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A review on mobility models in disaster area scenario

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Abstract

Communication network plays a big part for us in our lives. It is needed to perform daily tasks, access information and communicate each other anytime, anywhere and from any device. Nowadays, the communication network is a priority when it comes to a disaster scenario such as earthquakes, typhoons, tsunamis etc. The fixed communication network may be partially or fully destroyed or may be overloaded due to the aftermath of the disaster. It is crucial for rescue teams to establish a disaster recovery network for them to communicate with each other during their Search and Rescue (SAR) operations and mission critical. The disaster recovery network must be established within a short period to ensure the smooth operation of the rescue teams. Mobile Ad-Hoc Network (MANET) is a favourable approach for recovering the communication network as it can be deployed rapidly after the disaster rather than fixed communication network. MANET is an infrastructure-less network that can be deployed instantly and maintained easily. MANET can be used to address the issue of increasing communication requests, especially for data, speech, and video stream transmission. Due to limitations on scalability, repeatability, speed and cost, software simulations are often chosen instead of field-test experiments to verify the characteristics of designated topology control and protocols used in MANET for the disaster area scenario. The behaviour of the protocols used in MANET is highly affected by nodes' mobility model. The mobility model shows the nodes' movement and should be able to resemble the real-life situation for the designated scenario. Most of existing mobility models, such as random-based movements show unrealistic movement in concerns with the rescue teams' movement as they will not move randomly during their SAR operations. Instead, their movements are influenced by existing obstacles such as walls, trees and others. This paper reviews the existing mobility models used for investigating the movement of the rescue entities in the disaster area scenario. Some of other resilient disaster communication networks aside from MANET and MANET simulation tools were also reviewed. The main aim of this paper is to find the ideal mobility model that can realistically describe the movement of the rescue entities in the disaster area scenario. A comparative analysis, which includes the approaches and limitations on the related works was presented. By the end of this paper, a conclusion is drawn and suggestions aspects for future researches were stated.

Keywords

Disaster area network, MANET, Mobility model, Post-disaster, Node mobility, Network performance.

1.Introduction

Disaster struck does not announce itself and people usually caught with the ad hoc situation. Disaster is divided into two types which are natural disasters and man-made disasters. Natural disasters happen because of a natural phenomenon or process such as earthquakes, tsunamis, typhoons and others. Man-made disasters happen as a consequence of technological or human hazards such train accident, traffic collision, aviation incident (plane crash), structural collapse and others. Such disaster struck events may cause fixed network infrastructure to be partially or fully-destroyed. The deployment of the fixed network infrastructure will be almost impossible to be re-established and recovered within a short time, especially in remote area where one had never existed.

During the disaster struck, two entities would be existed which are victims and rescue teams like firefighters, police, volunteers and medical teams. The communication network is vital, especially after the disaster struck as the rescue teams need to coordinate the Search and Rescue (SAR) operations and mission critical. The real-life situation can remain unknown to the rescue teams involved in the SAR operations or it can be totally different from what it was before the disaster due to the damages. Subsequently, the exchange of data on the latest condition at the disaster area plays a big part and is crucial to save lives and

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ease possible damages [1]. Network connectivity and data is a challenging problem, especially in Public Protection and Disaster Relief (PPDR) due to the dynamic mobility and harsh environment. Historical data show that the communication demand often experiences extreme increment especially after the disaster struck. To cope with various of rescue operations, the network can be efficiently adapted, making the loss of life and possession to be minimized as much as possible. An alternative way needs to be deployed to recover the communication network in the disaster area.

Mobile Ad-Hoc Network (MANET) is a type of wireless ad-hoc networks where every device able to travel independently in any way. MANET is an infrastructure-less network and a self-aligning pointing to support the movement of devices. MANET is easy to maintain due to its self-configured, self-repairing and self-recovery network [2, 3]. MANET characteristics of being decentralize and infrastructure-less network allows users to establish a dynamically reconfigurable wireless network with the absence of a fixed infrastructure network.

Figure 1 shows the operation of MANET on how nodes (users) communicate with each other even without the present of the fixed infrastructure network. If the destination node is outside the source range, the neighbour node will act as a relay to forward the message until it reaches to the destination [2]. However, the network is a stand-alone. People usually carry on their mobile devices with them anywhere and anytime. MANET can join the mobile devices even when the fixed infrastructure is absent as their mobile devices are equipped with the wireless technologies such as Bluetooth and Wireless Fibre (WiFi), hence MANET can be easily formed.

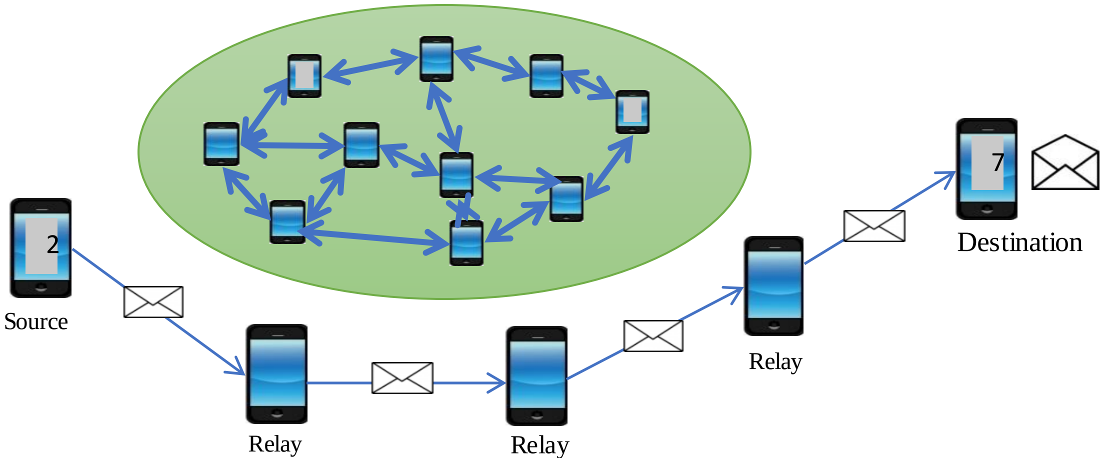

Figure 1 MANET operations [3]

MANET can be considered as a promising solution, especially in an unfavourable conditions such as disaster response and recovery where fixed infrastructure is unavailable due to the aftermath of the disaster [4]. The communication network can be recovered within a short time, making delays and errors in SAR operations and mission critical to be minimized. Thus, the MANET can be considered as one of the best approach for SAR operations due to its rapid deployment, making the rescue teams to immediately respond to the victims call for help upon receiving [4, 5].
The objectives to focus the current aspects in this area are as under:

1. To report and study the existing mobility models used in the disaster area scenario.
2. To discuss the requirements of designing a realistic mobility model based on the movement of the rescue entities in the disaster area scenario.
3. To present a comparative analysis of the related works.

2.Literature reviews

2.1Mobility models in disaster area scenario

For the past years, there are some works that evaluated the performance of the nodes in disaster area scenarios by adapting the existing and/or proposing a new mobility model when performing simulative analysis. The mobility model produces the movement traces of nodes and can be generated by using software like Bonnmotion [6]. The previous works mostly evaluated the network performance of routing protocols and algorithm schemes under certain mobility models in a case of the disaster area scenario, tactical area network or multi-hop network.

In 2004 Aschenbruck et al. [1] proposed a new mobility model, namely, Disaster Area (DA) mobility model which is based on the tactical issues of civil protection where the concept of room separation is introduced. The network performance was evaluated between the DA model, Gauss-Markov (GM) and Random Waypoint (RWP) model by varying number of nodes and its velocity. However, certain aspects are not yet feasible. For example, group mobility is ignored, and the RWP model determines the mobility of agents within each sub-area.

In 2007 Boldrini et al. [7] proposed Home-cell Community-based Mobility Model (HCMM) for opportunistic networks. Two properties which are contact duration and intercontact time were analysed to demonstrate that the proposed model can generate realistic movement patterns for opportunistic networks. The contact duration was defined as the time period during which any two devices are within radio range of one another. Meanwhile, intercontact time was defined as the time interval between two consecutive node contacts. The proposed model, The HCMM retains the socially conscious characteristics of the Community-based Mobility Model (CMM). Nonetheless, this paper does not evaluate performance on node mobility using network performance metrics such as throughput, Packet Delivery Fraction (PDF), Normalized Routing Load (NRL), overhead, and energy consumption. As a result, the proposed model's efficiency in performing SAR operations has yet to be determined in the disaster area scenario.

In 2007 Nelson et al. [8] proposed a gravity-based model known as Event and Role-based Mobility Model (ERMM) that implements “Flee” and “Approach” action. The authors compared changes in the network topology. Numerous topologies were generated, and ten sets of simulation results from the ERMM and Random Walk (RW) model are presented. However, the authors' interest in this work was limited to the mobility patterns of objects in a disaster scenario and their topological implications for the network graph. Communication between nodes was not considered. Thus, it is necessary to analyse the effects of various parameters in communication and routing in disaster scenarios in order to determine their performance in terms of node mobility.

In 2009, Rollo and Komenda [9] proposed Tactical Networks Mobility Model (TNMM). Basic characteristics of the mobility model such as node spatial distribution and average node degree were analysed between the TNMM model and the RWP model. The TNMM is goal-oriented and compatible with a range of mobile units as well as stationary wireless sensors. Depending on the created objectives, the nodes can form temporary groups and move in formations throughout the area, simulating the behaviour of real-world tactical units. However, the authors did not conduct a comprehensive study of network efficiency in terms of node mobility. It is important to understand the model's performance under adverse conditions such as obstacles and signal interference during the SAR operations. Therefore, how routing overhead may affect the energy consumption, as it is one of the factors that cause nodes to communicate for an extended period of time prior to the physical network being installed successfully.

Papageorgiou et al. [10] proposed architecture for mission-critical MANETs namely, Mission Critical Mobility Model (MCMM). To investigate the properties of MCMM, a simulation was carried out extensively, demonstrating the distinctions between the MCMM, Human Obstacle Mobility (HUMO), Obstacle Mobility (OM), and the RWP models. Properties such as resulting network connectivity and impact on a MANET's efficiency are observed. It is concluded that both in the MCMM and the HUMO models, the nodes traverse the entire accessible space, (network area), while in the OM model, the nodes traverse pathways. In the case of the RWP model, the existence of constraints is neglected. Even so, harsh conditions with insufficient power make it impossible for the nodes to interact if other efficiency measurements such as energy consumption and overhead are not being considered.

To depict the realism of the rescue teams’ displacements in the case of action in a disaster area scenario. Pomportes et al. [11] proposed Composite Mobility (CoM) model where a few models are being incorporated. Various aspects of the proposed model have been evaluated and compared to the RWP, Reference Point Group Mobility (RPGM) and Levy-walk models. Although the evaluation of the proposed model showed that it keeps the realism, the authors stated that there is still a space of elements to be considered for improvement such as modelling a model on a macroscopic scale. The performance of the CoM model can be evaluated in terms of the network performance metrics to see how well the model can efficiently improve the communication of the rescue teams and its energy consumption as it is crucial to maintain the network communication as long as possible.

