Performance Evaluation of Ad-hoc Routing Protocols in Hybrid MANET-Satellite Network

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Abstract. Hybrid MANET-satellite network is a natural evolution in achieving ubiquitous communication. Their combination gives full play to respective advantages—autonomy and flexibility of MANET, wide coverage and resilience to natural disasters of satellite network. Although large quantities of researches have been conducted on hybrid MANET-satellite network, there are relatively few researches on its routing. In this paper, we construct a basic model of hybrid MANET-satellite network and explore the performance and applicability of ad-hoc routing protocols in hybrid network. Simulation results by NS3 demonstrate that the hybrid network working in ad hoc manner can acquire the performance that conforms to the standard of QoS.

Keywords: MANET · Satellite · Hybrid network · Ad-hoc · Routing

1 Introduction

Satellite network is a momentous pillar of global information infrastructure due to its wide coverage and resilience to natural disasters. Latest advancement in satellite commutation technology enables satellite network to provide 99.99% availability [1]. As a result, satellite based IoT [2,3] comes into sight as supplement and extension to terrestrial IoT network with limited coverage. Low earth orbit (LEO) satellite network whose altitude ranges from 500 km to 1500 km gains academic and commercial popularity for low propagation delay, low launch cost and small propagation loss [4]. OneWeb, Iridium and Globalstar, targeted to global communications and Internet service, are well-known LEO satellite constellations.

On the other hand, mobile ad-hoc network (MANET) meets with great favor among numerous terrestrial networks. MANET came into being for military

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tactical network in the beginning. MANET is an autonomous, temporary and multihop wireless network consisting of mobile nodes. It can be deployed in infrastructure-less environment temporarily. Different from the single hop propagation of cellular network, packets in MANET are transmitted in a store-and-forward way from source to destination via intermediate nodes [5]. Due to its independence of Internet infrastructure and expeditiousness in deploying network, applications of MANET are expanded to desert, forests and coastal waters.

Hybrid MANET-satellite network is a natural evolution in achieving ubiquitous communication [6], which gives full play to respective merits of MANET and satellite network. Various projects about hybrid or integrated systems have been proposed for various purposes, such as SANSA [7], SALICE [8] and MONET [9]. However, these projects either focus on physical layer or discuss the methodology on network layer. A few of them study the performance of routing protocols in hybrid network in detail.

In this paper, we construct a basic model of hybrid MANET-satellite network and apply ad-hoc routing protocols to the hybrid network after obtaining snapshots of satellite network. Simulation results by NS3 verify that ad-hoc routing protocols are applicable to the hybrid network and the delay of hybrid network is up to the standard of QoS.

The remaining of this paper is organized as follows. Section 2 gives a brief review of background and related work. Section 3 depicts a basic model of hybrid MANET-satellite network and introduces the routing mechanism of the hybrid network. Section 4 provides simulation results and analysis. Finally, Sect. 5 concludes the paper.

2 Background and Related Works

2.1 Routing Protocols of MANET

In MANET, all the mobile nodes are equipped with a wireless transmitter and a receiver, which means every node can work as a transceiver or router of other nodes. Because mobile nodes move freely and arbitrarily, the topology of the MANET changes in a random and stochastic manner. The highly dynamic nature of MANET places severe restrictions on routing protocols designed for them [5].

MANET routing protocols are classified into two main categories, the proactive and the reactive. Proactive protocols update the routes within the network periodically, so that when source node needs forward a packet, the route already exists and can be used immediately [10]. Destination-Sequenced Distance-Vector (DSDV) and Optimized Link State Routing (OLSR) are typical proactive protocols. On the other hand, reactive protocols invoke a route determination procedure only on demand [11]. Thus, when a route is needed, some sort of global search procedure is initiated. Examples of reactive protocols include Ad hoc on-demand Distance Vector (AODV) and Dynamic Source Routing (DSR).

