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ARTICLE

An Internet Access Solution: MANET Routing and a Gateway Selection Approach for Disaster Scenarios

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Abstract After natural and man-made disasters, the telecommunication infrastructure is usually severely damaged, thus hampering communication and rescue services. It is impossible for disaster victims to make use of communication devices such as cellular phones, iPads, or their laptops to make a connection with the outside world (Internet). With infrastructure less and decentralized features, the mobile ad hoc network (MANET) can play an important role in improving communication in post-disaster affected areas. Therefore, the important functionalities of a MANET that allow users to create dynamically configurable wireless networks without fixed infrastructure using common devices such as mobile phones is necessary. This paper reports on the development of new techniques for routing selection and gateway load balancing in MANETs. Network fairness, throughput, and packet delays are measured empirically. The proposed mechanisms can reduce network congestion and consequently improve communication in affected areas.

Keywords Internet · MANETs · Gateway · Load balancing · Routing selection scheme · Disaster scenario

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1 Introduction

The rising number of devices that can connect to the Internet makes living effortless. In addition to communications devices, a number of “things”—including any physical object, can also be connected to the Internet through wireless networks. This concept is referred as the “Internet of Things”, which is the capability to connect unconnected devices. The Internet of Things (IoT), can offer unlimited access to, for example, home appliances using smart home apps on phones. According to the research firm ABI Research, more than 30 billion devices will be connected wirelessly by 2020 [25]. The Internet now has turned into a communication backbone for most people. Wireless technologies like WiFi, ZigBee, Bluetooth, RFID, and cellular are driving the growth of the Internet of Things. However, in the event of a disaster, it is common to have a collapse of structure. Power can go out, servers can go down, and devices can become unworkable due to service communication failures. There are also connectivity difficulties for disaster victims from communication network infrastructures. With less infrastructure and more decentralized features, mobile ad hoc networks (MANETs) are ideal for solving this type of problem. Without being connected to the Internet, all devices in a disaster area with a wireless networking capability can dynamically form a network to exchange information.

The expansion of wireless technologies has brought data transmission via radio waves and nodes in a network that can communicate with each other without a fixed station access point. The structure can form and deform in a network on the fly without relying on any network system. MANET has gained popularity since the production of smart computing devices and the development of wireless communications. The transmission of information from a source to a destination across an inter-network is called routing. To forward data packets from a source to a destination, the neighbor’s node, also known as routers (because it performs data packet forwarding), will send the data packet through multi-hop nodes until the data packet arrives at the destination. Thus, the topology network in a MANET is known as unpredictable and can be changed rapidly [1]. IEEE 802.11 is a standard for wireless communications. Two operational modes are defined by the IEEE 802.11 standard: infrastructure-based and infrastructure-less (ad hoc). Infrastructure-based acts such as a Wi-Fi hotspot enable devices to connect to the Internet. However, for dynamic environments, in which people or devices can only connect to the Internet for a temporary time, an infrastructure-less or an ad hoc mode is more efficient. Nodes in an ad hoc mode are the Independent Basic Service Set (IBSS) or the ad hoc network. Every node can communicate with each other after a synchronization phase. If one of the nodes (in this case we called it node A) in the network is connected to a wired network, all nodes have wireless access to the Internet via node A. Node A will serve as a router or gateway for all nodes in this ad hoc network. In a real environment of communication, an ad hoc network is basically a communication among user’s mobile networks. Thus, user’s devices will support functioning as a network that can offer network infrastructures such as routers, switches, and servers. As long as it is within transmission range, nodes can communicate with each other.

The main contributions of this paper are as follows:

- We develop a gateway load balancing scheme for improving network congestion.
- We develop a routing selection method to simplify the network path process and consequently improve packet delay performance.

The remainder of the paper is organized as follows: in Sect. 2, the state of MANET applications, gateway, and routing are presented. In Sect. 3 the scenario and problem formulation are defined. Section 4 is devoted to the proposed scheme, while in Sect. 5, the discussion of simulation results is given in detail. Finally, in Sect. 6, concluding remarks and future work are presented.

2 Related Work

2.1 Applications of MANET

MANET was originally proposed for military application, and then was extended to applications in other fields. Deployment in disaster scenarios is the most challenging, but it can be a significant application [2]. After a disaster occurs, information about the victims involved is necessary so that the victims can be rescued quickly. For example, the earthquakes and tsunamis that occurred in the Great East Japan earthquake, in the Wenchuan earthquake in China, and the tsunami in Indonesia and floods in Malaysia (see Fig. 1) were extreme events and national disasters.

