Gateway Discovery Algorithm Based on Multiple QoS Path Parameters Between Mobile Node and Gateway Node

Safdar Hussain Bouk, Iwao Sasase, Syed Hassan Ahmed, and Nadeem Javaid

Abstract: **Several gateway selection schemes have been proposed that select gateway nodes based on a single Quality of Service (QoS) path parameter, for instance path availability period, link capacity or end-to-end delay, etc. or on multiple non-QoS parameters, for instance the combination of gateway node speed, residual energy, and number of hops, for Mobile Ad hoc NETworks (MANETs). Each scheme just focuses on the ment of improve only a single network performance, i.e., network throughput, packet delivery ratio, end-to-end delay, or packet drop ratio. However, none of these schemes improves the overall network performance because they focus on a single QoS path parameter or on set of non-QoS parameters. To improve the overall network performance, it is necessary to select a gateway with stable path, a path with the maximum residual load capacity and the minimum latency. In this paper, we propose a gateway selection scheme that considers multiple QoS path parameters such as path availability period, available capacity and latency, to select a potential gateway node. We improve the path availability computation accuracy, we introduce a feedback system to updated path dynamics to the traffic source node and we propose an efficient method to propagate QoS parameters in our scheme. Computer simulations show that our gateway selection scheme improves throughput and packet delivery ratio with less per node energy consumption. It also improves the end-to-end delay compared to single QoS path parameter gateway selection schemes. In addition, we simulate the proposed scheme by considering weighting factors to gateway selection parameters and results show that the weighting factors improve the throughput and end-to-end delay compared to the conventional schemes.**

Index Terms: **End-to-end quality of service (QoS) metrics, gateway selection, mobile ad hoc network (MANET).**

I. INTRODUCTION

Mobile Ad hoc NETworks (MANETs) [1] are on demand, spontaneous, self-administrative, with no infrastructure and plug-n-play networks. There are two major MANET scenarios, the first one is a stand alone MANET and the second is an interconnected MANET [2]. In the stand alone scenario, an ad hoc network is not connected with any other network and all communication is destined within the network premises. On the other hand in interconnected MANET, the ad hoc network is connected with infrastructure network(s).

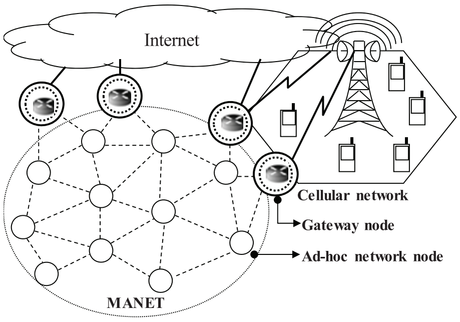

Fig. 1. Interconnected MANET.

Recently, research in the field of MANETs has been aimed on the assimilation of MANETs with the infrastructure networks, e.g., cellular [3] or data networks [4] to extend the network services and coverage to network users beyond the bounds of time and place with a definite level of Quality of Service (QoS). The communication between the infrastructure network and the MANET is provided by some MANET nodes called gateway nodes that are equipped with multiple interfaces. These gateway nodes provide a bridge between multiple networks and may be mobile or fixed, as shown in Fig. 1. An ad hoc node must discover and select a suitable gateway node from a number of gateways before starting communication with the node in the infrastructure network. Hence, the gateway discovery and selection is an important factor to enable the integration between both networks. This research lies in the category of the gateway selection.

Gateway selection is a process that selects a potential gateway node out of multiple discovered gateway nodes based on network, link, and path or gateway node parameters. In the literature, several gateway selection methods [5]–[12] have been proposed that consider different QoS or non-QoS parameters to select a potential gateway node. Most of the gateway selection methods consider hop count, delay, mobility traces, link connectivity, and residual load capacity of gateway nodes or a combination of these parameters.

The gateway selection schemes in [5], [6] select a prospective gateway based on hop count. A gateway discovery message is broadcasted by the gateway and based on that message each node calculates its distance to the gateway. The gateway with the shortest path in terms of hop count is selected for relaying traffic from MANET to the infrastructure network.

In [7], the Ghassemian *et al*. propose a gateway selection scheme that considers delay, jitter, hop count, and bit error rate as additive cost of a path or route between the MANET node to a gateway router and an edge gateway router. A gateway node

---

Manuscript received May 4, 2011; approved for publication by Christos Douligeris, Division II Editor, May 11, 2012.

This work was partly supported by Keio University 21st Century Center of Excellence Program on “Optical and Electronic Device Technology for Access Network” and Fujitsu Laboratories.

S. H. Bouk and N. Javaid are with the Department of Electrical Engineering, COMSATS Institute of Information Technology (CIIT), Islamabad, Pakistan, email: {bouk, nadeemjavaid}@comsats.edu.pk.

I. Sasase is with the Department of Information and Computer Science, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama-shi, Kanagawa, 223-8522, Japan, email: sasase@ics.keio.ac.jp.

S. H. Ahmed is with the Institute of Information Technology, Kohat University of Science and Technology, Kohat, Pakistan, email: sani9585@gmail.com.

that has a path with the minimum cost value is selected by the MANET node for Internet traffic.

Another gateway selection scheme that considers Mobility-Tracing-Value (MTV) as a basic criterion to select a gateway is proposed in [8]. If a neighboring node does not receive a Hello message until its duration expires, then the MTV value increases. Hence, the larger value of MTV denotes the higher probability of link failure. A gateway node on a path with the minimum MTV is selected. If two routes have the same MTV value, then the hop count is the second option to select a gateway.

A hybrid gateway selection criterion is proposed in [9]. The weighted sum is computed based on the Euclidean distance between MANET nodes and the mobile gateway and load on a gateway node. Based on this weight value a MANET node selects a gateway node.