2.2 Routing Strategies of Satellite Network

From the perspective of connection, there are two kinds of routing scheme for single-layered satellite network, the connectionless and the connection-oriented. The rapid development of Internet has promoted the application of connectionless scheme in IP-based satellite network. Ekici et al. [12] introduces a distributed routing algorithm (DRA) which selects the path for each packet independently. DRAW in [13] improves DRA's applicability to variable topology. Guo et al. [4] proposed a novel routing algorithm WSDRA whose has much less overhead and delay than DRA.

Virtual topology method is a significant component in the connection-oriented scheme. The Snapshot method is a milestone in the development of virtual topology based satellite routing scheme. Gounder et al. firstly proposed the concept of snapshot in [14]. They defined the snapshot as the topology of the satellite network at a particular instant of time. Song et al. [15] and Tan et al. [16] proposed snapshot integration routing (SIR) method and dynamic detection routing algorithm (DDRA) respectively to improve routing performance. Tang et al. [17] slightly optimized the snapshot based routing by reassigning inter-satellite link (ISL) when simultaneous switch of routing table happens in all satellites.

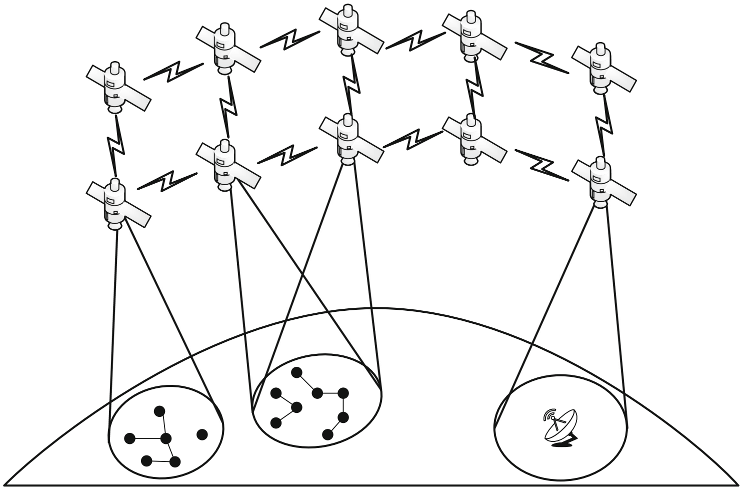

Fig. 1. Model of hybrid MANET-satellite network

3 Hybrid MANET-Satellite Network

3.1 Network Model of the Hybrid Network

Inspired by projects about hybrid networks mentioned above, we construct a model of hybrid MANET-satellite network, as is shown in Fig. 1. It consists of terrestrial MANET, satellite networks and satellite ground station. Terrestrial MANET contains mobile nodes equipped with antenna to communicate with satellites. As long as mobile nodes lie in the footprint of satellites, they can deliver messages to satellites or receive messages from satellites. The backbone of the satellite network comprises LEO constellation. It is responsible for transmitting messages to ground station. To simply our research, we assume that all the satellites transmit messages to a fixed ground station.

3.2 Routing Mechanism of the Hybrid Network

Conventional MANET routing protocols normally assume that nodes move in an entirely arbitrary manner and they can only connect temporarily with other nodes within a certain range. When nodes' random movement brings on link breaks, nodes have to reestablish connections based on network conditions before transmitting packets. Both nodes' movement and link breaks are unpredictable in MANET, while the satellite segment of the hybrid network owns predictable dynamic topology. For the efficiency of routing, we proposed a routing mechanism specified to the hybrid network, which takes regularity and predictability of satellites into account.

