Study on Research Challenges and Optimization for Internetworking of Hybrid MANET and Satellite Networks

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Abstract. The integrated MANET and satellite network is a natural evolution in providing local and remote connectivity. The features of this integrated network, such as requiring no fixed infrastructure, ease of deployment and providing global ubiquitous communication, give advantages of its being popular. However, its unpredictable mobility of nodes, lack of central coordination and limited available resources emphasizes the challenges in networking. A large library of studies has been done in literature, yet some issues are still worth tackling, such as gateway selection mechanisms, satellite link management, resource management and so on. As a basic step of internetworking, the issue of gateway selection is studied specifically and corresponding optimization scheme for achieving load balancing is described.

Keywords: Internetworking, hybrid MANET-Satellite network, gateway selection, load balancing.

1 Introduction

The current trend of communication is shifting towards global ubiquitous networking and universal access for mobile users that wish to communicate with others through heterogeneous technologies (e.g. cellular networks, Wireless LANs and Satellite networks)[1][2]. The ultimate goal of wireless communication is to allow users to communicate reliably at anytime and anywhere. A mobile ad hoc network (MANET) is a self-configuring infrastructure-less network with mobile devices connected by wireless. Due to the cost-effective and ease of deployment, MANETs are widely used in military applications, emergency rescue operations and applications in infrastructure-less or remote areas for extending communications. Despite that MANETs are normally envisioned to operate as stand-alone networks, they can be extended by integrating with other networks (e.g. cellular networks and satellite networks). In order to achieve a real sense of worldwide communication, satellite, sometimes, is the only solution for MANET to communicate with other parts of the world [3] and bridge the digital divide [2]. In this regards, satellite is not only utilized as a component of an alternative routing path but also considered as part of integrated complete system. Convergence of satellite and terrestrial networks is becoming a key factor in forming the foundation for efficient global information infrastructure [3].

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The integrated MANET and satellite network is therefore a natural evolution in providing local and remote connectivity in a highly mobile, dynamic and normally remote environment. Since both MANET and satellite networks possess their own unique characteristics, the integration work inevitably raises significant research challenges in terms of system architecture, overall routing protocol design, mobility management, resource allocation and management, and provisioning of Quality of Service (QoS) and Quality of Experience (QoE). On one hand, MANETs are characterized as dynamic network topology, unreliable channel share, self-configuration format and limited resources. On the other hand, satellite network is characterized as costly resources, long propagation delay, errors due to propagation and handovers and variable round trip time (RTT).

The rest of this paper is organized as follows: Section 2 presents the architecture of the integrated MANET-Satellite network. The relevant research challenges are discussed in Section 3. As one of the challenges, the issue of gateway selection for achieving load balancing is studied specifically in Section 4, and corresponding optimization schemes are described in Section 5. Section 6 explains the simulation setup and result analysis. Finally, conclusion comes in Section 7.

2 Architecture

Existing satellite systems can be geostationary earth orbit (GEO) systems and non-geostationary (NGEO), for example, low/medium earth orbit (LEO/MEO). Both of them can be the satellite constellation in integrated networks [4]. These two types share some issues when integrated with MANET, but also have their own particular problems. In this paper, we discuss not only the common issues, but also the issues mainly target to a certain satellite constellation type. A general architecture of the integrated network is depicted in Figure 1. A MANET cluster consists of a set of MANET nodes connecting to each other by appropriate wireless way (e.g. WiFi). A general MANET node (MN) is only equipped with WiFi interface and thus directly connect to other nodes as long as they are in wireless link range. Each cluster has at least one node with satellite interface capable of performing communications to a satellite. If the interface is activated, the node is a gateway node (GW). The internetworking related operations are also done in gateway nodes. The general node has all the services of a MANET node, including sending and receiving information without any specific task. A gateway node acts as a general node and also an entrance or exit to another network via satellite interface. It is used to forward traffic for external network (e.g. another MANET or satellite network), which means it is possible to communicate with different types of networks. That means the only way for a general mobile node to communicate with external networks is to communicate via a gateway node. Each MANET network has one or more gateway nodes capable of performing links to satellite network. When a node equipped with satellite interface is in de-active state, it is a potential gateway node (PGW). Under certain conditions, these nodes are activated to be gateway nodes to perform connections and allow MANET cluster to communicate with backoffice (BO) or other networks in remote area without direct link range and access information provided by other networks.