In [10], an adaptive QoS-aware Internet Gateway (IG) selection scheme is proposed that selects a gateway based on two parameters that are the maximum *residual capacity* of an IG and the minimum *hop-count* of a path between a mobile node and an IG. The residual capacity of an IG (δ_{current}) is computed by subtracting the current traffic load of an IG from its total load capacity (C).

$$\delta_{\text{current}} = C - \sum_{i=1}^{l} \lambda_i K_i \tag{1}$$

where λ, K, and l are the average traffic arrival rate per second, the average packet size per second and number of nodes connected to IG, respectively. The second parameter that has been considered for gateway selection is the hop-count between a MANET node or source node (s) and an IG or destination node (d), denoted as $H(s,d)$ and is computed as

$$H(s,d) = \begin{cases} \min\{H(p)\} : s \overset{p}{\to} d, & \text{if there is a path} \\ & \text{from } s \text{ to } d \\ 0, & \text{otherwise.} \end{cases} \tag{2}$$

An IG is selected based on the following criterion

$$\zeta_{IG} = \alpha \left(\frac{\delta}{\delta_{\text{max}}} \right) + (1-\alpha) \left(\frac{H_{\text{max}}}{H} \right) \tag{3}$$

where $\alpha (0 \leq \alpha \leq 1)$ is the weighting factor that is determined by the services and network status. The δ, δ_{max}, H, and H_{max} are the residual IG capacity, hop-count, maximum residual capacity among all IGs, and the maximum hop-count among all paths to the IGs, respectively. A gateway node with the maximum ζ_{IG} is selected to forward traffic from a mobile node to the infrastructure network.

In this IG selection criterion, the residual capacity parameter ($\delta/\delta_{\text{max}}$) normalizes the residual capacity value between 0 and 1 for all path(s) to IG(s), however, the hop-count parameter (H_{max}/H) fails to normalize the hop-count value and results in a value ≥ 1. In result, the hop-count parameter dominates the IG selection criterion.

The Link-connectivity prediction based Location-aided Routing (LLR) protocol for hybrid wired and wireless network is proposed in [11], where MANET is connected with the infrastructured network through gateway node(s). It estimates the route expiration time by calculating the link expiration time between every two neighboring nodes on the route. Let i and j are two neighboring nodes in a route between a wireless node and a gateway, with (x_i, y_i) and (x_j, y_j) coordinates, respectively. Also, let v_i and v_j are speed of the node i and j in θ_i and θ_j moving directions, respectively. The link expiration time (LET) between node i and j is estimated as

$$\text{LET} = \frac{-(ab+cd) + \sqrt{(a^2+c^2)r^2 - (ad-bc)^2}}{a^2+c^2} \tag{4}$$

where, $a = v_i cos\theta_i - v_j cos\theta_j$, $b = x_i - x_j$, $c = v_i sin\theta_i - v_j sin\theta_j$, and $d = y_i - y_j$.

In [12], a weight based gateway selection algorithm is proposed. It calculates the weights of gateway nodes by considering residual battery power, speed of a gateway node and number of hops. The gateway with a higher weight is selected as a default gateway. This scheme slightly improves the network throughput, however, the end-to-end delay and packet drop ratio depends on the proper selection of the weighting factors, which is quite difficult in dynamic scenarios.

The gateway selection schemes discussed above either consider available capacity of a gateway node, number of nodes registered with a gateway, movement trace information, and route expiration time or bit error rate. The basic gateway selection criterion in almost every scheme is based on the parameters related to the gateway node. In MANET, multi-hop paths are established from a MANET node to gateway nodes. Hence, it is possible that multiple paths may have some common nodes through which traffic is relayed from a MANET node to the gateway node(s) or vise versa. These common nodes may create bottleneck to degrade the network throughput. Also, it is observed in [13] that average packet delay decreases and network throughput increases when traffic is forwarded over a path with larger end-to-end connectivity duration. It indicates that the network throughput depends not only on the gateway capacity or solely on the path stability but also on the capacity and stability of the path between a MANET node and a gateway node. Also, selecting a stable path does not guarantee the throughput improvement, because multiple nodes may select the same path to forward traffic and cause congestion. In result, it degrades the throughput or increases the end-to-end delay.

Based on our knowledge, none of the gateway selection algorithm considers the combination of end-to-end (path from a MANET node to gateway node) QoS path parameters, i.e., path availability time period, load capacity of a path and the path latency. In this paper, we propose a gateway selection scheme that considers multiple QoS path parameters such as path availability time period, available load capacity and latency of a path, to select a potential gateway node. We improve the path availability computation accuracy by considering the epoch length of each node, introduce feedback system to update path dynamics of the active paths used by the traffic source node(s) and propose an efficient method to propagate QoS parameters in our scheme. Our proposed gateway selection algorithm is simulated with the simple proactive gateway discovery scheme, however, our proposed gateway selection algorithm can easily be adapted by any gateway discovery scheme.

Rest of the paper is organized as follows. Section II describes the proposed gateway selection algorithm and gateway discovery method. Simulation results are discussed in Section III. Finally, Section IV concludes this paper.

II. PROPOSED GATEWAY SELECTION ALGORITHM

In this section we discuss the proposed gateway selection algorithm along with the gateway selection parameters and discovery process. The performance of the gateway selection algorithm depends on these gateway selection parameters, which directly affects the QoS that an infrastructure network provides to the MANET. Therefore, we consider multiple QoS path parameters in our gateway selection algorithm that provide better QoS in MANET. These parameters compute the end-to-end (path between a MANET node and a gateway node) path availability period, available load capacity and latency of a path.

