QoS Routing for MANET and Satellite Hybrid Network to Support Disaster Relives and Management

Xin Yang, Zhili Sun, Ye Miao, Haitham Cruickshank
Institute for Communication Systems
University of Surrey
Guildford, UK
{xin.yang, z.sun, y.miao, h.cruickshank}@surrey.ac.uk

Abstract—**Communication technologies are very important for disaster management. Satellite network's advantage of large coverage and Mobile Ad hoc Network's (MANET) advantage of high flexibility could be ideal for disaster management. In this paper, the authors propose a novel scheme for providing reliable wireless communications in disaster sites with a hybrid network of terrestrial MANET and satellite network. In comparison with normal wireless routing approaches, i.e. AODV and AOMDV, the proposed scheme could achieve higher packet delivery ratio, higher throughput and lower delay; meanwhile it could also balance traffic loads at gateways to maximum satellite links' utilization.**

Keywords— MANET; satellite communication; QoS; load balancing.

I. Introduction

Disasters, such as floods and earthquakes, are tragedies that could lead to massive damage to buildings and even human lives in addition of losing communication infrastructures. Take earthquakes for example, there have been 74 earthquakes of magnitude of 6 or above happened all over the world just in the first half of 2015 [1]. The worst one of them could be the April 2015 Nepal earthquake, which killed nearly 9,000 people while injured about 23,000 [2].

In most circumstances, governments and independent rescue teams would go to the disaster site as soon as possible after the tragedy happens to save as many lives as they can. However, due to the massive destructive power of natural or man-made disasters, basic infrastructures like mobile base stations and antennas could be totally damaged. Hence, the lack of reliable communications for rescuers would hamper rescue process, which could then lead to more life and money loss.

Mobile Ad hoc Network (MANET) and satellite networks are applicable for disaster sites due to their flexibility. MANET is a kind of wireless network that does not require additional network infrastructures, such as Access Point (AP) or Base Station (BS), other than normal mobile nodes. Each mobile node will act as both transceiver and router to form a temporary and self-organized wireless network [3]. This characteristic potentially promotes mobility for mobile nodes to suit various scenarios, especially for situations that lack network infrastructures. Satellite networks usually cover a large area; many of them could provide global coverage. Based on the different orbit heights from low to high, communication satellite orbits could be classified as Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO) [4]. The hybrid network of MANET and satellite network, with the advantage of global coverage and high flexibility and mobility, could be an ideal selection, sometimes the only selection, for providing a reliable communication network for disaster sites.

In this paper, we present a novel routing mechanism for offering reliable MANET-satellite hybrid networks for disaster management to fulfil Quality of Service (QoS) requirements. Its performance is compared with some original reactive MANET routing protocols, i.e. Ad hoc On-demand Distance Vector routing (AODV) and Ad hoc On-demand Multipath Distance Vector routing (AOMDV). In our previous research, proactive routing protocols could not achieve satisfying performance, hence they will not be discussed in this work. Their performances are judged based on Packet Delivery Ratio (PDR), average throughput and average end-to-end delay.

The following part of this paper is arranged as follows: Section 2 presents the designed architecture of proposed MANET-satellite hybrid network. The principles of the proposed routing mechanism are described in Section 3, and its performance will be demonstrated in Section 4. Finally, a brief conclusion and ideas about future work are included in Section 5.

II. Network Architecture

Based on MANET's advantage of high mobility and satellite network's advantage of large coverage, the combination of these two instances of communication networks could ideally provide networks to any disaster site on earth. The designed hybrid network is demonstrated as Fig. 1.

As Fig. 1 shows, MANET is used on the disaster site, and satellite links are used to transmit packets between the disaster site and the main network gateway at the HeadQuarter (HQ). The dashed lines represent for wireless communication links. Every rescue team member carries a hand-hold device for data transmission; hence these hand-hold devices act as the mobile nodes in MANET.