In 2011 Reina et al. [12] presented the comparative evaluation of MANETs routing protocols which were Ad-hoc On-demand Distance Vector (AODV), Ad-hoc On-demand Multipath Distance Vector (AOMDV) and Dynamic Source Routing (DSR) under realistic disaster scenarios. The DA model has been used as the mobility model and some performance metrics such as throughput, PDF, NRL and average End-to-End Delay (E2E) has been considered in the comparison of the routing protocols. As a result, AODV outperforms AOMDV and DSR. However, the communication paths between nodes have a limited lifespan. Thus, other routing protocols should be considered to determine the suitability of alternative algorithms.

In 2012 Raffelsberger and Hellwagner [13] evaluated the performance of several MANET routing protocols in the case of emergency response scenario. The DA model has been used to simulate the movements of the first responder in a hybrid indoor/outdoor environment. AODV, Optimized Link State Routing (OLSR), Better Approach to Mobile Ad-hoc Network (BATMAN) and Dynamic MANET on-demand (DYMO) are selected as the routing protocols used and their performance are evaluated in terms of PDR, average PDR and packet delivery delay. Results showed that the nodes have diverse connectivity characteristics which led to increment in the packet loss rate. Some nodes are intermittently connected, resulting a higher packet loss.

In 2013 Conceição and Curado [14] proposed a new mobility model based on force vector, namely Human Behavior for Disaster Areas (HBDA), in which it imitates the real movement of nodes in the search missions. The authors investigated the performance of the HBDA in terms of the density distribution of nodes, node degree, area coverage, topology changes and throughput. It is concluded that the HBDA model enables a more realistic simulation of the disaster scenarios rather than random-based movement decisions. However, the scalability of the network was not considered in this work. Thus, a network hierarchy must be created that allows the routing protocol to scale in order to simulate a large number of nodes.

Martín-Campillo et al. [15] presented an analysis of the performance of the opportunistic routing in an emergency scenario by using the DA model. The emergency scenario's characteristics are analysed to determine their effect on the routing method's performance in terms of suitability for various performance requirements such as delivery rate and lifetime. In prolonged emergency scenarios involving a dense network of nodes or a large number of messages, an energy-efficient forwarding method is required to avoid depleting the node's battery. As a result, communication between nodes can continue for a longer period of time despite the harsh environment.

Reina et al. [16], proposed an adaptive broadcasting scheme based on topological conditions with the aim to improve the connectivity in the disaster scenarios. Through simulations, the DA model is used to depict the realistic node movement and validate the proposed approach in terms of reachability and Save Re-Broadcast (SRB). This approach considered both the tactical movements of the rescue teams and the communication flows between them in order to achieve an optimal design. The optimal probabilistic scheme's performance can be compared to that of other existing broadcasting schemes in terms of energy efficiency and lifetime despite the possibility of obstacles and signal interference in the real-life situation of disaster scenario.

Reina et al. [17], also conducted a performance comparison of MANETs routing protocols, AODV, AOMDV, and DSR, using the same mobility model. The difference between this work and the previous work [12] is that this work evaluates the routing protocol's performance in terms of dropped packets and hop count in addition to throughput, PDF, NRL, and E2E. According to the simulation results, AODV produces the optimal routing metrics. Meanwhile, AOMDV may be a viable option if end-to-end Quality of Service (QoS) is a concern, provided the environment is not particularly noisy. Nonetheless, specific routing protocols for rescue teams operating in disaster areas are required to address the issue of difficult conditions and limited connectivity, as demonstrated by real-life situation of disaster scenarios.

In 2014 Ebenezer [18] proposed Large Scale Disaster Mobility Model (LSDMM) to address the concerns on the unrealistic representation of complex real-world geographical constraints and the absence of a technique for path modelling in the absence of a known route. This approach enables the node to choose the combination of the nearest cell and the cell with the highest node density with a high probability. Through the simulative analysis, the simulation area is divided into different obstacle regions based on their density, which are dense, sparse and obstacle free. The LSDMM takes not only geographic constraints into account, but also spatial and temporal dependencies. Degree of spatial dependence is around 1 for LSDMM, which is higher than RWPA and DA models, whose values are negligible. The author only considered an average node degree and average link duration of the nodes and statistics are determined in relation to the transmission range. However, as the range expands, an increment in the overhead may occur, thus reduce the overall network capacity.

Reina et al. [19], also proposed a new probabilistic broadcast scheme based on similarity/dissimilarity metrics and integrated it into the existing DA model. Due to the probabilistic nature of the proposed approach, the results of each generation run for each individual in the population will be averaged out. Calculations of reachability, retransmissions, and delay were used to identify non-dominated solutions and generate new generations. However, the performance of other routing protocols, and optimization algorithms must be considered in order to develop a solution that is suitable for use in disaster-affected areas and accurately depicts the movement of rescue teams.

In 2015 Arbia et al. [20] evaluated the performance of different routing protocols, namely, OLSR Version 2 (OLSRv2), AODV Version 2 (AODVv2), Greedy Parameter Stateless Routing (GPSR) and Directed Diffusion (DD) while using different type of communication technologies. The authors studied the network performance in an urban critical and emergency scenario. The simulative analysis has been conducted using the DA model and performance metrics such as Packet Reception Rate (PRR), packet delay and energy consumption have been considered. Results showed that WiFi technologies gave better performance with respect to the PRR and energy consumption while Wireless Body Area Networks (WBAN) performs better in packet delay. If the location information is available, GPSR with WiFi outperforms other routing protocols. In contrary, if the location information is unavailable, DD routing protocol with WBAN gives better performance.

Meanwhile, in 2016 Wang et al. [21] proposed a novel mobility model based on Disaster Area Wireless Networks (DAWNs) namely Catastrophic Intensity-based Rescue Mobility Model (CIBRMM). The authors evaluated the performance between the CIBRMM and Traditional Mobility Model (TMM) in terms of the rescue time with different number of affected areas and Catastrophic Intensity (CI). Nonetheless, the authors neglected to consider the performance of the routing protocols used during the rescue process in this work. The network performance metrics such as throughput, PDF, overhead, and NRL must be evaluated by simulating some real-life situation in order to analyse the communication network's efficiency during the SAR operations.

In the same year, a synthetic mobility model proposed by Gondaliya and Atiquzzaman [22] namely Role-based 3-Tier Mobility Model (RTTMM). Through this paper, the authors analysed the RTTMM with the ERM model in terms of average device degree, maximum device degree and clustering coefficient. The RTTMM is found to be more effective and more applicable in the disaster area scenario than ERM. The authors also evaluated the performance of the Delay Tolerant Network (DTN) routing protocols under RTTMM in terms of delivery ratio, latency, average overhead ratio and cost per message. Results showed that MaxProp routing protocol outperforms other DTN routing protocols in terms of delivery ratio, but having decrement with the message size beside having high latency, overhead ratio and cost per message. Instead, Encounter Based Routing (EBR) protocol showed the next best performance in terms of delivery ratio with the lowest latency, stable overhead ratio and cost per message.

In 2017 Stute et al. [23] proposed Natural Disaster (ND) model which use reverse engineering approach based on 126 knowledge experts for the large-scale natural disasters. The disadvantages in this work, are the differences in the nodes' speed that will act as transport nodes are not being considered. In the real-life situation, there will be some nodes that are using the vehicles to transport the victims from the disaster area. They would join and/or leave the group during the operations. The speed of the transport nodes is different as the vehicles are involved during the SAR operations. Therefore, the scalability of the current simulator must be increased to support simulations with significantly more nodes. A realistic communication model encompassing all users in a disaster scenario needs to be considered and evaluate the performance in order to determine the communication network's efficiency during the SAR operations.

Sani et al. [24] attempted to study the Transmission Control Protocol (TCP) performance in MANET routing protocols. By using the DA model in the simulation experiment, the authors considered PDR, average throughput and average E2E delay as the performance metrics for the performance evaluation. For the mobility model, the routing protocols are evaluated against different traffic scenario and node density. Results showed that AOMDV outperforms DSR and ZRP in terms of throughput and E2E delay. However, DSR yields better in terms of PDR while Zone Routing Protocol (ZRP) gives the worst performance compared to others.

Al-Shehri et al. [25] presented a comprehensive comparison between the tactical and commercial MANETs on performance and design characteristics. The simulation was carried out under three different mobility models which are RPGM, RWP and Manhattan-grid model. Results showed that the RPGM model with two-ray ground model produces the most accurate performance predictions for mobile tactical networks.

In 2018 Kim et al. [26] proposed a novel routing protocol for Unmanned Aerial Vehicle (UAV) relayed tactical MANET, where different features from the typical MANET was shown. The authors proposed two scenarios to be used for the network congestion and link breakage. Through this paper, the authors have discussed on operating procedure and further issue for admission control for each of the scenarios. The impact of the UAV relay has been evaluated with concerns to PDR and E2E delay under the RPGM model.

In 2020 Kim et al. [27] proposed a MANET location-based routing scheme by applying dual channels known as sub-GHz and 2.4 GHz channels for the indoor disaster scenario. This paper studied and proposed a new scheme with concerns to the firefighter communications as the indoor disaster environment were not being considered in the previous researches. Performance evaluation has been conducted under the RWP model and analysed in terms of PDR, end-to-end E2E delay and initial routing table configuration time. Results showed that the Dual-Channel-based Routing (DCR) outperforms than the other two routing protocols which were OLSR-mod and Destination-Sequenced Distance-Vector (DSDV)-mod with respect to the metrics considered and scalability.

Younes and Albalawi [28] proposed an analytical model for the link and route lifetime in the mobile multi-hop networks. The RWP model has been used in the simulation by varying different network characteristics. The proposed analytical model was validated by comparing the analytical and simulation results. However, as the transmission range increase, the interference from the neighbour nodes increased, causing decrement to the network throughput.

2.2 Disaster resilient communication networks

For the past years, there has been improvements made by the researchers in terms of the disaster resilient communication networks. The improvements are made to ensure that the communication can be established successfully within a short time, despite having such scenario such as during the disaster struck. During the SAR operations, it is crucial to have a good communication network, which is robust, reliable and fast-deployment. Good communication networks will increase the performance of the mobility as the information can be delivered and received well by the rescue teams. Thus, the SAR operations can be conducted smoothly even in the disaster area scenario.

2.2.1Movable and deployable resource units (MDRUs)

A new vision of disaster resilient networking was discovered by Sakano et al. [29] which was based on MDRUs. The MDRU is known as a transportable unit which is equipped with general physical infrastructures to deliver the information and communication services. It supports both communication and information processing operations, which can be rapidly transported and instantly deployed upon arrives at the disaster area.

