The Diverse Technology of MANETs: A Survey of Applications and Challenges

Fatemeh Safari*, Izabela Savic, Herb Kunze, Jason Ernst, and Daniel Gillis

***Abstract*—In recent years, mobile ad hoc networks (MANETs) have shown much potential in providing wireless network solutions for a variety of situations. MANETs are made up of a variety of devices (both mobile and internet of things (IoT)) which form a wireless network that provides wireless network functionality and cloud services and can be used to provide wireless services to devices in areas where fixed infrastructure is not accessible. Although it is not necessary for a node to be connected to fixed wireless or cellular infrastructure for the network, even a single node connected to infrastructure opens up a wide range of new research opportunities and applications. Due to the variety of compatible devices, MANETs are the perfect technology for a wide variety of scenarios, such as: military, search and rescue operations, and more. Our contribution is a complete survey of the applications of MANETs, which to our knowledge has not been previously documented. This survey will discuss the industries MANETs are used in (e.g. education, smart city, etc.), the benefits and services they can provide users, and will also explore the challenges this technology still experiences**

***Index Terms*—Applications, challenges, emergency services, MANET, military, mobile ad hoc network, natural disaster, smart city**

I. Introduction

Mobile ad hoc networks (MANETs) are a type of network made up of mobile nodes that form an instant self-configuring and self-healing network without fixed topology or the need for existing information and communications technology (ICT) infrastructure [1], [2]. They are easy to deploy, flexible in when and where they can be set up, have no (or low) installation, maintenance, or repair costs, have no central administration requirements, and do not depend on existing infrastructure [1]. MANETs allow users to communicate regardless of geographical location, and without a physical network requirement. Nodes (e.g. mobile or IoT devices) in the network operate as both router and host, and can easily be inserted or removed from the network because they are typically mobile [2]. The lack of traditional and expensive ICT infrastructure makes MANETs a prime candidate for a variety of different applications including, for example, military communications, search and rescue operations, and natural disaster response [3]. They are particularly useful in these situations since the technology can be implemented quickly and at a low cost, without the need for traditional ICT infrastructure [1]. And while MANETs are not the only type of ad hoc network (see, for example, vehicular ad hoc networks [4-6], sea ad hoc networks [7, 8], flying ad hoc networks [9], [10], and wireless sensor networks [11-13]), their applications across a variety of sectors will be the focus of this paper. While MANETs have great potential to solve a variety of problems, it is necessary to understand how they have been used to support solutions in a variety of sectors so that we may better understand their limitations, and identify existing gaps in their use. A deeper understanding of the applications of MANETs could aid in bridging the digital divide, and providing (for example) remote, rural, and/or Indigenous communities at the 'last mile' of the internet with a variety of services such as access to healthcare [14], education, and more [15-17]. For more information on the digital divide and its impacts on remote, rural, and/or Indigenous communities, see [17].

The paper is organized as follows: in Section II, we present a brief history of MANETs and discuss several characteristics that inform their use and limitations. Following this, we provide a summary of the applications of MANET technology across a variety of sectors (Section III). Finally, we conclude this paper in Section IV.

II. Mobile Ad Hoc Networks

With the emergence of packet ratio communication in the 1970s [18], the development of wireless networks without reliance on wired infrastructure became feasible. The mobility and flexibility provided by this technology led to the popularity of wireless networks. Over the past decades, telecommunication services have witnessed far-reaching changes. Wireless technologies have developed rapidly, have enhanced life dramatically, and have provided the ability to access network connections almost anywhere at any time. Due to the availability and affordability of such technologies, a majority of people now have access to and rely on mobile devices for their day-to-day activities.

Mobile ad hoc networks, or MANETs, are a self-configured and self-organized multi-hop network [19] that is formed by a collection of wireless devices (laptops, smartphones, sensors, etc.) without the need for pre-existing infrastructure. Each node/wireless device connected to the MANET is treated as both router and host to facilitate transmission of messages from sender to receiver. That is, every node is responsible for routing, security, and providing quality-of-service (QoS) [20, 21]. As such, these types of networks provide alternative network and communications access to locations where infrastructure is inadequate, inaccessible, not operational, or non-existent. Due to the lack

Manuscript received January 25, 2023; revised February 9, 2023; accepted April 21, 2023.

Fatemeh Safari, Izabela Savic, Jason Ernst, and Daniel Gillis are with the School of Computer Science, University of Guelph, Guelph, Ontario, Canada.

Herb Kunze is with the Department of Mathematics and Statistics, University of Guelph, Guelph, Ontario, Canada.

*Correspondence: safarif@uoguelph.ca (F.S.)

doi: 10.18178/ijfcc.2023.12.2.601

of infrastructure required, it is possible for MANETs to provide network connections anytime, anywhere.

Before we explore the ways in which MANETs have been used, it is necessary to discuss their overarching characteristics. These are important because they inform when and how a MANET can be used, and the challenges/limitations that come with their use. We consider characteristics such as their dynamic topology and distributed operation, the types of devices used to form the network, how the networks function, and more. We also consider some of the challenges specific to implementing and maintaining MANETs.

A. Characteristics of MANETs

Dynamic Topology: Since MANETs are formed mainly by mobile devices, nodes can join or leave the network at any time. This means that topological changes must be managed to account for new or lost linkages [22]-[24]. Any application of MANET technology will need to consider how these changes might affect network performance.

Distributed Operation: The lack of central authority in MANETs forces all nodes to operate independently with no external control or management. Routing decisions are made independently; thus, decisions are made in a distributed manner [22-26].

Heterogeneous network: MANETs are typically formed by a collection of different device types and communication technologies (e.g. Wi-Fi or Bluetooth), resources, and signal strength. As such, it is possible for a MANET to be composed of both short-range and long-range devices [22-24], [27-29], This composition could impact network performance, potentially limiting communication in some settings.

Multi-hop communication: Network nodes may have limited transmission range. This means that sender and receiver nodes do not typically lie in each other's transmission range. To account for this, MANET routing typically involves multiple hops messaging using intermediate nodes to send data to the intended destination [22-24], [28, 30]. Again, this is an important consideration depending on the application of the technology.

Lightweight terminals: MANET networks are typically comprised of mobile devices with limited resources, and each node acts as both the router and host [22-24], [31, 30].

Shared Media Access: All nodes in MANETs use a shared wireless channel to transmit data. Using shared media can lead to congestion in data transmission, so MANETs need to use congestion control mechanisms to increase network throughput [32].

Limited link capacity and quality: The connection between nodes is made via wireless links, which have a smaller/limited bandwidth compared to wired links. Environmental factors (e.g. noise, congestion, signal interference) can lead to transmission signal strength loss, which in turn can degrade the wireless link capacity [22-24], [33, 34].

Scalability: Since MANETs are not dependent on pre-existing infrastructure, mobile nodes can join or leave the network easily. As a result, the network grows or shrinks according to need. However, this can lead to increases in route maintenance, link updating, and other actions that limit the functionality and quality of service [22-24], [29, 35].

These characteristics coupled with features of mobility, accessibility, cost-effectiveness, and rapid deployment suggest that MANETs have potential in a variety of applications. However, MANETs are not without their challenges. We explore these challenges in the next section before discussing the various uses of MANET technology.

B. MANETs Challenges

There exist several open challenges affecting MANET applications, including issues related to dynamic topology, routing, device discovery, reliability, quality of service, bandwidth, power, security, and implementation. [28, 36]. We explore each of these issues below.

Dynamic Topology: MANETs are intended to support dynamic topologies. However, the ability for nodes to quickly leave and join the network renders the topology unpredictable [37] since frequent position changes lead to a highly dynamic topology [38]. This quick creation/destruction of nodes results in a network that is difficult to monitor and secure [39, 31, 40]. Further, updating and sharing dynamic link information among nodes becomes more challenging [41]. This is particularly true given the specific application. For example, aerial networks can be quite challenging to implement and maintain given the speed and distance of aircrafts that act as nodes in the network [42]. Additionally, MANETs require distributed data storage and data replication which are both negatively affected by node mobility [43].

Routing: Due to the dynamic topology, selection/creation of routing protocols can be difficult since nodes may leave or join at any time, and move in and out of being a neighbour to another node. This causes continuous routing information changes [39]. As previously mentioned, the source and destination do not need to lie within range of each other, so routing protocols aim to make the most efficient route between sender and receiver.

Device Discovery: Node authentication is required to recognize honest nodes entering the network [31]. Discovery protocols "permit networked nodes to broadcast and receive messages" [42], thus device discovery is integral to the functionality of the network [42]. Further, when nodes enter the network, dynamic updates need to occur to inform other nodes of changes and to ensure optimal route selection [31, 41]. Without device discovery, nodes would be unable to join the network, affecting message transmission.

