	2014	Survey	0	0.5	0.5	0	1
[103]	2019	Proposed solution	1	1	0	0	2
[104]	2020	Architecture	1	1	0	0	2
[105]	2021	Architecture	1	0.5	1	1.5	4
[106]	2017	Proposed solution	1	1	1	2	5
[107]	2021	Survey	0	0.5	0	2	2.5
[108]	2018	Proposed solution	0	0.5	0.5	0	1
[109]	2017	Survey	1	1	1	2	5
[110]	2021	Model	1	0.5	0.5	2	4
[111]	2021	Proposed solution	1	0.5	1	2	4.5
[112]	2016	Survey	1	0.5	0	0	1.5
[113]	2021	Framework	1	1	0	1	3
[114]	2018	Model	0	0.5	1	2	3.5
[115]	2018	Survey	1	0.5	1	2	4.5
[116]	2021	Survey	0	0.5	1	2	3.5
[117]	2021	Proposed solution	1	0.5	1	2	4.5
[118]	2020	Survey	1	1	1	2	5
[119]	2019	Architecture	1	1	1	1	4
[120]	2021	Survey	0	0.5	1	2	3.5
[121]	2019	Architecture	0	0.5	0.5	0	1
[122]	2019	Architecture	1	0.5	1	2	4.5
[123]	2019	Proposed solution	0	0.5	0.5	0	1
[124]	2022	Model	0	0.5	0	2	2.5
[125]	2021	Survey	0	0.5	0	0	0.5
[126]	2016	Survey	0	0.5	0	0	0.5
[127]	2020	Proposed solution	1	1	1	2	5

Table 1: Continued.

Classification			Quality assessment				
Ref	Year	Type	A	b	C	d	Score
[128]	2020	Architecture	1	1	0.5	2	4.5
[129]	2021	Survey	0	0.5	0.5	2	3
[130]	2019	Proposed solution	0	0.5	0.5	2	3
[131]	2016	Architecture	1	1	0.5	0	2.5
[132]	2018	Survey	1	0.5	0.5	0	2

(i) A comprehensive background on the different terminologies is provided in Section 2.

(ii) Section 3 describes the research methodology through the definition of research objectives, questions, inclusion/exclusion criteria, and search strings.

(iii) Search results are then provided in the form of tables in Section 4 so that significant information can be extracted.

(iv) In the next section, the existing survey-based studies are summarized and compared to our study.

(v) Finally, Section 6 presents the conclusion to the paper along with lessons learned and future outcomes.

2. Background

2.1. Disasters. Disasters can be categorized into two main types, that being natural and human-made disasters. Natural disasters are those that occur naturally and are considered one of the most destructive forces of nature. For instance, tsunamis are normally caused by underwater earthquakes and can cause a large flow of water toward the land which in turn can cause massive damage. The increased destructiveness of natural disasters is usually because of the unpredictability of their occurrence. Establishing an effective system for the verification of a disaster's severity and potential damage is the way to prevent or mitigate the loss of lives and assets [133].

The second type of disaster that can occur is human-made, or more specifically any accident such as the collision of vehicles. The severity of this disaster in comparison to natural disasters is similar, however, the former can be avoided by following proper rules and regulations. Therefore, there is also a need for an effective management system that can ensure reducing the risk of accidents efficiently.

2.2. Space-Air-Ground Integrated Network. SAGIN was introduced to resolve the problems faced due to limited network capacity and coverage present in a ground communication system. It is expected that networks will provide more resources than the current situation to cope with the increasing demands in traffic and various other services. Though to compensate for such issues, new technologies such as cloud computing, big data, and the Internet of Things (IoT) are being employed. However, they also have certain limitations. To overcome all the limitations of existing technologies, the interconnection of space, air, and ground network segments with modern information network technologies are being investigated these days. This has resulted in the creation of SAGIN.

In recent years, SAGIN has been used by multiple organizations including SpaceX [134] and Global Information Grid [135]. SAGIN provides large coverage, strong resilience, and high throughput. Thus, different parts of the earth, such as rural or mountainous regions can be monitored for earth mapping through SAGIN. Moreover, it can be applied for the service of Intelligent Transportation System (ITS) [136], military reconnaissance, and disaster relief.

The SAGIN architecture comprises three main segments: space, air, and ground. These segments can either work interoperationally or independently (as presented in Figure 1). In the space segment, the network is composed of constellations and satellites as well as their corresponding terrestrial infrastructures (ground stations). These constellations and satellites are present in different orbits and have different characteristics. They are divided into three classifications, Medium Earth Orbit (MEO), Geostationary Earth Orbit (GEO), and Low Earth Orbit (LEO) satellites [137].

The air network segment can be considered an aerial mobile system that can use either aircraft for information transmission, procurement, and processing or UAVs or hot air balloons. And the ground network segment consists of terrestrial networks such as cellular networks, wireless local area networks (WLANS), or vehicular ad-hoc networks (VANETs).

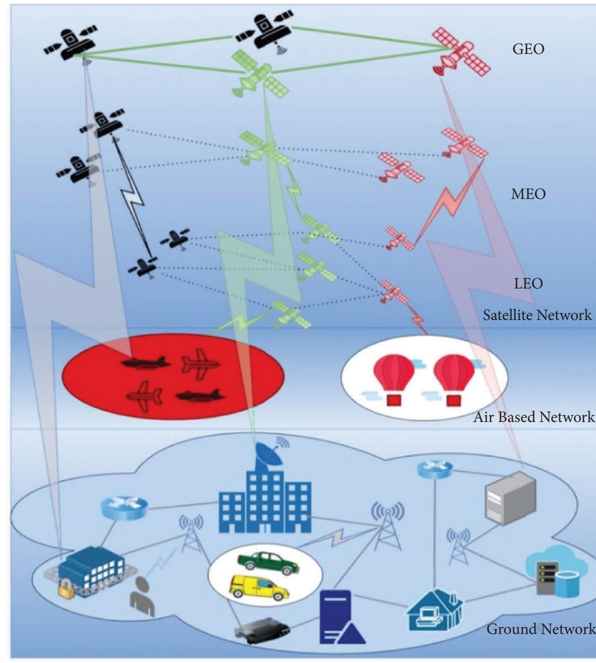

Figure 1: Space-air-ground integrated network architecture.