A. Gateway Selection Parameters

The detailed description of the gateway discovery parameters is as follows.

A.1 Path Availability Period

In MANET, nodes move at random speed and direction that result in a dynamic topology. Consider an example of a Random Walk mobility model [15] where movement of each node is a sequence of random length intervals called *epochs* during which a node moves in a direction θ at the constant speed v. In this situation the link availability period between two nodes is varying at different time intervals. And the path availability period between two nodes that are not immediate neighbors of each other, is equal to the minimum link availability period between intermediate nodes in that path. The path availability period, L_i, of a path i between a MANET node and a gateway node indicates the total time that a gateway is accessible by a MANET node through that path. Our path availability period estimation is based on the link connectivity prediction method in [11], where L_i represents the minimum link availability period and l_u is the link availability period between two neighboring intermediate nodes in a path from a source MANET node (S) to the gateway node (G).

$$L_i = \min\{l_u\} \tag{5}$$

where u denotes the link between intermediate nodes in path i. In [16], link connectivity period, l_u, of a link between node m and n is computed as follows. Let node m and n on path i are in the transmission range t_r of each other and the current positions of nodes m and n are (x_m, y_m) and (x_n, y_n), respectively. Suppose θ_m and θ_n are moving directions and v_m and v_n are speeds of node m and n, respectively. Then, l_u of node m and n is computed as

$$l_u = \frac{-(\alpha\beta + \gamma\rho) + \sqrt{(\alpha^2 + \gamma^2){t_r}^2 - (\alpha\rho - \beta\gamma)^2}}{\alpha^2 + \gamma^2} \tag{6}$$

where $\alpha = v_m cos\theta_m - v_n cos\theta_n$, $\beta = x_m - x_n$, $\gamma = v_m sin\theta_m - v_n sin\theta_n$, and $\rho = y_m - y_n$.

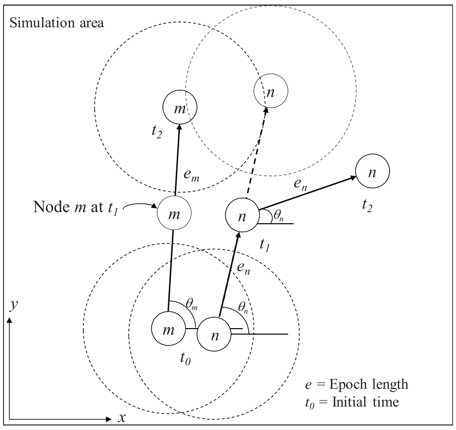

Fig. 2. Mobility pattern in MANET.

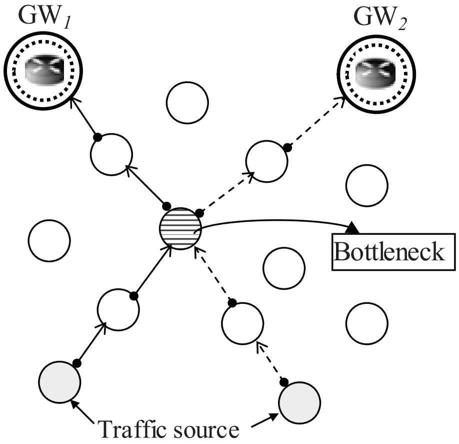

Fig. 3. Bottleneck situation in MANET.

In (6), it is assumed that the epoch lengths of node m and n are same, which is not true in real scenarios. This situation is shown in Fig. 2. According to the link estimation time in (6), node m and n are estimated to be in the transmission range of each other till time t_2, as movement of node n is shown by dashed line after time t_1 in Fig. 2. However, epoch length of $n(t_1 - t_0)$ is shorter than the epoch length of m $(t_2 - t_0)$ and after time t_1 node n randomly selects another direction and speed. In this situation, m and n are in the transmission range of each other till time period of $(t_1 - t_0)$.

In our proposed scheme, l_u is estimated as follows. First, l_u is computed as in (5). If l_u is greater than epoch length of m (e_m), then $l_u = e_m$, otherwise, if l_u is greater than the epoch length of n (e_n), then $l_u = e_n$. Conversely, if l_u is less than e_m as well as e_n, then the link connectivity time is same as computed by (6). The overall path availability time period is computed in similar way by our proposed scheme as in (5).

A.2 Residual Load Capacity of a Path

In multi-hop MANET there can be multiple paths to the gateway node(s). Also, there is possibility that multiple paths may have some common node(s) in the paths between mobile nodes to the gateway nodes, as shown in Fig.3. If traffic is forwarded through these nodes then the common node(s) in the end-to-end paths are overloaded and results in a bottleneck situation that will increase the delay and packet loss. Almost all previous proposals just compute the traffic load of a gateway node and based on that information they select gateways. On the contrary, in our proposed scheme we select gateway nodes accessible through a path with maximum available load capacity. The residual load capacity of a path is the minimum available load capacity at any node, including intermediate nodes and the gateway node, in that path. Suppose the maximum load capacity of a node m is μ and the current traffic load handled by m is λ_m, then the residual load capacity, c_m, at node m is computed as

$$c_u = \mu - \lambda_m, \quad \text{where } \lambda_m = \sum_{j=1}^{s} r_j k_j. \tag{7}$$

In (7), λ_m is the current traffic load on node m that is relaying traffic from s traffic sources, and r_j and k_j denote the average packet arrival rate and the average packet size of the traffic from source j, respectively. The overall residual load capacity C_i of path i is computed as

$$C_i = \min\{c_j\} \tag{8}$$

where c_j denotes the residual capacity of the intermediate nodes in the route including gateway node.