The MDRU composes of the concept of movable and quickly deployable resource units [29]. Besides, the MDRU deployment is facilitated in an easily-handled manner. Once the MDRU is setup, it will create the network access which is WiFi and Fixed Wireless Access (FWA). The network established will be hybrid networks consisting of mesh and ad hoc networks. Service providers can establish dedicated virtual networks to its covered users by offering multiple network services via adaptation of network slicing technology [30]. Thus, the cooperation between MDRUs was proven to cover the disaster areas dynamically.

Sakano et al. [31] also proposed a van-type resource unit which is compact, and agile, assuring its robustness and reliability of the system. The equipment inside the van-type MDRU is modularized to be portable equipment. The field-tests experiments have been conducted and the results showed that the MDRU-based technology has a large potential in achieving effective disaster response.

MDRU is easy to configure as it can be installed promptly, cutting the installation time and support large coverage. It is one of the ideal ways in terms of network coverage as the service can even reach even in the isolated places [31]. However, this approach is not commonly used if we are to evaluate its performance in terms of the node's mobility since it is conducted through the field-test experiments making it time consuming, large scalability and high costing.

2.2.2Long range (LoRa) – based technology

LoRa Alliance proposed a low-powered Wide Area Network (WAN) technology, which aims at the wireless devices that link to local, territorial or national networks. It focuses on securing two-way communication which is mobility and localization services through star topology. The gateway will serve as a transparent bridge between end-devices and network server on the back-end via IP networks [32].

LoRa requires a license from Semtech company and implementation of specific hardware, and it is not dependent on Low Power Wide Area Network (LoRaWAN) and thus can be used in a device-to-device fashion [33].

While LoRa devices and wireless radio frequency technology is defined as a long-range, low power wireless platform that has emerged a critical technology in the world of Internet of Things (IoT), LoRaWAN is showing its capability in exploiting transmitted packages to calculate the current position without utilizing the current Global Positioning System (GPS) or Global System for Mobile (GSM) communication [34].

The combination of these two technologies results precise location of remote area and indoor use cases prediction solution in an efficient, flexible and economical way where the cellular and WiFi or Bluetooth Low Energy (BLE) are ineffective. LoRaWAN is a powerful technology, especially in determining the geolocation of a physical entity, where its long-range capabilities can be reached up to 15km due to its sensitivity of the receivers. LoRaWAN is good at minimalize its energy consumption as it utilizes low power technology of LoRa to calculate the geolocation rather than GPS or GSM.

Sciullo et al. [35] has proposed a LORA-based mobile emergency management system known as LOCATE. LOCATE is a novel phone-based Emergency Communication System (ECS) that enables long-range communication between victims and rescue teams in critical environments lacking 3/4G cellular connectivity. It enables multi-hop distribution of alert messages that contain only the most critical information about the requester’s location and emergency type. The system is composed of a mobile application that communicates with a LoRa device BLE. The users will then generate the message alert via the LOCATE system, and it will be re-broadcast by their peers until it reaches the rescue personnel that capable of handling the emergency. The performance was evaluated using OMNeT++ simulations, utilising the dissemination protocol's capability to distribute the emergency request across large-scale scenarios.

A method for facilitating LoRa device-to-device communication through smartphones in the disaster area scenario is proposed in [33].

They proposed developing their own firmware for a low-cost LoRa device. They demonstrated two applications that utilize the proposed firmware's flexibility. They have demonstrated a novel device-to-device LoRa-based chat application for mobile users on Android and iOS, as well as a console-based interface for traditional computer users. Besides, they contributed by demonstrating how other infrastructure-free technologies can gain benefits from their approach through integration with Delay-Tolerant Networking (DTN7) software.

Although the approach eases the users, especially in the world of the IoT, however, it is quite complicated to understand how it actually works and it might take a little time before it can be properly implemented.

2.2.3Flying Ad-Hoc networks (FANETs)

A Flying Ad-hoc Network (FANET) is a network comprised of a collection of small UAVs that communicate ad hoc in order to accomplish high-level objectives. The primary characteristics of FANETs that stand out are their mobility, lack of central control, self-organizing nature, and ad hoc nature. These characteristics of FANETs make them well-suited for disaster areas where physical communication infrastructure has been destroyed or is unavailable. It is rapidly deployable, adaptable, self-configurable, and has a low operating cost network. However, establishing a reliable and a robust communication system with UAVs is a significant challenge because it requires a suitable communication architecture and routing protocols that can be configured with highly dynamic flying nodes.

Khan et al. [36], presented a suitable communication architecture for FANETs and an overview of various routing protocols. The authors concluded in their paper that a multi-layer UAV ad hoc network would be more suitable for use in FANETs. Furthermore, some researchers proposed the use of UAVs in conjunction with MANETs and LoRa technology to establish a reliable and resilient communication system.

Nowadays, Wireless Mesh Network (WMN) has got the attention and thoroughly investigated in a variety of fields, including architecture, implementation and protocol creation. Multi-Radio Multi-Channel (MRMC) has been acknowledged by many organizations, especially in rural network, battlefields and natural disasters, where the rapid communication network is needed for implementation. WMN composes of mesh nodes from gateways, routers and clients [37].

Molla et al. [38] proposed connectivity via multiple Radio Access Networks (RANs) carried by a Wireless Multi-Hop Network (WMHN) that combines existing Flying Mesh Networks (FMNs) with additional opportunistic MANETs created by the rescuers. GSM, WiFi and LoRa technologies are chosen due to their native support by smartphones. It is then being implemented by a single embedded Software Defined Radio (SDR)-based making it a reliable and resilient wireless network for SAR operations. To improve the connectivity and coverage for the rescuers or survivors, the authors proposed using a drone or balloon to form the FMN as the GSM base station.

These solutions do not seek to substitute the existing solutions, but rather to provide a complement to them [38]. Due to the fact that the smartphones support GSM, WiFi, and in some cases, LoRa, they can leverage the WMHN to connect to the command post via the RANs, thereby resolving the connectivity issue.

Solpico et al. [39] proposed an application of Vehicle-Hub (V-Hub) standard for disaster resilient communication by using LoRa beacons, mobile cloud, UAVs and DTN. The V-Hub standard is intended to leverage Vehicle-To-Everything (V2X) connectivity to create an information and communication system in the disaster area scenarios. The beacon and data aggregator communicate via LoRa to allow survivors and rescuers to be discovered, detected, and communicate. The aggregators may be carried by hand or mounted on vehicles as part of the rescue kit.

Therefore, it is suitable for use as a payload for a small Unmanned Aerial Vehicle (UAV). The UAV will then perform long-range surveillance scouting operations as part of the initial wave. To simplify, the survivors and the rescuers will transmit their data via LoRa beacons to an aggregator mounted on a flying UAV. After landing in the mobile command centre, the UAV uses the DTN to transfer aggregated data to the information kiosks and mobile cloud servers. It allows communication in the disaster scenario, despite having damaged communication infrastructure. All of this allows the rescue mission planners, policymakers, and decision makers to make more informed and timely decisions in the face of disrupted communication lines [39].

Qiu et al. [40] proposed an integrated air-ground heterogeneous network architecture to fully capitalize on the potential advantages of different types of UAVs. High-Altitude Platforms (HAPs), Low-Altitude Platforms (LAPs) and ground segments is integrated to improve the coverage and capacity for underserved scenarios. Wide coverage, especially in rural and remote areas is achieved through utilization of the HAPs layer, while local network optimization mainly for temporary or emergency scenarios is achieved by utilizing the LAPs layer. The ground layer is utilized for serving the urban areas. The authors highlight that each of the layers have their own role and act as a complementary towards each other via integration approach.

However, the proposed solution in [40] only focuses on providing additional capacity and wide coverage for the designated areas without taking energy consumption into account. Thus, in the future, energy efficiency needs to be considered especially in the disaster areas as we need to ensure the communication between the rescue teams can last longer as possible before the fixed infrastructure can be fully recovered.

Overall, FANETs really have their own characteristics that provide a more resilient disaster networking especially during the disaster struck. However, it is a challenging issue for the UAV in terms of their flight time and how it can affect the performance of the mobility nodes. Besides, it is quite costing to provide the UAVs to cover a large-scale area scenario.

3.Methodology

Data analysis

This paper has reviewed the existing mobility models in the related areas where various approaches have been proposed and evaluated under different mobility models to solve different issues while considering different performance metrics. The complete criteria, details and sources of each paper reviewed can be found from *Table 1*, *Figure 2* and *Figure 3*.

Table 1 Papers collection criteria

Reference	**Year**	**Source**	**Criteria**	
			Inclusion	**Exclusion**
Aschenbruck et al. [1]	2004	ITL	Human mobility in MANET disaster area.	Difference in number of nodes and speed of nodes.
Boldrini et al. [7]	2007	IEEE	Realistic movement patterns.	Opportunistic network.
Nelson et al. [8]	2007	MOBICOM	Gravity-based model in disaster area scenarios.	Topological implications.
Rollo and Komenda [9]	2009	Springer	Mobility model in tactical network.	Topology control.
Papageorgiou et al. [10]	2009	ACM	Mission critical MANET.	Lack of efficiency measurements.
Pomportes et al. [11]	2010	IEEE	Rescue teams' displacement in disaster area scenarios.	Scalability of network.
Reina et al. [12]	2011	IEEE	Performance of routing protocols in disaster area scenarios.	Different routing protocols.
Raffelsberger and Hellwagner [13]	2012	IEEE	Emergency response scenario/ Disaster mobility model.	Different of MANET routing protocols.
Conceicao and Curado [14]	2013	Springer	Movement of node in search missions.	Scalability of network.
Martini-Campillo et al. [15]	2013	JNCA	Movement of nodes in disaster scenarios.	Focus to opportunistic networks.
Reina et al. [16]	2013	IMIS	A broadcasting scheme based on topological conditions.	Focus to connectivity only.
Reina et al. [17]	2013	Springer	Performance of routing protocols in disaster area scenarios.	Different routing protocols.
Ebenezer [18]	2014	ICCIT	Node movement in large scale disaster.	Probabilistic approach.
Reina et al. [19]	2014	Springer	A broadcast scheme based on similarity/dissimilarity metrics.	Neglect other routing protocols, and optimization algorithms.
Arbia et al. [20]	2015	IEEE	Tactical ad hoc networks.	Different of routing protocols and communication technologies.
Wang et al. [21]	2016	IEEE	Mobility model in disaster area scenario.	Disaster Area Wireless Networks (DAWNs).
Gondaliya and Atiquzzaman [22]	2016	SCITEPRESS	Mobility model in post-disaster scenario.	Different of delay tolerant routing protocols.
Stute et al. [23]	2017	ACM	Mobility model for large scale natural disaster.	Different roles and activities.
Sani et al. [24]	2017	IEEE	Disaster recovery scenario.	Different traffic scenario and node density.
Al-Shehri et al. [25]	2017	IEEE	Mobile tactical networks.	Design characteristics of the commercial and tactical MANETs.
Kim et al. [26]	2018	IEEE	Tactical ad hoc networks.	Different scheme of routing protocols.
Kim et al. [27]	2020	IEEE	Firefighter communications.	Different of MANET routing protocols.
Younes and Albalawi [28]	2020	IEEE	Mobile Multi-hop Network.	Different network characteristics.