Reliability: Similar to a regular Wi-Fi connection, it is necessary to minimize packet losses, data transmission errors, etc. to ensure network reliability [31]. Node mobility can negatively influence the reliability of the network [44], so methods to improve reliability are necessary. This is important regardless of how the network is used (e.g. communication, video conferencing, gaming, etc.).

Quality of Service: Quality of Service (QoS) describes the performance of a network observed by an application [45]. The aim is to achieve a certain level of quality to transmit data packets. The most common parameters are end-to-end delay, jitter, reliability, and bandwidth [46]. High-quality service is key for critical/time-sensitive applications. Providing QoS in a dynamic network environment, however, is challenging [47]. For example, in maritime environments, the lack of quality of service can lead to network data congestion which affects the operation of applications that are important for communication, etc. [48]. The stochastic nature of MANET communication also means that QoS is not guaranteed [31, 49].

Bandwidth Constraints: MANET wireless links typically have far lower capacity/bandwidth than cabled ones [41]. Bandwidth is further constrained by the limited transmission range of nodes in the network, by the fact that nodes move in and out of transmission range [41], and by the potential reduction in signal strength during transmission due to environmental factors such as fading, blockage, noise, and interference conditions, multiple access, etc. [50, 51] (for example, underwater wireless ad hoc networks suffer from limited bandwidth capacity as a result of the underwater environment [52]). Beyond this, application bandwidth is also reduced because of increases in routing overhead required to manage route discovery given a changing topology [53, 41].

Battery Constraints: Energy consumption is a major concern because mobile devices have limited battery power, and because the wireless nature of MANETs requires more energy consumption to transmit packets than wired networks [54]. In scenarios in which scattered items are used, energy efficiency is important as battery replacement or charging may be extremely difficult/impossible [13]. Energy efficiency also shows great importance in making grid functionalities feasible in MANETs [55]. To extend the lifetime of the network and its nodes, energy-efficient routing algorithms are needed to select the optimal route with minimum average energy consumption. To combat this, some existing research has mentioned the use of solar-based devices, or renewable energy to power nodes [7, 56]. This challenging issue has received significant research attention in this field [57, 31].

Security: Like other networks, MANETs are vulnerable to a variety of attacks [58, 59], including eavesdropping [60], spoofing [61, 62] and denial-of-service [63, 59] which tend to occur more frequently than for wired networks. MANETs are also vulnerable to man-in-the-middle attacks, jamming, flooding, replay attacks, gray-hole attacks, session hijacking, wormhole attacks, malicious code, and more [41, 49, 64, 65]. As such, the security of the network should be established to “ensure that the connectivity between nodes remains unaffected by external influences” [42]. These security concerns are common to all applications but particularly relevant for certain MANET applications where sensitive or private information needs to be shared (such as in the case of MANETS used for aerial, healthcare, maritime, military, commerce, or smart city purposes). For example, protection against these types of attacks is incredibly important to ensure aircraft communications or military operations are undisturbed [42]. In the world of commerce, there is an additional subset of attacks to consider, which include impersonation attacks, colluding attacks, double spending, non-repudiation of transaction location source, and the reset and recovery attack [42, 66, 67]. These attacks can result in loss of money, or having a product delivered to a customer while the vendor receives an invalid payment. Along with security against cyber-attacks, privacy/confidentiality is also important [40], [68]. Consider, for example, how location privacy in vehicular networks is important for protecting a driver’s identity, or how privacy on social networks can prevent identity theft, stalking, etc. While some of these considerations may not be part of the “traditional” security concerns, they help protect digital and physical security. Various solutions have been proposed by [21].

Implementation of MANETs: Although MANETs can provide infrastructure-less regions internet access, their implementation can suffer from cost and lack of knowledgeable operators. In the case of [69] which requires mobile base stations, the cost of these base stations can be high. This can lead to fewer towns having access to this technology due to a lack of funding. This also applies to the case of [70], in which supplies rely on financial support from the Ministry of Education which may not always have adequate funding, which forces students to purchase their own devices. In addition, very few papers discuss whether there will be any training to teach users how to use their MANET applications, and if there will be trained operators to ensure that bases are up and running (like in the case of [69]). In the case of [70], cooperation between teachers and the National Research and Education Networks is proposed to support this initiative. Cost and knowledgeable operators can affect all applications, as the purchasing of additional equipment and training of community members depend on the availability of funding.

Clearly, the successful use of MANETs in any sector requires a thorough understanding of these challenges (as well as others - see for example [64]).

III. MANET APPLICATIONS

We explore some applications of MANET technologies, focusing on their use in military operations, before and after natural disasters, during search and rescue operations, to facilitate education and health care, entertainment delivery, supporting smart cities, and in commercial and civilian applications, Internet of Things applications, and finally, Maritime applications. While this does not represent a complete picture describing the use of MANETs, it speaks to their versatility and potential.

A. Military Battlefield

One requirement of a successful military is the ability to provide real-time information to battlefield soldiers [71]. However, accomplishing this requires addressing several unique challenges. Routing protocol with low network convergence time is required in the military battlefields for real-time communication. Soldiers must be able to build their own ad hoc networks without a central point of control [71]. Beyond this, battlefield network hardware needs to 1) be strong enough to survive any battlefield conditions [71, 72] 2) work in different climate conditions, and 3) be optimized for size, weight, and power since it will be carried by soldiers or used in combat vehicles [71]. Additionally, building network infrastructure in enemy territory is often difficult, and it is typically targeted in attacks. As battles progress, regions in which military personnel are located may change, rendering any infrastructure useless [73].

As discussed, MANETs can support a lack of existing infrastructure, and highly dynamic nodes, and do not require a central point of control. These characteristics of MANETs make it the perfect technology for military communication applications.

To use this technology the military has deployed two categories of equipment: IP-enabled military radios/smartphones, and IP routers. The routers are stored on military vehicles and contain the equipment necessary to "join and participate in a MANET" [71], where the IP-enabled radios are given to dismounted soldiers to connect into MANETs as clients [71]. The military makes use of Radio Aware Routing to minimize convergence time so that there is no delay in information while nodes are entering and exiting the network [71]. In addition to communication, MANETs in a military operation must enable QoS, traffic management, threat control, and intrusion prevention through the integration of firewalls as well as IPV6, Type 1 and next-generation Suite-B encryption [71].

The application of mobile ad hoc networks in military operations is not limited to the ground. Both [74, 75] explore the application of MANETs in Unmanned Aerial Vehicles (UAVs) as well as helicopters. Mobile ad hoc networks can be applied to UAVs to accomplish tasks such as aerial photography, reconnaissance, and monitoring agents in the field [75, 72]. They can also be used to increase the operational range of the network by forming a multi-hop communication network which can increase mission capabilities [75].The studies performed by [74] shows that in the case of UAVs the AODV routing protocol has the least delay in comparison to Geographic Routing Protocol (GRP) and Dynamic Source Routing (DSR) protocols, however, it is noted that GRP has better throughput than AODV and DSR, while DSR has the lowest overhead. For the simulations studied in [75], which uses helicopter nodes, it is noted that the proposed algorithm had a higher packet delivery ratio in comparison to DSR and Clustering Based Routing Protocol (CBRP) algorithms, as well as a lower end-to-end delay, and reduced swarm change for higher stability in comparison to DSR and CBRP.

The characteristics that make MANETs suitable for ground and aerial operations can be applied to boats, underwater vehicles, etc. [7, 52]. Specifically, MANETs can be used for communication between naval entities and can also be used for underwater video surveillance, and remote control of autonomous or remotely operated objects [52].

As military operations develop, so will MANET applications on a military scale. However, it is clear that MANETs are already an important part of military operations.

B. Natural Disaster

Global warming and changing weather patterns have resulted in an increase in landslides due to torrential rain, as well as other natural disasters [76]. On average it is said that natural disasters kill 45,000 people globally each year [77]. The tools provided by MANETs for natural disaster situations can be grouped into two scenarios: pre-disaster and post-disaster. The tools used pre-disaster can be used to detect natural disasters before they happen, and aid in evacuation settings while the tools used post-disaster can be used to aid in communications and more after the disaster has happened.

1) *Pre-disaster tools*:

One example of pre-disaster tools is the Grass-Root Information Distribution System discussed in [76] which was developed for landslides to minimize the damage caused by landslides as well as help local residents decide whether to evacuate. The Grass-root system consists of a fixed type monitoring system, as well as mobile devices that locals own [76]. The goal of the system is to "capture disaster information for the residents in the local area, deliver it to the local MANET, and share it among residents in the local area" [76]. Disaster information can be gathered either through a fixed monitoring system or directly from local residents.[76]. This information is distributed to the residents' devices using MANETs and can be used to alert residents to possible disasters. The simulations described in [76] show that the proposed routing algorithm has a much higher data reception rate for each node in the simulation in comparison to the ER protocol, showing a better data distribution in comparison to the ER protocol. In addition, this technology had such success that it was requested by residents to be installed in Midori, Nabaragawa, Yamakuragawa, Togegwa, and Nenotanigawa [76].