3. Research Methodology

A systematic literature review (SLR) has been conducted for the purpose of examining the advancement in the disaster management area. The approach of SAGIN and ITS (Intelligent Transportation System) is closely examined and discussed in this research for their applicability in this area. The main rationale for this study is to scrutinize and review different architectures and solutions for disaster management systems. To provide an effective SLR, this paper employs the methodology given in [138] for the provision of impartial research in the selection of data and the representation of its results. The research methodology is presented in Figure 2.

In the initial step of this SLR, the research objectives to determine the purpose of this survey were defined (as demonstrated in Figure 2). Afterward, these research objectives were transformed into the research questions. In the next step, all the existing research was gathered using a search string. After the collection process, screening was performed to filter out the research articles based on the keywords, abstract, and then the contents of the research article. In the final step, the data was extracted to answer the research questions.

3.1. Research Objectives. This research provides attention to the following research objectives:

RO1: To produce a thorough assessment of the latest research conducted in relation to disaster management systems

RO2: To present different existing ITS-based disaster management systems for the case of human-made disasters

RO3: To analyze the SAGIN-based architectures and solutions for disaster scenarios

RO4: To identify different research gaps in terms of challenges and issues

3.2. Research Questions. The identification of research questions is required to provide the selection of research papers related to that specific question. The formulated research questions are presented in Table 2.

3.3. Search String. The next step in this systematic literature review is the selection of different publication channels used to search for relevant articles pertaining to the defined research questions (RQs). After this, a search string is defined to search the previously defined publication channels. Using the defined search string, multiple research articles were collected, and then their results were aggregated to provide a solution to the RQs. The selected publication channels have been specifically chosen that overly provide a close relationship between their scientific accuracy and the objects of this research. The selected publication database in which the search string has been applied ranges from IEEE to Science Direct. Complete detail of all the publication sources along with the search string are provided in Table 3.

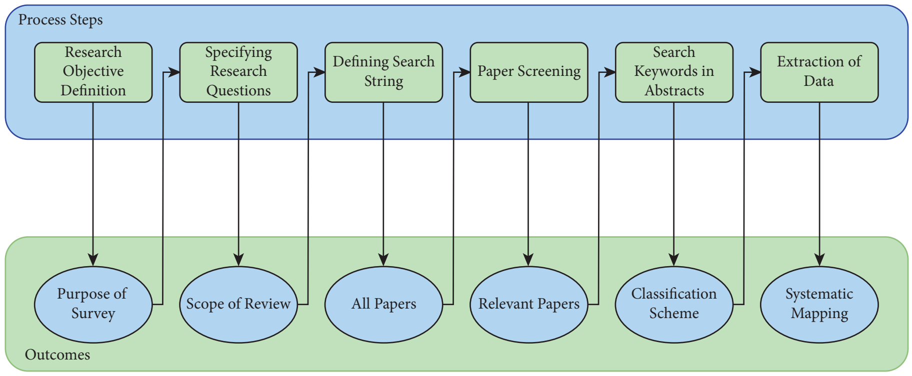

Figure 2: Research methodology.

Table 2: Research question.

Number	Research questions	Motivation
RQ1	What are the channels of publication focusing on DMS?	To search and quantify the quality of different publication sources and to investigate research related to DMS
RQ2	How the frequency of recent publications related to DMS has been changed over time?	To find out the trend in the research of DMS and explain the number of publications related to DMS made in the last 10 years
RQ3	How are different methods and techniques being used for developing an effective SAGIN-based DMS?	To identify and describe the different approaches used for an effective SAGIN-based DMS
RQ4	What are the main challenges that can occur while establishing a DMS using SAGIN?	To identify the different issues and challenges presented in the existing studies for SAGIN related systems

Table 3: Search string for the collection of papers from digital libraries.

Source	Search string	Context
Google scholar IEEE Xplore Springer MDPI Science direct	("Disaster management" OR "emergency management" OR "rescue" OR "rescue operation" OR "accident management") AND ("space-air-ground network" OR "space-air-ground integrated network" OR "SAGIN" OR "space information network" OR "SIN" OR "STN")	Disaster management, rescue operation, emergency situation

3.4. Screening for Relevant Results. Not all the collected research articles were considered in this SLR as some were less related to the defined RQs. Therefore, some results were filtered and excluded using the study provided by [139]. The provided study defines the screening of research articles while considering two phases. In the first phase, the collected research articles are filtered according to their titles. In the next phase, the filtered articles were further excluded/included based on their abstracts. The criteria which define the exclusion of research articles are as follows:

(i) Those research articles that are not published in any journal, conference, or technical report.

(ii) There is no innovation or use of emerging ideas and technologies in the research articles.

(iii) Those articles that have been published before 2010.

(iv) Research articles that had no relationship with the defined search string.

(v) Research papers that were not in the English language.

3.5. Quality Assessment. After the relevant research papers have been selected the next step in this SLR is to provide quality assessment (QA). This QA is conventionally performed to verify and evaluate the quality of the research articles collected and is performed using a questionnaire. However, for this SLR, the selected papers are assigned some quantitative values as per the mapping study presented by [140]. The values that are to be assigned are provided below as well as in Table 4.

(i) The research article provides an effective solution to the management of disasters. The possible answer to this question is either Yes **(+1)** or No (**0**). This marking is denoted by using **a**.

(ii) The research paper provides a concise answer to the use of SAGIN in favor of disaster management. The possible answer for this question ranges from Yes (**+1**), No (**0**), or **0.5** for partially answering the question. This scoring is performed while using the notation **b**.

(iii) The research paper in the question has been cited by other research articles along with answers to the research questions. For the research works that have not been cited since their publication is assigned, No (**0**). For those research articles that have 1–6 citations since their publication are assigned, **0.5**. And for those research works that have more than 6 citations are assigned a score of **+1**. For this scoring, the notation used is **c**.

(iv) The research work in question is from a reputable and recognized journal or conference publication. To evaluate this, the journal citation reports (JCR) and CORE ranking for computer science are considered for evaluation. The assigned score for either JCR or CORE is provided in Table 4. The scoring of this evaluation is denoted by **d**.

4. Analysis

In this section, a complete analysis of each research question, shown in Table 2, has been performed against different selected research articles. For all the selected primary research articles, their obtained QA score along with their publication name has been listed in Table 1.

