A Proactive Load-Aware Gateway Discovery in Ad Hoc Networks for Internet Connectivity

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ABSTRACT

When a Mobile Ad Hoc network (MANET) is connected to the Internet, it is important for mobile nodes to detect available Internet gateway (IGW) providing access to the Internet. Gateway discovery time have strong influence on packet delay and throughput. In most of the cases, a mobile node uses min- hops to the gateway to communicate a fixed host connected to an Internet. However, a minimum hop path may not always be efficient if some nodes along the path have longer interface queue of waiting packets. Thus, the focus of the paper is to first analyse existing load-aware routing protocols in MANET and then based on this analysis, devise a proactive load-aware gateway discovery scheme that takes in to account size of interface queue in addition to the traditional min hop metric. This approach also allows an efficient handoff from one Internet gateway to another Internet gateway and still maintains a seamless connectivity to a fixed host. We examine the impact of traffic load and node mobility in terms of two metrics: throughput and average end-to-end delay to assess the performance of the proposed protocol. Simulation results indicate that our protocol outperforms existing solution.

KEYWORDS

MANET, Internet Gateway Discovery, Load Balancing, Congestion, Mobile IP, Internet, AODV, NS2, Performance Evaluation.

1. INTRODUCTION

The most important features of Mobile Ad Hoc Networks [1, 2] are easy deployment and self-configurability. But one of the serious shortcomings of Mobile Ad Hoc Network is that communication is limited to the Ad Hoc domain only. The interconnection of Mobile Ad Hoc Network to Internet is acquiring paramount as this extends the Internet beyond its traditional scope to remote inaccessible areas making web services available anytime and anywhere. For such situation, Internet and MANET integration [3, 4, 37] is needed. When a mobile node in an Ad Hoc network wants to communicate with a fixed host on the Internet, it has to find an efficient and reliable Internet Gateway. For this purpose, mobile node either can send solicitation or may depend on periodic Internet gateway advertisement. Internet gateway discovery time have strong influence on packet delay and throughput. There have been different approaches for the Internet gateway discovery, such as proactive, reactive, hybrid and adaptive [5, 6, 7, 9, 11, 12, 13, 14, 15]. So, an efficient and reliable Internet gateway discovery for Ad Hoc networks becomes one of the key elements to enable the use of hybrid Ad Hoc networks in future mobile and wireless networks. Due to multi-hop nature of MANET, there might be several reachable gateways for a mobile node at some point of time. If a mobile node receives Internet gateway advertisements from more than one Internet gateway, it has to decide which Internet gateway to use for Internet access. In most of the present solutions, a mobile node initiates a handover when it receives an advertisement from an Internet gateway, which is closer in terms of number of physical hops than the one it is currently using. Many Internet gateway discovery approaches, uses minimum hop path for Internet Gateway selection [6, 7, 8, 10, 13]. However, a minimum

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hop path may not always be efficient if some nodes along the path have longer interface queue of waiting packets. A suitable metric for route selection is a general routing issue in MANETs [19]. Thus, the focus of this paper is to devise and evaluate a proactive load-aware Internet gateway discovery scheme that takes in to account size of interface queue in addition to the traditional minimum hop metric to efficiently select an Internet Gateway.

The remainder of the paper is organized as follows. In Section 2, related work for MANET-Internet connectivity has been presented. In Section 3, we present a detailed classification of load–aware routing protocols and techniques for supporting load-aware routing in Mobile Ad Hoc networks. Protocols under these categories are analyzed and their strengths and weaknesses are identified. A summary of these load-balancing protocols is presented in Table 1. In Section 4, we present our proposed algorithm for load-aware Internet gateway discovery scheme. Simulation results are presented and discussed in Section 5. Section 6, concludes the paper.

2. RELATED WORK

Several solutions/approaches have been proposed to deal with the integration of MANETs to the Internet. Providing Internet connectivity to MANET requires gateways that act as bridges between the MANET and Internet, since the gateway has to understand the Internet protocol (IP) as well as a MANET routing protocol (e.g. AODV [40]). Most of the proposed solutions require the addition of gateways and differ in the design and functionality of the gateways, number of occurrences, and the routing protocols used within the Ad Hoc network. This section gives a brief overview of various techniques for providing Internet connectivity to MANETs proposed so far in the literature.

In [9], E.M. Belding-Royer et al. proposed Mobile IP [10], which was supported by IPv4 Ad Hoc networks with AODV [20] routing protocols. The proposed scheme has a proactive agent solicitation procedure with AODV route search to register to Mobile IP. It distinguishes the location of destination nodes using F-RREP of FA, when a packet is sent to the Internet. In addition, it is capable of packet routing using default routing of FA. However, this proposal does not consider the selection between multiple Foreign Agents (FAs). Also, it delays the connection setup time because this proposal, first needs to ascertain that the destination is not within the Ad Hoc network before a mobile node can use the FA.

Hossam El-Moshrify et al. [11] proposed a solution in which mobile nodes can access the Internet via a stationary gateway node or access point. Three proposed approaches for gateway discovery are implemented and investigated. Also, the effect of the mobile terminals speed and the number of gateways on the network performance are studied and compared. A mobile node to efficiently discover an Internet gateway has used no load balancing approach in this proposal.

In [12], Jonsson et al. proposed an approach, called MIPMANET based on AODV [20], but it provides Internet access by using tunneling and Mobile IP with foreign agent care-of addresses. MIPMANET allows a visiting node to switch from its current foreign agent to a new one, a phenomenon known as handoff, only if it is at least two hops closer to the new one. It utilizes a new algorithm, called MIPMANET Cell Switching (MMCS), to determine when mobile nodes in the ad hoc network should register with a new foreign agent.

Hamidian et al. [13] proposed a solution, which provides Internet connectivity to ad hoc networks by modifying the AODV routing protocol. Three methods of gateway discovery for a mobile node to access the Internet are provided: proactive, reactive and hybrid approach. All of them are based only on the number of physical hops to gateway as the metric for the gateway selection.

Ratanchandani et al. [6] discusses a hybrid gateway discovery approach. AODV and two Mobile IP foreign agents are used to interconnect MANET and the Internet. However, the TTL of the foreign agent's advertisements is limited. Thus, only mobile nodes that are close to one of the foreign agents receive the advertisements. Nodes that are further away have to solicit advertisements reactively.

Lee et al. [14] proposed a more sophisticated approach in which advertisements are sent out only when the changes in the topology are detected. However, they rely on the use of source routing protocol, which limits the applicability and scalability of their approach.

Bin et al. [15] proposed an adaptive gateway discovery scheme that can dynamically adjust the TTL value of Agent Advertisements (GWADV messages) according to the mobile nodes MANET Internet traffic and their related position from Internet Gateways with which they registered. This protocol provides Internet access to MANET mobile nodes using mobile IP.

3. LOAD-AWARE ROUTING PROTOCOLS FOR MANETS

Routing with load balancing in wired networks has been exploited in different approaches [16, 17, 18]. There is a general tendency in most MANET routing protocols to use a few centrally located mobile nodes in a large number of routes. This results in congestion at the medium access control (MAC) level, which causes high packet delays and becomes bottlenecks when a large number of data packets pass through these few mobile nodes. As over utilized mobile nodes causes quick battery power depletion, thereby survival time of the whole MANET may be shortened. As a result, it is necessary to take into account the routing load and congestion conditions of mobile nodes in the route selection process to fairly balance and distribute the traffic load to the entire network nodes. In fact, a major drawback of most existing Ad Hoc routing protocols is that they do not have provisions of conveying the load or quality of a path during route discovery process. Hence, they often fail to balance the load on he different routes. In the following section, we analyze different proposed routing protocols that use route load as the primary quality of service (QoS) metric in MANET domain.