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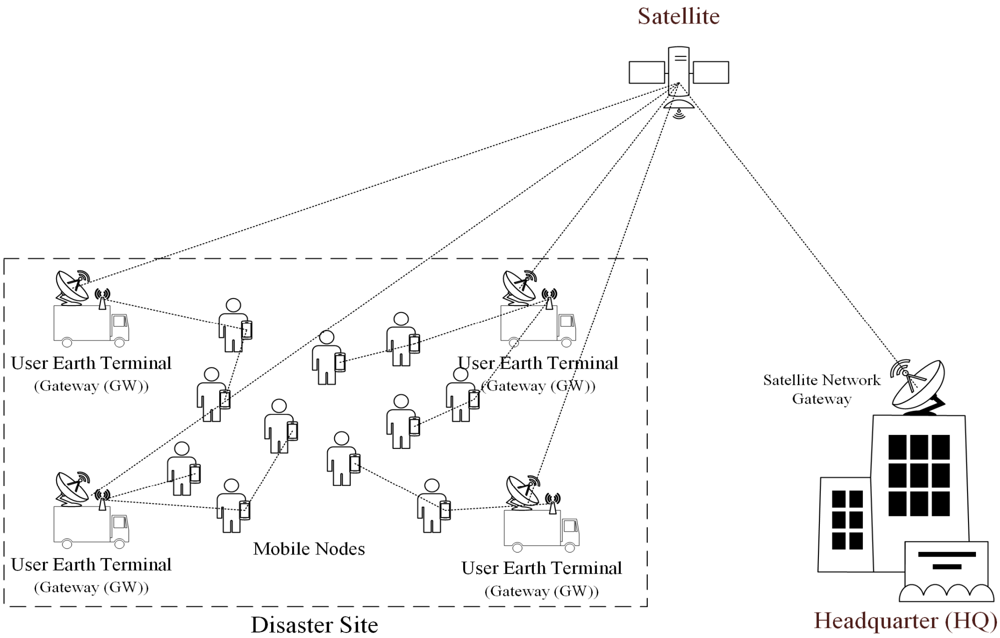


Fig. 1. Network Architecture

As described above, in order to allow mobile nodes to exchange information with the HQ far away from the disaster site, satellite links are used. However, due to the consideration of cost and energy consumption of the hand-hold devices, it could be inappropriate to give every device the ability for connecting satellites. Normally, the rescue team members would take vehicles to approach disaster sites. Satellite dishes could be easily fit to the vehicles, so these vehicles could act as gateways for the mobile nodes to get connected with satellites. One or two of the mobile devices could also have access to satellites directly. In addition, the gateways are also a part of the terrestrial MANET; packets are transmitted between mobile nodes and gateways in ad hoc manner.

III. Proposed Scheme

In disaster management, what matters most is to meet the requirement of successful delivery of packets since each packet may contain information about a survivor of the disaster. In comparison, the end-to-end delay of a packet could be less important as long as the delay is not dramatic; for instance, less than a few seconds delay normally would not lead to significantly different results in life-saving. According to the hypothesis above, we will mainly focus on routing protocol's performance on PDR, and the rest metrics will be less weighted.

In a hybrid network, gateways could always be the bottlenecks of network's performance since they are much fewer than mobile nodes and act as the 'bridges' between two different networks [5]. Therefore, the most critical parts in hybrid network routing could be gateway discovery and gateway selection.

A. Gateway Discovery

As described above, gateways in the proposed network are treated as mobile ad hoc nodes. Hence, normal MANET routing protocols could also work in the gateway discovery process.

Due to the complicated node movement patterns in the proposed scenario, which is generally each mobile node moving randomly within the disaster site with normal walking speed, proactive routing protocols may not offer reliable connections for all nodes; our previous research proves this already [6]. According to this reason, we deploy reactive routing protocols in disaster site. By broadcasting Route REQuest (RREQ) message when a node needs to discover a route to the destination, reactive routing protocols, such as AODV, could automatically adapt to topology changes [7].