A.3 Path Latency

Latency is the propagation delay plus processing time of a packet from one node to another node. Latency can either be increased when the packet is relayed in a hop-by-hop fashion from sender to the receiver node or when the traffic load is high on any node in the path. Latency of path i, Y_i, is the additive measurement of latency at each link on the path between the gateway and mobile node.

In last, the overall QoS value of a path i, δ_i, is computed as

$$\delta_i = \left(\frac{L_i}{L_{\text{max}}}\right) + \left(\frac{C_i}{C_{\text{max}}}\right) + \left(\frac{Y_{\text{min}}}{Y_i}\right) \tag{9}$$

where L_{max}, C_{max}, and Y_{min} are the maximum path availability period, maximum residual path load capacity, and minimum path latency from all the available paths between a MANET node and gateway node(s), respectively. After computing δ_i for every path to the gateway node(s), a gateway node is selected by the MANET node path with maximum δ_i is selected by the MANET node. A user can also set some preferences for individual parameter in δ_i to prioritize any of the parameters based on the network preferences.

B. Proposed Gateway Selection and Discovery Algorithm

In this section, we briefly discuss the gateway selection and the discovery algorithms along with the propagation mechanism of QoS parameters during the gateway discovery process. We analyze our gateway selection scheme in the hybrid gateway discovery algorithm [14], where each gateway node periodically advertises its parameters within a proactive region of k-hops, as show in Fig. 4. The gateway node advertises its parameters by sending the Gateway Advertisement (GW_ADV) message with its current parameters $l_{\text{GW\_ADV}}$, epoch (e), v, θ, x, y, Time-To-Live (TTL), and available capacity (c). When a node i in the proactive zone (TTL $< k$) receives the GW_ADV message, it computes the values l_i and c_i. If the values of l_i and/or c_i are less than the $l_{\text{GW\_ADV}}$ and/or $c_{\text{GW\_ADV}}$, then it updates the parameters in its routing table as well as in the GW_ADV message and forwards the message further to the MANET. The GW_ADV message is forwarded until TTL $< k$, as shown in Algorithm 1.

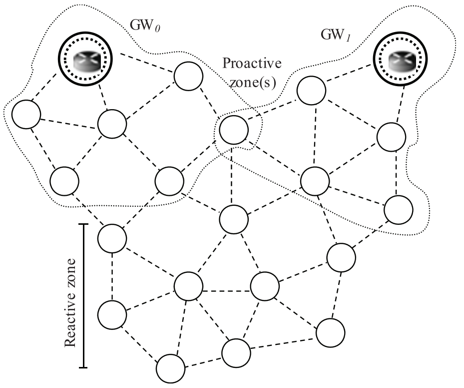

Fig. 4. Hybrid gateway discovery algorithm.

Algorithm 1 Gateway Discovery in *Proactive Zone*

```
GW node periodically sends GW_ADV message:
GW_ADV($l_{GW\_ADV}$ = Null, $e, v, \theta, x, y$, time_stamp, TTL = 0, $Y$, and $c_{GW\_ADV}$)
When node i receives GW_ADV message:
if (TTL < $k$) then
    Mobile node i computes $l_i$ as in (6) ;
    if ( $l_{GW\_ADV}$ = Null or $l_i$ < $l_{GW\_ADV}$ ) then
        $l_{GW\_ADV}$ = $l_i$ ;
    end if
    Compute $c_i$ as in (7) ;
    if ( $c_i$ < $c_{GW\_ADV}$ ) then
        $c_{GW\_ADV}$ = $c_i$ ;
    end if
    Replace $e, v$, and $\theta$ with $e_i, v_i, \theta_i, x_i$, and $y_i$ in GW_ADV message ;
    Update path parameters ($l, c, y$) in Node i's routing table ;
    TTL = TTL + 1 ;
    Forward GW_ADV message ;
end if
```

The MANET node j in the reactive zone discovers the Gateway Node by sending the GW_DISC message. Node j sends GW_DISC with its own parameters, i.e., e_u, v_u, θ_u, x_u, y_u, time_stamp, c_u, and other parameters, as shown in Algorithm 2. GW_DISC message is processed by each node at every hope and the minimum parameters of the path are forwarded until it is received by a gateway node or any node in the proactive region. If a node j in the proactive region receives GW_DISC message, it sends a unicast GW_ADV message to the sender of the GW_DISC message. Before sending a unicast advertisement message, the proactive region node finds the best available path to the gateway node from its routing table and it compares these path parameters (capacity and availability period) with the one in the GW_DISC message. The minimum of both the parameters along with the sum of path latency in the routing table and the latency of the GW_DISC message are added in the unicast advertisement message. On receiving the unicast advertisement message, the mobile node updates its routing table.

Algorithm 2 Gateway Discovery in *Reactive Zone*

```
Node u sends GW_DISC message:
GW_DISC($l_{GW\_DISC} = Null$, $e_u, v_u, \theta_u, x_u, y_u$, time_stamp, TTL = 0, and $c_{GW\_DISC}$)
When node j receives GW_DISC message:
if (Node j is in Reactive Zone) then
    Mobile node j computes $l_j$ as in (6) ;
    if ( $l_{GW\_DISC}$ = Null or $l_j < l_{GW\_DISC}$ ) then
        $l_{GW\_DISC} = l_j$ ;
    end if
    Compute $c_j$ as in (7) ;
    if ( $c_j < c_{GW\_DISC}$ ) then
        $c_{GW\_ADV} = c_j$ ;
    end if
    Replace $e_u, v_u$, and $\theta_u$ with $e_j, v_j, \theta_j, x_j$, and $y_j$ in GW_DISC message ;
    Update path parameters $(l, c, y)$ in Node j's Routing table ;
    TTL = TTL + 1 ;
    Forward GW_DISC message ;
end if
if (Node j is GW node or Node j is a node in Proactive Zone) then
    Node j computes $\delta_r$, as in (9), from its routing table ;
        where r = path(s) to GW node(s) ;
    index = max($\delta_r$)
    Generate GW_ADV message with updated $l, Y$, and $c$ values:
        $l = \min(l_{GW\_DISC}, l_{index})$,
        $c = \min(c_{GW\_DISC}, c_{index})$, and
        $Y = Y_{index} + delay_{GW\_DISC}$ ;
    Send GW_ADV message to the GW_DISC originator ;
end if
```