Collapsed structures are a common result of earthquakes. The capability of mobile devices to make voice phone calls are seemingly impossible for disaster victims that are trapped in the disaster [3]. The devices become unworkable due to communication services that have been damaged in the area. With decentralized and infrastructure-less features, a MANET can be one of the options to solve communication problems [3]. Hence, the significant functionalities of mobile ad hoc networks that allow users to build dynamically reconfigurable wireless networks without fixed infrastructure are very useful [4].

The development of mobile computing equipment and the infrastructure of network communication have made huge changes to the ways people communicate. People retrieve information, do their tasks, and communicate with each other using mobile devices. With mobile ad hoc networks, information exchange can be done ubiquitously without relying on fixed network infrastructures. Applications of MANET [5], [6] are shown in Table 1 with the scenario and potential services for each application.

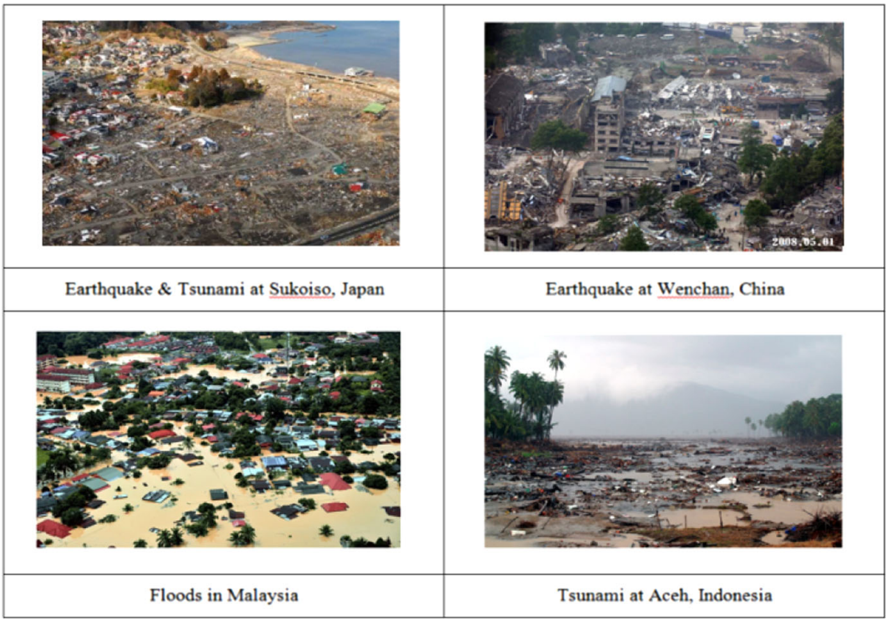

Fig. 1 A picture of disaster area

2.2 Routing Protocol in MANET

Routing is a challenging problem in mobile wireless networks. The objective of routing is to determine the best path for the packet to travel. A standard algorithm measurement for routing parameters is distance, bandwidth, delay and load for a path [1]. Routing consists of a routing protocol and routing algorithm. The task of a routing protocol is to exchange information about topology and link weights, while a routing algorithm calculates the distance between nodes. The standard algorithms used to compute the shortest path are Dijkstra's and Belman-Ford's [7].

Nowadays, a number of routing protocols have been developed by researchers to find the best alternative solutions in routing. Ad hoc routing protocols can be divided into three categories (see Fig. 2). The first one is proactive, which is based on a routing table. It is also known as table-driven. A table-driven routing protocol has routing information that is updated continuously by nodes, with no regard to when and how often such routes are wanted. The second category is reactive. Reactive routing protocol is routing on demand, which means that the information of a route from the sender to the receiver will only be provided when requested. Reactive routing has achieved the main goal of routing to reduce overhead network traffic. The third category is hybrid. Hybrid routing is a combination of the advantages of reactive and proactive protocols. In addition, this routing protocol identifies a zone to minimize the number of packets flooding in a mobile ad hoc network when it is broadcast [8].