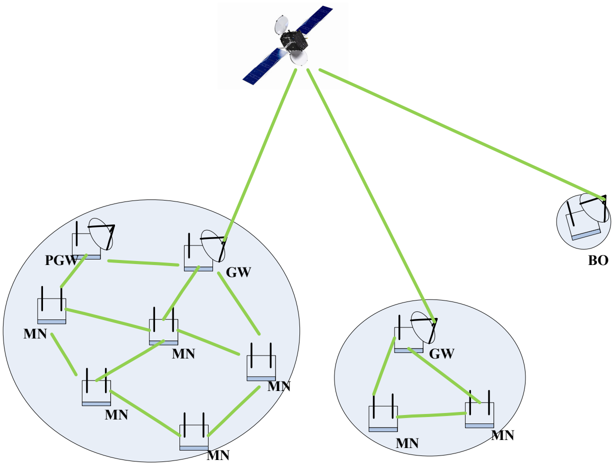

Fig. 1. Architecture of integrated network

The overall objective of integrating MANET with satellite network is to provide seamless broadband services to each node at any time in the network, overcome performance bottlenecks, and further optimize the usage of overall resources. In this regard, research issues should be considered at various aspects. Firstly, it is necessary to ensure the end-to-end communication. How to find a feasible route is always essential in a communication network. Based on the given criteria, different routing algorithms will be applied considering the link quality and QoS requirements. If there are two or more gateway nodes within the MANET, there should be an election process to select certain gateway(s) to perform the link to satellite. Secondly, as essential characteristics of MANET, mobility and scalability, require consideration when designing system. Ground segment handover and link layer handover are included in these issues. Another important aspect is to provide QoS guarantee which can be maintained by efficient resource management/allocation mechanisms. Load balancing is designed to balance load repartition and resource consumption over ground-part network. And CAC can be used to solve resource management issues especially in limited and costly resources network.

3 Challenges in Integrated Network

Since both MANET and satellite networks possess their own unique characteristics, the integration work inevitably raises significant research challenges in terms of system architecture, overall routing protocol design, mobility management, resource allocation and management, and provisioning of Quality of Service (QoS). In this section, four challenges will be discussed (routing interoperability, gateway selection mechanisms, satellite links' management and resource management) respectively.

To connect MANET with satellite networks, the routing interoperability, which means how to enable the routing protocols from both segments to understand each other and work together seamlessly, is a challenge. The routing integration solutions can be divided into two groups. On one hand, the existing routing algorithms are adopted with proper access design for the other segment. That means one or several mechanisms can be implemented in the integrated system and adopted for both segments. For example, extension mechanism can be done in ad hoc routing protocol to support routing across the gateway to the other network. In this case, mobile nodes in MANETs can be capable of discovering and maintaining routes to the destination in different network domains. On the other hand, disparate routing strategies can be adopted in two segments. In this case, the interface between two sets of mechanisms must be defined carefully to translate the protocols for communications between different segments. The advantage is that only the characteristics of each segment need to be considered when come to disparate routing protocols design.