The MANET is a dynamic topology network where data traffic is generated and forwarded through dynamic routes. In result, the overall path capacity either increases or decreases at random. Therefore, it is necessary to propagate the current state of the path to the data traffic source node(s). The intermediate node on the active path sends the path update message to the data traffic source node(s) in a unicast manner when a new connection is established through this path or an old connection is terminated. In this manner, the data traffic source node(s) select a potential gateway by using the updated path parameters.

Algorithm 3 Gateway Selection

```
Node computes $\delta_r$, as in (9), from its routing table ;
    where r = path(s) to GW node(s) ;
index = max($\delta_r$)
Select the GW with $path_{index}$ ;
```

The QoS parameters of each path to the gateway node(s) along with the path entries are maintained by the MANET node in its routing table. If a MANET node wants to send data traffic to a host in the infrastructure network, it calculates the overall QoS value of each path (δ_i) in the routing table and selects the gateway that has a path with maximum δ_i, as shown in the Algorithm 3.

III. SIMULATION ANALYSIS

To analyze the performance of our proposed gateway selection scheme in contrast with the existing gateway selection schemes, we simulate our scheme in NS2.30 [16] and the simulation parameters are shown in Table 1. In simulations, the network of 25 mobile nodes along with 5 gateways, is simulated over the 1 Km^2 area. Each MANET node has a maximum transmission range of 175 m. The network is simulated for 1000 s. We assume that all gateway nodes are equipped with 802.11b interface and are accessed by the MANET nodes that are within the transmission range or MANET nodes that have multi-hop path to gateway. The speed of MANET and gateway nodes is uniformly distributed between 0 and 1 m/s, 2 m/s, to 5 m/s in a RandomWalk [15] fashion. Energy consumption parameters are also defined in Table 1, where the transmission, receiving, idle, and sleep power are 0.316, 0.2, 0.05, and 0.001 Watts, respectively. In the beginning of the simulation, all nodes are assigned with the equal amount of energy, that is 1000 joules.

Table 1. Simulation Parameters.

Parameter	**Value**
Area	1000 m × 1000 m
Wireless MAC interface	IEEE 802.11b
Propagation	2.472 GHz
Propagation model	Two ray ground
Data rate	2 MB
Transmission rage	175 m
Number of MANET nodes	25
Number of gateway nodes	5
K	2-hops
Mobility model	Random walk
MANET & gateway node speed	1 m/s, 2 m/s,$\cdots$, 5 m/s
CBR packet size	512 bytes
CBR interval (σ)	0.3 s, 0.15 s,$\cdots$, 0.09 s
GW_ADV interval	10 s
GW_DISC messages interval	5 s
Simulation time	1000 s
Transmission power	0.316 Watts
Receiving power	0.2 Watts
Idle power	0.05 Watts
Sleep power	0.001 Watts

Data communication between MANET nodes and the infrastructure nodes is carried out in a Constant Bit Rate (CBR) manner. CBR packet size of 512 bytes and the CBR interval of 0.3, 0.15, to 0.009 s are considered in the simulations. Average number of 5 CBR connections per minute with the average connection duration of 80 s is implemented in the simulation. The simulation results are the average of 3 randomly generated traffic models executed over each of the 5 randomly generated movement scenarios. The performance of the proposed gateway selection algorithm is compared with the gateway selection schemes proposed in [10] and [11], which are referred as conventional 1 and conventional 2, respectively, in this paper. Figs. 5–15 show the simulated performances of the proposed scheme and the conventional schemes.

Figs. 5 and 6 show the CBR packet drop ratio for varying node speed and CBR interval. It is evident from the graphs that the proposed scheme outperforms the conventional 1 and also has higher success ratio compared to conventional 2. Conventional scheme 1 has the high drop ratio, because conventional 1 only selects a path with maximum bandwidth and minimum number of hops. Similarly, conventional scheme 2 only considers path stability. Due to the node mobility and multiple CBR connections, paths are not stable and path capacity varies in

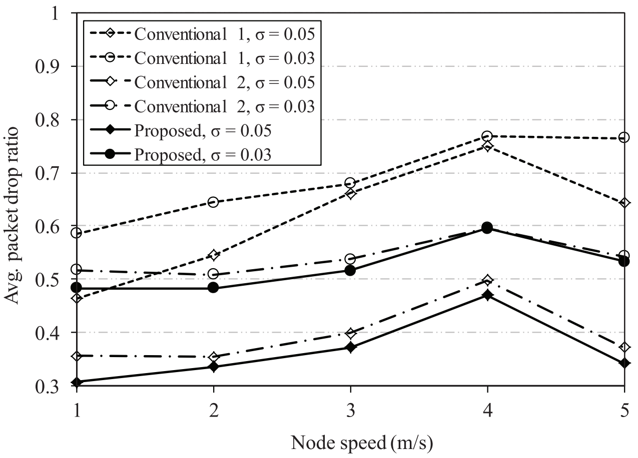

Fig. 5. Average packet drop ratio vs. node speed.