Table 1 Application of MANET

Application	Scenario and potential services
Military communication and operations	Keep the communication networks of soldiers, vehicles, and the military always in a good condition and ensure they stay connected
Emergency services	Emergency rescue operations take over the communication when existing communication infrastructure has been damaged or cut off for safety reasons. Emergency communication is usually used in rescue operations such as in earthquakes and floods as disaster relief to support medical teams
Commercial sectors	Shopping malls
	Airports
	Sport stadiums
	E-commerce
	Vehicular ad hoc network
Home networking	Indoor and outdoor internet access
	Personal area networks
Enterprise networking	Indoor and outdoor internet access
	Conferences
	Meeting rooms
Education	Virtual classrooms
	Ad hoc communication through meeting or lectures.
Sensor networks	Smart home applications: smart sensors for home appliances
	Geo-location tracking devices for humans or animals
Entertainment	Multi-user games
	Robotic pets

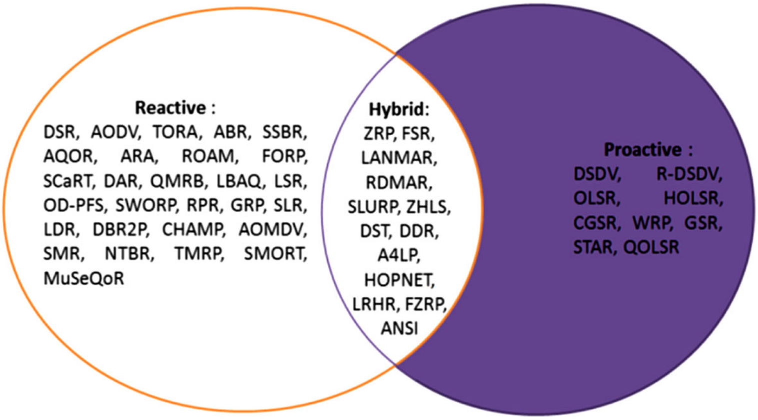

Fig. 2 Routing protocols in an ad hoc network

Generally, routing protocols in a MANET emphasize the shortest-path route from sender to receiver as the best solution for the success ratio in a network, but they cannot give the guarantees of QoS. The goal of a QoS routing protocol is to determine one or more paths from a source to a destination with a bandwidth requirement less than the total bandwidth available. Connections require sufficient bandwidth for transmission. Bandwidth is one of the critical issues especially in real-time applications [9]. An example of a real-time application is video conferencing applications, Voice-over-Internet Protocol (VoIP), online gaming, and some e-commerce transactions.

2.3 Gateway

To allow communication between MANET nodes and the Internet, a gateway as a door to let packets in and out of the network is required. This gateway is the Internet gateway (IG) which will route all packets to and from the Internet. The main task of the gateway is to control network traffic between two or more different networks. In one network, there can be several gateways. Each gateway has an average queue size to monitor. If the queue size exceeds a pre-set threshold, then congestion will occur. The congestion occurs when many packets want to go to the same gateway at the same time, which will drive packet loss. To avoid packet loss, efficiency of the gateway by a load balancing scheme is one of the control solutions.

2.4 Gateway Load Balancing Scheme

A gateway load balancing scheme purposely makes the task equal between all gateways. The equalization will balance from one gateway that has a heavy load to other gateways that have a light load. Previous works [10–16] have proposed several techniques to reduce congestion in terms of load balancing such as the Queue Base Load Balancing Algorithm, Aggregate Interface Queue Length, and the Hybrid Registration Mechanism, for example. All of these techniques are an enhancement of the AODV routing protocol method.

Gateway load balancing plays an important role as a way to avoid congestion. If there is more than one gateway in one network, load balancing between the gateways must be taken into account to provide a better throughput. The gateways receive packet data from MANET and transmit the contained information to the Internet via a cellular network. In addition, there are several proposed networking architectures using the MANET concepts such as case studies of a wireless networking architecture using MANET for mobile communication in the remote pastoral area in Tibet. This architecture show the effective use of such communication. The network architecture uses a solar-powered multi-functional standing station that can reduce network deployment cost. The standing station also has the functions of helping mobile networks to connect with each other and adapting data routing paths according to station energy level.

On the other hand, to allow people to interconnect through the Internet, [17] a wireless networking architecture has been proposed to connect the MANET to a Cellular network via a Terrestrial gateway and then to a Cellular network connected between the MANET and the Internet. Mu et al. [18] used almost the same case study as [17], involving a Communication Architecture for Maritime Sectors which used the integration of cellular, satellite, WiMAX, and Wi-Fi. The integration of MANETs and infrastructure networks extends the network coverage. Bhargava et al. [19] introduced a combination of a MANET and Cellular networks to achieve enhancement of the delivery packet ratio in a mobile ad hoc network. Manoharan and Mohanalakshmie [20] have proposed reaching the gateway of a network by path choice according to trusted nodes and uncongested routes. In this example, Manoharan and Mohanalakshmie introduced a trust-based hybrid gateway selection scheme with security element parameters to find the node trust, route trust, and residual route load capacity.