Another example of pre-disaster tools is the use of MANETs in underwater vessels and seismic or environmental monitoring [7]. In the event of underwater seismic monitoring, a seismometer is floated on the sea's surface and used to detect movements of the earth under the water. A MANET is used to relay that information to relevant authorities [7]. The same principle can be applied to detecting events such as tsunamis [7], which could save thousands of lives by helping evacuate residents in advance and alerting other ships and coastal administrators about areas to avoid [7].

2) *Post-disaster tools*

In a post-disaster situation, there is a very real chance that communication infrastructure may be damaged, if not entirely destroyed [37, 78]. This provides research motivation to focus on communication in disaster situations via MANETs. The research proposed in [78] makes use of survivors' devices and reprograms them to be able to "autonomously organize and form or restore a communication infrastructure" [78]. The simulations in [78] show that the COMVIVOR (Communication for Survivors) protocol allows the network to reach a steady state much more quickly than other protocols, allowing for restoration of communication earlier. With the network powered by personal devices, it is important that routing protocols consider battery life [79]. The routing protocol proposed in [79] "selects a k-node disjoint path between a source-destination pair based on the lifetime of the path". The importance of energy efficiency in a routing protocol cannot be understated as the loss of a single node affects network lifetime, connectivity, and capacity [79]. To support their research, [79] were able to show that with the introduction of multiple channels in their framework, the energy consumption and end-to-end delay decrease while the throughput and node lifetime increase. This allows for a more stable, long-lasting, and effective network.

After a disaster, many victims will attempt to send messages to family and friends to let them know they are safe, however, this often requires the internet [37]. The research in [37] makes use of MANETs to connect nodes which are not in internet range to those that are. The proposed routing protocol allows victims to contact family and friends about their well-being while providing more reliable communication. [75] even goes one step further by proposing to use helicopters to bridge to nodes or networks to increase network connectivity. In the case of a remote community facing a disaster, a helicopter could act as a gateway between communities, or between existing wireless infrastructure.

Another difficulty in a post-disaster situation is the purchasing of goods. In the aftermath of large disasters, a majority of people may no longer have cash-at-hand, and may not be able to gain access to banks due to blocked roads or electronic failures [66]. The research proposed in [66] makes use of MANETs to enable victims to conduct financial transactions in a disaster area. To confirm the usability of their product, [66] showed that the transaction completion ratio of multilevel endorsement was able to reach 65% to 90% depending on the number of nodes present in a 3 x 3 km radius. This suggests that the proposed research could allow victims to perform transactions and purchases post-disaster in the event of a bank outage. Once a natural disaster has ended, and search and rescue operations have been completed (discussed further in the next section), rebuilding of the community must begin. Some utility company protocols require that visual inspection occurs for damage assessment, followed by the prioritizing of the repairs which need to be done [80]. This makes the time-to-repair inefficient, due to time spent travelling to the location and visual inspection [80]. The research done by [80] aims to reduce the time-to-repair by creating a MANET communications app which can be used by residents in the disaster area, as it allows them to upload images and exact coordinates of the damage [80]. This can remove the first-pass inspection required by companies [80], which in turn reduces the time-to-repair. The ad hoc network aids in the gathering and escalating of information [80]. The application also provides two-way communication which allows a company to update residents with the status of repairs [80]. This helps provide real-time information to both repair companies and victims, and also helps minimize repair time due to visual inspection requirements [80].

C. Search and Rescue Operation

Search and rescue operations are typically conducted using manned aircraft (e.g. helicopters) and ground-based personnel with vehicles and search animals [42] to locate individuals facing various life-threatening situations. Research indicates that the first 72 hours are most crucial for an individual's survival [56, 69] Thus, search and rescue operations must have access to information quickly, and maintain communication to organize rescue efforts. Two examples from recent history where rescue operations were hindered by lack of communication included Hurricane Katrina [81], and the attack on the World Trade Center (where signal interference between radios used by rescue members made it difficult to locate victims [56]).

To assist in search and rescue operations, a Disaster Area Wireless Network has been proposed to create an ad hoc network usable by helicopters, trucks, and mobile devices [81]. This is accomplished by deploying routers attached to helium balloons that are tethered to the ground [81]. This network is quickly deployable, has high bandwidth, and the network topology can be easily updated by deploying additional balloons [81]. In addition, simulation findings explored in [81] show that the proposed protocol has a significant reduction in packet loss and end-to-end delay, as well as a higher packet delivery ratio and throughput in comparison to the traditional AODV protocol. This protocol addresses the challenge of mobility in Disaster Area Wireless Networks and can improve the communication between nodes in a disaster area.

MANETs can also be formed in disaster scenarios to support emergency information exchange using Wi-Fi-enabled notebooks in the possession of rescue workers [69]. Within a few hours following a disaster, a peer-to-peer network is made with a local wireless intranet that uses P2P and MANET technology [69]. This approach supports push-to-talk, mobile social networking, Voice over Internet Protocol, instant messaging, and more [69]. The information can then be transmitted to headquarters hundreds of kilometres away using mobile base stations or satellite connections [69].

Robinson *et al.* (2013) [42] describe a very different approach than that of the previously discussed works. Specifically, they describe the use of aerial MANETs. Helicopters or other aerial machines are often the most effective and efficient way to assess disaster areas, and they are the most commonly used method during local disaster responses in the United States [42]. They enable rescuers to see the number of damaged structures, the extent of damage, and the potential number of individuals affected and allow rescuers to assess any potential hazards to the rescuers via MANETs that transmit information collected (e.g. video, sensory data) to rescue volunteers on the ground [42].

Finally, MANET networks can be helpful for notifying search and rescue operations at sea [7]. If we imagine each ship to be a node in the network, a ship could send information as soon as a disaster occurs, and the nodes could forward the information to the correct authorities. This could help search and rescue operations be deployed more quickly.

D. Education

Quality education is listed as the 4th of 17 sustainable development goals identified by the United Nations [82]. However, the methods for accomplishing this goal can prove challenging in developing countries and rural or remote areas. For example, the International Telecommunications Union report of 2017 identified that approximately 9 in 10 individuals in Africa and Asia-Pacific have no internet access [83].

The Government of Zimbabwe introduced a new curriculum in 2015 with Information Communication Technology as a "cross-cutting theme", in which a majority of the information communication technology environments can be achieved through the use of mobile devices [83]. With the lack of existing infrastructure in Makoni East (Zimbabwe), MANETs can be used to ensure that students in rural locations can receive the same education as students in an urban area of Zimbabwe [83]. Tsimba *et al.* (2020) proposed a bring-your-own-device strategy for students since mobile devices had lower costs in comparison to laptops and tablets. Educators were then able to use technologies such as Bluetooth and SHAREit to share resources (e.g. textbooks, typed notes, video tutorials, etc.) with students regardless of where they were [83]. The ability to access remote learning on a mobile device (known as mobile-learning or m-learning) allowed educators and students not to be limited by print books (which are often quite expensive or are hosted in libraries that are too far away) [83]. Further, the application of MANET technology meant that students could use the network to share data. This can mitigate or eliminate struggles associated with a lack of infrastructure or funding [83].

Chaamwe *et al.* (2014) also explored the use of MANETs to provide e-Learning to students in rural Zambia. Like rural Zimbabwe, rural Zambia struggles due to inadequate infrastructure, lack of qualified teachers, and insufficient learning resources [70]. To combat these struggles, Chaamwe *et al.* (2014) suggested setting up a tele center with a server connected to the internet. The data are loaded to the main server manually or can be downloaded from the internet [70]. Mobile devices can access the material on the server as well as the internet using the server [70]. These mobile devices also serve as routers for other mobile devices in range but not in range of the server [70].

Ichaba *et al*. (2020) proposed an enhanced zone routing protocol to provide better support in MANET-based m-Learning. Their work included the development of a guide for implementing MANET-based m-Learning and a discussion on the lack of specifications for models in research that make it difficult to implement MANETs in these settings [84]. Ichaba *et al*. (2020) expand their research by exploring the enhanced Zone Routing Protocol (ZRP) and traditional ZRP protocol in a simulation using the characteristics of a campus. They note that enhanced ZRP performs better than the traditional ZRP protocol and would be more suited to support campus learning, thus making it a candidate for m-Learning as well [84].