3.1 Taxonomy of Load-Aware Routing Protocols in MANET

The existing load balancing routing protocols for Mobile Ad Hoc networks can be categorized into three major groups based on their basic technique [19] (Figure 1).

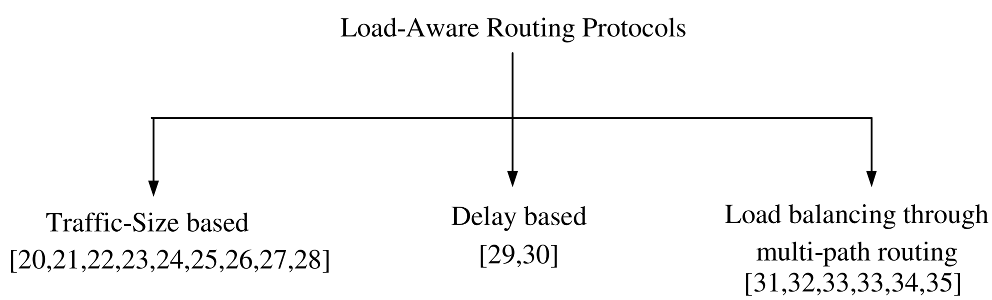

Figure 1. Load-aware routing protocols classification

The first is "Traffic-Size" based [20, 21, 22, 23, 24, 25, 26, 27, 28], in which the load is balanced by attempting to distribute the traffic evenly among the network mobile nodes. The second type is the "Delay" based [29, 30], in which the load is balanced by attempting to avoid mobile nodes with high delay. The third type is "Load balancing through multi-path routing" [31, 32, 33, 34, 35] in which traffic can be distributed into multiple routes simultaneously.

3.1.1 Traffic-Size Based Routing

In DLAR (Dynamic Load–Aware Routing) protocol [20], the load metric of a mobile node is defined as the number of packets buffered in the node interface queue, and the load metric of a route is the summation of the load metrics of mobile nodes along that route. However, this technique does not optimally reflect the actual load since buffered packets may vary in size. In the route discovery phase, it selects the least-loaded routes according to the load information collected by the route request (RREQ) packets, and periodically monitors the congestion status of active sessions and dynamically reconfigures the routes that are being congested during the route maintenance.

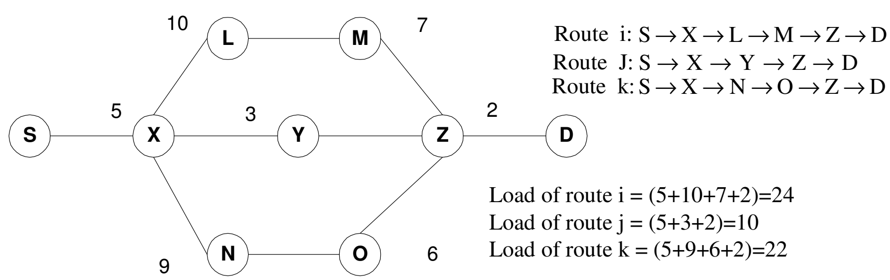

Figure 2. An Ad Hoc Network with routing load

Consider Figure 2. In this network, DLAR protocol adds the routing load of each intermediate mobile node along each path and then select least loaded route (i.e., route k: $S \rightarrow X \rightarrow N \rightarrow O \rightarrow Z \rightarrow D$ as against to min-hop route j: $S \rightarrow X \rightarrow Y \rightarrow Z \rightarrow D$. In DLAR, the destination waits for an appropriate amount of time to learn all possible routes. Then, it sends a route reply (RREP) choosing the least loaded route. Hence, the source may have to wait for a considerable amount of time before it is able to transmit data. Intermediate nodes also periodically attach their load information with data packets. On detecting congestion, the destination broadcasts a route request packet towards the source. Moreover, the load measurements do not consider the channel contention from neighboring mobile nodes.

In [21], Hassanein et al. proposed a protocol based on the concept of balancing traffic load, namely, the Load-Balanced Ad Hoc Routing (LBAR) protocol. This protocol defines the load metric of a node as the total number of routes flowing through the node and its neighbors. This method is not optimal since it does not account for the various traffic sizes of each route. It is an on-demand routing protocol intended for delay-sensitive applications where users are most concerned with packet transmission delay. Hence LBAR focuses on how to find a path, which would reflect least traffic load so that data packets can be routed with least delay.

In [22], Wu and Harms proposed a Load-Sensitive Routing (LSR) protocol to resolve the neighbor effect. It defines the load metric of a mobile node as the total number of packets buffered in the node interface queue and its neighbors. It uses information about the local load as well as the load in the neighborhood to select a route. In this, the destination compares the current path load with the initial load information, and starts a route request phase (as in DLAR [20]) if it detects congestion. This technique is similar to the one used in DLAR [20], which does not take into account the different sizes of the buffered packets. Even though the load metric of

LSR [22] is more accurate than those of DLAR [20] or LBAR [21], it does not consider the effect of access contentions in the MAC layer (e.g. IEEE 802.11 DCF). Therefore, this protocol may regard different situations that may result in different access delays as the same in terms of traffic load metric.

In [23], Kim et al. proposed a routing protocol with Minimum Contention Time and Load Balancing (MCL) that selects a route with minimum contention among many possible routes between source and destination in the route selection procedure. It uses the medium contention information as the main route selection metric. The medium contention information of a node reflects both the medium contention time and traffic load associated with the node. By using the medium contention information in the route selection procedure, it reduces the end-to-end delay and distributes traffic evenly throughout the network. In this protocol intermediate nodes are not allowed to reply to route requests in the route discovery procedure even though it has a path to the destination. MCL [23] does not use this route cache mechanism in order to prevent traffic from concentrating on a few mobile nodes.

In [24], Li et al. proposed a Contention Sensitive Load Aware Routing Protocol (CSLAR) that utilizes the contention information collected from IEEE 802.11 Distributed Coordination Function (DCF). With this information, the channel's contention situation and the neighbor's traffic load can be estimated and considered for making routing decisions. Route selection for mobile node is based on the three metrics in CSLAR: contention information from MAC layer, number of packets in its queue and number of hops along the route. This represents a typical cross layer approach, in which every mobile node collects and processes the contention information from MAC layer periodically and passes this parameter to the routing agent during the route discovery process. Based on the NAV (Network Allocation Vector) entry, queue length and number of hops, the overall load (route_load) at a particular mobile node is calculated as per the equation (1).

$$\text{route\_load} = a \times A_{NAV} + b \times A_{qlen} + c \times N_{hop} \quad (1)$$

where A_{NAV} implies the average busy portion of each second, A_{qlen} implies average queue length, N_{hop} implies the number of hops and the selection of constants a, b, c is to balance the effects of three costs. The value of A_{NAV} and A_{qlen} can be obtained from equations (2) and (3) respectively.

$$A_{NAV} = \alpha \times C_{NAV} + (1-\alpha) \times A_{NAV} \quad (2)$$

$$A_{qlen} = \beta \times C_{qlen} + (1-\beta) \times A_{qlen} \quad (3)$$

Where C_{NAV} refers the busy portion of the current second, α and β are constant in range [0, 1].