A comprehensive analysis of a disaster management system that employs the use of SAGIN is a difficult challenge as it consists of different architectures and different other factors such as machine learning, artificial intelligence, and different types of network functions. Using the previously defined research questions, this research has made use of 50 research works from the last 10 years and was used to analyze the different research questions. Due to the limitation of fewer available works on the topic, we have short-listed research articles which were most relevant to find the research gap.

4.1. RQ1 Assessment: Key Publication Channels Targeted for DMS. For the selection of different primary research articles, various publication channels were made use of. A list of the selected research papers along with their publication channel has been provided in Table 5. Also provided in the Table is the number of occurrences of research articles published in a particular journal (J) or conference (Conf.).

4.2. RQ2 Assessment: Frequency of Change in Research with Respect to Time. The quantity of the various selected research articles that have been published over the last decade is represented in Figure 3. It can be seen from the figure, that the majority of the research was conducted from 2018 to 2021 with the later years seeing more publications in this specific research area which ultimately points toward the growing interest in this research topic.

4.3. RQ3 Assessment: Approaches Used for Design of SAGIN Based DMS. From the analysis of different research articles, it is found that different approaches in research have been made to design an effective DMS as shown in Figure 4. Inspired by the research work conducted in [141–143], the findings of some of the more recent works, have been summarized in Table 6. Each approach used in the selected research articles has been classified below:

4.3.1. Proposed Solution. For an efficient DMS, different research articles have provided different types of solutions, whether this is the form of a routing protocol or an efficient algorithm that overall improves the system [9, 26–28, 30–32, 35–38, 40, 41, 43, 44, 48, 51, 64, 65, 72, 73, 75, 76, 81, 89, 93, 96, 99, 101, 103, 106, 108, 111, 114, 117, 123, 127, 130].

4.3.2. Surveys. Some of the reviewed research articles have presented the conduction of either surveys or reviews [10, 12, 13, 15, 18, 21, 24, 29, 33, 39, 41, 52, 53, 55, 56, 61, 66, 67, 77, 88, 91, 92, 94, 98, 100, 102, 107, 109, 112, 115, 116, 118, 120, 125, 126, 129, 132] for the concept of SAGIN overall or in the field of DMS.

4.3.3. Architecture. One of the major approaches in the selected research articles was the formulation of architectures that can be used for the improvement of SAGIN or the scenario of a disaster [11, 16, 17, 20, 22, 23, 34, 35, 42, 46, 47, 54, 58, 59, 62, 63, 82–86, 104, 105, 119, 121, 122, 128, 131].

4.3.4. Framework. Some of the research has been focused on creating a framework that could be used for further research in SAGIN-based structure and its various applications [25, 44, 45, 48, 49, 69, 74, 79, 82, 84, 90, 95, 113].

4.3.5. Model. Similarly, different authors have defined specific models for either the transmission characteristics or other network characteristics for the betterment of data transmission between the different components of SAGIN [19, 30, 50, 51, 57, 60, 71, 78, 80, 87, 97, 110, 114, 119, 124].

4.3.6. Platform. Only 1 research article has focused on creating a platform for the monitoring of the different components or network characteristics of SAGIN [14, 68, 70].

Over the course of the last decade, different research has been conducted using the concept of SAGIN. However, not all the research has made use of the term SAGIN, as some have made use of the term space information network (SIN) or space transmission network (STN). The premise of all the terms is the same which is the use of geostationary satellites

Table 4: Quality assessment criteria.

a		b		C		d		
Presence of effective DMS		Presence of SAGIN		Citation criteria		JCR and CORE ranking criteria		
Criteria	Score	Criteria	Score	Criteria	Score	Sources	Ranking	Score
Yes	1	Yes	1	More than 6	1	Journal	Q1	2
							Q2	1.5
							Q3 or Q4	1
							No JCR rank	0
No	0	Partial	0.5	From 1 to 6	0.5	Conference	CORE A	1.5
							CORE B	1
		No	0	No citations	0		CORE C	0.5
							No CORE rank	0

Table 5: Publication channels.

Publication name	Reference	Channel	Number of occurrence
Chinese Journal of Aeronautics	[9, 61, 92]	J	3
Journal of King Saud University-computer and Information Sciences	[10]	J	1
International Conference on Space Information Network (SINC-2016)	[11, 132]	Conf	2
International Conference on Advances in Computer Science & Engineering (CSC-2013)	[12]	Conf	1
ZTE Communications	[13]	J	1
IEEE Wireless Communications	[14, 23, 36, 38, 66, 79, 82]	J	7
2021 International Wireless Communication and Mobile Computing (IWCMC)	[15, 31, 42]	Conf	3
2015 International Conference on Wireless Communications & Signal Processing (WCSP)	[16]	Conf	1
2014 IEEE Fourth International Conference on Big Data and Cloud Computing	[17]	Conf	1
IEEE Communications Surveys & Tutorials	[18, 21, 52]	J	3
2020 Information Communication Technologies Conference (ICTC)	[19]	Conf	1
2020 IEEE 3rd International Conference on Computer and Communication Engineering Technology (CCET)	[20]	Conf	1
IEEE Internet of Things	[22, 26, 27, 37, 69]	J	5
IEEE Network	[24, 35, 44, 47, 83, 84, 93, 98, 116]	J	9
2020 IEEE 23rd International Multitopic Conference (INMIC)	[25]	Conf	1
ICC 2021—IEEE International Conference on Communications	[28, 80]	Conf	2
China Communications	[29, 60, 65]	J	3
International Journal of Communication Systems	[30, 30]	J	2
IEEE Systems Journal	[32]	J	1
Journal of Physics: conference series	[33, 34, 103]	J	3
2018 IEEE 18th International Conference on Communication Technology (ICCT)	[39]	Conf	1
International Journal of Performability Engineering	[40]	J	1
Scientific Reports	[41]	J	1
IEEE Communications Magazine	[43, 46, 63, 67, 90]	J	5
IEEE Journal on Selected Areas in Communication	[45]	J	1
2020 International Symposium on Recent Advances in Electrical Engineering & Computer Sciences (RAEE & CS)	[48]	Conf	1
2021 International Conference on Digital Futures and Transformative Technologies (ICoDT2)	[49]	Conf	1
2019 15th International Wireless Communications & Mobile Computing (IWCMC)	[50]	Conf	1
IEEE Transactions on Intelligent Transportation Systems	[51, 53, 74]	J	3
Intelligent and Converged Networks	[54, 125]	J	2
2021 IEEE/CIC International Conference on Communications in China (ICCC Workshops)	[55]	Conf	1

Table 5: Continued.