In addition to providing e-learning to rural areas, MANETs can be used to support learning in urban schools as well. They can be used to set up video broadcasts between students and/or teachers in various rooms. For example, a teacher could conduct a science experiment from one room, and students in another room could broadcast the video and watch it in real time to conduct the experiment [85]. El Kamoun (2017) also demonstrates that the proposed protocol outperforms Destination Sequenced Distance Vector (DSDV), as well as AODV in some cases, and is suitable for a low-mobility network, thus supporting the proposed protocol's suitability for classroom learning. Abdullah *et al.* (2012) further explored the use of MANETs for video multi-party conferencing via Microsoft Net-Meeting. This research shows the ability to use MANETs to support multi-party video conferencing with minimal nodes, allowing for a faster exchange of information between multiple people which may not be possible using direct audio-video communication technologies [86]. Similar to El Kamoun, the proposed algorithm by Adbullah *et al*. (2012) is also able to outperform the AODV protocol, as well as DSR, when it comes to end-to-end delay of real-time packet delivery. This shows that the protocol proposed in [86] has the potential to improve conference learning using MANETs, and make the application of MANETs in video conferencing more feasible.

Overall, MANETs can be used to aid in the delivery of education in both rural and urban areas. As technology continues to infiltrate and transform education, it is likely that this trend will continue as technology continues to advance [84].

E. Healthcare

Adequate accessible healthcare is arguably one of the most important infrastructures a jurisdiction needs to provide to its residents. With approximately 4.8 million Canadians without access to a primary care provider [87] in 2019, and the average hours worked by physicians surpassing 50 hours per week in 2017 [88], it is evident that the healthcare system is struggling. Although MANETs cannot solve the physician or staffing shortage, it can aid in providing physicians and healthcare staff with tools that allow them to work more efficiently and assess patients more easily.

To begin, Abid *et al*. (2014) discuss typical wireless monitoring tools used in healthcare which could benefit from the use of mobile ad hoc technologies. These tools include, for example, motion capture, electromyography, pulse oximeters, maternal uterine and fetal heart rate monitors, electrocardiograms and more [89]. By connecting these tools to MANETs they can be used during a disaster recovery scenario to quickly assess the health of the patient without requiring them to be brought to a hospital first [89].

Li *et al*. (2005) discuss the use of e-healthcare emergency applications which utilize mobile ad hoc grids, by exploring the example of a serious car accident in which the driver has become seriously injured and is unconscious. In this scenario, a police officer arrives first and collects the victim's personal and family information using their PDA (personal digital assistant) [55]. Upon the arrival of the ambulance and paramedics, a MANET grid is created by a group of devices (e.g. police's PDA, physical sensors attached to the victim, biomedical system, etc.) to process collected data, and collab-orate for "prehospital treatment suggestions" [55]. The e-healthcare applications can use the MANET for distributed data discovery (e.g. data collected from biosensors), or job scheduling (e.g. analyzing received data across multiple devices) [55]. Such an application can aid in quicker assessment of a patient's data, and in devising a treatment plan for the patient.

A MANET-based cardiac patient monitoring system was proposed by Kumar *et al.* (2015) [14] to measure body temperature and heart rate. With a lack of existing infrastructure, the monitoring system can make use of ad hoc networks to transmit data [14]. This allows the application to be used for patients who may live in remote areas which may lack healthcare facilities and doctors [14]. Such tools aid in reducing the costs of providing care in these areas [14], making it more affordable for patients who have to pay out of pocket. The research in [13] explores a similar system but for elderly patients. Hamoud *et al.* (2017) examine the performance of AODV, DSV, and Optimized Link State Routing Protocol (OLSR) protocols for collecting 4 sensor data. They are able to conclude that DSR is most suitable for small networks, AODV for networks with higher mobility (e.g. outdoor activities), and OLSR is most suitable for indoor settings [13]. Overall, Hamoud *et al.* (2017) conclude that a hybrid protocol would be best suited for the use of real-time home monitoring.

Healthcare applications are not limited to sharing data between sensors placed on the bodies of patients with emergency response personnel and healthcare providers. The research in [38] explores the use of MANETs in a nanometer-sized setting. Specifically, they explore the use of MANET-connected nanodevices (nanonodes) inside the human body. While their size limits their computational capabilities, a MANET-based nanonetwork can be created inside the body that is supported externally by gateway sensors attached to the skin that are connected to a computer. Nanonodes inside this network can be used to administer a drug, or monitor important medical parameters [38]. The nanonodes will then pass any relevant data to the gateway where it can then be read on a computer by a medical physician. This application of MANETs can aid in providing healthcare in a less invasive manner while still accomplishing the same goals.

F. *Entertainment*

Entertainment can take on many forms, from video game consoles to films, streaming services and more. With the development of wireless technologies, most modern devices can integrate with wireless services. This includes older video game consoles such as the Nintendo Wii, the Nintendo DSI, and the Sony PlayStation Portable [90], as well as more recent consoles such as the Nintendo Switch. Some of these gaming consoles also include technology that allows an ad hoc mode (although no consoles currently support multi-hop mode) [90]. Currently, most networked video games use a Client/Server paradigm, with some supporting P2P connections [90].

Kaiser *et al.* (2010) explored a new protocol to minimize network delay, while also not allowing the gaming to suffer from MANET challenges (e.g. packet loss) [90]. The new protocol is called the multipath Optimized Link State Routing (OLSR) protocol, which computes two possible routes (whenever possible) between each client and server [90]. The testing results showed that the modified OLSR routing protocol had fewer and shorter disconnections compared to the original OSLR protocol, however, the number of disconnections was not 0 as some nodes were only able to calculate a single route between client and server [90]. Ultimately, this protocol could be used to reduce the length of time a player sees their screen freezing, thereby improving the gameplay experience, this conclusion supported by simulation findings that show that the proposed algorithm has fewer disconnect times and number of disconnections than the traditional OLSR protocol [90]. Salim *et al*. (2008) also discussed a new protocol called FLIP (flexible protocol) which caters to mobile device communication for multiplayer gaming [44]. The discussed protocol aimed to improve latency, reliability and robustness in gaming, as well as lay down a base protocol for future research [44].

G. *Smart City*

Smart cities represent a "business oriented and appealing environment for the people" and is a booming technology. Although there is no universally accepted definition, it is generally agreed upon that making a city "smart" is done by integrating various communication technologies to automate offered services [91]. A smart city service can be described as a service using a variety of factors including area coverage (which can range from a small area to a city-wide area) depending on the action required [91].

Jacob *et al*. (2016) create their own smart city with four domains: smart governance (the master domain that collects all smart city information), smart transport (provides real-time traffic monitoring and a cab sharing application), smart health (contains the application allowing a request for ambulance), and Fire & Emergency (contains the destination and type of an occurring emergency), where the domains each have their own server and require data to be passed between them [91]. Both the cab-sharing application, ambulance request and fire & emergency make use of the traffic monitoring application [91]. There are many applications available with a smart city set up like this: when an ambulance is en-route to a hospital, all vehicles along the chosen path can be notified to help the ambulance pass safely and easily [91]. Or, in the event of a road blockage or traffic, all vehicles within a certain radius can be notified of the block and stay away from it. Jacob *et al.* (2016) explore two simulation settings, the first scenario is a traffic block notification, and the second scenario is an ambulance notification scenario. In the case of the first scenario AODV performs best, and in the second scenario DSR performs best [91]. Overall, Jacob *et al.* (2016) is noted that "a heterogeneous routing protocol that can handle both fixed networks and mobile networks equally efficiently" [91] is needed.

Cardone *et al*. (2011) discuss the use of MANETs in smart cities to support monitoring applications. Such applications can be used to monitor noise/light pollution, anti-theft protection, structural monitoring, etc [92]. In their research, they focus on a structural monitoring application that triggers an alert if something irregular is detected (e.g. flexure of critical support) [92]. In this case, if a MANET node (e.g. civilians walking around) detects an urgent data packet, it will then broadcast a hop-limited broadcast request [92]. In the event of this monitoring application, it can notify the correct authorities about a possible structural problem and also notify residents if they should evacuate a building, possibly saving many lives [92].

Sharif *et al.* (2018) continue to explore the applications of MANETs in smart cities by focusing on the Smart Transportation domain. A few various implementations are discussed. To begin, one application contains the use of GPS and guiding data of the city which has the location of intelligent traffic lights [6]. The intelligent traffic lights gather information from passing vehicles to update their traffic statistics [4]. Each vehicle will send a request message to an intelligent traffic light to retrieve the correct location of each vehicle after a certain interval of time [6]. Vehicles are also able to send warning messages of high traffic to the closest intelligent traffic light [4]. This application of MANETs in a Smart Transportation scheme can be used to lower the pollution of the smart city, making it a greener city [4]. Another concept is the use of a social network of vehicles which is accomplished by clustering vehicles based on their characteristics (e.g. driving route history, driver behaviour, regularity of contact between vehicles, the path the vehicle is most likely to follow, and so on) [6], [68]. This network can then be used to share traffic messages, warning messages, and more between vehicles [68]. Overall, the use of MANETs in Smart Traffic technologies can help limit traffic congestion in populated areas, while also making driving experiences safer [68].