In [25], Zheng et al. proposed a novel Dynamic Load-aware based Load-Balanced routing (DLBL) protocol for Ad Hoc networks. This protocol considers intermediate node routing load as the primary route selection metric. It distributes the computing overhead of route selection to all the intermediate nodes from the source to the destination to shorten the response time in route discovery and route reconstruction while congestion or link break occurs. It balances load by avoiding congested routes to shorten the end-to-end delay of packet delivery. It can also provide many redundant routes during the route discovery period, resulting in the decrease of the route reconstruction overheads. The average delay is computed taking in to consideration queuing, contention, and transmission delay, and assuming propagation delay as negligible.

In [26], Altalhi et al. proposed a Traffic-Size Aware routing scheme that uses the size of the traffic, through and around the network nodes, as the main route selection criterion. This scheme is used to balance the load amongst the network nodes, and to avoid creating congested areas. The nodes are also aware of the size of the traffic (in bytes) that is routed through their neighbors. For any path that consists of multiple hops, the load metric of the path is the sum of all the traffic that is routed through all the hops that make up that path. This scheme is an extension to the Virtual Path routing protocol (VPR).

In [27] Yuan et al, proposed an Adaptive Load balancing protocol (AODV-LB) to balance the load in Ad Hoc network and alleviate congestion in the network. It is implemented in the process of route request. When a RREQ message is flooded in the network, not every intermediate node, which receives the message, broadcast it. Before broadcasting the RREQ again, the intermediate node itself first makes a decision if it is qualified. If its interface queue occupancy is under the threshold value, the node is qualified and able to broadcast it. If the node's queue occupancy is over the threshold value, it is not qualified and drops the RREQ. By doing so, the overloaded nodes are excluded from the newly created paths, and an on demand routing protocol using this scheme distribute the traffic load evenly on the nodes in network. The threshold value used as a criterion is dynamically changing according to the interface queue occupancy of nodes around the backward path. The threshold is variable and changing adaptively with the current load status of network.

In [28], Lee et al. proposed a novel load balancing protocol for Ad Hoc networks. This protocol is simple but very effective to achieve load balance and for congestion alleviation. It enables each node to forward RREQ messages selectively according to the load status of the node. Overloaded nodes do not allow additional communications to setup through them so that they can be excluded from the requested paths within a specific period. Each node allows additional traffic flows as long as it is not overloaded. This protocol utilizes queue occupancy and workload to control RREQ messages adaptively. Each node maintains a threshold value, which is a criterion for decision of whether or not to respond to a RREQ message. The queue occupancy and the workload increment are used as input parameters for calculation of the threshold. The threshold value of a node dynamically changes according to the load status of the node based on its queue occupancy and its workload within a specific period.

3.1.2 Delay Based Routing

In [29], Sheu et al. proposed a Delay-Oriented Shortest Path Routing (DOSPR) protocol which utilizes medium contention time information as the main route selection criterion. Although it assumed IEEE 802.11 as the MAC protocol, it limited the range of contention of a mobile node to its neighbors only. But, in reality, the range of contention of a node covers not only its neighbors but also the neighbors of its neighbors. This protocol uses a table driven approach rather than an on-demand one. The main contribution of DOSPR is the factorization of access contention delay at the MAC layer to the total delay computation.

In [30], Song et al. proposed a Load Aware Routing protocol (D-LAOR) that is based on delay measurements. The node's load value is defined as the average packet transfer delay at this node. With this definition, the queuing, contention, and transmission delays are all considered. However, one problem remains unsolved. When a mobile node becomes idle for a short duration, its average delay become very small. According to this approach, more traffic flows may be routed through this node, even if this mobile node may be adjacent to a congested node.

It utilizes both the estimated total path delay and the hop count as the route selection criterion. Since the overhead of redundant routing information can have serious impact on the overall performance of MANET, this protocol also has a mechanism in new route selection to avoid a congested node by selectively dropping the route request packets.

3.1.3 Load Balancing through Multi-Path Routing

In [31], Wang et al. proposed a new multi-path routing protocol for Ad Hoc wireless networks named Multi-Path Source Routing (MSR). Each discovered route is stored in a route cache with a unique route index. So, it is easy to select multiple paths from the cache. In order to monitor real time information on each path in MSR, probing packets are sent periodically to each path, and measure their round-trip time (RTT), and then estimate path delay using Karn's Algorithm. Delay is an important quantity to reflect the path performance such as congestion. So if a path has a longer delay, less traffic is dispatched there in order to alleviate congestion. According to the delay of each path, traffic is distributed over different paths in order to achieve a minimum mean delay for the whole network.

In [32], Wu et al. proposed path-selection criteria (correlation factor) and an on-demand multi-path calculation algorithm that can provide load balancing and reduce the frequency of on-demand route discovery. Correlation factor metric is used to describe the interference of traffic between two node-disjoint paths. The correlation factor (η) of two node-disjoint paths is defined as the number of links connecting the two paths. Although the frequency of on-demand route discovery for multi-path routing is less than that for single path routing, the total control overhead is larger for on demand multi-path routing because searching for diverse multiple paths is usually more costly than searching for a single path. On demand multiple path routing can gain some improvement of end-to-end delay in a shared channel MANET. The network load can be distributed more evenly in multi path routing. In order to balance the network loads, multiple paths were used simultaneously. If a path is broken, an error message is sent back to the source node and the traffic on that path will be transferred to some other paths that are still alive. When all paths are broken, a new multiple path discovery is initiated again.

In [33], Pham et al. proposed a Multi-Path Routing with Load Balance (MRP-LB), which maintains multiple routes for each source destination pair and spread traffic evenly on to these routes, i.e. the total number of congested packets on each route is equal. In this protocol, data packets are likely to arrive out of order since they are sent on different paths and experience different delays. This protocol consists of two phases, Route Discovery and route Maintenance. After the Route discovery phase, the source node has the current information about the load on each route. However, this information may not be accurate in later stage since nodes along the routes are processing packets with different rates. In order to ensure that the source has up-to-date information about the load on the routes, destinations periodically sends Load Packets (LPs) to the sources. The nodes along the routes add their number of congested packets into Total_Congested_Packets field of the LPs. When LPs reach the sources, the sources have the current information of the number of congested packets on each route and update their cache accordingly by extracting information from Total_Congested_Packets.

3.2 Observation

Load aware routing generally has the advantage of balancing the network traffic and avoiding excessive end-to-end delay caused by congested nodes. Distributing the routing tasks has eminent advantages, such as reducing the possibility of power depletion and queuing delay in the hosts with heavy duties. A summary of load balancing routing protocols in wireless Ad Hoc networks discussed above is presented in Table 1. The table contains different columns. In the first column, the name of load-aware routing protocol is listed. Then, the "Best Effort Routing

Extension" column indicates the best effort routing protocol that is extended by or is most closely related to the corresponding load aware routing protocol. The "Proactive/Reactive" field indicates whether this load routing protocol is reactive (on-demand) or proactive (table driven). Lastly the "Comments" field contains additional information about the load aware routing protocols such as routing load metric used by the protocols.