Publication name	Reference	Channel	Number of occurrence
Journal of Communication and Information Networks	[56–58]	J	3
2019 IEEE International Conference on Unmanned Systems (ICUS)	[59]	Conf	
KTH Royal Institute of Technology	[62]	Thesis	1
IEEE Access	[64, 87, 110, 114, 122]	J	5
IEEE International Geoscience and Remote Sensing Symposium IGARSS	[68]	Conf	1
7th International Conference on Hydraulic and Civil Engineering & Smart Water Conservancy and Intelligent Disaster Reduction Forum (ICHCE & SWIDR)	[70]	Conf	1
Natural Hazards and Earth System Sciences	[71]	J	1
4th International Conference on E-Business, Information Management, and Computer Science	[72]	Conf	1
Journal of Wuhan University	[73]	J	1
Electronics	[75]	J	1
28th Wireless and Optical Communications Conference (WOCC)	[76]	Conf	1
Sensors	[77, 88]	J	2
IEEE Transactions on Aerospace and Electronic Systems	[78]	J	1
IEEE Intelligent Transportation Systems Magazine	[81]	Mag	1
IEEE Internet of Things Journal	[85, 100, 117, 120]	J	4
IEEE World Congress on Services (SERVICES)	[86]	Conf	1
IEEE Transactions on Network Science and Engineering	[89]	J	1
IEEE Sensors Journal	[91]	J	1
International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences	[94]	J	1
International Conference on Space Information Network (SINC-2017)	[95]	Conf	1
ICC 2020—2020 IEEE International Conference on Communications	[96]	Conf	1
Entropy	[97]	J	1
Computing, Communications and IoT Applications (ComComAp)	[99]	Conf	1
International Conference on Security, Pattern Analysis, and Cybernetics (SPAC)	[101]	Conf	1
17th International IEEE Conference on Intelligent Transportation Systems (ITSC)	[102]	Conf	1
2020 IEEE Sustainable Power and Energy Conference (iSPEC)	[104]	Conf	1
Mobile Networks and Applications	[105]	J	1
ISPRS International Journal of Geo-Information	[106]	J	1
IEEE Communications Standards Magazine	[107, 128]	Mag	2
International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences	[108]	J	1
Science China Information Sciences	[109]	J	1
IEEE Transactions on Systems, Man, and Cybernetics: systems	[111]	J	1
EGU General Assembly Conference Abstracts	[112]	Conf	1
IEEE International Conference on Services Computing (SCC)	[113]	Conf	1
International Journal of Digital Earth	[115, 127]	J	2
Computer Networks	[118]	J	1
90th Vehicular Technology Conference (VTC2019-Fall)	[119]	Conf	1
Proceedings of the 3rd International Conference on Computer Science and Application Engineering	[121]	Conf	1
IEEE Pacific Rim Conference on Communications, Computers, and Signal Processing (PACRIM)	[123]	Conf	1
Journal of King Saud University-Computer and Information Sciences	[124]	J	1
International Conference on Optical Communications and Networks (ICOCN)	[126]	Conf	1
Big Earth Data	[129]	J	1
Journal of Communications and Information Networks	[130]	J	1
International Conference on Space Information Network (SINC-2018)	[132]	Conf	1

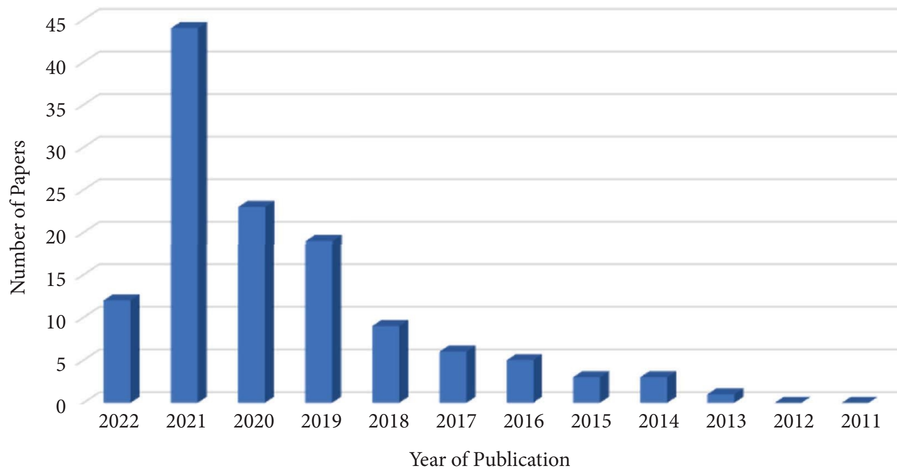

FIGURE 3: Distribution of selected research papers by year.

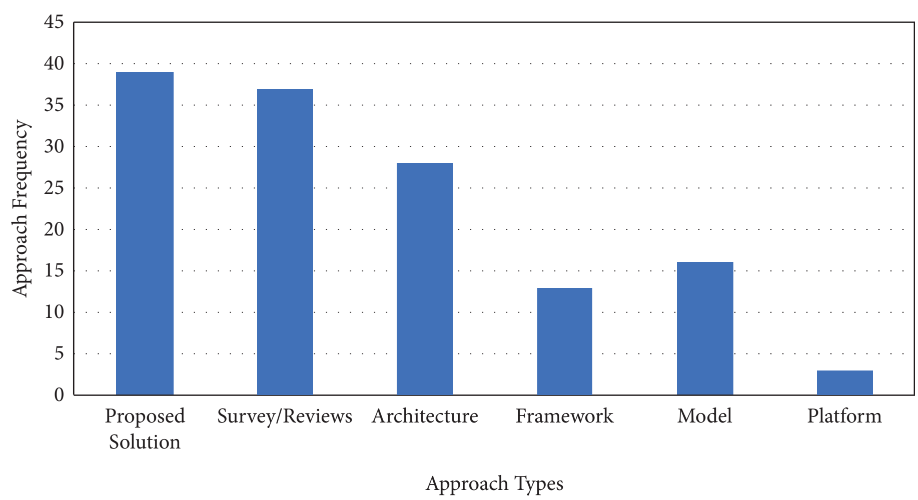

FIGURE 4: Research approaches in SAGIN based DMS.