The routing mechanism consists of three steps. The first step is to acquire snapshots of satellite segment. By calculating the visibility among satellites in STK in advance, we obtain the data about predictable topology variation of satellite network. The dynamic topology of satellite network is converted into a sequence of static topology after we divide the simulation time T into N equal slots, $[t_1, t_2], [t_2, t_3], \ldots, [t_N, t_{N+1}]$. There are two critical criteria in acquiring snapshots: (1) The slot duration is short enough to guarantee the accuracy of snapshots. (2)We should control the complexity of space and time for the efficiency of routing. A practical approach is to make Δt ($\Delta t = T/N$) no more than the minimum of all visibility durations.

$$\Delta t \leq min\{\tau_1, \tau_2, \ldots, \tau_N\} \tag{1}$$

Secondly, mathematical representations of snapshots are extracted from visibility data. The topology keeps static within a snapshot if no ISL is added or broken. During $[t_n, t_{n+1}](n = 1, 2, 3 \ldots, N)$, if a continuous direct line-of-sight exists between i and j, then i and j are visible to each other. Snapshots S_n are represented by an adjacency matrix M_N whose element is $e_{i,j}(n)$. $e_{i,j}(n)$ represents the pairwise contacts between i and j during slot $[t_n, t_{n+1}]$.

$$e_{i,j}(n) = \begin{cases} 1 \text{ if } i \text{ is visible to } j \\ 0 \text{ else} \end{cases} \tag{2}$$

Thirdly, ad-hoc routing protocols are applied to the hybrid network, where MANET nodes move stochastically and satellite nodes move determinately. For satellite segment, a new snapshot, corresponding to the topology of satellite network during particular slot [14,18], is loaded at the beginning of each slot.

Table 1. Parameters of hybrid MANET-satellite network

Parameter	Value
Mac type	IEEE 802.11
Area acreage	250 m × 250 m
Size of packet	64 bytes
Maximum velocity	2 m/s
Number of source nodes	2, 4, 6, . . . , 20
Number of terrestrial nodes	26
Orbit altitude	1000 km
Half cone angle	10°
Number of planes	6
Satellites per plane	4
Simulation time	200 s, 300 s, 400 s, 500 s, 600 s

4 Simulation and Analysis

4.1 Simulation Settings

A communication scenario is constructed in AGI Systems Tool Kit (STK). The visibility dataset generated by STK is used to produce snapshots of satellite networks. We have established a hybrid MANET-satellite network in NS3, whose specific simulation parameters of hybrid MANET-satellite network are listed in Table 1. Routing mechanism demonstrated in Sect. 3 is adopted in extensive simulations to evaluate the performance and applicability of ad-hoc routing protocols in the hybrid network. We observe the performance by altering the simulation time and the number of source nodes separately.

4.2 Performance Metircs

The reliability and timeliness are significant in communication, so we assess the performance of four ad-hoc routing protocols in the hybrid network through average delay and packet delivery rate (PDR).

Delay. The overall time of a message travelling from the source node to the destination node is called delay.

$$AverageDelay = \frac{1}{N}\sum_{k=0}^{n-1}(rt_k - st_k) \tag{3}$$

rt_k: the moment when the kth packet arrives at the destination
st_k: the moment when the source generates the kth packet
N: number of packets successfully delivered

PDR. The ratio of packets delivered to the destination successfully to total number of packets sent by the source node is named PDR (Packet Delivery Rate).

$$PacketDeliveryRate = \frac{P_d}{P_s} \times 100\% \tag{4}$$

P_d: number of packets successfully delivered
P_s: number of packets the source node generates

4.3 Results and Analysis

In Fig. 2, the PDR of the hybrid network falls dramatically at 400 s. Snapshot transition is a probable explanation for this phenomenon. It is very likely that snapshots from 200 s to 400 s are quite different from each other. Routing strategies cannot respond to topology changes timely, especially proactive ones. For proactive routing protocols, when enormous differences exist among snapshots, routing tables based on the previous snapshot are useless for the routing of the next snapshot. In the hybrid network, PDRs of different protocols are close to each other when simulation time is less than 400 s. When simulation time is more than 500 s, the growth rate of PDR slows down and value of PDR tends to be stable, which means that the maximum PDR of the hybrid network is around 70%, 20% less than that of MANET. It is because link breaks in satellite segment are more frequent. The PDRs of reactive protocols exceed those of proactive ones for the first time at 500 s, which indicates reactive protocols are more flexible in the case of great topology changes.