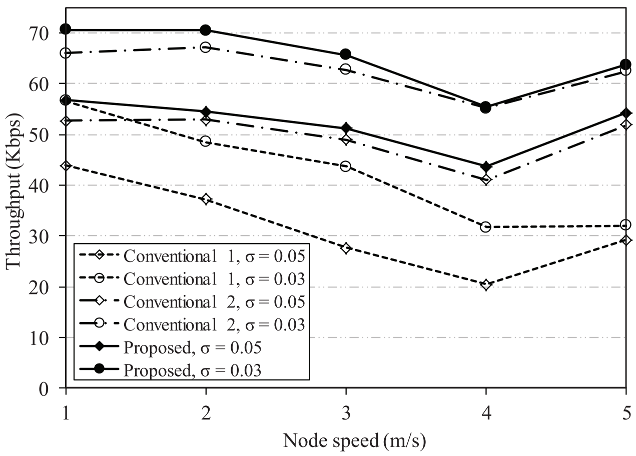

Fig. 7. Average throughput vs. node speed.

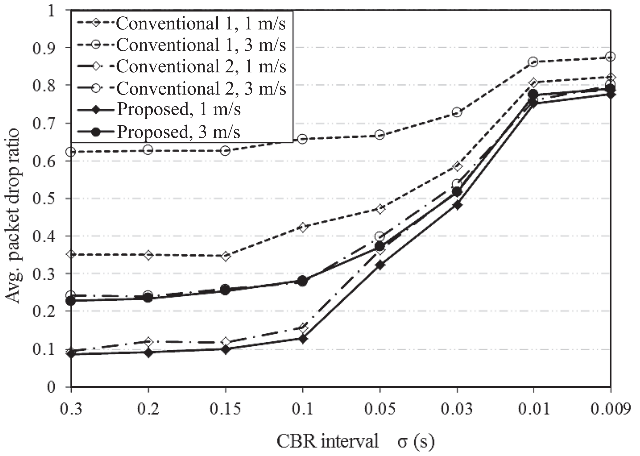

Fig. 6. Average packet drop ratio vs. CBR interval (σ).

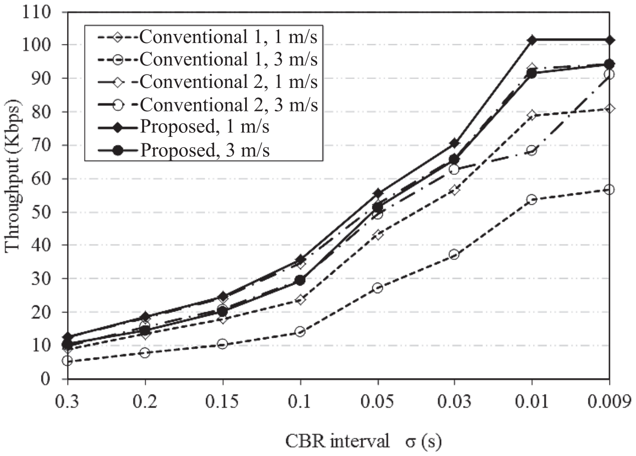

Fig. 8. Average throughput vs. CBR interval (σ).

time and neither of the conventional schemes can cope with the dynamic nature of MANET. On the other hand, the proposed scheme not only selects the gateway with the stable path and the path with minimum load and latency. Our scheme also uses the feedback mechanism to inform the source node about the path status in time. Hence, source node forwards data traffic through real time, stable and less overloaded path. In result, the CBR packet drop of the proposed scheme is less than both the conventional schemes and that is also evident from the simulation analysis shown in Figs. 5 and 6. It is observed that our proposed scheme averagely reduces the packet drop ratio about 68% and 32% compared to conventional 1 for CBR rate of 0.05 and 0.03, respectively. It also reduces 8% and 4% in packet drop ratio compared to the conventional 2 for CBR rate of 0.05, 0.03, respectively.

Average throughput versus node speed and CBR interval is shown in Figs. 7 and 8, respectively. It shows that the proposed scheme improves the throughput compared to the conventional schemes. This improvement of the throughput by the proposed scheme is only because, it considers the normalized (values between 0 and 1) multiple QoS path parameters, i.e., path stability time period, maximum available load capacity and minimum path delay. It precisely computes the path stability by considering the epoch length of the individual nodes in the path, which reduces packet loss and improves the throughput.

Figs. 9 and 10 depict the average end-to-end delay experienced by data packets for varying node speed and CBR interval, respectively. It shows that the proposed scheme has less end-to-end delay compared to conventional 2 and slightly higher end-to-end delay in contrast to the conventional 1 scheme. The reason of improved end-to-end delay performance by the proposed scheme compared to conventional 2 is that it considers end-to-end delay as one of the gateway selection parameter. Conversely, our scheme has slightly higher latency compared to conventional 1 because, conventional 1 forwards data traffic through shortest but unstable, which results in a very high packet loss and reduced throughput.

The average energy consumption is shown in Figs. 11 and 12. It is evident that conventional 1 has less average energy consumption per node because it selects unstable paths and due to this unstability, most of the data traffic is not carried out to the destination node. In result, it has less energy consumption

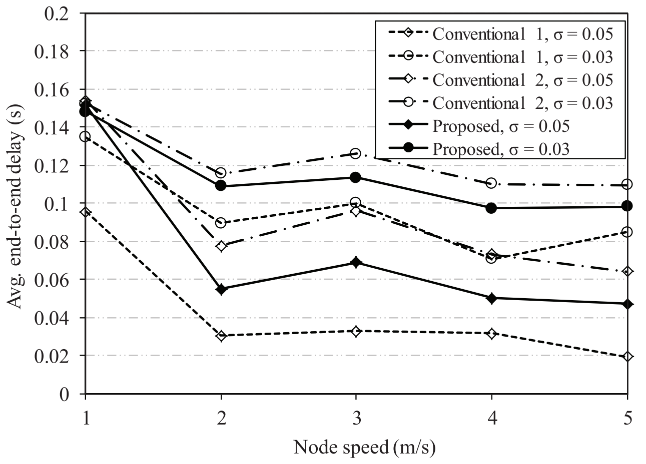

Fig. 9. Average end-to-end delay vs. node speed.