TABLE 6: RQ3: algorithm/approaches used for an effective SAGIN based DMS.

Ref	Approach	Methodology	Issues	Tools and technologies	Evidence
[10]	Survey/literature review	Conducted a review on the use of 6G-enabled SAGIN for the improvement of SAGIN infrastructure	Several open challenges discussed	Review work	No evidence was provided for this work
[13]	Survey/literature review	Discussion on green communication of air-ground integrated heterogeneous networks (AGIHN)	Decreasing natural resources, the complexity of the radio environment, and improvement of energy efficiency	Integration of 6G and AGIHN logical proposal	No evidence was provided for this work
[14]	Simulation platform and case study	Provision of a SAGIN simulation platform that supports node mobility, protocols, and control algorithms	Complex architecture, dynamic network conditions, high mobility, and SAGIN demand	NS-3 simulator	Experimentally evaluated along with a case study

Table 6: Continued.

Ref	Approach	Methodology	Issues	Tools and technologies	Evidence
[15]	Survey	Discussion on the architecture of SAGIN as well as reviewing its different layers	Limited network resources and interoperability between different network segments in a specific heterogeneous network (HetNet)	Review work	No evidence was provided for this work
[18]	Survey	Surveying recent progress in space-air-ground-sea integrated network (SAGSIN) security as well as countermeasures	Consideration of either single network segments or integration of two-tiered network segments. Jamming and eavesdropping attacks on UAVs resulting in interruption of space-ground communication	Review work	No evidence was provided for this work
[19]	Definition of an SDN model along with a load balancing algorithm	An SDN-based model for SAGIN which provides high network flexibility. The proposal of a load-balancing algorithm referred to as LBMRE-OLSR	Existing network architectures are limited in the addressing of real-time dynamic changes in topology as well as frequent information exchanges in emergency situations	OPNET modeler 14.5	Experimentally evaluated and showed optimized results in terms of end-to-end delay and packet loss rate
[20]	The proposed architecture of an SDN-based SAGIN	Proposal of an SDN-based SAGIN architecture as well as the designing of a strategy of controller placement for dynamic topologies of space-based UAV to optimize the average delay between switch and controller	Traditional networks are unable to provide effective communication	MATLAB 2020a	Experimentally evaluated and results show a reduction in maximum delay and average delay between switch and controller
[22]	Proposed SAGIN architecture with the incorporation of civil aircrafts (CA)	Presentation of a novel architecture that makes use of CA, augmented space-air-ground integrated vehicular networks (CAA-SAGIVN) to enable a breakthrough in service-oriented fair allocation, and collaboration with multiple sky platforms	Nonuse of CA as a valuable resource in SAGIN as well as no progress in communication problems in disaster scenarios and remote areas	None	An existing testbed is not valid for the testing of the proposed architecture
[23]	Proposal of a novel architecture using AI	A novel coded storage-and-computation architecture using AI that accelerates distributed machine learning offers flexible computational offloading and reliable storage	Frequent dynamic connections and link errors in SAGIN increase the issue of computation slowdown and data failure as well as constrain the improvement of AI service efficiency	Simulated using use cases	The evaluation provided that the proposed framework provides better performance in terms of average offloading and average retrieval delay in unreliable network situations

Table 6: Continued.

Ref	Approach	Methodology	Issues	Tools and technologies	Evidence
[25]	Proposal of SAGIN for disaster management. Also, the proposal of the framework for the enhanced detection and communication of disasters using internet protocol (IP)	For the application of disaster management, the implementation of SAGIN using IP is proposed. A framework is also proposed, along with a simulation for a disaster scenario	Limitation of air-ground, terrestrial, and space-ground network in the event of a disaster scenario	Satellite tool kit (STK)	Experimentally evaluated and shows the effectiveness of communication in a disaster scenario
[26]	Proposed a scheme for encrypted data retrieval in SAGIVN, known as ERDSS	The main purpose was to perform fuzzy retrieval over misspelled words and sort the results by relevance score, while ensuring precised and effective data retrieval and sharing scheme	Due to the incorporation of multiple communication and network services, SAGIN is vulnerable to security threats	Eclipse using Java, PyCharm using Python	Evaluated through simulation using a real data set in a simulated SAGIVN environment which showed the potential of the ERDSS
[27]	Proposal of a novel attestation approach in SAGIN-based IoV networks	Novel attestation approach proposed for the verification of the trusted state of virtual services and network nodes in SAGIN-based IoV networks	The problem of remote attestation and solution for the trust and security problems on the Internet of Vehicles (IoV) based on the SAGIN	Prototype system with 5 servers. VM with Ubuntu 14.04	Experimentally evaluated which showed the efficient verification of the trusted state of nodes and services
[28]	Proposal of secure and efficient handover authentication scheme along with batch verification mechanism for SAGIVN	A novel group-based handover authentication scheme with anonymity in a disaster area SAGIVN based on aggregate proxy signature technique	Previous work only focused on a single-tier network rather than taking full advantage of the SAGIN architecture	Security analysis and comparison of the proposed scheme with existing schemes	The evaluation demonstrated the effectiveness of the proposed scheme in terms of handover latency and average signalling cost
[32]	Use of space-arial-assisted end-edge-cloud orchestrated computing framework and the proposal of an alternating optimization algorithm	To satisfy the computing of remote IoT applications by using a specialized cloud-based framework. Formulation of a fairness-aware resource scheduling problem to reduce the maximum task execution delay among IoT devices. Also, the proposal of an alternating optimizing. An algorithm based on the block coordinate descent method	Neglection in the optimization of user computing delay in the worst scenario, which is the maximum computing delay of users	MATLAB R2012a	Evaluation through simulation where results showed an improvement in the reduction of computing delay of IoT devices. Also, an outperformance of the proposed end-edge-cloud orchestrated scheme in comparison to the end-edge computing coordination method
[42]	Proposal of new network architecture with the combination of SAGIN and IoT	To take advantage of SAGIN's large satellite coverage aside from the ground network propagation delay, a network architecture using SAGIN and IoT is proposed	Limitation of network capacity and coverage and the option of only relying on ground-based network	None	Logical proposal of architecture
[48]	A framework for air traffic control based on SAGIN is proposed. satellite communication protocol specifications (SCPS) are proposed for air traffic communication	Discussion on the issues faced by the aviation industry. Aside from this, a framework, ADS-B, incorporating the use of SAGIN is proposed which would ensure the safe operation of flights	Communication of airplanes and ATC centres for the safe operation of flights	STK	Framework logically discussed. SCPS showed enhanced performance and proves itself viable to be used for space links

Table 6: Continued.