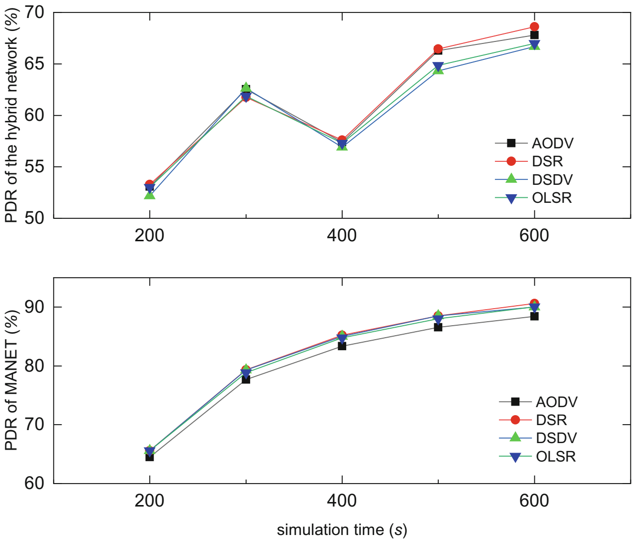

Fig. 2. PDR vs. simulation time

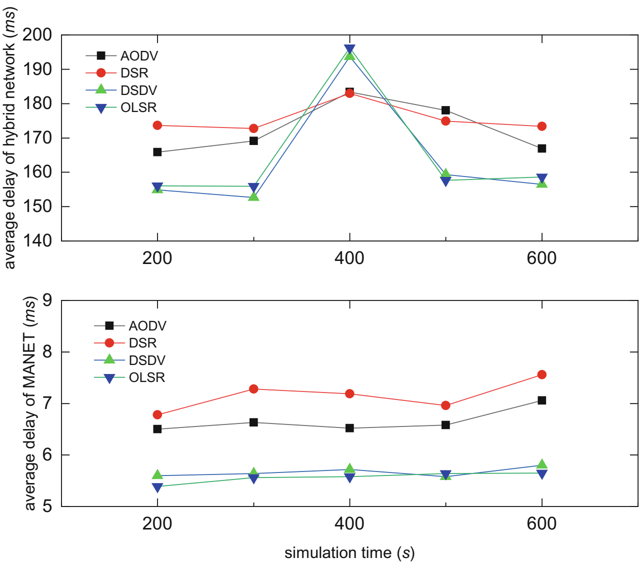

Fig. 3. Average delay vs. simulation time

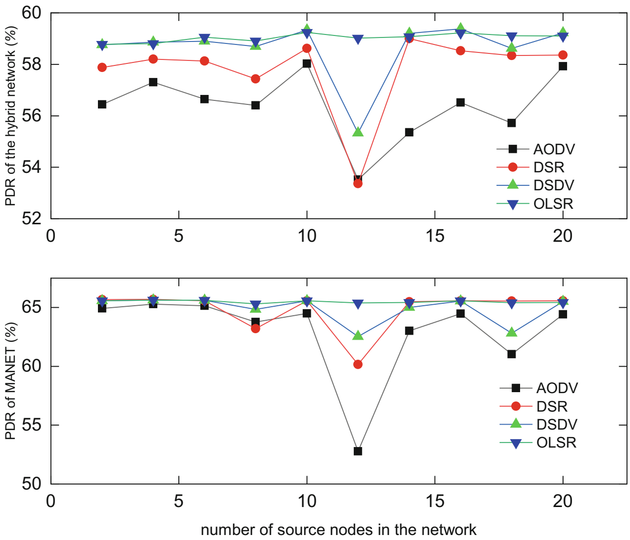

Fig. 4. PDR vs. number of source nodes

In Fig. 3, for hybrid network at 400 s, the delay of OLSR and DSDV rise by 27% suddenly and delay of AODV and DSR rise by 6%. By contrast, the delay of MANET keeps stable. The upsurge is mainly ascribed to snapshot transition where topology changes dramatically. Most nodes in the network have to