When a MANET is connected to a satellite, it is important for mobile nodes to detect available gateways providing access to the satellite segment. The key part of routing for hybrid networks is the gateway selection and normally, two approaches can be applied in the computation of the routing decision. One is to compute the best gateway(s) in terms of the parameters considered and afterwards the routing path. Another is to compute the routing paths and then weigh them by the parameters of the relevant gateways. Each MANET node should be registered in one gateway by three steps: gateway discovery, gateway selection and registration. Since the current MANET routing protocol does not exploit base stations, the gateway detection scheme, which could be done in three ways, should be implemented. The proactive gateway discovery is initiated by the gateways. The gateway periodically broadcast advertisement messages including the gateway information. The mobile nodes respond to these advertisements by requesting registration. The reactive discovery scheme allows the mobiles nodes to broadcast gateway solicitation message to find the proper gateways [6][7]. After the gateways send advertisements to reply these messages, the mobile nodes will reply by requesting registration. Hybrid approach uses combination of proactive and reactive approaches. Under certain conditions, proactive approach is used on some mobile nodes, whilst others use reactive scheme. Normally the hop number is considered: gateway broadcasts the advertisement periodically within the radius of n-hop, while for the nodes which are located n-hop away from the gateway, reactive approach is used.

Satellite link management, which is also known as gateway placement problem, may have major impact on network performance and power consumption of the satellite gateway nodes. A minimum number of gateways should be activated so to save terrestrial and satellite resources. There are several reasons that can trigger the turn on or off a satellite link in the integrated network. The premise for this mechanism design is that devices can provide the user with the capability to turn on or off link as they wish to do. The mechanisms can be implemented in related nodes instead of end users which reduce the time for end users to configure the network.

Efficient resource management/allocation mechanisms maximize the efficiency of transmission capacity, in order to better provide QoS guarantee. QoS is essential to ensure the end-users' satisfaction in the integrated network where different characteristics of networks coexist and as well as all different types of traffic. Data traffic can be large data rate demanding, or time-sensitive and loss-sensitive. The purpose of QoS mechanisms is to ensure that network resources are appropriately used to provide relevant level of service to each type of traffic. Both satellite and ad hoc segments present some challenges in terms of QoS. Thus, in integrated networks, except for those, the coherency of QoS policies set up in two segments is equally important.

4 Load Balancing Based Gateway Selection Schemes

Gateway is the most important part in integrating Satellite and MANET networks, since quite a lot interworking operations are done in this part. Efficient and adaptive gateway selection reduces packet loss and delay due to the congestion on gateways or sudden unreachability of the gateway. Load balancing is a mechanism used in multiple links in order to balance load repartition and resource consumption over the network. In integrated MANET-Satellite network, all the MANET traffics are routed by the back office via satellite links which have limitation in terms of both amount and bandwidth. By using load balancing scheme, congestion in an overloaded gateway may be alleviated and data rate in an underused gateway may be increased [8][9]. In this case, it is possible to improve the overall throughput and reduce the delay caused by the congestion on gateways. What kinds of parameters should be considered to perform the load balancing mechanisms is still under study. It is hard to maintain absolute evenly traffic distribution because of the flapping problem caused by the synchronized rerouting. However, the optimal schemes can be considered to alleviate the flapping effect. Besides that, load balancing methods can also be integrated with multipath routing and gateway selection schemes in order to optimize the bandwidth utilization.

In the hybrid networks, gateways are always the bottleneck. There will be massive packets routed toward gateways to reach remote users. Selecting a proper gateway is the basic step for meeting QoS requirements. Among all the QoS considerations, load balancing is considered for evenly distributing traffic through the whole network in order to decrease the potential delay caused by congestions, and improve the resource utilization. As mentioned, efficient routing protocol dealing with node mobility should be considered. Since the available bandwidth of satellite is always the most valuable resource. Routing algorithms should take into account, first if a specific node is a satellite gateway and second, what are the specific characteristics of the satellite connection.