Table 1. Summary of Load Balancing Ad Hoc Routing Protocols

Load Aware Routing	**Best Effort Routing Extension**	**Reactive/ Proactive**	**Comments**
DLAR [20]	DSR	Reactive	Number of packets buffered in the node interface queue as the primary route selection metric.
LBAR [21]	DSR	Reactive	Load metric of a node as the total number of routes flowing through the nodes and its neighbors.
LSR [22]	DSR	Reactive	Load metric of a node as the total number of packets buffered in the interface queue and its neighbors.
MCL [23]	AODV	Reactive	Uses the medium contention information (medium contention time +traffic load associated with the node) as the main route selection metric.
CSLAR [24]	DSR	Reactive	Uses three metrics for route selection (i) contention information from MAC layer (ii) Number of packets in its interface queue (iii) and number of hops along the route.
DLBL [25]	DSR	Reactive	Considers intermediate node routing load as the primary route selection metric.
Altalhi [26]	VPR (Virtual path routing protocol)	Reactive	Uses the size of the traffic, through and around the network nodes, as the main route selection criterion.
AODV-LB [27]	AODV	Reactive	A threshold value is used to judge whether a node is overloaded or not.
Lee et al. [28]	AODV and DSR	Reactive	Uses interface queue occupancy and workload to control RREQ messages adaptively.
DOSPR [29]	DSDV	Proactive	Uses medium contention time information as the main route selection criterion and analyzed the medium access delay of a mobile node in IEEE 802.11.
D-LAOR [30]	AODV	Reactive	Uses both the estimated total path delay and the hop count as the route selection criterion.
MSR [31]	DSR	Reactive	Round trip time (RTT) is used to distribute the load between multiple paths.
Wu et al. [32]	DSR	Reactive	A Multi-path calculation protocol combined with path selection criteria (correlation factor).
MRP-LB [33]	DSR	Reactive	A multi-path routing protocol with a load balancing policy, which spreads data traffic evenly on multiple routes.

4. PROPOSED INTERNET GATEWAY DISCOVERY SCHEME

Based on the above analysis of load-aware routing protocols in MANET, we propose a proactive load-aware Internet gateway discovery protocol for Internet access. A communication scenario where an Ad Hoc network is connected to a fixed one via two gateways has been considered (see Figure 3). CBR sources wish to start sending traffic from the Ad Hoc domain towards fixed network through an Internet gateway.

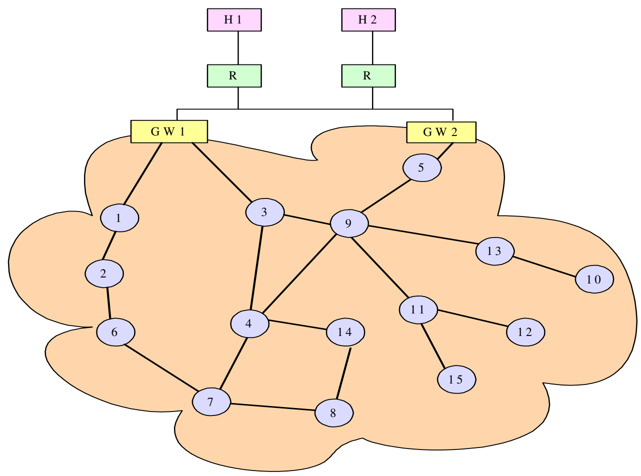

Figure 3. Basic model of the connectivity framework

Currently Ad Hoc networks with Internet connectivity usually use the shortest path selection algorithm for path computation, which is based on the hop counts to gateways. Existing gateway selection schemes using shortest path algorithm typically find a route and select a gateway with the minimal hop count.

$$H(s,d) = \begin{cases} \min\left\{H(p) : s \xrightarrow{p} d\right\} & \text{if there is a path from s to d} \\ \infty & \text{otherwise} \end{cases}$$

where p is a path, H is the shortest-path distance from s to d which is the sum of its links in any path p, s is the source node, and d is the destination node (i.e., Internet gateway). One of the advantages of using the shortest path selection algorithm with the hop count attribute is rapid convergence and thriftiness of resources. This attribute enables a mobile node to reach a wired network using the minimum number of hops. However, if all mobile nodes select the nearest gateway, as their serving Internet gateway, then this gateway would become a bottleneck, resulting in high processing latency. This weakness motivates the selection of Internet gateway based on some other metrics.

In this paper, for selection of a particular Internet gateway by a mobile node, we propose modification in the Internet gateway advertisement message, which is periodically broadcasted in the MANET domain and also in the routing table maintained at each mobile node. We introduce an additional metric called gateway_adv_queue. This metric takes into account the effect of interface queue occupancy level along a route. For this, we added an additional field rt_qlen_metric to record the effect of this metric along a route to the Internet gateway in routing table of each mobile node. The modified structure of Internet gateway advertisement message GWADV_New used to implement our approach is depicted in Table 2. Internet gateway periodically broadcasts modified gateway advertisement message throughout MANET domain in order to inform all the mobile nodes about the availability of that Internet gateway. Upon reception of a GWADV_New message, mobile nodes that receive gateway advertisement message, periodically updates it's route entry for that Internet gateway and select their preferred Internet gateway based on the new introduced metric. Mobile nodes store a default route entry in their table. A mobile node creates a new route entry in its routing table for every mobile node as well as for every fixed node that it wishes to communicate. A routing table maintained at a mobile node MN_A wishing to communicate to fixed node FN_X (0.0.1) and some other mobile nodes in the Ad Hoc network is shown in Table 3.

Table 2. Structure of modified Internet gateway advertisement message (GWADV_New)

Type	Reserved	Prefix Size	Hop Count
Broad_Cast ID			
Destination IP Address			
Destination Sequence Number			
Source IP Address			
Lifetime			
gateway_adv_queue			

Table 3. The Routing table of mobile node (MN_A) containing entries for a fixed node and mobile nodes

Entry #	Destination address	Next hop Address	Number of physical hops	rt_qlen_metric
1	FN_X (0.0.1)	default (-20)	-1	-1
2	default (-20)	GW_X (1.0.0)	3	5.8
3	GW_X (1.0.0)	MN_A (1.0.3)	3	5.8
4	MN_B (1.0.5)	MN_C (1.0.6)	7	-1
5	MN_C (1.0.6)	MN_D (1.0.7)	7	-1
6	MN_D (1.0.7)	MN_E (1.0.8)	5	-1

MN_B, MN_C and MN_D are mobile nodes. GW_X represents gateway node. The next hop entry for fixed node FN_X (0.0.1) is set to default (-20), so that mobile node should look up this default entry and discover an appropriate gateway for forwarding packets. The second entry indicates the gateway chosen by the mobile node for its Internet connection. The third entry indicates next hop towards the particular Internet gateway. When a mobile node wants to communicate with a destination, it tries first to find a direct route within the MANET, and if it does not manage to do it, it then uses its default route.

4.1 Interface Queue Occupancy Algorithm

We illustrate congestion level accumulation along a path with the help of Figure 4 [36]. In this, the avg_q_occupancy of mobile node N2 can be calculated by q_occupancy of mobile node N2 it self, and $nb\_q\_occupancy_1$, $nb\_q\_occpancy_2$, $nb\_q\_occupancy_3$ and $nb\_q\_occupancy_4$ of nodes G, N1, N5 and N6. The number of neighbors of node N2, i.e. n is 4. Before initiating a gateway discovery, an Internet gateway computes its own avg_q_occupancy and fills it gateway_adv_queue, which is an additional field of Internet gateway advertisement message. This field contains total load of whole path traversed so far. Here load is referred to as the number of packets in the interface queue of a mobile node. Now, we give the algorithm for computation of interface queue occupancy level [36].