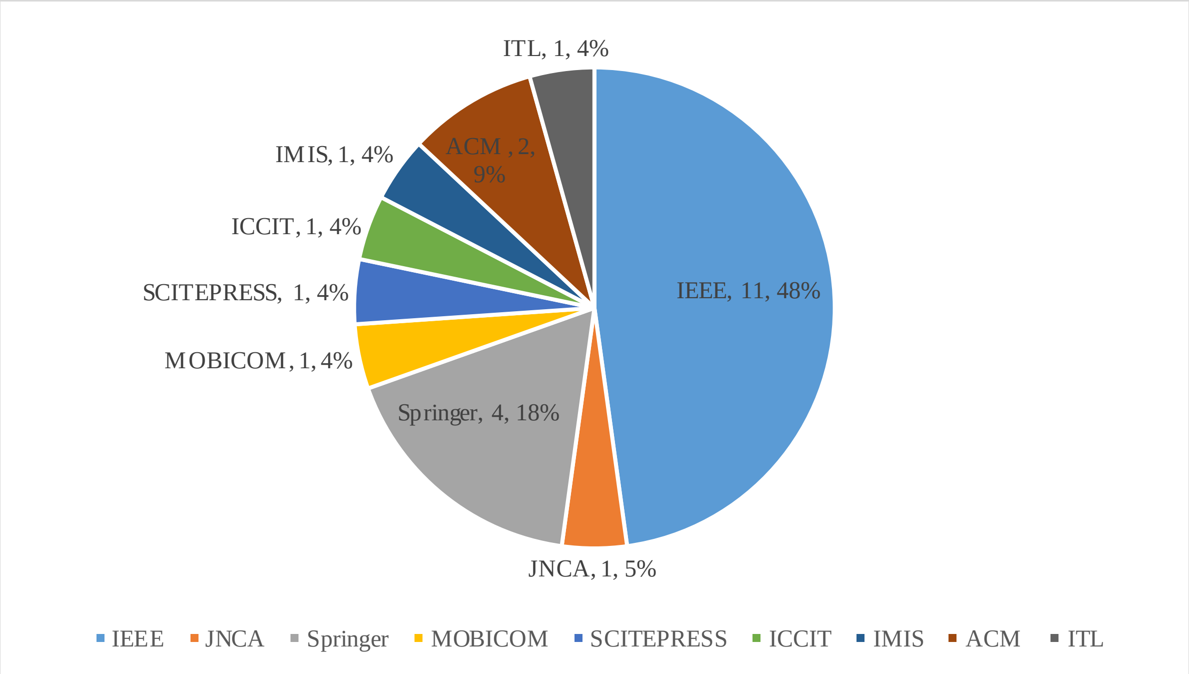

Figure 2 Sources of paper collection

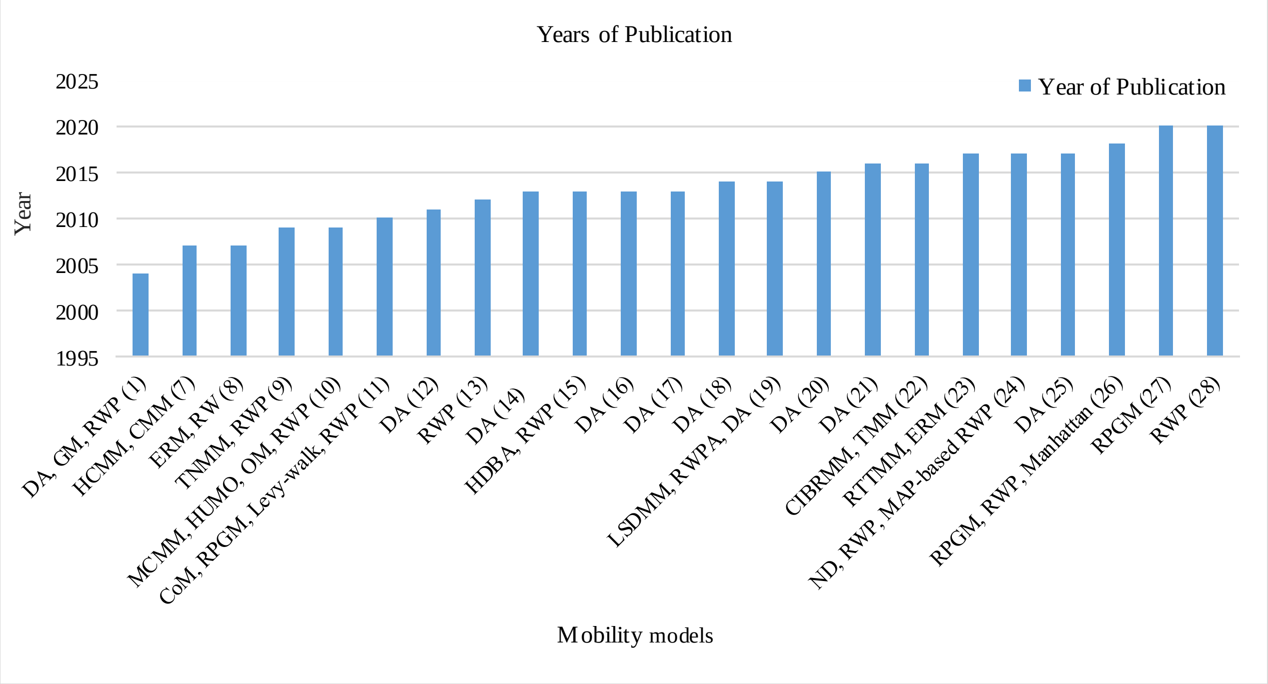

Figure 3 Years of paper publication

4.Mobility model

4.1 Mobility model and dependency

A mobility model is a collection of rules for generating paths for mobile entities. The mobility models are used in the software simulations to generate varies in the network topology as an outcome of node movement [21]. The network topology in disaster areas always changes due to people moving around using the mobile devices, as the result of the node's mobility. Mobility features consist of node speed, direction and pause of nodes.

During the disaster scenarios, the direction of nodes may change due to harsh environments such as the existence of obstacles. As a result, the mobility of nodes is affected and a device node may disconnect from a network [5]. Due to the node's mobility that need to be considered especially during the SAR operations where obstacles may exist, the process of determining the route may be difficult [22]. Hence, a suitable approach needs to be proposed in order to improve the network performance of the rescue teams in the case of disaster area scenarios.

Modelling the mobility of nodes can be challenging, as we must select appropriate algorithms and protocols for implementation. When simulating a MANET, it is critical to use a more realistic mobility model in order to accurately reflect the actual movement pattern of nodes. The mobility pattern will determine the node speed, direction, position and the way the nodes are moving within their range area that has been set [7]. Speed and direction changes will eventually happen, but within an acceptable time frame [23]. This behaviour has an effect on signal strength, battery life, bandwidth utilization and the result of the MANET's efficiency.

During the disaster, it is hard to assume the actual movement of nodes, victims' location and number of first responders working in the emergency as it is all different when in the real situation [24]. Each of the mobility models is being influenced by a certain dependency or restrictions. Generally, the mobility models can be classified according to the types of dependencies and constraints that are taken into account when creating the model. There are five types of dependencies which are random-based movement, temporal-based dependencies, spatial-based dependencies, geographical restrictions and hybrid characteristics. *Figure 4* shows the summarization between the existing mobility models applied in the disaster area and their dependencies.

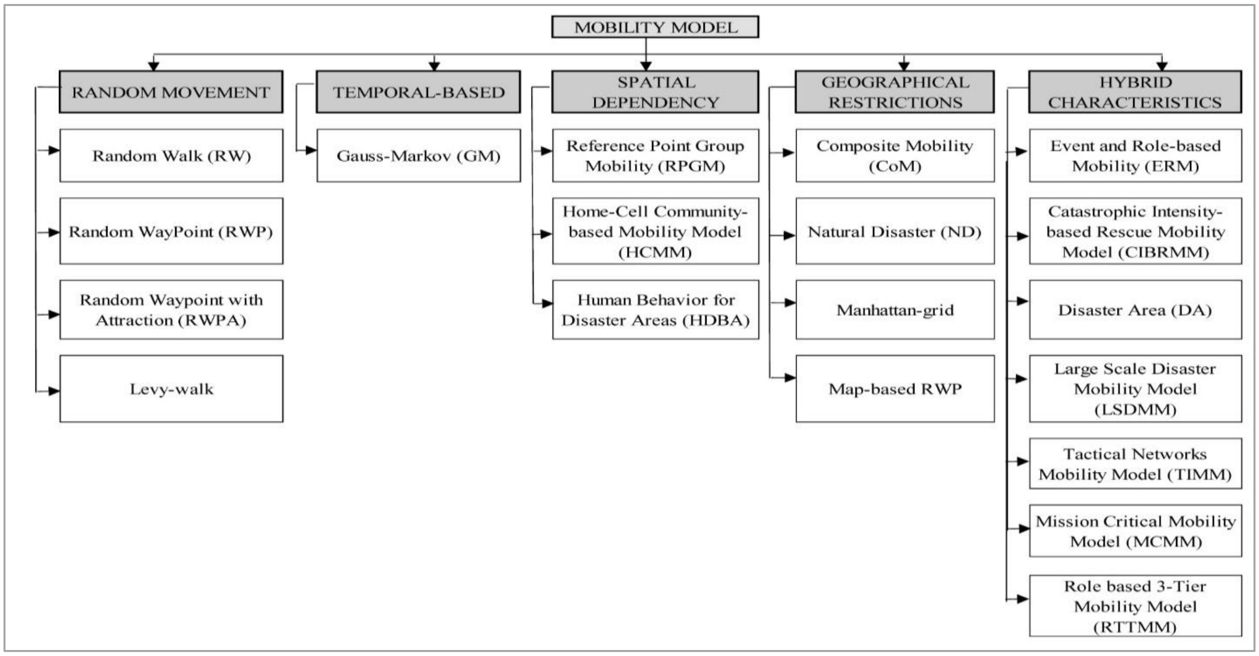

Figure 4 Mobility models and its dependencies

4.1.1Random-based movement

There are neither dependencies nor any other restrictions modelled or nodes move randomly. Manaseer and Alawneh [41] stated that random-based movement is being unrealistic in representing the node movement, despite having difficulty to adapt to the special conditions and limitations that are present in the disaster areas. Aschenbruck et al. [5] explained that the random-based movement is indeed simple to implement yet only optimal paths is realized in terms of requirement for modelling model in the disaster area. However, at least heterogeneous velocity may be incorporated quite easily.