H. Commercial and Civilian Environment

The development of MANET communication has attracted the interest of both academia and industry and is on its way to becoming an industry standard [59]. In fact, the number of applications that can support this technology includes tools that are used in the day-to-day life of many people. This includes chat and e-commerce applications, databases, traffic sharing applications, and more [3, 59, 93, 94].

1) Chat applications

Yan et Chen proposed a reputation system for MANET chatting called AdChatRep. The AdChatRep application was designed to use MANETs to provide an interface for social networking for those close to each other. The system uses a reputation rating for individual nodes to encourage trust and communication between users [93]. The user reputation is generated using the following model: the trusted server will generate/predict the node reputation and issue the reputation token to the node [93]. The node will generate the reputation of other nodes while chatting using the reputation token and MANET social networking experience of the other nodes [93]. To provide a wider application usage, AdChatRep was designed to support node-to-node chatting as well as community chatting (see [93] for further details). The possibilities for an app such as this are endless when it comes to the topics users can chat about, and where this application can be deployed.

2) Databases:

MANET databases are databases stored in the nodes of a MANET [94]. Each node has a local database that stores reports, where reports are “a set of values sensed or entered by the user at a particular time, or otherwise obtained by a local peer” [94]. A report can describe information such as the number of available parking spots in a lot, or the number of available shirts at a merchant, etc. The nodes will then communicate reports and queries to discover neighbours, and the reports are propagated to users using multi-hop transmissions [94]. The MANET database can be used to substitute a client-(local)-server approach, which can have accessibility and availability problems due to cost, propagation delays, device limitations and more [94]. The MANET database can provide information with media such as maps, menus, etc. since it tends to have a larger bandwidth than cellular infrastructure, and is free. It can also be combined with client-server search, or used on its own. MANET databases function through the use of report pulling and report pushing [94]. Similar to node discovery, report pushing involves flooding the network with a query and receiving answer reports from nodes that have them [94]. Network pushing can be done by flooding reports to be consumed by peers, or through the use of a hierarchy-based method, [94]. Regardless of the methods used, MANET databases can have applications in social networks, emergency response, airport applications, mobile e-commerce, transportation safety and more [94]. This is due to the fact that it allows for dynamic information to be stored, and kept up to date by other nodes. For example, a user in a mall can check the inventory of a merchant’s store, get real-time information regarding baggage information, and more [94]. The options in MANET database applications are endless.

3) E-commerce:

With the new generation of WiFi and telecommunication protocols, the cost of implementing a MANET in a retail business is low [59]. This has opened up an application area for MANETs in a commercial environment. The use of MANETs in the retail industry provides opportunities to share product information with customers, monitor and understand customer movements in stores, allow customers to share in real-time their shopping experience, and also provide service announcements to shoppers [59], [3].

In addition to improving commerce, there is also the potential of developing a reliable MANET for e-commerce as well [59]. Varaprasad proposed a query-based approach using MANETs for mobile commerce. The application has three types of agents: a user agent (acquire services to handle), directory agent (keeps track of the advertised ser-vices), and service agent (responsible for making services available to the user agent) [95]. In this case, a transaction to gain product information uses the following steps: the customer will send their information and location information to the server, the server will send the requested customer information to the central database and get information about the vendor products to send to the customer, the server will then provide the list of products to the customer [95]. Simulations showed that the proposed steps are able to provide the intended customer with all requested product information in a secure manner [95].

Evans *et al.* (2006) embarked on a different approach by discussing the use of MANETs in shopping malls by having a sensor located in various parts of the building to provide shoppers with connectivity [96]. It uses a Ubiquitous Business Environment Model which is a model that works on a limited space with a boundary [96]. That boundary can be made up of MANETs [96]. The use of u-commerce (or ubiquitous commerce) would allow customers to buy goods online, through retail outlets, or that are linked to a centralized system. Evans *et al.* (2006) described the use of u-commerce as a breath of fresh air to the commerce industry [96], and also provides MANETs with the ability to display their versatility in yet another application.

I. Internet of Things

With the ubiquity and low cost of smartphones, tablets, and other electronic devices, it was estimated that in 2020 there were 26 billion internet-connected devices [97]. This network of devices connected to the internet is typically referred to as the Internet of Things (IoT) [39], and provides an opportunity to use such devices as nodes in a MANET [39]. Applications designed with and for the IoT can support smart homes, wireless communications, wildlife monitoring, environmental monitoring, and more [98].

Dattana *et al.* (2019) explored the use of MANETs for stable data flow in smart homes. The public has recently become interested in smart homes since they enable users to remotely control all of the equipment (e.g. lighting, temperature, etc.) and monitor the environment at home. [99]. Traditional smart home systems generate a wireless network using Wi-Fi or Bluetooth [99]. Dattana *et al*. (2019) proposed the use of a MANET wireless network to support 3 smart home functionalities: remote control, enquiry, and alert. The protocol proposed by Dattana *et al*. (2019) aims to solve the MANET difficulties of route stability and route recovery [99] to improve the system performance by reducing node energy consumption, improving the quality of and shortening the time of communication [99]. This in turn would allow homeowners to receive notifications about their home quicker, and for nodes to have a longer "life" [99].

Alam *et al*. (2018) explored the use of MANETs to deliver cloud services to smart devices in the IoT framework. Specifically, access to cloud services was provided to a MANET of IoT devices if at least one device had internet access [97]. The proposed framework followed several steps: 1) MANET formation, 2) Accessing the ad hoc network when in range, 3) registration of smart devices in MANET, 4) registration of MANET smart devices in the cloud, 5) implementing IoT-Cloud-MANET model among smart devices, and 6) commencing communication [97]. Making use of this IoT-Cloud-MANET model (which discovers and connects nearby smart devices with no centralized infrastructure) is especially useful for machine-to-machine networks [97]. In this case, smart devices are considered nodes and can use cloud services to discover devices and process data (images, video, etc.) [97]. It is possible for several MANETs to connect to the same cloud and utilize its services in real-time [97]. This new framework enhances the capabilities of smart devices by enabling devices to share resources, storage, and services [97].

J. Maritime Networks

Maritime transport is the most important method of transportation when it comes to the distribution of goods on a global scale. Maritime transportation is responsible for roughly 90% of traded goods, and as the demand for global transportation increases, the maritime trade volumes are expected to triple by 2050 [100]. To ensure the safety of boats and goods in transportation, these vessels use Very High Frequency (VHF) radios for functions such as navigation, ship-to-shore communication, distress calling, National Oceanic and Atmospheric Administration weather broadcasts, etc. [101]. Boats also make use of the Automatic Identification System (AIS) to share data such as location, course, heading, destination, tonnage, speed, and more [102]. The use of MANETs communication using the VHF band can aid in eliminating the need for "high-cost IP networks currently provided by satellite communication" [103]. In addition to cost, there are additional difficulties regarding maritime networks. Once they are configured, maritime networks are left "virtually" unmanaged, and the bandwidth connecting maritime ships is often "insufficient even to support the network traffic generated locally" [40].

To explore the usage of MANETs in a maritime network, Moshin *et al.* (2015) explored four different scenarios to investigate how marine traffic patterns affect the effectiveness of MANET routing protocols [103]. For the first scenario, the NS2 simulator was used. There were 50-200 nodes spread within an area of 400x300km range [103]. For the second scenario, real ship locations were simulated. This was done by simulating 60 static nodes located in the English Channel between Clacton-on-Sea (UK) and Middleburg (France) over a 200x200km simulation area [103]. These ship locations were collected from the live AIS data website [103]. For the third scenario, the same parameters as the second scenario was used, except real mobility patterns (consisting of ship speed and direction) were extracted from the AIS data [103]. For the fourth scenario, vessel traffic was simulated in the North Sea using AIS data (speed, location, and direction) of 30 mobile vessels over a 300x300km area [103]. Moshin *et al*. (2015) explored the effectiveness of 3 MANET routing protocols: Ad-hoc On-Demand Vector Routing (AODV), Ad-hoc On-Demand Multipath Distance Vector Routing (AOMDV), and Destination-Sequenced Distance-Vector Routing (DSDV). It was shown that on average the use of AOMDV routing protocol had a better packet delivery ratio than DSDV and AODV protocols [103]. It was also shown that scenarios 3 and 4 (which used real-life data) had better packet delivery ratios because most vessels use navigational routes that follow pathways [103]. Further, it was shown that AOMDV performed best and that communication with MANETs using existing VHF infrastructure available on ships was effective up to a 40km range [102]. Overall, Moshin *et al.* (2015) were able to show that MANETs can be applied to low-cost small vessels using existing onboard equipment to support communication.