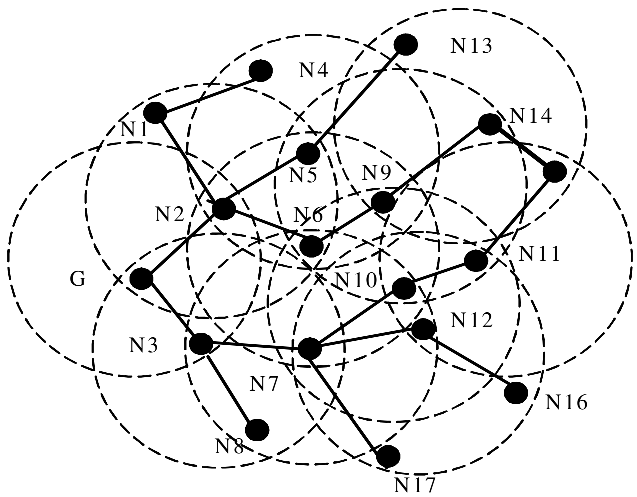

Figure 4. A Proactive Load-Aware Internet gateway advertisement (GWADV_New)

Algorithm I: Computation of Congestion Level

congestion_level_conversion()

{

Step 1: Each mobile node computes the average queue occupancy (i.e. avg_q_occupancy) using mobile node's current queue occupancy in its radio range.

Step 2: Every mobile node maintains and updates its neighbor's information by periodic exchange of one hop Hello packets containing the sender's address and current queue occupancy.

Step 3: // q_occupancy $\leftarrow$ node's own queue occupancy

// $nb\_q\_occupancy_k$ $\leftarrow$ node's neighbor's queue occupancy, and

// n $\leftarrow$ number of neighbor nodes

Compute level of congestion at a particular node along a path i.e. avg_q_occupancy as per the following:

$$avg\_q\_occupancy = \frac{q\_occupancy + \sum_{k=1}^{n} nb\_q\_occupancy_k}{n+1} ;$$

Step 4: Convert congestion level equivalent to physical hops by dividing avg_q_occupancy to 1000.

avg_q_occupancy_eq_phy_hop = avg_q_occupancy/1000;

}

4.2 Internet Gateway Selection Method

In multiple gateway environments, a mobile node receives multiple gateway advertisements. Here, we use proactive approach in which every gateway sends its advertisement periodically. Whenever a mobile node receives a non duplicate gateway advertisement, it updates the value of rt_qlen_metric and selects a suitable gateway by comparing the gateway_adv_queue in the gateway advertisement message with the rt_qlen_metric in its routing table. Further, this mobile node broadcasts gateway advertisement to its neighbors. Now we describe the algorithm for selecting an appropriate Internet gateway by mobile nodes [35].

Algorithm II: Selecting an Efficient Internet Gateway

```
gateway_selection_congestion_hop()
           {
Step 1:    // Initialization
              (i)     gateway_adv_queue  ←0;
              (ii)    HopCount  ←0;
Step 2:    Internet gateway broadcast an advertisement
Step 3:    If a mobile node receives a duplicate Internet gateway advertisement, then
           drop it and exit.
Step 4:    For each unique Internet gateway advertisement arrival at a particular
           mobile node,
              (i)     gateway_adv_queue ← gateway_adv_queue  +
                         avg_q_occupancy_eq_phy_hop + 1;
              (ii)    HopCount++;
Step 5:    //Check whether an advertisement is from the same Internet gateway
           If (advertisement from the same Internet gateway)   &&  (ad_dst_seqno   >
           default_rt_seqno) Then
Step 6:    // Whether an advertisement reached through a less congested path?
           If (gateway_adv_queue  =< rt_qlen_metric) Then
Step 7:    // Update routing table of mobile node
           // hop_count refers a field in a mobile routing table
              (i)     rt_qlen_metric  ←  gateway_adv_queue;
              (ii)    hop_count  ←  HopCount;
              (iii)   Also update route table next hop address towards this gateway;
Step 8:    // In case gateway advertisement is being received from a different Internet
           //gateway, make a hand off to another Internet gateway.
           Else if (advertisement is not from the same Internet gateway &&
           gateway_adv_queue <= rt_qlen_metric ) then
Step 9:    // Update the following entries in the mobile node
              (i)     Make new discovered Internet gateway as default gateway;
              (ii)    Also update default_rt_seqno, rt_qlen_metric, ad_src, hop_count,
                      default_rt_expiration_time, etc in the mobile node's routing table;
Step 10:   Else keep on using current gateway as the default gateway;
Step 11:   Repeat step 2;
           }
```

In the above Internet gateway selection algorithm, it is to be noted that for every fresh gateway advertisement received from the same gateway, the value of rt_qlen_metric in a mobile node routing table is replaced only when gateway_adv_queue field value of gateway advertisement is less than the rt_qlen_metric field value in the routing table. In case, the gateway_adv_queue metric field value in gateway advertisement becomes less than the rt_qlen_metric, and also the gateway advertisement comes from a different gateway, the mobile node need to switch new gateway as the default gateway otherwise default gateway remains the same. The congestion level of the route is accumulated in the gateway advertisement as it traverses the network.

5. SIMULATION MODEL AND PERFORMANCE EVALUATION

In this section, we apply the above proposed gateway discovery algorithm, which is implemented using the network simulator ns-2.28 [38] and compare it with A. Hamidian [13] proactive discovery solution in the same simulation environment. In Ad Hoc network domain, we use AODV routing protocol. The simulations were conducted on an Intel Pentium IV Processor at 3.0 GHz, 512 MB of RAM running Fedora Core 2 Linux.

5.1 Simulation Environment and Scenarios

The studied scenario consists of 15 mobile nodes, two fixed hosts and two gateways. The topology is a rectangular area with 1200 m length and 500 m width. All the fixed links have a bandwidth of 10Mbps. Each wireless transmitter has a radio range of 250m. In order to support wireless LAN in the simulator, the Distributed Coordination Function (DCF) of IEEE 802.11 is adopted as MAC layer protocol. All simulations were run for 500 seconds of simulation time. Six of the 15 mobile nodes are constant bit rate (CBR) traffic sources sending data packets with a size of 512 bytes, to one of the two fixed hosts. They are distributed randomly within the mobile Ad Hoc network. All the six traffic sources start sending data packets after 50 seconds of the start of simulation time. The destination of each of the data sessions is one of the fixed nodes in the wired network.