Ref	Approach	Methodology	Issues	Tools and technologies	Evidence
[49]	Proposal of a SAGIN framework for the monitoring of accidents	Enhancement in the performance for the monitoring and detection of accidents is performed through the proposed framework	Limitations in accident monitoring systems such as timely detection of accidents, using accurate information to initiate rescue operations, and unavailability of a feasible framework for rescue operations	MATLAB, STK	Evaluated through simulation which showed better performance as compared to SGIN and AGIN and traditional accident monitoring system

and air and ground devices to create a network. The only difference that SIN and SAGIN have is that the former also makes use of sea networks. As such, this research has also included the research that uses these terms. Furthermore, this research has also devised a taxonomy that showcases the use of the different terms of SAGIN, SIN, and STN in relation to the mitigation of a disaster. This devised taxonomy is presented below in Figure 5. The taxonomy presents the different characteristics of disaster mitigation techniques as well as the different types of disasters and their locations where they normally occur.

Some of the selected research work is focused on designing an architecture of SAGIN which can be then used for different types of scenarios and case studies. While some of the research works have made use of existing architecture and instead proposed solutions to a different aspect of SAGIN.

Murtaza and Jianwei [34] present those multiple architectures that have been proposed over the years incorporating the use of SAGIN, however, most of the proposed work is general abstracts or is based on a single dedicated application. The authors present that for there to be an effective SAGIN architecture, the proposed work should be based on the TCP/IP stack. Another issue that the authors discussed was that due to the orbital positions of space nodes, the management of the dynamic network topologies is difficult. Hence, the authors have proposed a SAGIN-based architecture that is based on the TCP/IP stack while also proposing a simple mechanism that would help in maintaining static IPs for all the space nodes (satellites).

Another research approach made was the integration of SAGIN with IoT conducted by [42] which not only provides large satellite coverage but also provides the different characteristics of ground network propagation delay. Another unique research approach conducted by [22] is the integration of artificial intelligence (AI) with SAGIN. The authors made this research in order to resolve the issues of data failures and computation slowdowns in SAGIN. As such, the authors proposed a novel coded storage-and-computation architecture (CSC-AI) that provides reliable transmission of big data as well as fast computational offloads.

Some authors have focused their research on SIN and proposed different architectures. In [16], the authors have proposed an autonomous-based system (AS) architecture that has several components ranging from the use of GEO satellites as the backbone nodes of the network, LEO satellites for the purpose of enhanced coverage nodes, and the use of high-altitude platforms for the sake of meeting service requirements for emergency situations. The authors also proposed a hierarchal AS network model which basically divides the complex SIN network into smaller AS networks for easier control of the topology. Similarly, Yu et al. [58] proposed a system architecture for SIN as well as conducted a preliminary integrated demonstration environment for the proposed architecture.

Other authors have, however, focused their research on improving the architecture of SAGIN by incorporating either the use of vehicular networks [22, 46, 54] or software defined networks (SDN) [11, 17, 20, 47] or mobile edge computing (MEC) or all these terms combined.

Some research has focused on the design or the model of different network protocols or characteristics that would ultimately help in the improvement of SAGIN-based architecture. In [19], the authors have proposed an SDN-based SAGIN model as well as a new load-balancing dynamic routing algorithm for disaster scenarios that is based on the multidimensional resources and energy (LBMRE-OLSR), which through simulation showed a reduction in end-to-end delay and packet loss rate. Another model presented by [30] is based on the scenario of emergency logistics which is then used for a proposed novel scheme of cross-network radio scheduling in SAGIN based on a genetic algorithm and unified resources mapping. Other research articles that propose routing protocols include [9], which proposed a multipath routing algorithm based on network coding for resolving issues of high bit error rate and long propagation delays in SINs.

Another research area that has seen research on SAGIN is the security perspective. Different researchers have either focused on the encryption of data [26, 28, 43] or the trustworthiness of nodes [27, 37] present in the network.

4.4. RQ4: Different Issues and Challenges to Overcome for an Effective SAGIN Based DMS. After a comprehensive review of the selected papers, it can be presented that different solutions and characteristics have been proposed in relation to SAGIN and disaster management systems. However, though some of the papers have discussed the shortcomings and challenges presented in the research area, this paper has