2.5 MANET Mobility Model

A mobile ad-hoc network consists of wireless mobile devices communicating with each other through neighbors that act as a relay. In a disaster recovery area, node mobility in an actual situation represents a victim that has mobile devices. We choose random access waypoint as the mobility model in our network simulation to represent the movability of victims as free to move randomly in the disaster recovery area. MANET network performance is significantly affected by node mobility due to mobile nodes connected to each other using a multi-hop wireless link [21]. The communication link can be connected or disconnected because of mobility and nodes join and leave the network randomly.

In addition, because of this movability, MANET topology is uncertain and may change rapidly owing to mobility. Normal routing protocols which work great in a static network will not give the same result in a mobile ad hoc network [22]. In developing routing protocols for MANET in a disaster recovery area, the characteristics of MANET such as dynamic topology, bandwidth constraint, and power constraint should be taken into account to improve the accuracy of data transfer and to keep network overhead low [23]. With an efficient routing selection scheme, network performance can be improved even though node mobility is a big challenge.

To simulate node mobility in a mobile ad hoc network, a mobility model should mimic the movement of real victims in a disaster recovery area. The mobility pattern will determine node speed, direction, position, and the way the nodes are moving within the area that has been set. This behavior has an effect on node signal strength, battery power, bandwidth uses, and the consequences to MANET performance. There are several mobility models [23] for ad hoc networks such as the Random Walk model, the Random Waypoint model, the Reference Point Group model, and Gauss-Markov Mobility, for example. However, in this study, we choose the Random Waypoint model as the mobility model in our disaster recovery scenario because this model can act in place of the random motion of nodes that can move with a random speed at any time, and in any direction in the scenario area. In addition, MANET is most commonly simulated by applying the Random Waypoint as its mobility model. This model mimics people moving around randomly using their mobile devices [24].

In the Random Waypoint model, mobile nodes randomly choose a destination and move towards it within minimum and maximum allowed speeds. In our simulation, we have set the mobility speed at 2 mps. After reaching the destination, mobile nodes stay in one location for a specified time period (pause time) before they continue to choose another destination node randomly. This process is repeated until the simulation ends. Radha and Shanmugavel [23] show how throughput performance using the Random Waypoint model compares better to another mobility model. In reality, lower mobile speed will give greater performance in increasing the throughput and control network overhead.

3 Problem Formulation

Each node within a MANET network only can communicate with the nodes in the same network. If the victims attempt to connect to the Internet to let their family and friends outside know that they are safe, they will want to send a message, to share the information they are safe, and perhaps even share a video of the situation. However, the message must go through the Internet. Therefore, to provide Internet access for disaster victims in a disaster area (see Fig. 3), we propose an enhancement of the gateway load balancing and routing selection scheme.

We assume the scenario of a post-disaster situation with no electricity sources or backup because in this study we are focusing on achieving better network performance by improving the scheme of routing and gateway load balancing. In this scenario, we assume three of the MANET nodes are in Internet range while the others are not. Therefore, these three nodes will be a gateway for the other nodes to connect to the Internet.

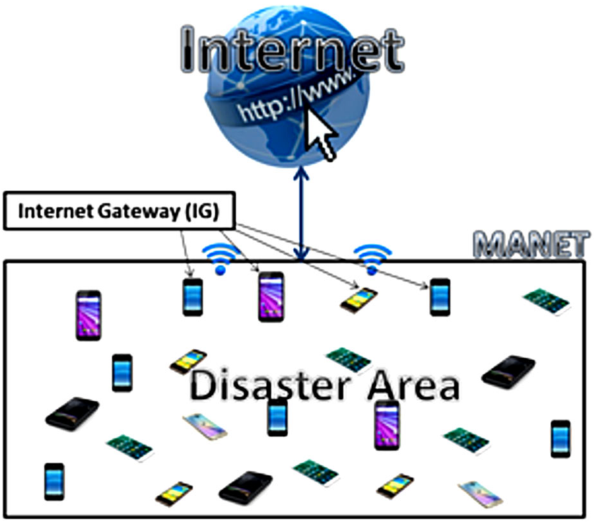

Fig. 3 MANET linked to the Internet

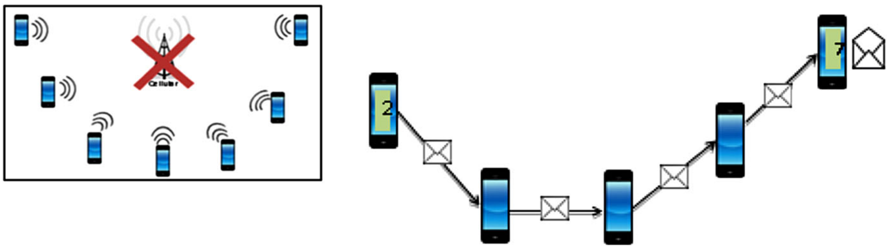

Fig. 4 Neighboring node acting as a relay

During normal situations, most devices rely on the communication infrastructure. However, after a disaster occurs, network devices are isolated due to collapsed and damaged infrastructures of communication. By using a MANET, however, the nodes can still communicate with each other. For example, if the destination node is not in the source range, then a neighbor node will act as a relay to forward the message until it reaches the destination (see Fig. 4).