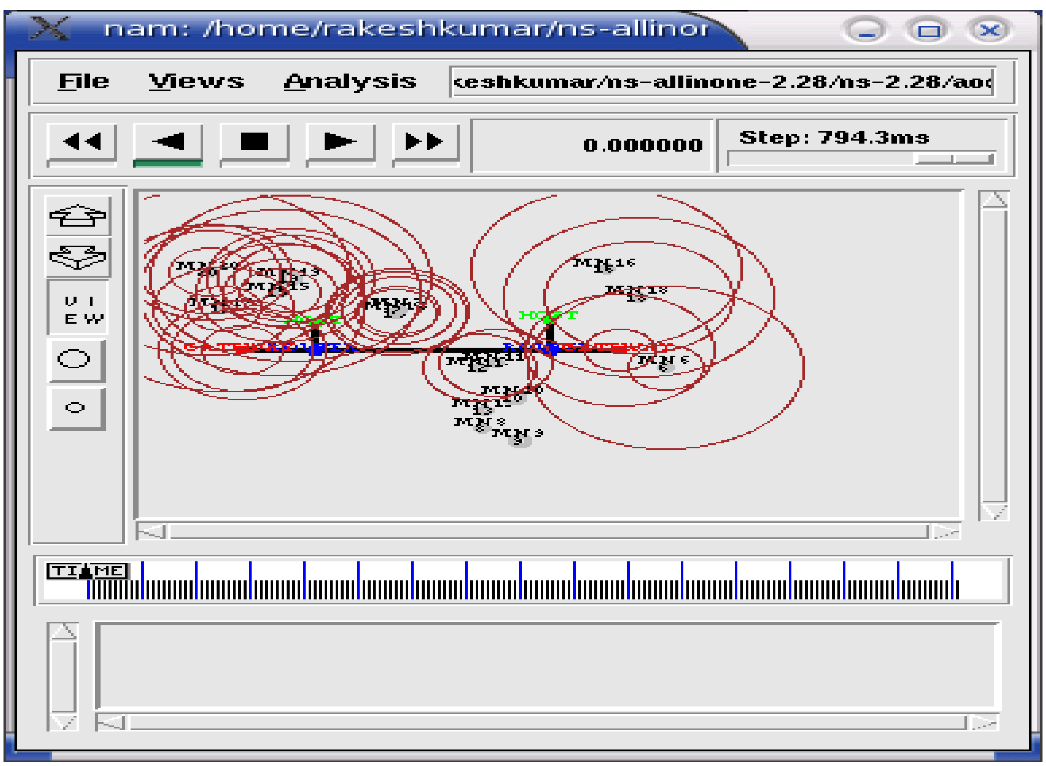

Figure 5. A Snapshot of the simulation scenario

Data rate of mobile node 7 is kept constant at 5 packets /sec (5 * 512 * 8 = 20 Kbps) till the entire simulation while the data rate of mobile nodes 6, 8, 10, 12 and 20 vary from 5 packets/sec to 30 packets/sec as per Table 4. For fair comparisons, all discovery protocols use the same set of mobility and traffic pattern. A snapshot of the simulation scenario is shown in Figure 5. We compared our proposed protocol with Hamidian proactive approach [13] for MANET-Internet scenarios. The parameters that are common for all simulations are given in Table 4.

5.2 Movement Model

The mobility model used in this study is the Random Waypoint Model [39]. As per this model, a mobile node remains stationary for a specified pause time, after which it begins to move with a randomly chosen speed towards a randomly chosen destination within the defined topology. The node repeats the same procedure until the simulation ends. The random speed is chosen to be a value, which is uniformly distributed between a defined minimum and maximum value (see Table 4).

5.3 Communication Model

The communication model is determined by four factors: number of sources, packet size, packet rate and the communication type. This study uses the CBR (constant bit rate) communication type, which uses UDP (user datagram protocol) as its transport protocol (see Table 4).

5.4 Performance Metrics

To assess the effectiveness of the proposed gateway discovery mechanism, we used the following performance metrics:

Throughput: It is defined as the ratio of total number of data bits (i.e. packets) successfully received at the destination to the simulation time.

End-to-End Delay: It is defined as the delay for sending packets from source node to the fixed host. This metric includes all the possible delays caused by buffering during the Internet gateway discovery latency, route discovery latency, queuing at the interface queue, retransmission delays at the MAC layer, and propagation and transfer times.

Table 4. Simulation Parameters

Parameter	**Value**
Number of mobile nodes	15
Number of traffic sources	6
Number of Internet gateway	2
Number of fixed node	2
Topology size	1200 × 500 m
Transmission range	250 m
Traffic type	Constant Bit Rate (CBR)
Standard packet sending rate of mobile node MN7	5 packets/ sec (20 Kbps)
Packet sending rate of mobile nodes MN6, MN8, MN10, MN12 and MN20	varied from 5, 10, 15, 20, 25 and 30 packets/sec
Packet Size	512 bytes
Mobile node speed	0-20 m/sec

Pause time	5 seconds
Mobility model	Random waypoint
Carrier sensing range	500 m
Simulation time	500 sec
Wireless channel bandwidth	2 Mbps
Interface queue limit (wireless and wired node)	50 packets
Interface queue limit (wired node)	50 packets
Wired link bandwidth	10 Mbps
Internet gateway broadcast advertisement interval	5 seconds

5.5 Simulation Results & Discussion

We examine the impact of traffic load and mobility in terms of two metrics: throughput and average end-to-end delay to evaluate our proposed protocol.

5.5.1 Effect of Traffic Load

Throughput of mobile node 7 obtained at the destination is better than proactive gateway discovery [13] (see Figure. 6) as our protocol uses load-balancing technique to uniformly distribute traffic across different routes (routes need not be shortest). As the traffic rate of source nodes increases, congestion start building across some mobile nodes due to minimum hop metric used in Hamidian approach [13], thereby packet drops start occurring due to interface queue overflow. However, in our case as mobile node chooses a route having lighter traffic, resulting lesser packet drops.

Figure 7 shows average packet delay of traffic experienced by mobile node 7. When the load increases, the average end-to-end delay does not increase much in case of our proposed protocol as it avoids nodes with congestion along a path even though it has to traverse more number of hops to connect the Internet gateway. Hamidian approach uses shortest path selection algorithm for Internet Gateway discovery. End-to end delay is also lesser in our case due to handoff taking place from one Internet gateway to another Internet gateway by a mobile node which becomes closer and having lesser congestion along that route.

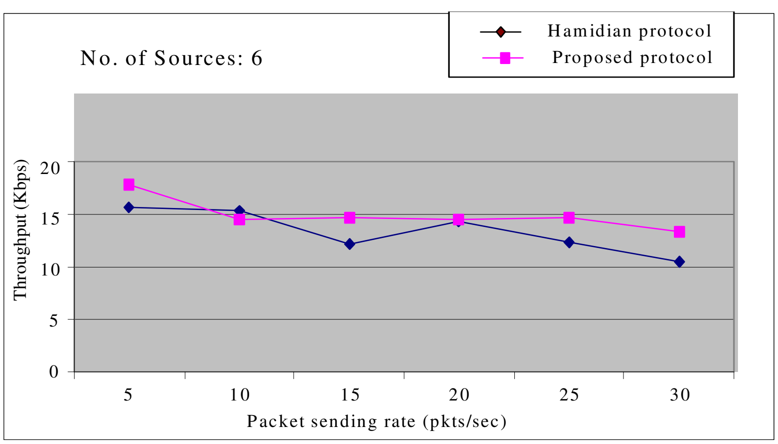

Figure 6. Throughput of mobile node 7

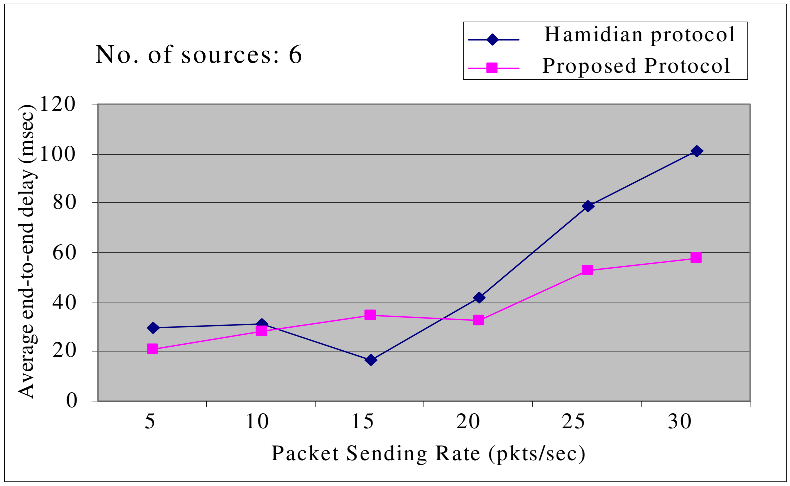

Figure 7. Average end-to-end delay of mobile node 7

Also, if a mobile node looses connection to the old Internet Gateway, it can detect a new Internet Gateway quicker. Consequently, throughput is increased (Figure 6). Thus, it performs better than proactive gateway discovery of [13].