Current developments in MANET ship-to-ship communication were also explored in [48]. They list that British researchers Pullin *et al.* (2008) demonstrated that ship-to-ship communication using 160Mh VHF-MANET was possible [104] and that Wu Huafeng also researched the use of short wave MANET to provide long-distance ship-to-ship communication (tens of miles and more) [105]. Li *et al.* (2018) also discuss the use of three heterogeneous wireless communication networks (MANET being one of the 3) for ship communication [48]. The MANET network would be responsible for ship-to-ship communications, whereas cellular gateways and satellite gateways are used to interface with MANET to provide onshore and offshore communication [48].

All in all, the potential for the use of MANETs for ship-to-ship and ship-to-shore communication is clearly there, however, it needs to be developed and further refined.

IV. Conclusion

MANETs are a technology that is here to stay and can have many uses and benefits for various sectors in today's society. It is important that this technology continues to be expanded upon to accomplish milestones such as improving the quality of education in remote areas or aiding in saving lives post-disaster. This paper investigated a broad set of MANET applications and newly proposed improvements. This paper concludes that there is a possible application for MANET use in almost every domain or industry sector today. In addition, this paper also discusses the challenges that MANETs still face, which influence their ability to "get the job done" when it comes to industrial applications. The research surveyed in this paper provides a foundation regarding the potential of MANETs, while also leaving room for future researchers to build upon as well.

CONFLICT OF INTEREST

The authors declare no conflict of interest。

AUTHOR CONTRIBUTIONS

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

We certify that the submission is original work and is not under review at any other publication

REFERENCES

[1] E. Huang, W. Hu, J. Crowcroft, and I. Wassell, "Towards commercial mobile ad hoc network applications: A radio dispatch system," in *Proc. 6th ACM International Symposium on Mobile ad Hoc Networking and Computing*, 2005, pp. 355–365.

[2] D. Ramphull, A. Mungur, S. Armoogum, and S. Pudaruth, "A review of mobile ad hoc network (manet) protocols and their applications," in *Proc. 2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS)*, 2021, pp. 204–211.

[3] A. Singh, D. M. Kumar, R. Rishi, and D. K. Madan, "A relative study of manet and vanet: Its applications, broadcasting approaches and challenging issues," vol. 132, Jan. 2011, pp. 627–632.

[4] G. S. Khekare and A. V. Sakhare, "A smart city framework for intelligent traffic system using vanet," in *Proc. 2013 International Mutli-Conference on Automation, Computing, Communication, Control and Compressed Sensing (iMac4s)*, IEEE, 2013, pp. 302–305.

[5] M. Lee and T. Atkison, "Vanet applications: Past, present, and future," *Vehicular Communications*, vol. 28, p. 100310, 2021.

[6] A. Sharif, J.-P. Li, and M. A. Saleem, "Internet of things enabled vehicular and ad hoc networks for smart city traffic monitoring and controlling: A review," *International Journal of Advanced Networking and Applications*, vol. 10, pp. 3833–3842, 2018.

[7] E. Chauhan, M. Sirswal, D. Gupta, and A. Khanna, "A critical review: Sanet and other variants of ad hoc networks," in *Proc. International Conference on Innovative Computing and Communications*. Springer Singapore, 2021, pp. 1093–1114.

[8] H. M. Taher, "Sea ad hoc network (sanet) challenges and development," *International Journal of Applied Engineering Research*, vol. 13, no. 8, pp. 6257–6261, 2018.

[9] I. Bekmezci, O. K. Sahingoz, and Temel, "Flying ad-hoc networks (fanets): A survey," *Ad Hoc Networks*, vol. 11, no. 3, pp. 1254–1270, 2013.

[10] A. Chriki, H. Touati, H. Snoussi, and F. Kamoun, "Fanet: Communication, mobility models and security issues," *Computer networks (Amsterdam, Netherlands: 1999)*, vol. 163, pp. 106–877, 2019.

[11] Y. Liu, "Wireless sensor network applications in smart grid: Recent trends and challenges," *International Journal of Distributed Sensor Networks*, vol. 8, no. 9, p. 492819, 2012.

[12] H. Dubois-Ferrie`re, L. Fabre, R. Meier, and P. Metrailler, "Tinynode: A comprehensive platform for wireless sensor network applications." Association for Computing Machinery, 2006, p. 358–365.

[13] M. Hamoud, R. Hassoun, A. F. Mahmoud, M. Alkubeily, and A. S. Ahmad, "Comparison of manet routing protocols used in home health-monitoring system for elderly patients," *International Journal of Science and Research (IJSR)* 6, no. 2, pp. 988-993.2017.

[14] S. Kumar, A. Soni, and R. Kumar, "Remote patient monitoring and manet: Applications and challenges," *International Journal on recent and innovation trends in computing and communication*, vol. 3, no. 6, pp. 4275–4283, 2015.

[15] M. Asch, "A case study on the replicability of the rhpman data storage scheme," Master's thesis, School of Computer Science, University of Guelph, Guelph, Canada, 2022.

[16] N. Durish, "A case study in the design and development of a community-based internet assessment initiative in rigolet, nunatsiavut, canada," Master's thesis, School of Computer Science, University of Guelph, Guelph, Canada, 2020.

[17] N. Durish, R. Gill, P. Houlding, C. Flowers, I. Shiwak, R. I. C. Government, J. Ernst, and D. Gillis, "Co-designing a community-led internet assessment tool in rigolet, nunatsiavut, canada," in *Proc. 2021 IEEE International Symposium on Technology and Society*, IEEE, 2021, pp. 1–8.

[18] R. Kahn, "The organization of computer resources into a packet radio network," *IEEE Transactions on communications*, vol. 25, no. 1, pp. 169–178, 1977.

[19] R. Bruno, M. Conti, and E. Gregori, "Mesh networks: commodity multihop ad hoc networks," *IEEE Communications Magazine*, vol. 43, no. 3, pp. 123–131, Mar. 2005.

[20] L. R. Raju and C. R. K. Reddy, "A survey on routing protocols and QoS in mobile ad hoc networks (MANETs)," *Indian Journal of Science and Technology*, vol. 10, no. 9, pp. 1–8, Feb. 2017.

[21] J. G. Ponsam and R. Srinivasan, "A survey on manet security challenges, attacks and its countermeasures," *International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)*, vol. 3, no. 1, pp. 274–279, 2014.

[22] N. Raza, M. Umar Aftab, M. Qasim Akbar, O. Ashraf, and M. Irfan, "Mobile ad-hoc networks applications and its challenges," *Communications and Network*, vol. 8, no. 3, pp. 131–136, 2016.

[23] S. Kumar and S. Kumar, "Study of manet: Characteristics, challenges, application, routing protocol and security attacks," *International Journal of R&D in Engineering, Science and Management*, vol. 2, no. 5, pp. 266–274, 2015.

[24] S. Corson and J. Macker, "Mobile ad hoc networking (manet): Routing protocol performance issues and evaluation considerations," *Internet Requests for Comments*, RFC Editor, RFC 2501, January 1999.

[25] G. Mamatha and D. S. Sharma, "Analyzing the manet variations, challenges, capacity and protocol issues," *International Journal of Computer Science & Engineering Survey (IJCSES)*, vol. 1, no. 1, pp. 14–21, 2010.

[26] A. K. S. Ali and U. Kulkarni, "Characteristics, applications and challenges in mobile ad-hoc networks (manet): overview," *Wireless Networks*, vol. 3, no. 12, pp. 6–12, 2015.

[27] H. Al Amri, M. Abolhasan, and T. Wysocki, "Scalability of manet routing protocols for heterogeneous and homogenous networks," *Computers and Electrical Engineering*, vol. 36, no. 4, pp. 752–765, 2010.

[28] D. E. M. Ahmed and O. O. Khalifa, "An overview of manets: applications, characteristics, challenges and recent issues," *International Journal of Engineering and Advanced Technology*, vol. 6, no. 4, pp. 128–133, 2017.

[29] J. Hoebeke, I. Moerman, B. Dhoedt, and P. Demeester, "An overview of mobile ad hoc networks: Applications and challenges," *Journal-Communications Network*, vol. 3, no. 3, pp. 60–66, 2004.

[30] S. Mirza and S. Z. Bakshi, "Introduction to manet," *International Research Journal of Engineering and Technology*, vol. 5, no. 1, pp. 17–20, 2018.