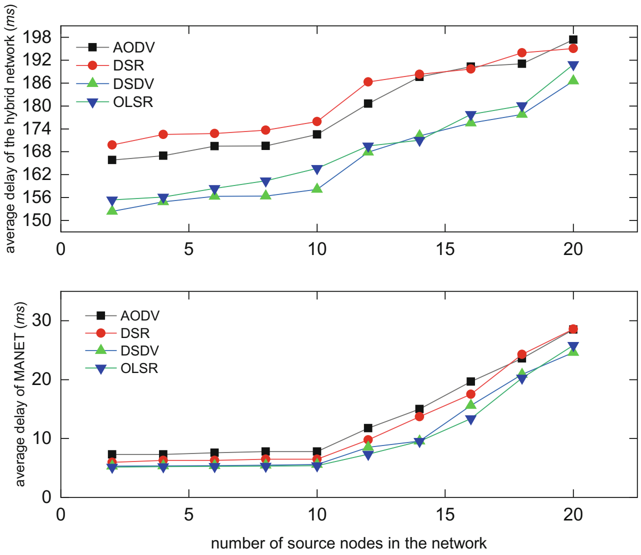

Fig. 5. Average delay vs. number of source nodes

re-establish routes in this case, which adds to the end-to-end delay. The sharp increase of delay corresponds to the sudden decrease of PDR in Fig. 2 at 400 s. The minimum and maximum of the delay in hybrid network are 152 ms and 196 ms respectively, both of them meeting the requirement of QoS class1 [20]. The upper subgraph shows that although the delay of reactive protocols is around 20 ms more than that of proactive ones under normal circumstances, the reactive protocols are more robust in dynamic environment, for the delay of AODV and DSR raises slightly, while that of DSDV and OLSR raises dramatically. Thus, AODV or DSR may be adequate for networks that are sensitive to delay jitter.

It is obvious in Fig. 4 that the trend of PDR in hybrid networks is the same as that in MANET on the whole. Except a few extremes, the PDR of hybrid network fluctuates around 58%, 7% less than that of MANET. The PDRs of AODV, DSR and DSDV all drop to the lowest when number of source nodes increases to 12. On the contrary, the PDR of OLSR remains stable, almost unaffected by the number of source nodes, which is attributed to the periodic maintenances and update of routing information of OLSR. When the number of source nodes equals 12, the PDR of the hybrid network and MANET slump to the minimum. Possible reason is that severe congestion makes packets at queue tail discarded. PDR of both networks rises to average again when number of source nodes exceeds 12. This phenomenon deserves further research.

In Fig. 5, the delay of both networks start to grow when number of source nodes exceeds 10 and the delay of hybrid network varies from 150 ms to 200 ms. This result is reasonable because the scale of satellite network is much larger than that of MANET. Furthermore, the typical value of end-to-end delay for

LEO satellites from [19] is 80–120 ms. Thus, it is meaningless to compare the delay of hybrid network with that of MANET. The delay of OLSR is the lowest in the hybrid network, which is attributed to the mechanism of OLSR. OLSR requires each node to maintain at least one table to store routing information about every other node in the network. Whenever a route is needed, there is negligible delay in determining the route. Consequently, OLSR is preferred for real-time communication. DSR and AODV perform worse than OLSR and DSDV in average delay. It is because route information may be unavailable when a packet is to be transmitted. Nodes have to wait until a route has been determined.

5 Conclusions

In this paper, we construct a basic model of hybrid MANET-satellite network and study the performance and applicability of ad-hoc routing protocols in hybrid network with MANET as a reference. Based on simulations by NS3, we come to three conclusions. Firstly, the delay of ad-hoc routing protocols in hybrid network conforms to the standard of QoS class1 [20]. Secondly, OLSR applies to hybrid networks that place high requirement for reliability and real-time performance. Last but not least, reactive protocols are more suitable for hybrid networks that are sensitive to delay jitter due to their robustness to topology changes.

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