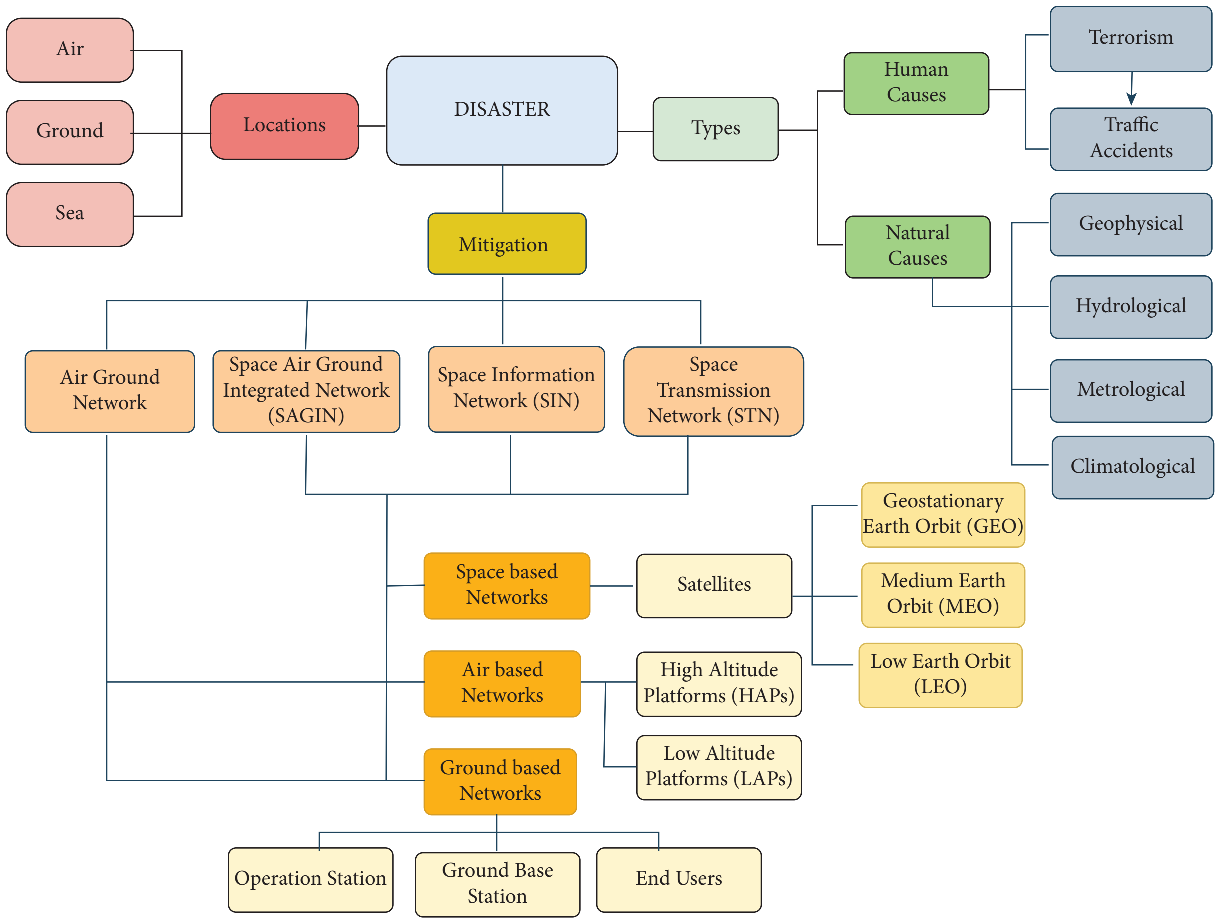

Figure 5: Devised taxonomy for disaster mitigation techniques.

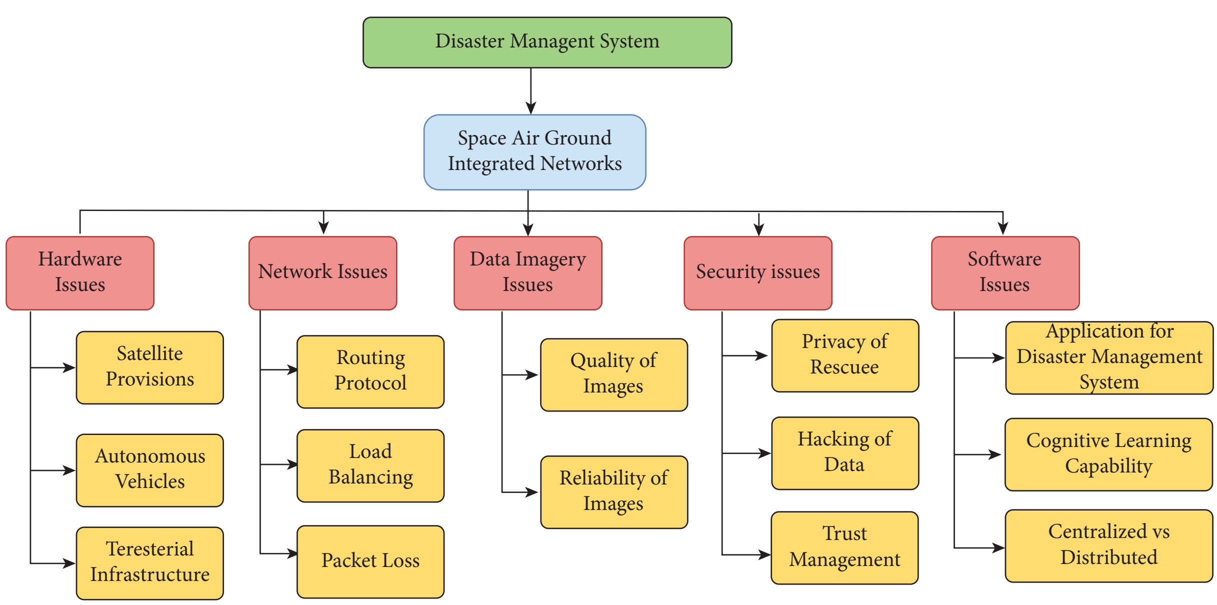

Figure 6: Different challenges and issues.

Table 7: Comparison of this study to other studies.

Problem discussed	[10]	[29]	[41]	[56]	[61]	[66]	[92]	[94]	[100]	[132]	This paper
Overview	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Applications	✓	✗	✗	✓	✓	✓	✓	✗	✓	✓	✓
Trends and future direction	✗	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓
Limitation and challenges	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓
Extensive analysis	✗	✓	✗	✓	✗	✗	✗	✓	✓	✓	✓
Taxonomy	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓

identified some additional issues and challenges that need to be resolved for a proper SAGIN-based disaster management system. These different challenges are also presented illustratively in Figure 6.

4.4.1. Hardware Challenges. Hardware-based challenges are one of the biggest as well as the most critical issue present. The reason for this deduction is that even with the introduction or proposal of different architectures or routing/communication protocols. The actual implementation of a SAGIN-based architecture can be difficult due to a critical scenario such as a disaster in a remote or a hilly area where even with a small landslide or snowfall the terrestrial infrastructure needed for a SAGIN can get damaged.

4.4.2. Networking Challenges. Another issue that is also critical is the issue of network-based characteristics and routing/communication protocol. As in a disaster scenario, reliability as well as fast communication of the latest information related to that disaster is a key factor to be used in rescue operations. As such, an effective routing/communication protocol is needed for the effective dissemination of data.

4.4.3. Data Imagery. As in any disaster situation, the first and foremost information required by a rescuer is the availability of images that show the current situation of the disaster area. However, the collection of multiple images as well as the transfer of images to the disaster Head Quarters (HQ) can prove to be difficult as the reliability of these images is very important as they would be used to launch a rescue operation. Any misinformation related to the imagery data can prove a disaster.