4.1.1.1RW model

RW [42] is a mobility model in which a node travels in a random speed and direction from its current position to a new one. Originally, RW model was proposed to mimic the unpredictable behaviour of particles in physics. It is sometimes referred to as Brownian Motion. Because it is believed that some mobile nodes move in an unexpected manner, the RW model is proposed to imitate their movement behaviour. RW model is similar to RWP model as both models employ a high degree of randomness in their node movement. Consider that the RW model being a variant of the RWP model with no pause time. In RW model, on the other hand, the nodes alter their speed and direction at each time interval.

4.1.1.2RWP model

RWP [42] is a model that includes the pause time between changes in destination and speed. It is known as a simple stochastic model in which a node always moves towards a random destination by randomly choose a velocity from a uniform distribution (min_speed, max_speed). RWP model is one of the commonly used models for evaluating the network performance of the ad-hoc network because of its simplicity and easiness to model.

Although the model is used widely in the ad-hoc network environment, it is still unrealistic to represent the node movement in the disaster area scenario especially when evaluating the performance of the rescue teams. This is because, the movement patterns of the rescue teams should not move randomly but instead, move systematically as they will move according to their group leader during the SAR operations.

4.1.1.3RWPA model

There are extensions to the RWP model that add attraction points to produce a more realistic non-equally distributed mobility [5]. The probability that a node will move towards the next destination by considering the area with or within an attraction point is larger than the other destination. The nodes visit some destinations more frequently than others. As a result, they continue to traverse the whole simulation area.

4.1.1.4Levy-Walk model

Levy-Walk [43] is similar to RW model, but its walk time and pause time is more complex. Human walks of tens of kilometres in outdoor settings resemble a shortened version of Levy-Walk observed in animals. Levy-Walk model is a great model for simulating a variety of statistical patterns observed in human walking under certain conditions.

4.1.2Temporal-based

Changes in nodes' speed and direction may suddenly happen if random-based movement model is used. While concerning many aspects such as acceleration and deceleration, it is still quite unrealistic. Thus, the model presented realizes such aspects by using the temporal dependencies. The temporal dependencies describe that the current movements depend on the past ones [44]. The GM is one of the temporal-based mobility models in which a single tuning parameter is utilized to control the randomness degree in the mobility pattern. In other words, if the node travels outside the simulation area's boundaries, the node's direction is forced to reverse 180 degrees. As a result, the nodes are repositioned away from the simulation area's boundary [45]. The future velocity and direction (time interval t + 1) are dependent on the current values (time interval t). After the interval, each node's movement is altered [5].

4.1.3Spatial dependency

Spatial dependency describes that the movement of one node depends on the movement of surrounding units as there may be nodes that move together in groups [5].

4.1.3.1RPGM

RPGM [6] model is a widely used model for group mobility. Their movements are simulated by the model using the path taken by a logical centre. The movement of nodes within a group is determined by allocating a reference point to each node. The actual position of a node is computed by adding a random movement vector to the reference point's position. The absolute positions of the reference points vary according to the arbitrary mobility model. On the other hand, the relative positions of reference points within a group remain constant.

4.1.3.2HCMM

HCMM [7] incorporates the concepts of the Community-based Mobility Model (CMM) as well as the concept of determining preferential locations where users spend the majority of their time. It is designed for opportunistic networks. According to the authors, the HCMM retains the socially conscious characteristics of the CMM.

4.1.3.3HBDA model

The HBDA is a force vector-based mobility model proposed by Conceicao and Curado [14] in which it imitates the real movement of the nodes during search missions. The optimal position between neighbours will be determined from the obtained list of in-range nodes. Meanwhile, a force vector is determined according to their distances to the neighbours. The resultant force vector will be normalized if the node's position is not optimized. Velocity between Min_Velocity and Max_Velocity will be generated randomly to compute a vector towards the next position and the process will be repeated until the end of the execution. The HDBA model enables a more realistic simulation of the disaster scenarios rather than random-based movement decisions.

4.1.4Geographical restrictions

It is unrealistic to predict that the nodes in all types of scenarios are allowed to travel the whole simulation area. Indeed, different approaches need to be taken to restrict the node movement to specified regions of the simulation area. Several models characterized with the geographical restrictions will be overviewed and discussed with concerns to the disaster area scenarios.

4.1.4.1CoM model

The CoM [11] includes a realistic model of human displacement, team mobility and obstacle avoidance. RPGM is used to depict the group mobility while Levy Walk is replaced instead of RWP model to show a better realism. The Voronoi diagram is integrated as one of the model components in concern to the obstacle avoidance. Although the evaluation of the CoM showed that it keeps the realism, the authors stated that it still has a space for improvement such as modelling a model on a macroscopic scale.

4.1.4.2ND model

The ND model is proposed by Stute et al. [23] in which a reverse-engineering approach is used. It is based on 126 knowledge experts for the large-scale natural disasters. The ND model is a model in which mobile node movement is influenced by the different roles and activities in a specific scenario. However, the speed of transport nodes is not considered in their work and some improvements are needed such as applying a realistic communication model encompassing all users in a disaster area scenario.

4.1.4.3Manhattan-grid model

The Manhattan-grid model is a map-based approach mobility model where the simulation area is divided into squared blocks. The nodes are modelled as pedestrians that randomly distributed on the streets. They will keep moving on the vertices of the squares (streets) until they reach a corner. The nodes' velocity is changed over time [5].

4.1.4.4Map-based RWP

Map-based RWP [5] is a model in which node moves with random speed and direction following a map.

4.1.5Hybrid characteristics

In order to create a more realistic node movement considering a specific scenario, many researchers have proposed a hybrid mobility model. The hybrid model is the combination of some or all of the previous dependencies.

4.1.5.1ERM model

The ERM [8] is a gravity-based model in which a simplified law of physic in which “Flee” and “Approach” actions is defined. The ERM model allows the objects to react or respond to the existence of a variety of the disaster events, depending on the node's specific role.

4.1.5.2CIBRMM

The CIBRMM is a DAWNs-based mobility model proposed by Wang et al. [21] which consists of two stages of procedures known as Opening Lifeline Stage (OLS) and Spreading Rescue Stage (SRS).

The CIBRMM is a model in which nodes have to fulfil all tasks in one raw squares area before moving to the next so the Catastrophic Intensity (CI) value should be zero in one of the four adjacent areas. The next movement of nodes can only move in three other directions and cannot move to the area in which CI value equals to zero. The nodes cannot move outside the current area boundary before all areas with the same seismic intensity cleared.

4.1.5.3DA mobility model

The DA mobility model proposed by Aschenbruck et al. [1] is based on the tactical issues of civil protection where the concept of room separation is introduced. It is believed that the DA model nearly fulfil the requirements for modelling, model with respect to the disaster area scenario. Each node will be assigned to one of the tactical areas (as can be seen in *Figure 5*). The tactical areas are divided into four different areas which are Incident Location (IL), Casualty Treatment Areas (CTA), Transport Zone (TZ) and Technical Operational Command (TOC). The CTA is then divided into two sub-areas which are Patient Waiting for Treatment (PWT) and Casualties Clearing Station (CCS). Except for the nodes that may need to join/leave their current location, such as transport nodes, all the nodes will be placed in their assigned area.

4.1.5.4LSDMM

LSDMM [18] is proposed as a solution towards the concerns on the unrealistic representation of complex real-world geographical constraints and the absence of a technique for path modelling in the unknown route. The model makes it possible to place obstacles easily and realistically in large-scale disaster scenarios. As for the simulation area, it is divided into different obstacle regions. The obstacle regions are classified based on their density, which are dense, sparse and obstacle free regions.

Besides, the activity cells are used to model the disaster region. State transitions are used to model the movement of nodes within each cell of the simulation area. In terms of node movement, destination and path selection are determined using a probabilistic approach based on criteria. This approach enables the node to choose the combination of the nearest cell and the cell with the highest node density with a high probability. This model takes not only geographic constraints into account, but also spatial and temporal dependencies. Degree of spatial dependence is around 1 for LSDMM, which is higher than RWPA and DA models, whose values are negligible.

4.1.5.5TNMM

The TNMM model [9] is a generalization of the DA model and is inspired by several other mobility models, especially the group-based mobility. The TNMM is goal-oriented and compatible with a range of mobile units as well as stationary wireless sensors. Depending on the created objectives, the nodes can form temporary groups and move in formations throughout the area, simulating the behaviour of real-world tactical units.

4.1.5.6MCMM

The MCMM [10] combines hierarchical node structure, node operation modes, event-based destination selection, and the presence of physical obstacles that affect the node movement and signal propagation. In general, each node in the MCMM advances at a random speed between zero and a maximum value toward the chosen destination point. When the node reaches this stage, it waits a specified amount of time before repeating the operation. The destination selection process is analogous to that of assigning a task to a node in response to an occurrence that occurred at that site. The MCMM is the first systematic work on mobility models for mission-critical ad hoc networks. As a result, it can be used to generate accurate simulation results about the activity of such networks, especially those involving emergency teams and medical teams.

4.1.5.7RTTMM

The RTTMM is a synthetic mobility model proposed in [22]. The RTTMM resembles the movement of the rescue entities and the unique role assigned to each of them. The RTTMM incorporates five different roles of rescue entities which are relief worker, policeman, ambulance, emergency vehicle, hospital and relief camp and they are categorized into specific tiers. The mobile devices occupied by a policeman and relief worker are regarded as a tier-1 devices. The device mounted by the ambulance and the emergency vehicle are regarded as a tier-2 devices. The hospital and the relief camp usually placed in a fixed and distant location to avoid recurrence of the events known as Throw Boxes (TBs) and are referred as tier-3 devices.

Only one fixed TBs is allowed at each of the event area and it is placed in the centre. Under RTTMM, the rescue entities are assigned to the designated area based on the intensity of the events so that the relief workers will restrict their movement within the affected radius. Each of the rescue entities will act accordingly in the assigned role making the mobility model seem realistic to the movement of the rescue entities in the real-life situation.

4.2Tactical areas and its requirements

4.2.1Tactical areas

Aschenbruck et al. [1] discussed the characteristics of modelling mobility nodes in the disaster area scenario. They explained that the node movement of the rescue teams during disaster area was based on the analysis of tactical issues of civil protection. Situations such as those in crisis areas demonstrate the coordinated movement that is based on the room separation. Typically, the disaster area is divided into four tactical zones: the IL, the CTA (which includes PWT and casualty clearing stations CCS), the TZ, and the TOC.

After the disaster, there will be a few parties involved in each of the tactical areas. The IL is the area where the disaster struck happened. There will be the victims, the rescue teams, including firefighters, police and volunteers and also the transport nodes, which refer to the ambulance, helicopter or any transportation used during the SAR operation. The victims will then be transferred safely to the second area which is the casualty treatment areas.