B. Gateway Selection

In normal wireless networks, every mobile node will be assigned to an Access Point (AP). Wherever the mobile node's position is, it will try to connect to its AP before it can actually transmit any data. The main drawback of such mechanism is when a node has moved far away from its allocated AP, its transmission could involve many other nodes for packets relaying, which would lead to high delay, high bandwidth consumption and occasional low PDR.

In our proposed mechanism, the principle of multipath routing in AOMDV [8] is used in the gateway selection process. Instead of being assigned to a specific AP, each node will also monitor the status of all other available APs (gateways) according to three metrics:

- Residual path bandwidth. It is the available bandwidth along the path from source to destination. Residual path bandwidth B from source node n_s to gateway node n_g is:

$$\mathrm{B}(\mathrm{n}_i, \mathrm{n}_g) = \min b_{\mathrm{n}_i \mathrm{n}_{i+1}} \quad (i = 0,1, \dots, n-1) \qquad (1)$$

Where n is the hop count of the path, n_i is the i-th node from source node n_s along the path, $b_{\mathrm{n}_i \mathrm{n}_{i+1}}$ is the bandwidth between node n_i and node n_{i+1}.

- Latency. It is the overall latency of the transmission path from source to destination. Latency L from source node n_s to gateway node n_g is:

$$\mathrm{L}(\mathrm{n}_s, \mathrm{n}_g) = \sum_{i=0}^{n-1} l_{\mathrm{n}_i \mathrm{n}_{i+1}} \quad (2)$$

Where n_i and n_{i+1} have the same meaning as above, $l_{\mathrm{n}_i \mathrm{n}_{i+1}}$ is the latency from node n_i to node n_{i+1}.

- Reliability. It is the ratio of packets successfully delivered to the destination over all the packets sent. Reliability R from source node n_s to gateway node n_g is:

$$\mathrm{R}(\mathrm{n}_s, \mathrm{n}_g) = \prod_{i=0}^{n-1} r_{\mathrm{n}_i \mathrm{n}_{i+1}} \quad (3)$$

Where n_i and n_{i+1} have the same meaning as above, $r_{\mathrm{n}_i \mathrm{n}_{i+1}}$ is the reliability between node n_i and node n_{i+1}.

The original AOMDV keeps two routes that with the best two metrics, i.e. the lowest hop count, towards the destination; and only use the second route when the first fails [9]. Such mechanism is somehow more flexible than AODV, but it doesn't consider other metrics that could also affect packet transmission, so the final selected route may not be the best choice for the entire network. In contrast, in the proposed mechanism, monitoring latency could help select the shortest path from the source to the destination as lower latency usually means fewer hops; and residual path bandwidth and reliability is helpful when balancing gateways' traffic load, furthermore balanced traffic could maximum satellite links' utilization.

In detail, the proposed algorithm is described as Algorithm 1, in which Q indicates link quality, and αs are coefficients selected according to QoS requirements. For instance, if the transmitted information is delay-sensitive, then α_1 should be increased accordingly.

Algorithm 1: Gateway selection

Input: $B_{0, 1, \ldots, n\_gw-1}$, $L_{0, 1, \ldots, n\_gw-1}$, $R_{0, 1, \ldots, n\_gw-1}$. B is residual path bandwidth, L is latency, R is reliability, and n_gw is the total number of gateways on the disaster site.

Output: Next hop $node_{next}$ and selected gateway $GW_{selected}$.

```
BEGIN
for (n = 0; n < n_node; n ++) {
    if ((routing table is blank) or (routing table is outdated)) then {
        update routing table;
    }
    end if
    else {
        for (i = 0; i < n_gw; i ++) {
            Qi = α_B B_i + α_L L_i + α_R R_i;
            increase seq_num_i in the routing table;
        }
        sort Q_{0, 1, ..., n_gw-1} from the highest to the lowest;
    }
    choose GW_selected with the highest Q as the gateway;
    choose node_next according to the routing information about GW_selected in the routing table;
}
END
```