4 Proposed Scheme

In this study, we compare our proposed scheme with AODV routing protocol. AODV is one of the routing protocols used in mobile ad hoc networks [25]. AODV uses the hop count to find the shortest path from the sender to the receiver. It is a trusted metric, which is simple and effective. It uses a reactive routing protocol. The route from the sender to the receiver is only established when it is needed. A sender node will broadcast a Route Request (RREQ) for connection and an intermediate node will forward the message until it arrives at the destination node. A broadcast technique floods the network by sending messages to all nodes within range to find the best route [26]. Each node that receives the message will record temporary routes back and then the routes with less hop number are chosen. Therefore, the routing overhead can be reduced. However, the main problem is a delay because of the need to wait for the route connection to be established from the sender to receiver. In addition, when the nodes in the network are in a high-speed mobility, a broadcast storm causes MANET performance degradation due to packet delay and network congestion [27].

Therefore, we have proposed a scheme of gateway load balancing and routing selection protocol to balance the load at a gateway node and to intelligently choose the route. Our scheme uses both reactive and proactive routing protocols. Before communication nodes in the network begin working, the gateways in a MANET network will advertise their location periodically to all nodes within the range. Each node that receives the advertisement will store the information of the nearest gateway in a routing table. When a node outside the gateway range wants to send a message, other nodes will forward the message until it arrives at one of the gateways. However, if a gateway is in a heavy load condition, the notification will be advertised. Hence, the nearest node will find another nearest gateway that is available. As in our previous work [28], we use the forward and backward technique to prevent packet loss. We know packet delay will increase as the technique is used, so we made improvements using the notification of heavy loads at the first stage.

4.1 Proposed Gateway Load Balancing

Figure 5 illustrates a scenario where MANET nodes act as gateways. We assume that all nodes in MANET networks are isolated except for three nodes that are in Internet range. As shown in the flowchart (Fig. 6), the other nodes that want to communicate with nodes outside the MANET network must go through these three nodes. These nodes will be a gateway for the MANET network. Only the gateway will broadcast an advertisement to the nearest node in their coverage range. Nodes that receive the advertisement will keep the information of all gateways. Therefore, when the nodes receive a heavy traffic load notification from one of the gateways, the message will not be sent to that gateway. On the other hand, the message will be forwarded to other gateways that are available. Each gateway has an average queue size to monitor. If the queue size approaches full, notification will be sent to nodes in the coverage ranges [29].

4.2 Proposed Routing Selection Scheme

As in previous work [28, 30], our scheme will intelligently manage the transmission of a message from a node to a gateway. To initialize the route from the sender to receiver, those nodes will refer to routing tables to choose which routes are available. Figure 7 shows the flow chart of the proposed routing selection scheme. We propose a routing selection scheme to simplify the selection of the route.