At the casualty treatment areas, the involved parties will be the patients, which refer to the victims, medical teams and also the volunteers. The casualty treatment areas consist of two sub-areas which are PWT and CCS. Firstly, the transferred victims will have to wait for the treatment at the PWT. Then, they will be treated accordingly by the medical teams at the CCS.

As for the TZ, the parties involved will be the transport nodes. The transport nodes are referred to the transportation used during the SAR operations such as ambulances, helicopters and others. The node movement of the transport nodes is not limited to one area only. Instead, they will have to go back and forth from the incident location to the casualty treatment areas as they have to transfer the victims.

All the instructions for the SAR operations will be given by one or a few team leaders. They will be the one who will lead their team members during the SAR operations, making and deciding a good strategy to cope with the problem and come out with a solution. They will be in the TOC zone to observe and giving the instructions to their team members. The tactical areas and the involved parties in each of the areas are summarised in *Figure 5*.

4.2.2Requirements for the tactical areas

Aschenbruck et al. [5] explained a few requirements that are needed to be considered in the tactical scenario. The tactical communication system is used by military and civil authorities, such as civil defence forces. These forces are highly organised and disciplined, and their activities are highly organised as well. *Table 2* shows the relationship between dependencies, mobility models and supported requirements of the tactical areas.

Units and troops often travel in tactical formation within tactical networks. Even if the particular position has a negligible impact, this fact implies group mobility or movement. There will be a leader or group of leaders who will instruct their unit members' movement, including where and how to travel or which area to function in. Generally, the movements are motivated by the tactical considerations. As a result, the units usually take the shortest route to their destination.

The destination is determined by the working location, which is determined by tactical considerations. Typically, both the techniques and the scene are arranged hierarchically. Generally, the site is divided into tactical zones. Each unit or member falls under one of these categories. Usually, groups or members assigned to a particular position would remain close to it. However, some of them, such as the transport nodes, may have special tasks that require them to travel from one place to another. It is very normal for units to leave the scenario and be replaced by others later on, especially in tactical communication systems. There can be deaths in the military scenarios, and units transporting patients to hospitals may exist in civil protection scenarios. When units depart from a situation, others are usually requisitioned.

There are several distinct types of units, each with its own unique set of equipment. Some of them own and operate cars, which enables them to travel more quickly. Others are pedestrians, who travel at a slower pace than car owners. As a result, the velocity is heterogeneous depending on the form of nodes.

Finally, since the tactical scenarios take place in areas of destruction, obstacles may arise. Smaller ones can be overlooked because they have a negligible effect on the movement. However, larger ones, such as walls, homes, and so forth, would undoubtedly have a significant effect on them, influencing their movement.

Table 2 Relationship between mobility models and supported the requirements of tactical areas

Dependency	Mobility model	Group movement	Optimal paths	Tactical areas	Nodes join/leave	Heterogeneous velocity	Obstacles
Random	RW	X	X	(+)	X	(+)	X
	RWP	X	Y	(+)	X	(+)	X
	RWPA	X	Y	(+)	X	(+)	X
	Levy-Walk	X	X	X	X	X	X
Temporal	GM	X	X	(+)	X	(+)	X
Spatial	RPGM	Y	(+)	(+)	(+)	(+)	(+)
	HCMM	Y	X	X	X	X	X
	HDBA	Y	X	X	X	(+)	Y
Geographical	CoM	Y	X	X	X	X	Y
	ND	Y	X	X	X	X	X
	Manhattan-grid	X	X	Y	X	(+)	X
	Map-based RWP	X	X	X	X	X	X
	ERM	X	X	Y	X	Y	Y
	CIBRMM	Y	X	X	Y	X	X
	DA	Y	Y	Y	Y	Y	Y
Hybrid	LSDMM	Y	Y	Y	Y	Y	Y
	TNMM	Y	Y	Y	Y	Y	Y
	MCMM	Y	Y	Y	Y	Y	Y
	RTTMM	Y	X	Y	Y	Y	Y

X = not supported
Y = supported
(+) = not supported but can be modified to support

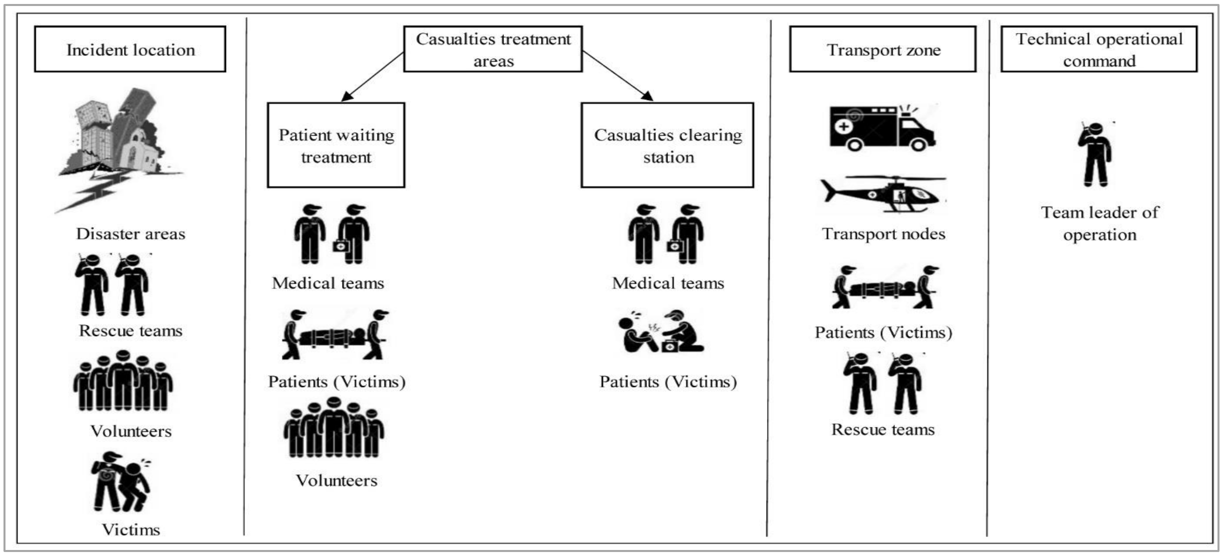

Figure 5 Tactical areas based on separation of rooms

5.Network simulation tools for MANET

In a MANET, node mobility is critical. Many of the researchers use simulation as a high-based and low-resources because of the inability to control variables or settings, which limits the number of experiments they can perform. The network simulation tools are essential for trying out ideas on your network before implementing them in your environments.

5.1Network simulator 2 (NS-2)

NS-2 [46], is a discrete-based event simulator and utilises C++ language and Object-Oriented Tool Command Language (Tcl) script. C++ is efficient when using a design, but difficult to visualise. NS-2 is well prepared with protocols, models, algorithms, and useful tools. The overall use of NS-2 is heavily concentrated among researchers due to its ability to generate node and traffic patterns. Besides, NS-2 lets you simulate the wired and wireless network functions. It is an alternative to other simulators to provide a variety of mobility models.

Nonetheless, it has several disadvantages. The design suffers for its lack of modularity and complexity. Some known disadvantages are that it has a high resource usage and is not scalable. NS-2 is typically used for simulations of a few hundred nodes or less.

5.2Network simulator 3 (NS-3)

NS-3 [47] is a free source software which based on discrete events, and utilises C++ language. NS-3 is not the current version of NS-2 and only limited to academic and research purpose. NS3 supports both network-related and non-network-specific research. Memory management, computation time, and scalability are better in NS-3 than in NS-2. While on the other hand, NS-3 also has a few drawbacks. The models available in NS-3 are quite few, lacks of Graphical User Interface (GUI) to build topology and has limited visualization support.

5.3Global mobile information system simulator (GloMoSim)

GloMoSim [48] is a discrete-based event simulator which utilises a message-based approach. It includes robust models and support networks of thousands of nodes on a large scale. Initially, it supported both wired and wireless networks, but now only wireless networks are supported. However, GloMoSim has not been updated since the year 2000. Thus, no in-depth documentation available for the users.

5.4QualNet network simulator

QualNet [49] is the commercial version simulator based on GloMoSim core and has many features over GloMoSim. It supports high scalability and primarily used to link large heterogeneous networks together. Many models and protocols are available in QualNet for both wired and wireless networks. It is well documented and backed up technically.

QualNet also comes with a powerful and useful GUI support for code development, besides coming with good debugging support and fast simulation results. Moreover, it supports unmatched platform portability and interface flexibility. However, it is a bit pricey, some source codes of files may be hidden, slow installation, and hard to deal with in Linux.

5.5 Objective modular NETwork testbed in C++ (OMNet++)

OMNET++ [50] is an object-oriented discrete event network simulator. OMNET++ is free for academic purpose, while the commercial version of OMNET++ namely OMNEST can be obtained from Simulcraft Incorporation for its license. OMNET++ has a generic architecture. OMNeT++ provides a large library class for developing various modules. Besides, it is able to handle both event-driven and process-based programming. Thus, it would be perfectly applicable to MANET simulation. However, OMNET++ has limited protocol supports, and their performance analysis as well as documentation seems to be inadequate [48].

5.6 Optimized network engineering Tool (OPNet)

OPNet [48] is a well-established and most widely used commercial simulation environment, written in the C++ language in which it simulates the behaviour and the performance of any type of the network. Compared to other simulators, OPNet has more advantages in terms of power and versatility. OPNet capable of executing and monitoring several scenarios in a concurrent manner. Furthermore, it provides a clear, user-friendly visualisation and grid computing for distributed simulation. Despite its lacking of energy model, OPNET is a bit pricey for the commercial purpose. It only provides limited wireless mobility and supports a limited set of protocols.

5.7 Opportunistic networking environment (ONE)

ONE [51] is a discrete-based event simulator, programmed in Java language with the purpose of examining DTN routing and application protocols. It is capable of generating node movement using a variety of movement models, either synthetic or existing. It also routes messages among nodes using a variety of DTN routing algorithms and node types. ONE simulator allowed the users to display both mobility and message transmission in real time via GUI. Besides, it allows the user to import mobility data from real-world traces or from other mobility generators. Numerous reports, ranging from the node movement to message passing and general statistics, can be provided. However, it can be unfamiliar to the user to deal with as the provided documentation seems inadequate.

5.8 Network simulator (NetSim)

NetSim [52] is a discrete-based event simulator and open source software, which is suitable for the network Research and Development (R&D) purpose. NetSim covers different type of networks such as Wi-Max, WLAN, Wireless Sensor Networks (WSNs), MANETs and others. It can modify and use the protocol libraries easily due to their simplicity. NetSim allows the custom code to be debugged during the simulation. Thus, minimizes the time needed to build and run the simulation to meet the user specific requirements. Besides, it has excellent programmability and inbuilt analysis framework and packet-animator. However, NetSim is restricted to the academic purpose.