5 Proposed Scheme

As is mentioned, most of the current gateway selection methods use number of hops along the path and gateway queue length to select the particular gateway [10][11][12]. If all nodes select a gateway with the least hop count and traffic load, there will be congestions along the path to that gateway. So we propose a novel solution to intelligently select gateways in a balanced way by enable gateways to broadcast independent gateway message (GM), provided with information of traffic situation on their own. The whole procedure is depicted in Figure 2. Gateway nodes disseminate gateway load information all over the network in a proactive manner, and normal nodes send local load information only to neighbors. When a node has data to be forwarded to a gateway, it checks if the selected gateway is overloaded in terms of the received gateway message. The node checks if the gateway switch is needed based on the combination of criteria and metrics set.

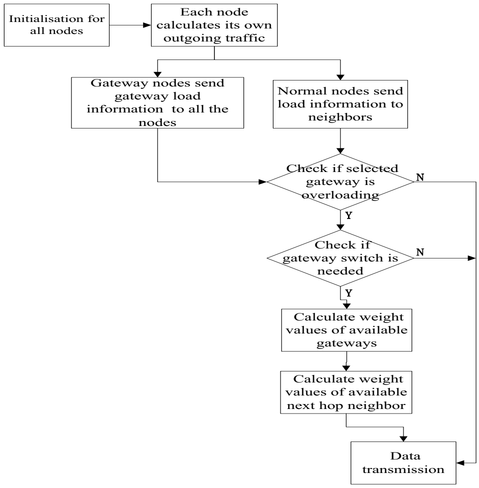

Fig. 2. Flow chat of proposed scheme procedure

Since the information of gateway state is disseminated periodically, different nodes may have different accurate information at the same time. That is to say, it can be possible that nodes close to gateways have a very good knowledge of gateways' state, but nodes farther away have poor information about that instead. In our proposed scheme, information of gateways' state is one aspect of routing path consideration. And another aspect is the traffic load situation of their neighbor nodes. They choose the least load neighbor node towards to the selected gateway. Then decisions of far-away nodes also help with distribute traffic among the overall network which alleviates traffic congestions in local nodes within MANET. In this case, the decisions made by near-gateway nodes and far-away gateway nodes cooperate to balance traffic in both terrestrial MANET and Satellite transmission links.

5.1 Gateway Discovery

By using the method of proactive gateway advertisement, the most accurate gateway information can be disseminated and mobile nodes can make proper estimation and decision thereby. Yet in this case, the larger network topology is, the higher overhead caused by control messages. How to manage the trade-off between control message overhead and information broadcast is the key point in proactive mechanisms.

In our design, the first step is to measure gateway traffic load and collect load information from each available gateway. By calculating the incoming packet number and size, a gateway node is able to determine how much traffic it is suffering. The collected load information id will be inserted into gateway load message, and disseminated to all nodes in MANET along with the broadcasting mechanism in the employed proactive routing protocol (e.g. OLSR). After comparing with the defined capacity (i.e. the maximum capacity for a gateway to process data forwarding), the gateway node can recognize if it is to overload. If the gateway realizes that the critical value is to be reached, which means the current gateway is approaching its maximum capability, a mark label will be set up. The mark label is inserted into gateway message to indicate if the gateway is overloaded or not.

When a general MANET node receives the gateway advertisement, it records the gateway identity, load information, mark label, advertisement sequence number and advertisement lifetime. Based on its decision criteria, a suitable gateway will be worked out.

5.2 Gateway Selection

In our scheme, intermediate nodes are involved in gateway switching. If an intermediate node receives overloading alert from a gateway, and it is having data forwarding toward this gateway, it should make decision if gateway switching is applicable. This is the main part in gateway selection scheme and most of the previous algorithms consider the node number registered in the certain gateway, as the gateway load factor assumes that every node generates a similar traffic which is not realistic. In this algorithm, intermediate nodes are asked to record the traffic sent out locally. The decision is based on the traffic to the specified gateway. If the traffic previously sent from current intermediate node to the gateway issuing alert reaches certain point (e.g. a defined threshold), the gateway switching should be carried out where possible. Otherwise, the current intermediate node may choose to stay with existing gateway without changes.