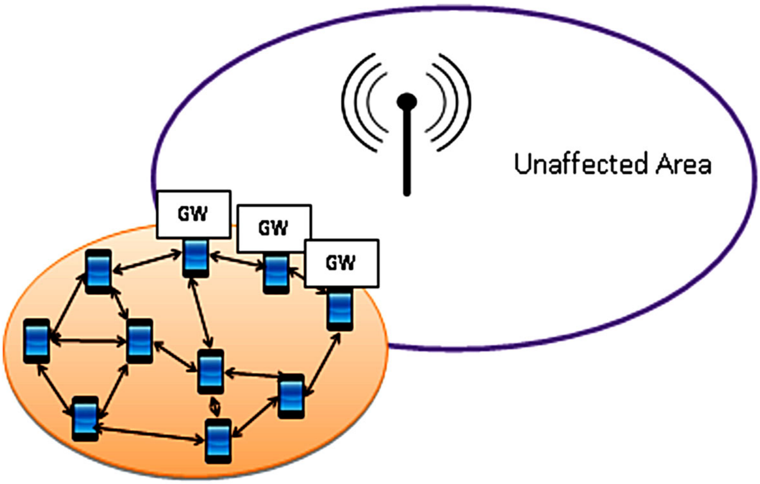

Fig. 5 Some MANET nodes act as gateways

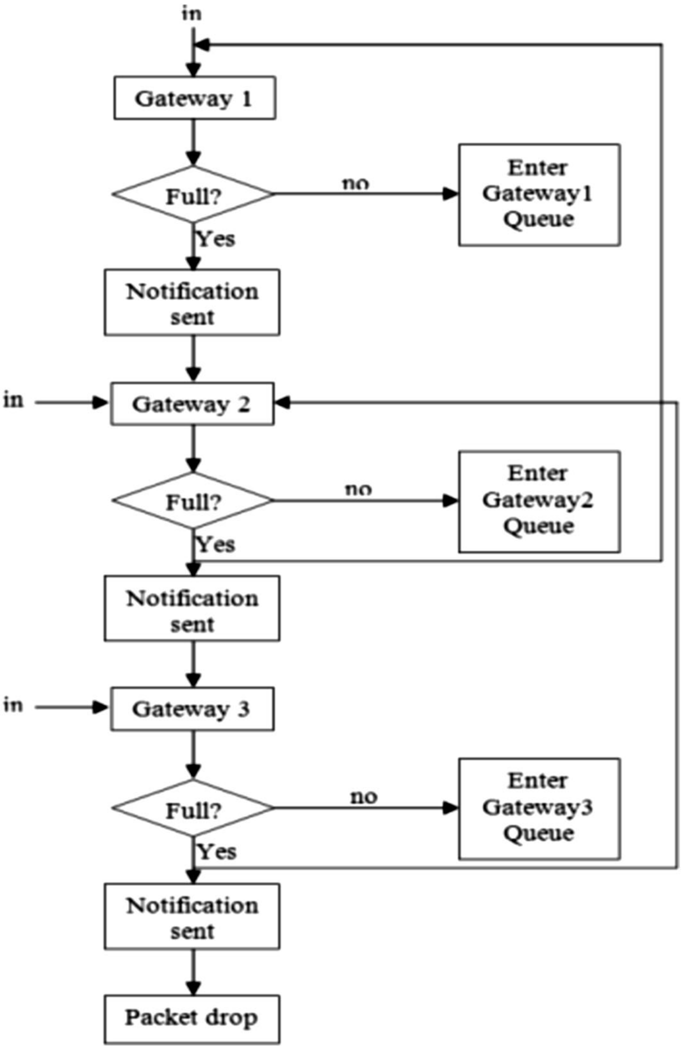

Fig. 6 Flowchart of the proposed gateway load balancing scheme

5 Performance Study Through Simulation

In a multihop wireless network, the evaluation of network performances can be done through analytical modelling, experimentation networks (testbeds), or software-based simulators. The analytical model involves certain simplifications and predictions of the performance. Oversimplification and the wrong prediction will lead to false results. Testbeds are generally used to set up a real application scenario on real hardware. Since the experiment uses actual equipment, the results obtained are practically accurate. However, since all the actual equipment can be expensive, usually only small-scale applications with a smaller number of nodes are