5.5.2 Effect of Mobility

Five different maximum speeds are used, which are 1, 5, 10, 15, and 20 m/sec. The pause time is consistently 10 seconds. Each data point representing an average value of 5 runs with the same traffic modes, but randomly generated mobility scenarios. Throughput of mobile node 7 obtained at the destination starts decreasing as mobility increases in both Hamidian approach [13] as well as in our proposed approach. But the effect is more severe on Hamidian approach [13] as compared to our approach (Figure 8).

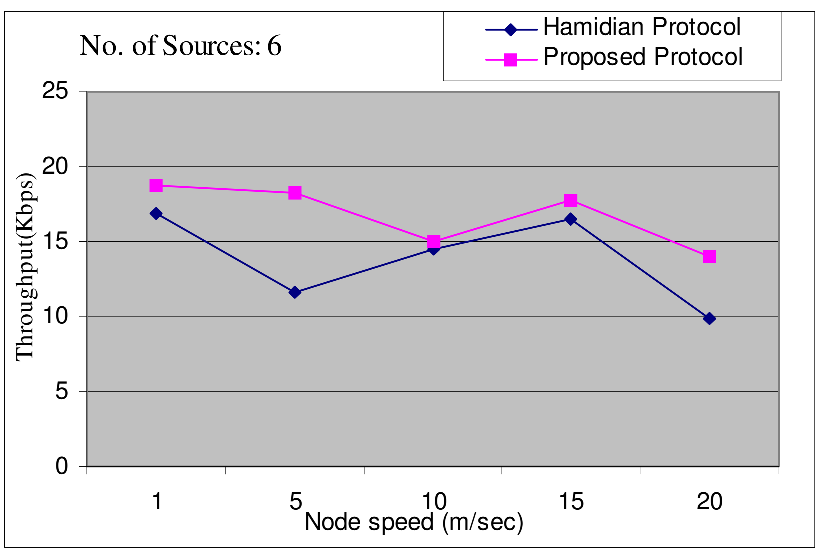

Figure 8. Throughput of mobile node 7

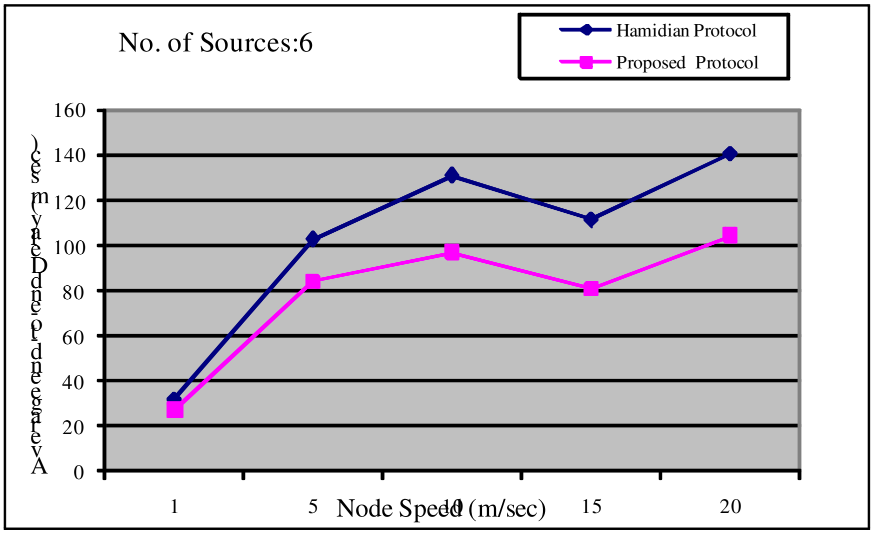

Figure 9. Average end-to-end delay of mobile node 7

The end-to-end delay is defined by delay from the source node to the Internet Gateway. Our approach enables lower packet delay to the Hamidian proactive approach [13]. Figure 9 shows the end-to-end delay for the two protocols as a function of node speed and our approach achieves lower average delay than Hamidian proactive approach [13]. The impact of mobility has lesser effect on end-to-end delay in our case. The reason is that our approach selects an Internet gateway along a path, which is less congested.

6. CONCLUSIONS

In this paper, initially we presented analysis of existing load-aware routing protocols for Mobile Ad Hoc network. Based on this analysis, a proactive load-aware Internet gateway discovery scheme using a new metric has been proposed. This Internet gateway discovery scheme is able to mitigate the congestion conditions in Ad Hoc networks for Internet access. We evaluated our proposed protocol performance through simulation for different traffic and mobility conditions. Simulation results confirm the performance in terms of throughput and delay improvement of our scheme as traffic load as well as mobility increases. This approach distributes the traffic evenly among the nodes in an Ad Hoc networks as traffic/mobility in MANET domain increases. In this approach, Internet gateway periodically broadcasts gateway advertisement proactively throughout MANET domain. Every mobile node creates/updates default routes to an Internet gateway as it receives next gateway advertisement based on interface queue and minimum hop. Our approach has been compared with an existing Hamidian [13] proactive route discovery scheme and support load balancing mechanisms. Through simulation it has been observed that our approach outperforms the existing approach as the traffic/mobility increases.

REFERENCES

[1] Carlos Cordeiro and Dharma P. Agrawal, "Ad Hoc & Sensor Networks, Theory and Applications," World Scientific Publishing, 2006, (paper back).

[2] C Siva Ram Murthy and B S Manoj, "Ad Hoc Wireless Networks, Architectures and Protocols", Pearson Education, 2004.

[3] Dave Cavalcanti, Anup Kumar, and Dharma P. Agrawal, "Integrated Heterogeneous Wireless Networks," Chapter 19 in Book, Wireless Ad Hoc Networking, pp. 483-503, Auerbach Publications, 2007.

[4] Rakesh Kumar, Manoj Misra, Anil K. Sarje, "Internet Access in Mobile Ad Hoc Networks," International Conference on Advance Computing and Communication (ICACC 2007) India, 9-10 Feb. 2007.

[5] Y. Sun, et al., "Internet Connectivity for Ad Hoc Mobile Networks," International Journal of Wireless Information Networks, Special Issue on Mobile Ad Hoc Networks (MANETs): Standards, Research, Applications, April 2002.

[6] P. Ratanchandani, and R. Kravets, "A Hybrid Approach to Internet Connectivity for Mobile Ad Hoc Networks," in Proceedings of the IEEE WCNC 2003, New Orleans, USA, vol. 3, pp. 1522-1527, March 2003.

[7] R. Wakikawa, J. Malinen, C. Perkins, A. Nilsson, and A. Tuominen, "Internet Connectivity for Mobile Ad Hoc Networks," Internet-Draft, draft-wakikawa-manet-global6-02.txt, Nov. 2002, Work in progress.

[8] Rakesh Kumar, Manoj Misra, Anil K. Sarje, "A Simulation Analysis of Gateway Discovery for Internet Access in Mobile Ad Hoc Networks," International Journal of Information Processing (ISSN 0973-8215), Vol. 2, No. 2, pp. 52-64, 2008.

[9] E.M. Belding-Royer, Y. Sun, C.E. Perkins, "Global Connectivity for IPv4 Mobile Ad Hoc Network, IETF Internet-Draft, draft-ietf-manet-globalv4-00.txt, November 2001.

[10] Tseng Y.C., Shen C.C, and Chen W.T., "Mobile IP and Ad Hoc Networks: An Integration and Implementation Experience," Technical Report, Department of Computer Science and Information Engineering, Chaio Tung University, Hsinchu, Taiwan, 2003.