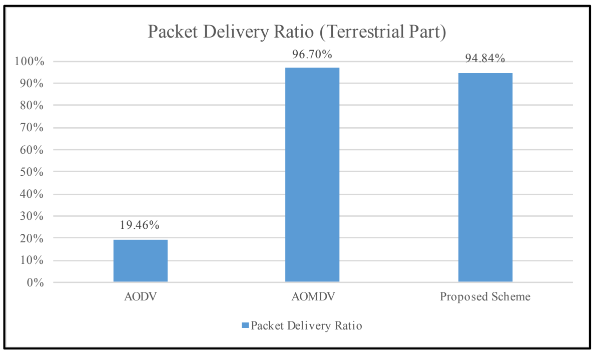
IV. SIMULATION RESULT

To examine the performance of the proposed mechanism, we compare it with AODV and AOMDV in a realistic simulation in ns-2. The simulated scenario is constructed by two parts: terrestrial MANET and satellite links. The two parts are connected via gateways as Fig. 1 illustrated. The disaster site is square, and four gateways are located at each corner respectively because vehicles carrying satellite dishes are unlikely to be driven into disaster sites. The simulation area size is selected as 500 m x 500 m, which is similar to the size of a shopping mall. 64 mobile nodes are used to represent 64 rescue team members, which number is chosen according to the real number (i.e. 62) of rescuers China sent to Nepal [10]. The mobile nodes move randomly in walking speed [11]. GEO satellite is used to simplify the overall settings in the simulation, as satellite links would not affect MANET routing performance. Simulation parameters are shown in Table I. The simulation runs for another 600 s to make sure all the packets sent in the last few minutes of 3600 s could be successfully received by HQ.

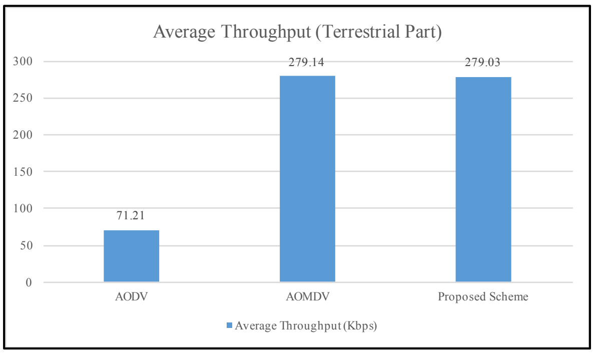
TABLE I. SIMULATION PARAMETERS

Parameters	Values
Area Size	500 m x 500 m
Gateway Number	4
Node Number	64
Maximum Moving Speed	1.5 m/s
Satellite Type	GEO
Simulation Time	3600 s

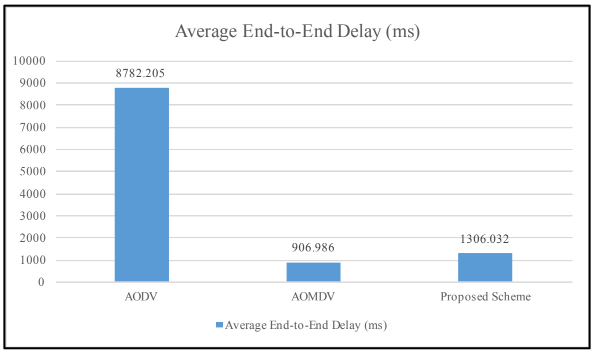
Transmission Control Protocol (TCP) is used to guarantee the successful delivery of every packet, while User Datagram Protocol (UDP) is usually used for real-time audio and video streaming that could also be used during rescue process. In our simulation, it is observed that the choice of transport layer protocol (TCP or UDP) will not affect network layer routing protocol's performance, hence the following results are based on simulations using TCP. The performances, i.e. Packet Delivery Ratio, average throughput and average end-to-end delay, of AODV, AOMDV and proposed scheme are illustrated as Figure 2. In addition, we mostly care about the PDR and average



(a) Packet delivery ratio (terrestrial part)