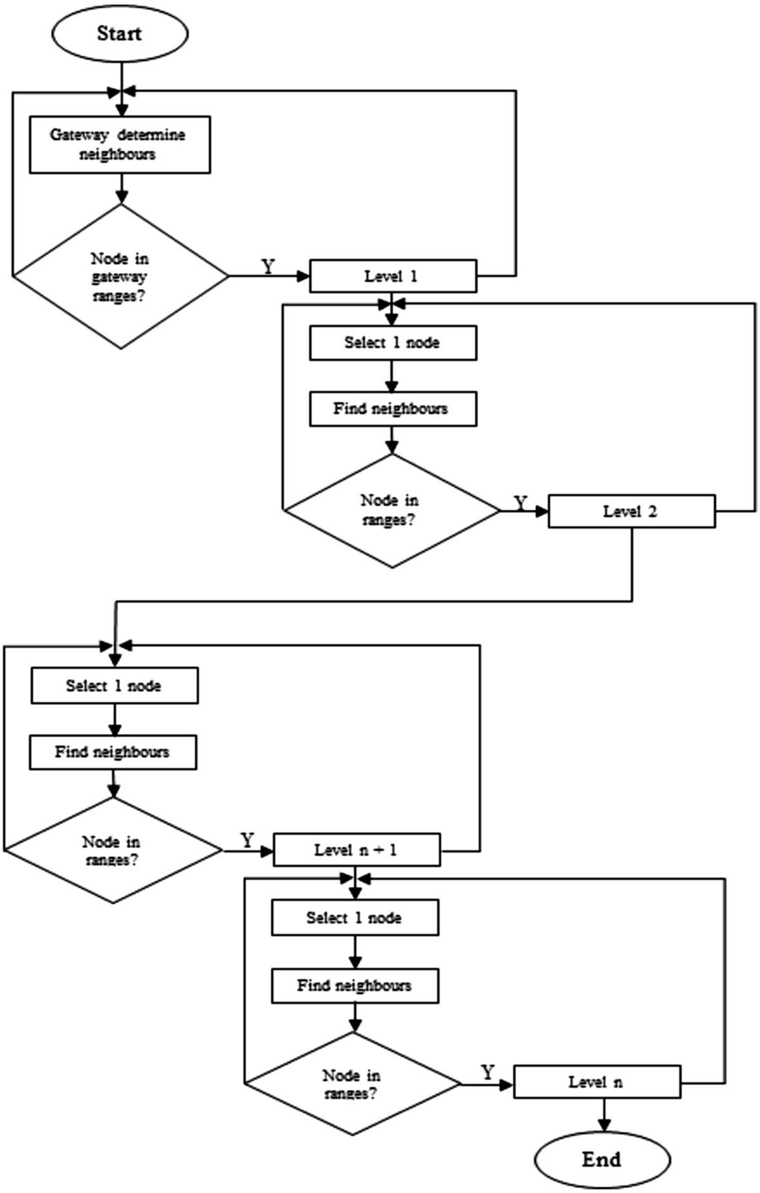

Fig. 7 Flowchart of the proposed routing selection scheme

involved. For economical experiments, a simulation is the best option because it can be carried out without the real hardware. Besides, simulation is more flexible in simulating MANET with a large queue size, large bandwidth, and a large number of nodes.

In addition, simulation results are easier to analyze as some information at critical points can be easily logged to diagnose network protocols. Table 2 lists commonly used simulation tools (both open and commercial) for simulation tasks [31, 32].

The Objective Modular Network Testbed in C++ (OMNET++) has been selected for network modeling and simulation tasks because of its availability and credibility. This simulation tool is a well-designed simulation package written in C++. It is open source and has extensive GUI support to make the tracing and debugging process easier to compare to other simulation tools [33]. Furthermore, OMNET++ allows the user to design and develop a scenario of network simulation graphically. These features will give a precise picture of the simulation at the state of execution. Those scenario topologies can be generated as NED files. In addition, OMNET++ supports hierarchical modeling. This feature allows zooming into the component level and displaying the state of each component during simulation to observe the data flow and node communications.

The basic entity in OMNET++ is a module. Each module has an actual behavior and can be formed as a submodule. The modules can communicate with each other by sending and receiving messages via connections. OMNET++ applicable can simulate a complex IT system, queuing networks, and hardware architecture, for example. In addition, it has an NET extension framework to support wireless and mobile network simulations. Many network researchers have used OMNET++ for simulation and performance evaluation of MANETs [31, 32, 34].

In this paper, we have conducted a simulation of a gateway load balancing scheme and a gateway selection path scheme using OMNET++. We have set MANET nodes to 50 and distributed them within the area of 1200 m $\times$ 800 m. The transmission range of each node is equal to 250 m. Using a Random Waypoint model, the mobility speeds are set to 2 mps and the data rate is 2 Mbps. The simulation time is 900(s). In this simulation, we have identified node 8, 15 and 49 as

Table 2 Commonly used simulation tools

Name	Type	Mobility	Simulation technique	Interface
NS-2	Open source	Support	Discrete event simulation	C++/OTCL
NS-3	Open source	Support	Discrete event simulation	C++/Python
OPNET	Commercial/academic	Support	Discrete event simulation	C
OMNET++	Open source	Support	Discrete event simulation	C++
GloMoSim	Open source	Support	Discrete event simulation	Parsec (C-based)
J-Sim	Open source	Support	Discrete event simulation	Java
Jane	Free	Native	Discrete event simulation	Java
QualNet	Commercial	Support	Discrete event simulation	Parsec (C-based)
SWANS	Open source	–	Discrete event simulation	Java
GTNets	Open source	No	Discrete event simulation	C++
NAB	Open source	Native	Discrete event simulation	OCaml
NCTUns	Open source	Support	Discrete event simulation	C

nodes that receives Internet coverage. Therefore, this node will be a gateway to all MANET nodes that do not have Internet coverage. The destination of all messages is the gateway. Gateways initialize current positions and then determine who the neighbor is, followed by nodes at each level determining their neighbor to find the easiest route to the gateway. Each message is passed up to a higher level in the sender transmission range.