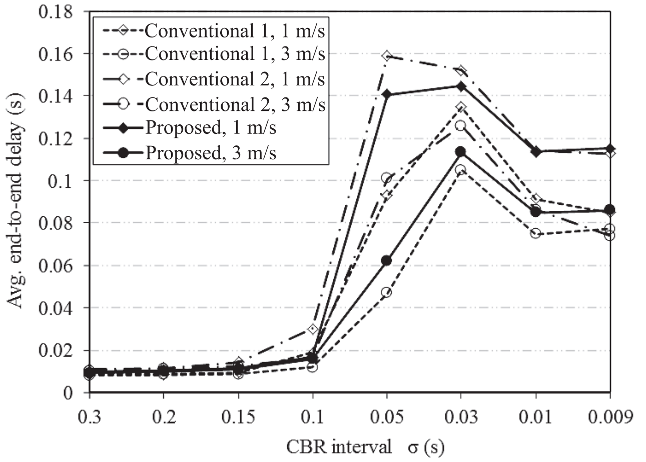

Fig. 10. Average end-to-end delay vs. CBR interval (σ).

per node. On the other hand, the proposed scheme selects more stable and less congested path compared to conventional 2 that consequently improves the throughput and also reduces control energy consumption and control overhead.

Fig. 13 depicts the average control overhead in terms of total number of messages processed in the network during simulation time versus the CBR interval (σ). The proposed scheme produces less control overhead compared to conventional scheme 2 because conventional scheme 2 selects the shortest and slightly less stable path. Conversely, the conventional scheme 1 has slightly less control overhead because it selects the gateway based on multiple parameters and hop-count parameter dominates the gateway selection criteria. In result, conventional scheme 1 has high drop ratio and less throughput compared to the proposed scheme.

We also simulate the proposed scheme by considering different weighting factors, w_1, w_2, and w_3, assigned to the path availability period, residual path load capacity and path latency, respectively, to compute the overall weight.

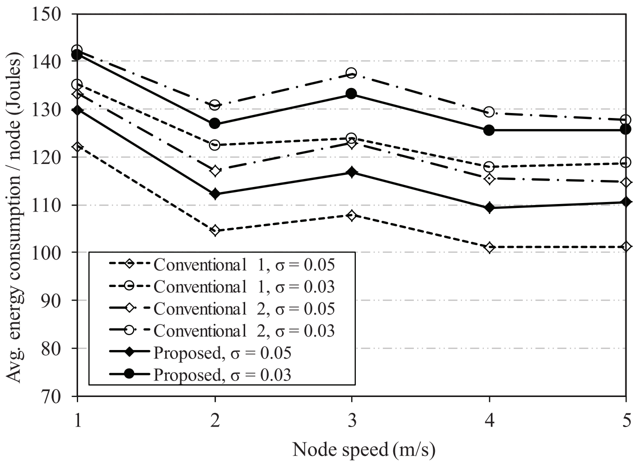

Fig. 11. Average energy consumption / node vs. node speed.

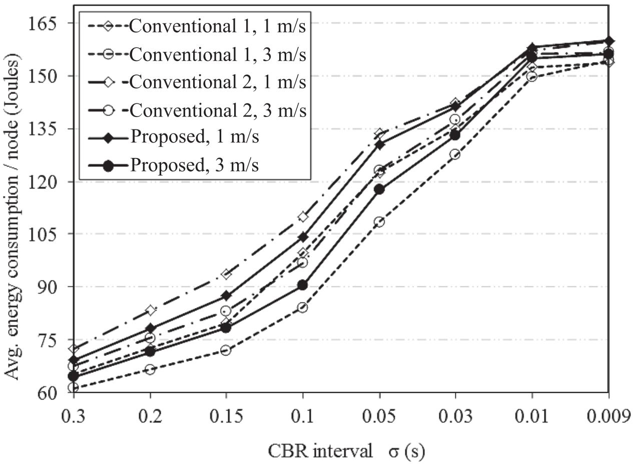

Fig. 12. Average energy consumption / node vs. CBR interval (σ).

$$\delta_i = w_1\left(\frac{L_i}{L_{\max}}\right) + w_2\left(\frac{C_i}{C_{\max}}\right) + w_3\left(\frac{Y_{\min}}{Y_i}\right) \tag{10}$$

Out of three above said parameters, two are assigned high weights (i.e., 0.4 to each of the two parameters) and one parameter is assigned less weight, i.e., 0.2.

Average throughput versus node speed is shown in Fig. 14. It shows that the proposed scheme improves the throughput compared to the conventional schemes even one of the three parameters is assigned less weight. It shows that by assigning higher weights to L_i, Y_i, and less weight to C_i, it improves throughput by 23.4, 3.2, and 0.7 Kbps compared to conventional scheme 1, 2 and the proposed scheme (without weights) with the CBR interval of 0.03 s. In other scenarios where less weight is assigned to L_i and Y_i, the proposed scheme with weights also improves the throughput compared to conventional schemes.