Algorithm 1: Mn_receive(GW1_msg, GW2_msg)

Input: GW1_msg, GW2_msg, which are two messages from two gateways respectively.

Output: Gateway choice & next hop node.

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begin

1. Abstract information about gateways.
2. Check if any gateway is overloading.
3. Calculate weight values of gateways.
4. Make decision about selected gateway.
5. Calculate weight values of neighbor nodes.
6. Choose next hop node.

return selected gateway, next hop node;

end

The gateway switching on intermediate nodes is based on the gateways' availability, which means if there is alternative gateway available, and if the load status on the alternative gateway is suitable to accept new traffic flow. Through receiving gateway load information from gateway message, each intermediate node can obtain such information. After receiving the gateway messages, the mobile nodes can choose their proper gateways for transmitting data in next time interval using the heuristic way, as specified in Algorithm 1.

Different gateways may have different threshold levels based on which gateways send overloading indication. And when it comes to decision making in intermediate nodes, in order to ensure the traffics are distributed as evenly as possible, we propose an adaptive overloading threshold based on current gateway traffics. T_{gw} is the proposed overloading threshold for gateways. L_{gw_n} is current traffic load of the nth gateways. The function is shown below:

$$T_{gw} = \frac{1}{n} \sum_1^n L_{gw_n}$$

In addition to that, we use the stable interval based on current gateway traffics to evaluate if the switch is needed. That means the gateway switching won't be carried out if the current load is within the stable interval as shown below. In this case, routing flapping which is caused by simultaneously reroute can be alleviated.

$$[T_{gw} - m * \sum_1^n L_{gw_n}, T_{gw} + k * \sum_1^n L_{gw_n}]$$

The main metric for evaluating gateway weight values (W_{gw}) is the weight value function for gateway. H_{gw_n} indicates the hop number of current local node to the nth gateway node.

$$W_{gw} = \alpha \cdot \frac{H_{gw}}{\sum_1^n H_{gw_n}} + \beta \cdot \frac{L_{gw}}{\sum_1^n L_{gw_n}}$$

In order to balance traffic overall network, we consider not only the gateway load levels but also neighbor nodes'. W_{nb} represents the weight value of a certain neighbot node. H_{nb_n} and L_{nb_n} record the hop number of the neighbor node and the nth gateway node and traffic load of the neighbor node, respectively. The weight value function of neighbor nodes is:

$$W_{nb} = \alpha_1 \cdot \frac{H_{nb}}{\sum_1^n H_{nb_n}} + \beta_1 \cdot \frac{L_{nb}}{\sum_1^n L_{nb_n}}$$

6 Simulation Setup and Result Analysis

6.1 Scenario Design and Parameters Setup

The scenario design for simulating gateway switching on intermediate nodes is shown in Figure 3. The MANET consists of 11 nodes communicating with each other through WiFi interface. Two out of them are equipped with satellite interfaces (GW1 and GW2). GEO satellite interface which has relatively stable latency compared with non-GEO is used in simulation. Gateway messages are disseminated across MANET. Nine general nodes are set as source nodes to issue UDP based CBR traffic towards the destination, backoffice. In order to evaluate the performance of the proposed scheme, the parameters are set for two stages (overall transmission rate is 64kb/s and 90kb/s, simulation lasts for 90s and 40s respectively).

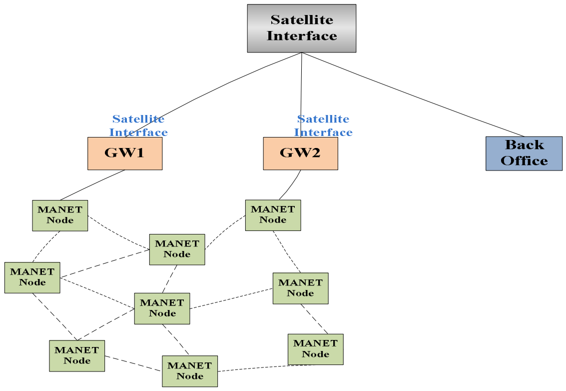

Fig. 3. Gateway selection scenario

The simulation software was implemented using NS-2. The proposed scheme is achieved on the basis of OLSR. The parameters are shown in following table 1.