4.4.4. Security Challenges. Another issue that poses a difficult challenge is the issue of security of either the entire architecture or structure of the SAGIN-based network or the encryption of data that is captured of the disaster scene and relayed to the HQ. In the situation of any such issue, the privacy of individuals caught in the disaster area would be at risk. From a network point of view, another security issue would be the misinformation provided due to trust issues of nodes being used in the SAGIN architecture. As such, an effective trust management scheme for all the nodes in either SAGIN or SIN is required.

4.4.5. Software Issues. Security issues are not a current problem in the scenario of SAGIN-based DMS, however, this can be an evident issue in the future. Disaster mitigation in terms of SAGIN is an application used by end users for the reporting of any type of disaster. This would be a key aspect to get real-time information regarding a disaster occurrence in a certain location. Another aspect related to software issues is that with the introduction of AI in network architectures, it is also an important challenge to implement such a mechanism of cognition in SAGIN architecture to formulate a rescue operation as quickly as possible while keeping in consideration past disasters.

4.5. Quality Assessment Score. The quality of selected articles is assured by the quality assessment criteria mentioned in the research methodology (subsection VII, Table 4), in the form of scores, as presented in Table 1. Through this assessment result, it would be possible for researchers to select their relevant papers according to their requirements.

5. Related Work

Disaster Management is a vast field of study and there are new approaches that are developed in different research studies. Many studies have been conducted to design new frameworks to improve this new paradigm of DM, but few survey studies and literature reviews have been performed to evaluate the research showing the new frameworks and approaches. These approaches are reviewed in this section.

The authors in [10] mainly presented the fundamental concept of SAGIN and 6G and key technologies of UAV and satellite-based communications. They also elaborated the 6G-SAGIN and its orientation towards the aspect of elemental design, as well as the concept of UAV-as-a-service to expand the comprehension of 6G-SAGIN. This research was presented in an elaborative and explanatory manner, however, there was little applicability discussed regarding the DMS.

The aerial platforms and the HSAT networks are surveyed in [29]. They discussed the technologies for disaster management. They outlined the challenges of the HSAT networks. However, the applications of the HSAT for DMS are not elaborated in the article.

SIN is observed to explicate the relationship between the services, security threats, and mechanisms in [41]. Additionally, they presented the future direction of research in the security of SIN. They explained the secure routing and anomaly detection of different security techniques from the perceptions of traditional methods and AI. They proposed a Deep Learning (DL) based anomaly detection scheme. Overall, this paper summarizes the upcoming technologies and delivers inspiration for future exploration, though, the problems related to DMS were not extensively discussed.

In this research study, theuse of UAVs as Aerial Base Stations (ABS) is simulated for communication during such disasterous situation where the communication is uneven and broken [56]. Effective communication probability (ECP) was used to evaluate the performance of a communication network, by measuring connectivity and throughput coverage. They proposed better communication can be acquired through the flexible implementation of ABS. The results show a noticeable increase in ECP when some ABS are deployed in optimal locations. This work is quite related to the scenario of the topic under consideration. However, the survey and comparison of the technique with other related studies can be extensive.

In [61], 6G-SAGIN from the aspect of a service-oriented network is reviewed to propose a service-oriented SAGIN management architecture. They discussed cloud-edge synergy technologies and heterogeneous resource orchestration technologies. Additionally, the prospective directions are presented. A similar study on UAV communication with an aspect of 5G/B5G wireless networks is produced in [100], with a brief introduction of SAGIN, as well as related challenges of integrated networks are also comprehended. This study entails an exhaustive review of several 5G techniques established on UAV platforms and the open issues and future directions for research. Still, the applications of SAGIN in DMS need some more substantial advancement.

To the best of our knowledge, there is no systematic literature review with a discussion of disaster management and SAGIN implementation techniques published yet with taxonomy and analysis. All the related research work on this area is summarized in Table 6, and the detailed comparison of other surveys with this study is summarized in Table 7.

6. Conclusions

The occurrence of disasters, either they be natural or human-made can be damaging. Therefore, there is an imperative need of a suitable and operationally effective disaster management system to alleviate the issues that arise from such disasters. Over the last decade, several investigations have been performed to overcome these concerns using UAV [20, 32], sensor networks [144], and SAGIN [56]. However, remote areas where ground networks are unable to reach can be responsible for more issues related to the provision of emergency response. In such situations, space networks which include the use of satellites and air networks, along with the use of aircraft and UAVs, integrated with a ground network (SAGIN) can solve the mentioned issues. This research provides a systematic literature review of 50 research articles, which constitute a comprehensive review of different research approaches adopted by the researchers. The research gap we have found in this paper indicates that several challenges are faced by disaster management systems such as hardware-based challenges, network-based characteristics, communication protocols related challenges, availability and accuracy of imagery data, and security and privacy issues that need to be tackled and their solutions need to be further investigated.

Acronyms

AGIHN: Air-ground integrated heterogeneous network
ABS: Aerial base stations
AI: Artificial intelligence
AS: Autonomous based systems
CA: Civil aircrafts
CAA-SAGIVN: Civil aircrafts, augmented space-air-ground integrated vehicular networks
CORE: Computing research and education
CSC-AI: Coded storage-and-computation architecture
DL: Deep learning
DM: Disaster management
DMS: Disaster management system
ECP: Effective communication probability
GEO: Geostationary earth orbit
HetNet: Heterogeneous network
HQ: Headquarters
HSAT: Hybrid satellite-aerial-terrestrial
IoT: Internet of Things
IoV: Internet of vehicles
IP: Internet protocol
IT: Information technology
ITS: Intelligent transportation system
JCR: Journal citation report
LBMRE-OLSR: Load balancing algorithm based on multi-dimensional resources and energy
LEO: Low Earth Orbit
MEC: Mobile edge computing
MEO: Middle Earth Orbit
QA: Quality assessment
SAGIN: Space-air-ground integrated network
SAGSIN: Space-air-ground-sea integrated network
SCPS: Satellite communication protocol specifications
SDN: Software defined network
SLR: Systematic literature review
SIN: Space information network
STK: Satellite tool kit
STN: Space transmission network
TCP/IP: Transmission control protocol/internet protocol
UAV: Unmanned aerial vehicles
VANET: Vehicular ad-hoc network
VM: Virtual machine
WLAN: Wireless local area network.

Data Availability

The data that support the findings of this study are available from the author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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