[11] Hossam El-Moshrify, M. A. Mangoud, M.Rizk, "Gateway Discovery in Ad hoc On-Demand Distance Vector (AODV) Routing for Internet Connectivity," 24th National Radio Science Conference (NRSC 2007), March 13-15, 2007,Faculty of Engineering, Alexandria University Alexandria 21544., Egypt.

[12] U. Jonsson, F. Alriksson, T. Larsson, P. Johansson, and G.M. Maquire, "MIPMANET: Mobile IP for Mobile Ad Hoc Networks," Proceedings of IEEE/ACM Workshop on Mobile and Ad Hoc Networking and Computing, Boston, MA USA, pp. 75-80, August 1999.

[13] A. Hamidian, U. Korner, and A. Nilsson, "A Study of Internet Connectivity for Mobile Ad Hoc Networks in NS2", Department of Communication Systems, Lund Institute of Technology, Lund University, January 2003.

[14] J. Lee, D. Kim, J. J. Garcia-Luna-Aceves, Y. Choi, J. Choi and S. Nam, "Hybrid gateway Advertisement Scheme for Connecting Mobile Ad Hoc Networks to the Internet," Proceedings of the 57th IEEE VTC 2003, Korea, pp. 1991-195, April 2003.

[15] S. Bin, S. Bingxin, L. Bo, H. Zhonggong, and Z. Li, "Adaptive gateway Discovery Scheme for Connecting Mobile Ad Hoc Networks to the Internet," Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing, vol. 2, pp. 795-799, 2005

[16] I. Matta, and M. Krunz, "Packing and Least-Loaded Based Routing in Multi-Rate Loss Networks," Proceedings of the IEEE International Conference on Communications (ICC), Montreal, Canada, 1997, pp. 827-831.

[17] A. Bestavros, and I.Matta, "Load Profiling for Efficient Route Selection in Multi-Class Networks," Proceedings of the IEEE International conference on Network Protocols (ICNP), Atlanta, GA, 1997, pp.183-190.

[18] A. Shaikh, J. Rexford and K. G. Shin, "Load-Sensitive Routing of Long Lived IP Flows," Proceedings of the ACM SIGCOMM Conference on Communication Architectures, Protocols and Applications, Cambridge, MA, 1999, pp. 215-226.

[19] Rakesh Kumar, Manoj Misra, Anil K. Sarje "Routing with Load Balancing in Mobile Ad Hoc Networks," "Proceedings of 3rd International Conference ObCom 2006: Mobile, Ubiquitous & Pervasive Computing, Dec 18-19, 2006, VIT University, Vellore, India.

[20] S. J. Lee, and M. Gerla, "Dynamic Load-Aware Routing in Ad Hoc Networks," Proceedings of IEEE International Conference on Communications, vol. 10, 2001, pp. 3206-3210.

[22] H. Hassanein and A. Zhou, "Routing with Load Balancing in Wireless Ad Hoc Networks," in Proc. of the 4th ACM Intl. Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems, Rome, Italy, July 2001, pp. 89-96.

[22] K. Wu and J. Harms, "Load Sensitive Routing for Mobile Ad Hoc Networks," Proceedings of Tenth International Conference on Computer Communications and Networks, (ICCCN '01), Phoenix, AZ, October 2001, pp. 540-546.

[23] X. F. Li B. C. Kim, J. Y. Lee, H. S. Lee, and J. S. Ma, "An Ad Hoc Routing Protocol with Minimum Contention Time and Load Balancing," IEEE GLOBECOM 2003, pp. 81-85.

[24] Y. Li, and H. Man, "Three Load Metrics for Routing in Ad Hoc Networks," IEEE Vehicular Technology Conference (VTC) Fall'04 Los Angles, CA, 2004, pp. 2764-2768.

[25] X. Q. Zheng Wei Guo, Renting Liu, and Yongchun Tian, "A New Dynamic Load-Aware based Load-Balanced Routing for Ad hoc Networks," International Conference on Communications, Circuits and Systems (ICCCAS 2004), vol. 1, 27-29 June, 2004, pp. 407-411.

[26] A. H. Altalhi and G. G. Richard, "Load-Balanced Routing through Virtual Path: Highly Adaptive and Efficient Routing Scheme for Ad Hoc Wireless Networks," IEEE, 2004, pp. 407-413.

[27] Y. Yuan, H. Chen, and M. Jia, "An Adaptive Load-Balancing Approach for Ad Hoc Networks," Intl. Conf. on WCNM 2005, vol. 2, 23-26 Sept. 2005, pp. 743-746.

[28] Y. J. Lee and G. F. Riley, "A Workload-based Adaptive Load-Balancing Technique for Mobile Ad hoc Networks," IEEE Wireless Communications & Networking Conference (WCNC 2005), vol. 4, 2005, pp.2002-2007.

[29] Sheu, S. T. & Chen, J. (2001). A Novel Delay Oriented Shortest Path Routing Protocol for Mobile Ad Hoc Networks. Proc. of IEEE International Conference on Communications, Helsinki, Finland.

[30] J. H. Song, V. Wong, and V. C. M. Leung, "Load-Aware On-Demand Routing (LAOR) Protocol for Mobile Ad Hoc Networks", Proceedings of IEEE Vehicular Technology Conference (VTC-Spring), Jeju, Korea, April 2003.

[31] L. Wang, L. Y. Shu and M. Dong, "Multi-Path Source Routing in Wireless Ad Hoc Networks," Proc. Of Canadian Conference on Electrical and Computer Engineering, vol. 1, March 2000, pp. 479-483.

[32] Kui Wu and Janelle Harms, "On-Demand Multi-path Routing for Mobile Ad Hoc Networks," EPMCC 2001, Vienna Austria, 20-22 Feb. 2001, pp. 1-7.

[33] P. Pham, and S. Perreau, " Multi-Path Routing Protocol with Load Balancing Policy in Mobile Ad Hoc Network, " Proc. IEEE Conf. on Mobile & Wireless Communications Networks (MWCN 2002), 2002, pp. 48-52.

[34] P. P. Pham and S. Perreau, "Analysis of Reactive Shortest Single Path Routing Mechanism vs Multi-Path Routing Protocol with Load Balance Policy," Proc. of IEEE INFOCOM, San Fransisco, California, USA, April 2003, pp. 251-259.

[35] Yi Fu, Kwang-Mien Chan, Kean-Soon Tan and Boon-Sain Yeo, "Multi-Metric Gateway Discovery for MANET," IEEE 2006.

[36] YuHua Yuan, HuiMin Chen, and Min Jia, "An Adaptive Load-balancing Approach for Ad Hoc Networks," IEEE 2005.

[37] M. S. Corson, J. P. Maker and G. H. Cirincione , "Internet-Based Mobile Ad Hoc Networking," IEEE Internet Computing, Vol. 3, No. 4, July-August 1999, pp. 63-70.

[38] NS 2 Home page : http://www.isi.edu/nsnam/ns/ index.html

[39] E. Hyytia, H. Koskinen et al., "Random Waypoint Model in Wireless Networks," Networks and Algorithms: Complexity in physics and Computer Science, Helsinki, June 16-19, 2005.

[40] C. Perkins, E. Belding-Royer and S. Das, "Ad Hoc on Demand Distance Vector (AODV) Routing Protocol," IETF Internet RFC 3561, July 2003.

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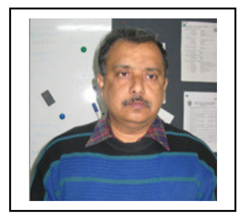

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