Table 1. Parameters in simulation for load balanced multi-gateway selection

Parameters	**Value**
Simulation Area	600 x 600m
MAC type	IEEE802.11
Number of Gateway Nodes	2
Number of Mobile Nodes	9
Transmission Range	45m
Traffic Type	CBR
Packet Size	512bytes
Simulation Time	280s

6.2 Result Analysis

We use throughput as the performance metric for comparison. Throughput is defined as the total number of bits successfully delivered at the destination in a given period of time.

Figure 4 and 5 present the comparison of gateway throughput with the use of standard OLSR and modified OLSR with the proposed scheme. X axis denotes the simulation period and Y axis denotes the throughput of gateway. The throughput records on gateway 1 and 2 are shown by curves with cross and star respectively. The source nodes start to send packets from 150s and observation starts from 160s to eliminate the simulator issues. The first simulation period is from 160s to 230s and the nodes are sending traffic at a total rate of 64kb/s. Then traffics are increased to 90kb/s in total during the second period which lasts to 280s. Since shortest path criteria is the only metric used in standard OLSR, in Figure 4 we can see the throughput of two gateways are quite different and there is no cross for two curves. If transmission rate increases, it is possible that one gateway is overloaded and the other is underused which may cause serious packet loss and transmission congestion.

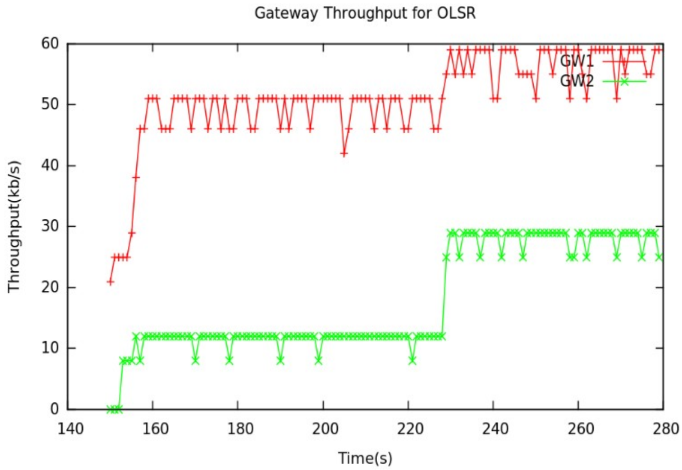

Fig. 4. Gateway throughput for OLSR

In Figure 5, gateway throughput changes and swings, and finally reaches stable and balanced. The blue and black lines marked as "T" are the thresholds for switch decision making. They are calculated based on overall gateway throughput at different stages. The aim of gateway switching is to evenly distribute traffic among gateways. That means the throughput level of gateways should be self-adaptive, and reach a stable level in proximity by which the network resource usage is balanced. In Figure 5 two curves cross each other. When a gateway is selected by MANET nodes, it is possible that another gateway is deselected. And thus throughput for the other gateway decreases accordingly. Since the gateway selection is independently implemented on MANET nodes, two gateways can be used simultaneously, and the final throughput levels will have chance to reach stable with balanced traffic distribution.