5.9 Java in simulation time (JiST) / scalable wireless network simulator (SWANS)

JiST/SWANS [53] represents SWANS built on JiST platform. It is a Java-based discrete simulator and can be simulated in a large network. By using JiST/SWANS, the computational overhead is low and requires less memory. However, the last version was updated in 2005 and no new development after that.

5.10 Java-based simulator (JSim)

JSim [54] is a Java-based discrete event simulator that is extensible and reusable across platforms. It creates and analyses quantitative numeric models based on experimental reference data. The calculations of JSim model are described in JSim's Mathematical Modelling Language (MML). It is a simple-to-read text-based language, and MML models are frequently expressed mathematically. It offers flexibility and the GUI library is also provided. The weakness of JSim is it required longer execution time.

6. Discussion

6.1 Simulation parameters

To measure the network efficiency of the mobility model, simulation parameters based on the specific scenario are considered. The mobility model is used to describe the movement of mobile users over time by taking into account their position, velocity, and direction. The radio propagation model is a mathematical experiment that is used to characterise radio wave propagation as a work of recurrence, distinct, and other conditions.

Bandwidth refers to the maximum amount of data that can be transferred over a particular link in a given amount of time, but does not indicate the speed at which data bits travel from one place to another. A packet is a small amount of data sent over a network such as a Local Area Network (LAN) or the Internet. Sending smaller packet size makes a difference guarantee each area is transmitted successfully instead of sending a large file as a single block of data. In a case such as disaster area scenario, it is crucial to determine the right packet size, as we want to ensure the packet containing the message is successfully sent and delivered.

Traffic model portrays the way the process of how a number of packets arrived to nodes on the network. Constant Bit Rate (CBR) is one of the most commonly used traffic patterns in the networks. Number of nodes refer to the number of mobile nodes in the designated scenario. Speed shows how fast the movement of nodes involved. Normally, the speed of pedestrian is around 1 m/s to 5 m/s. While, the speed of vehicles is around 5 m/s to 12 m/s. Simulation area portrays the size of the designated area for such scenario. Simulation time refers to the execution time of the simulation to run. Area coverage is the total amount of covered area during execution time.

A comparison of the existing mobility models used in terms of simulation parameters is presented for future references. The comparison made is based on the details given by the authors in their existing papers. Some details might be missing as the authors do not stated about it. *Table 3* and *Table 4* shows the simulation parameters used by the authors in their related papers.

6.2 Comparative analysis on related works

This paper presents a comparative study of the related work with respect to the approaches, mobility, model, scenario or environment, performance metrics and limitations. The comparative analysis is shown in Table 5. Complete list of abbreviations is shown in *Appendix I*.

Table 3 Simulation parameters I

Author	Mobility Model	Propagation Model	Number of nodes	Speed (m/s)	Simulation area (m × m)	Coverage (m)
Conceicao and Curado [14]	HDBA, RWP	N/A	25, 50, 75, 100	1 - 5	500 x 500	150
Boldrini et al. [7]	HCMM, CMM [7]	N/A	30	5	10 x 10	N/A
Wang et al. [21]	CIBRMM, TMM	N/A	100	N/A	20 x 20	N/A
Rollo and Komenda [9]	TNMM, RWP	N/A	Robots (5) Humans (5)	N/A	N/A	100
Aschenbruck et al. [1]	DA, GM, RWP	N/A	150, 200	1 - 2	200 x 200 550 x 500	50 - 100
Martini-Campillo et al. [15]	DA	N/A	10, 30, 50, 70	N/A	700 x 600 50 x 50	60
Ebenezer [18]	LSDMM, RWPA, DA	N/A	1500	N/A	N/A	200
Papageorgiou et al. [10]	MCMM, HUMO, OM, RWP	Two-Ray Ground	50	1, 2, 5, 7	N/A	N/A
Stute et al. [23]	ND, RWP, MAP-based RWP	N/A	500	0.5 – 1.5	5000 x 7000	10
Reina et al. [16]	DA	Two-Ray Ground	102	Pedestrians (1-2) Vehicles (5-12)	850 x 300	150
Reina et al. [19]	DA	Two-Ray Ground, Shadowing	200	Pedestrians (1-2) Vehicles (5-12)	550 x 500	30
Reina et al. [12]	DA	Two-Ray Ground	150, 200	Pedestrians (1-2) Vehicles (5-12)	350 x 200 200 x 200 550 x 500	30
Nelson et al. [8]	ERM, RW	N/A	Civilians (75) Ambulance (10) Police (15)	Civilians (1-4) Ambulance (17-20) Police (17-20)	1000 x 1000	150

Author	**Mobility Model**	**Propagation Model**	**Number of nodes**	**Speed (m/s)**	**Simulation area (m × m)**	**Coverage (m)**
Pomportes et al. [11]	CoM, RPGM, Levy-walk, RWP	N/A	RWP & Levy-walk: 400 CoM, RPGM, RWP, Levy-walk: 1000 Obstacles: 10 No obstacles: 1200	N/A	RWP & Levy-walk: 800 x 800 Obstacles: 600 x 600 No obstacles: 1200 x 1200	N/A
Reina et al. [17]	DA	Two-Ray Ground	IL: 30 PWT: 10 CCS: 15 TZ: 30 TOC: 2	Pedestrians (1-2) Vehicles (5-12)	IL: 200 x 200 PWT: 100 x 100 CCS: 150 x 150 TZ: 250 x 200 TOC: 100 x 50	50
Raffelsberger and Hellwagner [13]	DA	Wireless Shadowing model	25	N/A	400 x 300	100
Kim et al. [27]	RWP	N/A	10, 15, 20, 25, 30	1 - 5	80 x 80	22
Younes and Albalawi [28]	RWP	N/A	20 - 120	1 - 20	500 x 300	100 - 300
Kim et al. [26]	RPGM	N/A	25, 50, 75	N/A	1200 x 1200	N/A
Sani et al. [24]	DA	Two-Ray Ground	65, 95, 125, 155	N/A	800 x 800	N/A
Al-Shehri et al. [25]	RPGM, RWP, Manhattan	Two-Ray Ground, Free space model	25 - 250	N/A	1000 x 1000	N/A
Gondaliya and Atiquzzaman [22]	RTTMM, ERM	N/A	52	Relief workers (3) Ambulance and emergency vehicle (12) Police (7)	3000 x 3000	50
Arbia et al. [20]	DA	N/A	Rescuer (100) Firefighters (78) Ambulance (30)	N/A	480 x 260	N/A

Table 4 Simulation parameters II

Author	**Mobility Model**	**B/width (Mbps)**	**Packet size (kB)**	**Traffic pattern**	**Simulation time**
Conceicao and Curado [14]	HDBA, RWP	54	0.5	N/A	900 s
Boldrini et al. [7]	HCMM, CMM	N/A	N/A	N/A	N/A
Wang et al. [21]	CIBRMM, TMM	N/A	N/A	N/A	N/A
Rollo and Komenda [9]	TNMM, RWP	N/A	N/A	N/A	N/A
Aschenbruck et al. [1]	DA, GM, RWP	0.008	N/A	N/A	5 min
Martini-Campillo et al. [15]	DA	54	128	N/A	6000 s
Ebenezer [18]	LSDMM, RWPA, DA	N/A	N/A	N/A	10000 s
Papageorgiou et al. [10]	MCMM, HUMO, OM, RWP	N/A	0.062	CBR	N/A
Stute et al. [23]	ND, RWP, MAP-based RWP	2	50-100	N/A	7 days
Reina et al. [16]	DA	N/A	N/A	CBR	150 s
Reina et al. [19]	DA	2	0.5	CBR	300 s
Reina et al. [12]	DA	2	0.5	CBR	1500 s
Nelson et al. [8]	ERM, RW	N/A	N/A	N/A	1500 s

Author	**Mobility Model**	**B/width (Mbps)**	**Packet size (kB)**	**Traffic pattern**	**Simulation time**
Pomportes et al. [11]	CoM, RPGM, Levy-walk, RWP	N/A	N/A	N/A	N/A
Reina et al. [17]	DA	2	0.5	CBR	300 s
Raffelsberger and Hellwagner [13]	DA	54	N/A	UDP	3000 s
Kim et al. [27]	RWP	N/A	1	N/A	600 s
Younes and Albalawi [28]	RWP	8	0.5	CBR	1100 s
Kim et al. [26]	RPGM	N/A	N/A	CBR	N/A
Sani et al. [24]	DA	N/A	0.5	FTP	N/A
Al-Shehri et al. [25]	RPGM, RWP, Manhattan	N/A	0.5	N/A	N/A
Gondaliya and Atiquzzaman [22]	RTTMM, ERM	2	25	N/A	6000 s
Arbia et al. [20]	DA	54	N/A	N/A	3600 s

Table 5 Comparative analysis of the related works

Author	**Approach**	**Mobility model**	**Scenario/ Environment**	**Performance metrics**	**Limitations**
Aschenbruck et al. [1]	Comparison analysis in terms of performance between the selected mobility models by varying the transmission range.	DA, GM, RWP	MANET in disaster area scenario.	Relative mobility rate. Average node degree. Average link duration. Minimum number of links between a node and its neighbour. PDF. NRL. Transmission delay.	Energy consumption and overhead were not considered. Additional aspect like complex radio propagation model, including obstacles should be considered in the future.
Boldrini et al. [7]	Incorporating the concepts of CMM model and determining preferential locations.	HCMM, CMM	Opportunistic network.	Contact duration. Intercontact time.	Evaluation on network performance metrics were not considered.
Nelson et al. [8]	Implementation of concept "Flee" and "Approach" actions.	ERM, RW	Disaster area scenario.	Changes in network topology (topological implications for the network graph).	Communication between the nodes was not considered.
Rollo and Komenda [9]	Synthetic mobility model based on task-oriented methodology.	TNMM, RWP	Tactical network.	Node spatial distribution. Average node degree.	No comprehensive study on the efficiency in terms of node mobility.
Papageorgiou et al. [10]	Systematic work on mobility models that combines hierarchical node, operation modes, event-based destination selection and presence of physical obstacles.	MCMM, HUMO, OM, RWP	Mission critical in MANET.	Network connectivity and impact on a MANET efficiency.	Energy consumption and overhead were not considered.