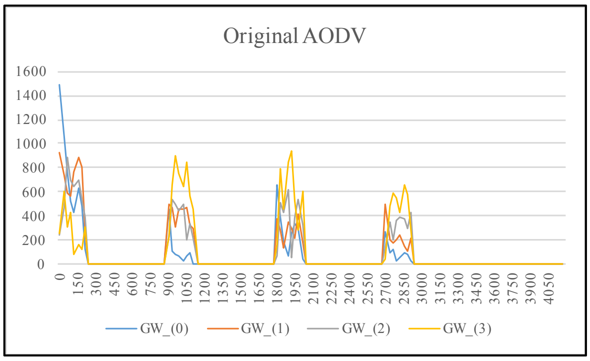


(b) Average throughput (terrestrial part)

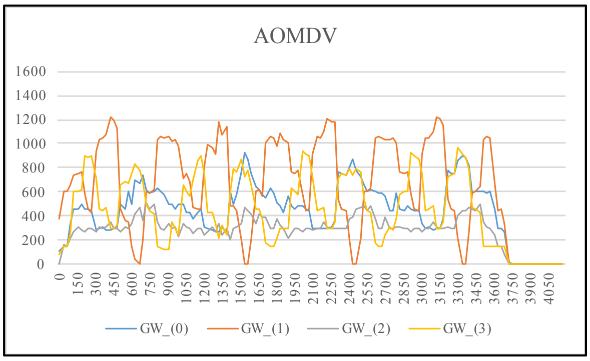


(c) Overall average end-to-end delay

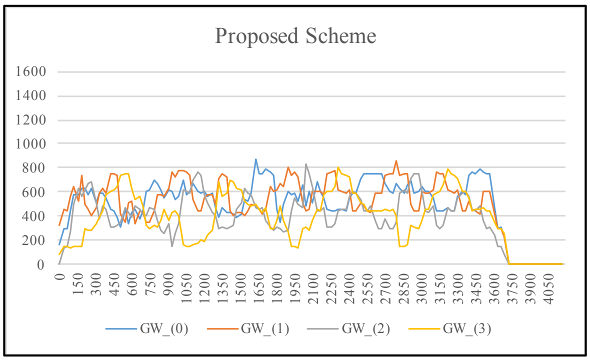
Fig. 2. Performance comparison



(a) Original AODV



(b) AOMDV



(c) Proposed scheme

Fig. 3. GWs' loads over time

throughput in the terrestrial MANET, so these two metrics of satellite links are not shown here.

From Fig. 2, it can be seen that when every mobile node is assigned with a fixed GW, the whole MANET performs the worst with the lowest PDR and average throughput, and the highest average end-to-end delay. In comparison, both AOMDV and the proposed scheme work well with similar performance. The proposed scheme has slightly lower PDR and throughput, and its delay is roughly 400 ms higher than AOMDV. However, as discussed above, such amount of delay difference would not have significant impact on disaster site communication scenarios. In order to further compare the performance between AOMDV and our proposed scheme, we monitor GWs' load over time. The result is demonstrated as Fig. 3.

From Fig. 3 it can be seen that the traffic loads at all GWs in the propose scheme are much more balanced than in the other two protocols; the numbers of packets received at each GW deviate much less in the proposed scheme than in the other two protocols as well. Such behavior could maximum satellite links' utilization and could avoid unexpected traffic bursts which may lead to communication failures [12].

V. Conclusion and Future Work

As described above, our proposed scheme could fulfil QoS communication requirements for disaster sites. Without assigning specific GWs to all mobile nodes as normal routing protocols do, the proposed scheme dynamically monitor all the GWs' status and choose the most suitable one when a node needs to transmit packets. The combination of MANET and satellite network helps provide a highly flexible temporary wireless network to almost any place on the earth. The scheme proposed in this paper could perform better than the classic MANET routing protocols in the case of disaster relieves and management.

In the future, we will examine the proposed scheme's performance in various scenarios and will make modifications accordingly. Future work will also focus more on the satellite part, which includes:

- Performance difference analysis on LEO, MEO and GEO satellite systems;
- For LEO satellites, the satellite formation's impact on network quality;
- Novel routing protocol design for satellite networks with massive LEO satellites;
- Joint routing optimization for both satellite and terrestrial parts.

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