When a message is received at higher level nodes and that node is not the destination, the nodes will forward the message to the higher level in the range. This process will be repeated until a message arrives at the destination node. If the higher level node is small (TTL ≤ 1), the message cannot be forwarded.

To reduce congestion and the complexity of routing selection, we simplify the routing table into several levels. Each node in that level that receives the message will forward the message to the next upper level instead of broadcasting it to all the nodes. The AODV routing protocol broadcast technique will result in packet

Node	Neighbour	Neighbour	Neighbour	Neighbour
0	11	44	33	25
1	32	35	36	13
2	39	14	42	18
3	46	10	24	0
4	12	27	9	43
5	38	43	33	6
6	1	5	33	44
7	2	22	4	17
8	28			
9	27	19	43	38
10	3	46	24	25
11	30	44	23	26
12	4	27	19	37
13	1	5	6	15
14	39	14	42	2
15	31	45	32	36
16	49	48	47	41
:	:	:	:	:
43	6	1	5	38
44	23	26	45	32
45	44	26	23	31
46	3	10	24	
47	16	49	48	28
48	49	16	29	47
49	29	16	48	47

Fig. 8 The complexity of the routing table

					15	49	8				
	31	45	32	36	35	13	29	16	48	47	28
6	23	26	44	5	1	38	41	49	7	8	
33	11	30	0	43	4	17	20	22	9	2	
40	25	24	10	3	27	12	39	19	14	42	18
21	46	34	37								

Fig. 9 Routing table of proposed routing selection scheme

Table 3 Node movement in proposed routing selection scheme

Gateway nodes
Level 1 (One Hop)
Level 2 (Two Hop)
Level 3 (Three Hop)
Level 4 (Four Hop)
Level 5 (Five Hop)
:
Level n (n Hop)

flooding (see Fig. 8) in the network, especially when there are many nodes in the network.

After applying the proposed algorithm, the complexity of the routing table can be simplified as below:

In this paper, we showed how our proposed scheme works. For example, node 11 wants to send a message to another node outside MANET, however, node 11 is not in Internet gateway range. Therefore, the message must go through a multi-hop communication via node 8, 15, or 49 to get to the Internet. Using our result of the proposed routing selection scheme as in Fig. 9, node 11 is at level 3. Thus, this node will look up at the upper level, which is level 2, to determine which node in level 2 is in node 11 range. In this study, our scheme determined node 44 is a node 11 neighbors which is in node 11 range. Therefore, the message is forwarded to node 44. The same step is repeated until the message arrives at the gateway node. The total number of hops is 3 (Table 3).

As shown in Fig. 9, the results of the routing table are obtained after applying our proposed algorithm. The complexity of the route can be simplified using our proposed routing selection scheme. Hence, this result indicates that the total number of hops can be minimized and the shortest path determined. Interestingly, this method can be executed on any node of a gateway on the Internet of Things.

6 Conclusions

In this paper, we have proposed new schemes for MANETs routing and gateway load balancing in a disaster scenario. In a disaster recovery scenario, the communication infrastructure may break down leading to a communication failure. Although MANET can be deployed for applications such as disaster recovery, the network will become congested with a high level of data traffic as victims seek to contact family and friends. To connect to an outside network, the nodes in MANET send a packet to the nearest gateway regardless of the gateway load. To overcome this issue, we introduced a gateway selection scheme to manage the traffic. These schemes can be used at gateways to equal the task between all gateways. In addition, this technique can significantly reduce congestion at each gateway, consequently improving MANET's performance by increasing the number of packet throughputs.

Other methods use fewer hop nodes as the shortest path, but this will cause a bottleneck, thereby decreasing network performance. MANET is a type of ad hoc network. A node in MANET can move randomly and nodes can connect to each other wirelessly. Because the nodes are mobile, the mobility has a significant impact on the routing performance. The performance of the routing scheme depends on the total duration of interconnection between any two nodes. However, the interconnection may be lost during data transmission caused by mobility. Therefore, our concern has been to simplify the routing selection process in an environment of mobility to reduce the complexity of the original routing table. The significance of the proposed scheme is the reduction of network congestion and consequently, improved packet transmission in MANET performance.

For future work, to provide reliable communication between nodes in MANETs, the route establishment process should have more reliable links. Reliable links will depend on the remaining battery lifetime of the node. Therefore, network lifetime will be another important performance metric to optimize.

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