Author	**Approach**	**Mobility model**	**Scenario/ Environment**	**Performance metrics**	**Limitations**
Pomportes et al. [11]	A composite mobility model that incorporates a group movement, mobility, human mobility and obstacle avoidance, which were RPGM, Levy-Walk and Voronoi diagram respectively.	CoM, RPGM, Levy-Walk, RWP	Disaster area scenario.	Distribution of node degree. Average node degree. Contact and intercontact times.	Evaluation only focused to the microscopic scale of the network.
Reina et al. [12]	Evaluate performance of MANET routing protocols which were AODV, DSR and AOMDV under the disaster mobility model.	DA	Disaster area scenario.	Throughput. PDF. NRL. Average E2E.	Communication paths between nodes have a limited lifespan.
Kim et al. [27]	MANET location-based routing approach by applying dual channels, known as sub-GHz and 2.4 GHz for the indoor disaster environment.	RWP	Firefighter communication indoor disaster environment.	PDR. E2E. Initial routing table configuration time.	Multicasting and broadcasting schemes need to be considered for performance evaluation under such scenario.
Raffelsberger and Hellwagner [13]	Evaluate performance of MANET routing protocols which were AODV, OLSR, DYMO and BATMAN under the disaster mobility model.	DA	Emergency response scenario.	PDR. Average PDR of mobile nodes operating inside the facility. Cumulative distribution function of the hop count. Packet delivery delay.	Some nodes are intermittently connected which results in higher packet loss.
Conceicao and Curado [14]	Mobility model based on force vector.	HDBA, RWP	Search missions.	Density distribution of nodes. Node degree. Area coverage. Topology changes. Throughput.	Scalability of the network was not considered.
Martini-Campillo et al. [15]	Evaluates performance of opportunistic routing protocols under disaster mobility.	DA	Emergency scenario.	Delivery rate. Lifetime.	Not energy-efficient towards a dense network of nodes or large number of messages.
Reina et al. [16]	Evolutionary computational approach by applying adaptive broadcasting scheme based on topological conditions.	DA	Disaster area scenario.	Reachability. Saved-Rebroadcast (SRB).	Performance evaluation only focused on connectivity improvement.

Author	**Approach**	**Mobility model**	**Scenario/ Environment**	**Performance metrics**	**Limitations**
Reina et al. [17]	Performance evaluation of different MANET routing protocols under disaster mobility.	DA	Disaster area scenario.	Dropped packets and hop count. Throughput. PDF. NRL. E2E.	Issue of difficult conditions and limited connectivity.
Ebenezer [18]	Destination and path selection using a probabilistic approach based on criteria.	LSDMM. RWPA, DA	Large scale disaster scenario.	Average node degree. Average link duration.	Overhead may occur as the transmission range expands, causing decrement in overall network capacity.
Reina et al. [19]A	New probabilistic approach based on similarity/dissimilarity metrics.	DA	MANET in disaster response scenarios.	Reachability. Retransmissions. Delay.	Only considered the performance of certain routing protocols.
Arbia et al. [20]	Evaluate performance of different routing protocols while using various communication technologies.	DA	Fire trigger in the shopping mall/urban critical and emergency scenario.	PRR. Packet delay. Energy consumption.	The study only considered for small tactical teams.
Wang et al. [21]	Movement of nodes based on the catastrophic intensity value.	CIBRMM, TMM	Disaster Area Wireless Networks (DAWNs).	Rescue time with different number of affected areas and catastrophic intensity.	Communication between nodes was not considered, thus no evaluation of network performance.
Gondaliya and Atiquzzaman [22]	Incorporation of five different roles of rescue entities, whereas the rescue entities is assigned to the designated area based on the intensity of the events so that the relief workers will restrict their movement within the affected radius.	RTTMM, ERM	Post-disaster scenario.	Delivery ratio. Latency. Average overhead ratio. Cost per message.	Decrement in message size as a number of devices and buffer sizes varied.
Stute et al. [23]	Reverse engineering, human mobility approach based on 126 knowledge experts.	ND, RWP, Map-based RWP	DTNs in large-scale natural disasters.	Delivery rate. Delay. Buffer occupancy. Delivery rate (for different roles).	Scalability of the network and realistic communication performance were not considered.
Sani et al. [24]	Evaluate TCP performance in MANET routing protocols by varying traffic scenario and node density.	DA	Disaster recovery scenario.	Average throughput. PDR. Average E2E delay.	Throughput in all routing protocols decreases as the TCP connection increase.

Author	Approach	Mobility model	Scenario/ Environment	Performance metrics	Limitations
Al-Shehri et al. [25]	Comprehensive comparison between tactical and commercial MANETs with concerns to their performance and design characteristics.	RPGM, RWP, Manhattan	Mobile tactical networks (focus to military communication).	PDR. Routing overhead. Average throughput. E2E delay.	Different radio propagation and mobility models needs to be considered as well as complex security issue due to the untrusted 3rd party suppliers of hardware and software components.
Kim et al. [26]	A novel routing protocol for UAV relayed tactical MANET, where different features from typical MANET was shown and 2 scenarios were proposed to be used for network congestion and link breakage.	RPGM	Tactical ad hoc networks.	PDR. E2E delay.	Corporation with ground MANET needs to be considered to extend the current network architecture.
Younes and Albalawi [28]	A proposed analytical model for the link and route lifetime in multi-hop network and comparison was made between analytical and simulation results.	RWP	Mobile multi-hop networks.	PDF of link lifetime. PDF of route lifetime. Bounds (maximum and minimum) of the route lifetime.	The increase the transmission range, the increase the interference from the neighbour nodes, which led to the decrement of network throughput.

7.Conclusion and future work

The aim of this paper is to find a commonly used mobility model for disaster area scenarios towards the movement of the rescue teams. This paper reviewed the existing mobility models that have been used to simulate the movement of nodes in the disaster area scenario. However, there are some researches that are included into this study, whereas the existing mobility models are evaluated under tactical area networks, opportunistic network and multi-hop network. This is because, the environment of this network is closely relatable with the conditions of the tactical teams. Thus, this paper has discussed the existing mobility models that have been applied in the case of the disaster area which focusing on the movement of the rescue teams without considering the approach taken by the related papers. From the comparative analysis made through this paper, it can be concluded that the DA mobility model is an ideal mobility model that shows the realism of the node movement especially when adapted in the post-disaster area scenarios. However, there is still space for improvement in terms of the node's mobility considering suitable algorithms and routing protocols used in order to enhance the network performance of the rescue teams during their mission critical and SAR operations. The enhancement made can be focused in terms of energy consumption, network lifetime, overhead and NRL as the network efficiency can be one of the challenging issues in designing the mobility model, especially in an unfavourable situation such as the disaster area scenario where the fixed infrastructure network may unavailable due to damage.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix I

S.No.	Abbreviation	Description
1.	AODV	Ad-Hoc on-demand Distance Vector
2.	AODVv2	AODV Version 2
3.	AOMDV	Ad-hoc On-demand Multipath Distance Vector
4.	BATMAN	Better Approach to Mobile Ad-hoc Network
5.	BLE	Bluetooth Low Energy
6.	CBR	Constant Bit Rate
7.	CCS	Casualties Clearing Station
8.	CI	Catastrophic intensity
9.	CIBRMM	Catastrophic Intensity-based Rescue Mobility Model
10.	CMM	Community-based Mobility Model
11.	CoM	Composite Mobility
12.	CTA	Casual Treatment Area
13.	DA	Disaster Area
14.	DAWNs	Disaster Area Wireless Networks
15.	DCR	Dual-Channel-based Routing
16.	DD	Directed Diffusion
17.	DSDV	Destination-Sequenced Distance-Vector
18.	DSR	Dynamic Source Routing
19.	DTN	Delay Tolerant Network
20.	DYMO	Dynamic MANET on-demand
21.	E2E	End-to-End
22.	EBR	Encounter Based Routing
23.	ECS	Emergency Communication System
24.	ERM	Event and Role-based Mobility
25.	ERMM	Event and Role-based Mobility Model
26.	FANETs	Flying Ad-Hoc Networks
27.	FMNs	Flying Mesh Networks
28.	FWA	Fixed Wireless Access
29.	GM	Gauss-Markov
30.	GloMoSim	Global Mobile Information System Simulator
31.	GPS	Global Positioning System
32.	GPSR	Greedy Parameter Stateless Routing
33.	GSM	Global System for Mobile
34.	GUI	Graphical User Interface
35.	HAPs	High-Altitude Platforms
36.	HBDA	Human Behavior for Disaster Area
37.	HCMM	Home-cell Community-based Mobility Model
38.	HUMO	Human Obstacle Mobility
39.	IL	Incident Location
40.	IoT	Internet of Things
41.	JiST	Java in Simulation Time
42.	JSim	Java-based Simulator
43.	LAPs	Low-Altitude Platforms
44.	LAN	Local Area Network
45.	LoRa	Long Range-based
46.	LoRaWAN	Low Power Wide Area Network
47.	LSDMM	Large Scale Disaster Mobility Model
48.	MANET	Mobile Ad-Hoc Network
49.	MCMM	Mission Critical Mobility Model
50.	MDRUs	Movable and Deployable Resource Units
51.	MML	Mathematical Modelling Language
52.	MRMC	Multi-Radio Multi-Channel
53.	ND	Natural Disaster
54.	NetSim	Network Simulator
55.	NRL	Normalized Routing Load
56.	NS-2	Network Simulator 2
57.	NS-3	Network Simulator 3
58.	OLS	Opening Lifeline Stage
59.	OLSR	Optimized Link State Routing
60.	OLSRv2	OLSR Version 2
61.	OM	Obstacle Mobility
62.	OMNeT++	Objective Modular NETwork Testbed in C++
63.	ONE	Opportunistic Networking Environment
64.	OPNet	Optimized Network Engineering tool
65.	PDF	Packet Delivery Fraction
66.	PDR	Packet delivery ratio
67.	PPDR	Public Protection and Disaster Relief
68.	PRR	Packet tmm
69.	PWT	Patient Waiting for Treatment
70.	QoS	Quality of Service
71.	R&D	Research and Development
72.	RANs	Radio Access Networks
73.	RPGM	Reference Point Group Mobility
74.	RW	Random Walk
75.	RWP	Random Waypoint
76.	RWPA	Random Waypoint with Attraction
77.	RTTMM	Role-based 3-Tier Mobility Model
78.	SAR	Search and Rescue
79.	SDR	Software Defined Radio
80.	SRB	Saved Re-Broadcast
81.	SRS	Spreading Rescue Stage
82.	SWANS	Scalable Wireless Network Simulator
83.	TBs	Throw Boxes
84.	Tcl	Tool Command Language
85.	TCP	Transmission Control Protocol
86.	TNMM	Tactical Networks Mobility Model
87.	TMM	Traditional Mobility Model
88.	TOC	Technical Operational Command
89.	TZ	Transport Zone
90.	UAV	Unmanned Aerial Vehicle
91.	V-HUB	Vehicle Hub
92.	V2X	Vehicle-to-Everything
93.	WAN	Wide Area Network
94.	WBAN	Wireless Body Area Network
95.	WiFi	Wireless Fibre
96.	WSNs	Wireless Sensor Networks
97.	WMN	Wireless Mesh Network
98.	WMHN	Wireless Multi-Hop Network
99.	ZRP	Zone Routing Protocol