[31] A. Gupta, P. Verma, and R. Sambyal, "An overview of manet: Features, challenges and applications," *International Journal of Scientific Research in Computer Science, Engineering and Information Technology* 4, no. 1. pp. 122-126, 2018.

[32] D. Kanellopoulos, "Congestion control for MANETs: An overview," *ICT Express*, vol. 5, no. 2, pp. 77–83, Jun. 2019.

[33] P. Goyal, V. Parmar, R. Rishi *et al.*, "Manet: vulnerabilities, challenges, attacks, application," *IJCEM International Journal of Computational Engineering & Management*, vol. 11, no. 2011, pp. 32–37, 2011.

[34] T. Sharma and V. Kumar, "Bandwidth aware on demand multipath routing in manets," *International Journal of Wireless & Mobile Networks*, vol. 6, no. 4, p. 101, 2014.

[35] M. Chitkara and M. W. Ahmad, "Review on manet: Characteristics, challenges, imperatives and routing protocols," *International journal of Computer Science and Mobile Computing*, vol. 3, no. 2, pp. 432–437, 2014.

[36] A. O. Bang and P. L. Ramteke, "Manet: history, challenges and applications," *International Journal of Application or Innovation in Engineering and Management (IJAIEM)*, vol. 2, no. 9, pp. 249–251, 2013.

[37] N. A. Mahiddin, N. I. Sarkar, and B. Cusack, "An internet access solution: Manet routing and a gateway selection approach for disaster scenarios," *The Review of Socionetwork Strategies*, vol. 11, pp. 47–64, 2017.

[38] F. Bu¨ther, I. Traupe, and S. Ebers, "Hop count routing: A routing

algorithm for resource constrained, identity-free medical nanonetworks," in *Proc. 5th ACM International Conference on Nanoscale Computing and Communication*, pp. 1–6, Sep 2018.
[39] R. Bruzgiene, L. Narbutaite, and T. Adomkus, "MANET network in internet of things system," *Ad Hoc Networks*, 2017.
[40] D. Kidston and T. Kunz, "Challenges and opportunities in managing maritime networks," *IEEE Communications Magazine*, vol. 46, no. 10, pp. 162–168, 2008.
[41] L. Raja and S. S. Baboo, "An overview of manet: Applications, attacks and challenges," *International Journal of Computer Science and Mobile Computing (IJCSMC)*, vol. 3, no. 1, pp. 408–417, 2014.
[42] W. Robinson and A. Lauf, "Aerial manets: Developing a resilient and efficient platform for search and rescue applications," *Journal of Communications*, vol. 8, pp. 216–224, 2013.
[43] M. Asch, P. F. Seymour, J. Ernst, and D. Gillis, "Incorporation of node mobility in data replication schemes in mobile ad hoc networks," in *Proc. 2019 IEEE 10th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*. IEEE, 2019, pp. 0230–0236.
[44] A. Salim and Q. Mehdi, "Suitability of manet protocols for heterogeneous mobile devices communication in gaming and multimedia," in *Proc. CGAMES'2008. 12th International Conference on Computer Games: AI, Animation, Mobile, Educational and Serious Games*, 30th July – 2nd August 2008, Louisville, Kentucky, USA.
[45] J. B. Ernst, S. C. Kremer, and J. J. Rodrigues, "A survey of qos/qoe mechanisms in heterogeneous wireless networks," *Physical Communication*, vol. 13, pp. 61–72, 2014.
[46] A. M. Abbas and O. Kure, "Quality of service in mobile ad hoc networks: a survey," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 6, no. 2, pp. 75–98, 2010.
[47] N. Kumar, "Mobile ad hoc network: Issue and challenges related to qos and solutions," *Int. J. Eng. Technol. Sci. Res*, vol. 4, no. 10, pp. 415–419, 2017.
[48] C. Liu, E. Lin, L. Cai, and G. Huang, "The challenges and key technologies of wireless transmission and mobile networking in near maritime environment," in *Proc. IOP Conference Series: Materials Science and Engineering*, vol. 382, p. 052028, jul 2018.
[49] P. Goyal, V. Parmar, and R. Rishi, "Manet: Vulnerabilities, challenges, attacks, application," vol. 11, 01 2011, pp. 32–37.
[50] C. Phillips, D. Sicker, and D. Grunwald, "A survey of wireless path loss prediction and coverage mapping methods," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 1, pp. 255–270, 2013.
[51] M. Takai, J. Martin, and R. Bagrodia, "Effects of wireless physical layer modeling in mobile ad hoc networks," in *Proc. 2nd ACM international symposium on Mobile ad hoc networking & computing*, 2001, pp. 87–94.
[52] M. Garcia-Pineda, S. Sendra, M. Atenas, and J. Lloret, *Underwater Wireless Ad-hoc Networks: A Survey*, in *Mobile Ad Hoc Networks: Current Status and Future Trends; CRC Press: Boca Raton, FL, USA*, pp. 379-411, 2011.
[53] X. M. Zhang, E. B. Wang, J. J. Xia, and D. K. Sung, "A Neighbor Coverage-Based Probabilistic Rebroadcast for Reducing Routing Overhead in Mobile Ad Hoc Networks," *IEEE Transactions on Mobile Computing*, vol. 12, no. 3, pp. 424–433, Mar. 2013.
[54] M. Ichaba, F. Musau, and S. Mwendia, "An empirical approach to mobile learning on mobile ad hoc networks (manets)," in *Proc. 2020 IST-Africa Conference (IST-Africa)*, 2020, pp. 1–14.
[55] Z. Li, L. Sun, and E. Ifeachor, "Challenges of mobile ad-hoc grids and their applications in e-healthcare," in *Proc. 2nd Int. Conf. on Computational Intelligence in Medicine and Healthcare (CIMED2005), Lisbon, Portugal*. 2005.
[56] R. G. Lakshmi Narayanan and O. C. Ibe, "A joint network for disaster recovery and search and rescue operations," *Computer Networks*, vol. 56, no. 14, pp. 3347–3373, 2012.
[57] W. A. Jabbar, M. Ismail, R. Nordin, and S. Arif, "Power-efficient routing schemes for MANETs: a survey and open issues," *Wireless Networks*, vol. 23, no. 6, pp. 1917–1952, Aug. 2017
[58] J. Swain, B. K. Pattanayak, and B. Pati, "A systematic study and analysis of security issues in mobile ad-hoc networks," *International Journal of Information Security and Privacy*, vol. 12, no. 2, pp. 38–45, Apr. 2018.
[59] W. Ning, H. Wang, and W. Wang, "Security issues on mobile ad hoc network for mobile commerce," In *Proc. SITE 2014: Informing Science+ IT Education Conference*, vol. 14, pp. 199-209. 2014.
[60] F. Abdel-Fattah, K. A. Farhan, F. H. Al-Tarawneh, and F. AlTamimi, "Security Challenges and Attacks in Dynamic Mobile Ad Hoc Networks MANETs," in *Proc. 2019 IEEE Jordan International Joint Conference on Electrical Engineering and Information Technology (JEEIT)*. Amman, Jordan: IEEE, Apr. 2019, pp. 28–33.
[61] A. P. Tapaswi, P. P. Nashikkar, R. S. Barge, A. M. Shinde, and P. Patil, "Extended eaack an secure intrusion detection system with detection and localization of multiple spoofing attackers in manet," *in International Journal of Scientific and Research Publications*, vol. 4, pp. 39–46, 2014.
[62] S. Shaw, K. Orea, P. Venkateswaran, and R. Nandi, "Simulation and Performance Analysis of OLSR under Identity Spoofing Attack for Mobile Ad-Hoc Networks," in *Computer Networks and Information Technologies*, V. V. Das, J. Stephen, and Y. Chaba, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, vol. 142, pp. 308–310, 2011.
[63] A. Alsumayt, J. Haggerty, and A. Lotfi, "Evaluation of Detection Method to Mitigate DoS Attacks in MANETs," in *Proc. 2018 1st International Conference on Computer Applications & Information Security (ICCAIS)*. Riyadh: IEEE, pp. 1–5.
[64] A. Singh, M. Kumar, R. Rishi, and D. K. Madan, "A relative study of manet and vanet: Its applications, broadcasting approaches and challenging issues," *Advances in Networks and Communications*. Springer Berlin Heidelberg, pp. 627–632, 2011.
[65] P. Khatri and P. Rajvanshi, *A Relative Study About Mobile Ad-Hoc Network (MANET): Applications, Standard, Protocols, Architecture, and Recent Trends*, pp. 156–173, 01 2020.
[66] B. Ojetunde, N. Shibata, and J. Gao, "Secure payment system utilizing manet for disaster areas," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 49, no. 12, pp. 2651–2663, 2019.
[67] R. Kaur, R. Singla, B. Kaur, and S. Singh, "Manets: Overview, tools, security and applications in health care," *Australian Journal of Basic and Applied Sciences*, vol. 11, no. 8, pp. 1–6, 2017.
[68] L. A. Maglaras, A. H. Al-Bayatti, Y. He, I. Wagner, and H. Janicke, "Social internet of vehicles for smart cities," *Journal of Sensor and Actuator Networks*, vol. 5, no. 1, 2016.
[69] H. Verma and N. Chauhan, "Manet based emergency communication system for natural disasters," in *Proc. International Conference on Computing, Communication & Automation*, 2015, pp. 480–485.
[70] N. CHAAMWE and L. SHUMBA, "e-learning using wireless ad-hoc networks to support teaching and learning in rural zambia," in *Proc. and Report of the 7th UbuntuNet Alliance Annual Conference*, pp. 51–58, 2014.
[71] D. Barker, "Bringing mobile ad hoc networks to the battlefield using cots open standards," *Extreme Engineering Solutions*, pp. 22-26, 2013.
[72] J. L. Burbank, P. F. Chimento, B. K. Haberman, and W. T. Kasch, "Key challenges of military tactical networking and the elusive promise of manet technology," *IEEE Communications Magazine*, vol. 44, no. 11, pp. 39–45, 2006.
[73] S. Katiyar, R. Gujral, and B. Mallick, "Comparative performance analysis of manet routing protocols in military operation using ns2," in *Proc. 2015 International Conference on Green Computing and Internet of Things (ICGCIoT)*, 2015, pp. 603–609.
[74] H. R. Hussen, S.-C. Choi, J.-H. Park, and J. Kim, "Performance analysis of manet routing protocols for uav communications," in *Proc. 2018 Tenth International Conference on Ubiquitous and Future Networks (ICUFN)*, 2018, pp. 70–72.
[75] A. M. S. Abdelgader, L. Wu, and M. M. M. Nasr, "A simplified mobile ad hoc network structure for helicopter communication," *International Journal of Aerospace Engineering*, 2016.
[76] T. OHTA, M. NISHI, T. TERAMI, and Y. KAKUDA, "Information dissemination using manet for disaster evacuation support," *IEICE Transactions on Communications*, vol. E102.B, no. 4, pp. 670–678, 2019.
[77] H. Ritchie and M. Roser. Natural disasters, Our World in Data Jun 2014. [Online]. Available: https://ourworldindata.org/natural-disasters# number-of-deaths-from-natural-disasters
[78] O. Briante, V. Loscr`ı, P. Pace, G. Ruggeri, and R. Zema Nicola, "Comvivor: An evolutionary communication framework based on survivors' devices reuse," *Wireless Personal Communications*, pp. 1–22, 2015.
[79] N. K. Ray and A. K. Turuk, "A framework for post-disaster communication using wireless ad hoc networks," *Integration*, vol. 58, pp. 274–285, 2017.
[80] A. Goncalves, C. Silva, and P. Morreale, "Design of a mobile ad hoc network communication app for disaster recovery," in *Proc. 2014 28th International Conference on Advanced Information Networking and Applications Workshops*, 2014, pp. 121–126.
[81] Y. Jahir, M. Atiquzzaman, H. Refai, and P. LoPresti, "Multipath hybrid ad hoc networks for avionics applications in disaster area," in *Proc. 2009 IEEE/AIAA 28th Digital Avionics Systems Conference*, 2009, pp. 5.E.2–1–5. E.2–11.
[82] The 17 goals — Sustainable development. [Online]. Available: https://sdgs.un.org/goals
[83] G. TSIMBA, B. MUGONIWA, and A. N. MUTEMBEDZA, "A mobile ad-hoc strategy to enhance ict based education in