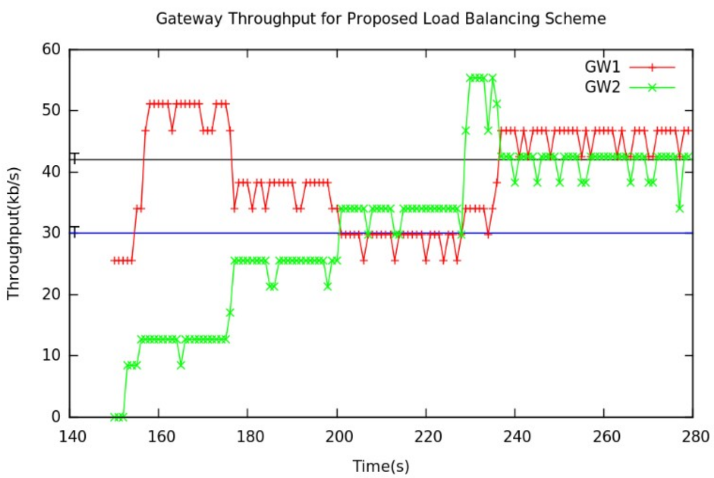

Fig. 5. Gateway throughput for proposed load balancing gateway selection scheme

Table 2 gives numerical comparison for two stages. It is shown that in both situations, the throughput can reach and maintain in an acceptable level.

Table 2. Throughput comparison for stage 1 and 2

		Throughput (OLSR)	Throughput (proposed scheme)
Stage 1	GW1	79.7%	46.9%
	GW2	20.3%	53.1%
Stage 2	GW1	37.8%	46.7%
	GW2	62.2%	53.3%

Apart from throughput, overall delay and packet loss rate are also used as performance metrics for comparison. Delay is defined as the delay for sending packets from source nodes to backoffice. And in our case, we calculate the average delay of all the packets delivered successfully. Packet loss rate is calculated by lost packets over overall sending packets. From the table, we can see the packet loss is high for using OLSR. The reason is congestions on general MANET nodes and gateways. Overall delay decreases because of the employment of feasible and uncongested paths.

Table 3. Performance comparison for two schemes

	Overall delay (ms)	Packet loss rate
OLSR	280.534	13/2567
Load balancing based OLSR	269.222	3/2567

From the simulation results, we can see that the load balancing scheme alleviate the gateway load at certain extent. The two gateways are simultaneously or alternatively used for traffic transmission. The simulation is executed with simple topology, and no mobility is introduced at this stage. Our purpose is to make a primary test to determine if enabling intermediate nodes to implement gateway switch is feasible. An interesting finding is that at some points, both of gateways are in operations for forwarding data. That is mainly because each intermediate node decides which gateway is to be selected based on its local traffic and overloading status on gateway. This feature will benefit to reduction of packet loss during gateway handover as not each intermediate node needs to switch gateway, which reduce the possibility of sudden unreachability to certain gateway. Comparing with the situation that the gateway switching is charged by source node and only happens when the overloading happens, our approach can take advantage of reacting with distributed manner.

Although the simulation test result proves the way of switching gateway on intermediate can be effective, there are still further details required to improve the load balancing scheme. For example, the corresponding routing protocol must take the factor of route loop into consideration, particularly when the issue of scalability is included. And the criteria to decide if a gateway is overloading might include multiple situations, e.g. unacceptable delay from gateway to satellite, energy consumption, and so on. As the same issue in proactive gateway discovery protocol, adaptive adjustment of gateway broadcasting time interval should be taken into consideration. Mobility of MANET nodes is also an important issue which affects packet loss rate and packet delivery delay, so must be carefully dealt with when improving load balancing scheme.

7 Conclusion

This paper first gives an introduction to the converged MANET-Satellite network. For realization of such integrated networks, a number of issues need to be addressed: routing interoperability, gateway selection mechanisms, satellite links' management and resource management. A large library of studies has been done in the literature, yet the issues are still worth tackling. Lots of interworking related operations can be done in gateways which makes gateway selection an essential part. We proposed a load balanced gateway selection scheme aims at alleviating congestion in overall network and distribute traffic as evenly as possible to achieve better network performance. The overall delay and packet loss rate can also be decreased. Resource management in integrated network is the key challenge which needs further study.

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