zimbabwean rural schools," in *Proc. 2020 IST-Africa Conference (IST-Africa)*, 2020, pp. 1–7.
[84] M. Ichaba, F. Musau, and S. Mwendia, "An empirical approach to mobile learning on mobile ad hoc networks (manets)," in *Proc. 2020 IST-Africa Conference (IST-Africa)*, 2020, pp. 1–14.
[85] N. EL KAMOUN, "Performance evaluation of routing protocols in manets deployed for e-learning purpose," *International Journal of Computer Applications*, vol. 178, pp. 41–47, 11 2017.
[86] M. I. Abdullah, M. M. Rahman, A.-u. Ambia, and M. Z. Mahmud, *Proc. Performance of Conferencing over MANET Routing Protocols*, pp. 214–218, Jun 2012.
[87] K. Smart. (20220. Critical family physician shortage must be addressed: Cma. [Online]. Available: https://www.cma.ca/news-releases-and-statements/critical-family-physician-shortage-must-be-addressed-cma
[88] Average hours worked per week by physicians, 1997-2017. [Online]. Available: https://www.cma.ca/sites/default/files/pdf/Physician%20Data/34-TrendData-e.pdf
[89] S. Abid, I. Shafi, and S. Abid, "Improving Energy Efficiency in Manet's for Healthcare Environments," *International Journal of Mobile Network Communications & Telematics*, vol. 4, no. 3, pp. 23–31, Jun. 2014.
[90] A. Kaiser, N. Achir, and K. Boussetta, "A multipath traffic balancing proposal to reduce gaming disconnections in manet," in *Proc. 2010 IFIP Wireless Days*, pp. 1–5, 2010.
[91] E. Jacob and P. Sivraj, "Performance analysis of manet routing protocols in smart city message passing," in *Proc. 2016 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*. IEEE, 2016, pp. 1255–1260.
[92] G. Cardone, P. Bellavista, A. Corradi, and L. Foschini, "Effective collaborative monitoring in smart cities: Converging manet and wsn for fast data collection," in *Proc. ITU Kaleidoscope 2011: The Fully Networked Human? - Innovations for Future Networks and Services (K-2011)*, 2011, pp. 1–8.
[93] Z. Yan and Y. Chen, "Adchatrep: A reputation system for manet chatting," in *Proc. 1st International Symposium on From Digital Footprints to Social and Community Intelligence*, New York, NY, USA: Association for Computing Machinery, 2011, pp. 43–48.
[94] Y. Luo and O. Wolfson, *MANET Databases*, 2009, pp. 1685–1691.
[95] G. Varaprasad, "Query based approach model for mobile commerce applications in manet," in *Proc. Communication and Networking, ser. Communications in Computer and Information Science*, Berlin, Heidelberg: Springer Berlin Heidelberg, vol. 56, pp. 439–443, 2009.
[96] C. Evans and B. Hu, "E-commerce to u-business: A model for ubiquitous shopping mall," in *Proc. 2006 First International Symposium on Pervasive Computing and Applications*, 2006, pp. 427–432.
[97] T. Alam and M. Benaida, "The role of cloud-MANET framework in the internet of things (IoT)," *International Journal of Online and Biomedical Engineering (iJOE)*, vol. 14, no. 12, 2018.
[98] D. Airehrour and J. Gutierrez, "An analysis of secure manet routing features to maintain confidentiality and integrity in iot routing," in *Proc. International Conference on Information Resources Management (CONF-IRM) at AIS Electronic Library (AISeL)*, 2015.
[99] V. Dattana, A. Kumar, A. Kush, and S. I. Ali Kazmi, "Manet for stable data flow in smart home and smart city," in *Proc. 2019 4th MEC International Conference on Big Data and Smart City (ICBDSC)*, 2019, pp. 1–4.
[100] Ocean shipping and shipbuilding. [Online]. Available: https://www.oecd.org/ocean/topics/ocean-shipping/
[101] Marine communications. [Online]. Available: https://www.boatus.org/study-guide/equipment/communication/
[102] R. Mohsin and J. Woods, "Performance evaluation of manet routing protocols in a maritime environment," in *Proc. 2014 6th Computer Science and Electronic Engineering Conference (CEEC)*, 2014, pp. 1–5.
[103] R. J. Mohsin, J. Woods, and M. Q. Shawkat, "Density and mobility impact on manet routing protocols in a maritime environment," in *Proc. 2015 Science and Information Conference (SAI)*, 2015, pp. 1046–1051.
[104] A. J. Pullin, S. Presland, and C. Pattinson, "Using ship movement in the irish sea for manet evaluation," in *Proc. 2008 Second UKSIM European Symposium on Computer Modeling and Simulation*. IEEE, 2008, pp. 394–399.
[105] H. Wu, W. Sun, and J. Peng, "An architecture of mp2p based on maritime mobile communication," *Journal of Dalian Maritime University*, vol. 35, no. 2, pp. 93–96, 2009.