On the other hand, for the weighting scenarios considered in the simulation, the proposed scheme has slightly higher end-to-end delay than conventional scheme 1 because it considers min-

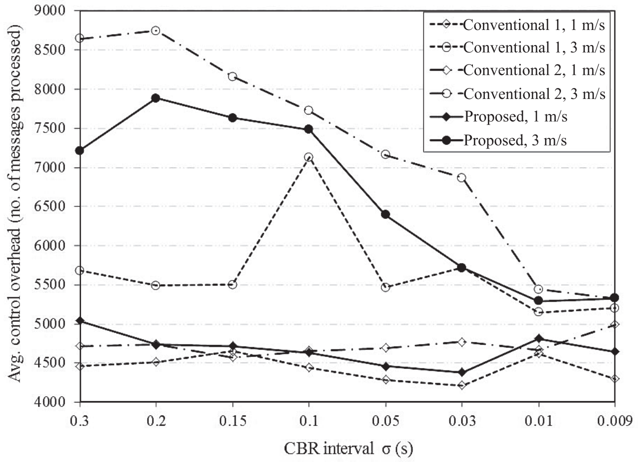

Fig. 13. Average control overhead vs. CBR interval (σ).

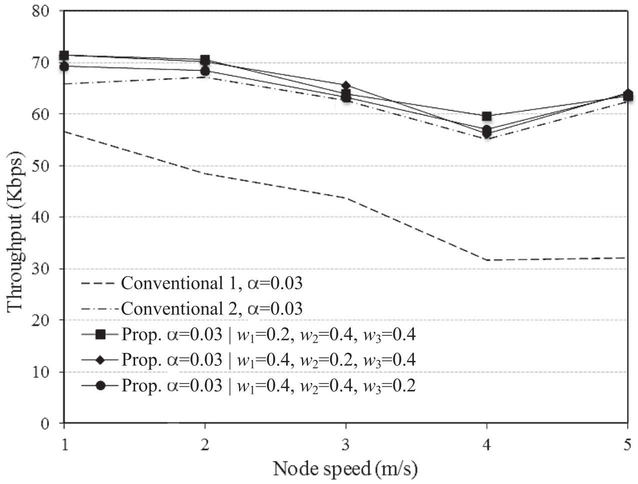

Fig. 14. Average throughput vs. node speed.

Table 2. Performance comparison of proposed scheme with weights.

Throughput			
	Proposed with weights (w_1, w_2, w_3)		
	0.2, 0.4, 0.4	0.4, 0.2, 0.4	0.4, 0.4, 0.2
Conventional 1	23.35 Kbps	23.1 Kbps	22.0 Kbps
Conventional 2	3.2 Kbps	2.90 Kbps	1.81 Kbps
Proposed (without weights)	0.7 Kbps	0.42 Kbps	−0.68 Kbps
End-to-end delay			
Conventional 1	0.0137 s	0.018 s	0.021 s
Conventional 2	−0.0129 s	−0.0083 s	−0.0058 s
Proposed (without weights)	−0.0035 s	0.0012 s	0.0036 s

imum hop-count as one of its GW selection parameter, as shown in Fig.15. However, the proposed scheme with weight has less end-to-end delay than conventional 2. The simulation results of the proposed scheme with weights are compared with the conventional 1, 2, and the proposed scheme without weights and summarized in the Table 2. The results show that the weighting factors improve throughput and end-to-end delay in some scenarios, however, the weighting factors are application specific.

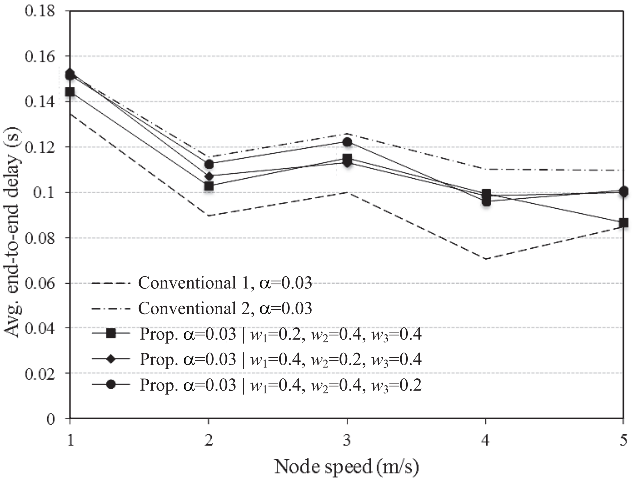

Fig. 15. Average end-to-end delay vs. node speed.

IV. CONCLUSION

We have proposed a gateway selection algorithm that considers multiple end-to-end QoS path parameters such as precise path availability period, path load capacity, and latency. The simulation results show that the proposed scheme improves the network throughput, success rate and reduces the packet drop ratio, end-to-end delay, and energy consumption per node compared to the conventional schemes.

REFERENCES

[1] G. Aggelou, *Mobile Ad Hoc Networks: From Wireless LANs to 4G Networks*, McGraw-Hill Professional, Nov. 2004.

[2] E. Baccelli, K. Mase, S. Ruffino, and S. Singh, “Address autoconfiguration for MANET: Terminology and problem statement,” IETF draft, Aug. 2008.

[3] H. Luo, X. Meng, R. Ramjee, P. Sinha, and L. Li, “The design and evaluation of unified cellular and ad-hoc networks,” *IEEE Trans. Mobile Comput.*, vol. 6, pp. 1060–1074, Sept. 2007.

[4] P. M. Ruiz, F. J. Ros, and A. F. Gomez-skarmea, “Internet connectivity for mobile ad hoc networks: Solutions and challenges,” *IEEE Commun. Mag.*, pp. 118–125, Oct. 2005.

[5] B. Shen, B. Shi, B. Li, Z. Hu, and L. Zou, “Adaptive gateway discovery scheme for connecting mobile ad hoc networks to Internet,” in *Proc. WiCOM*, Sept. 2005, pp. 795–799.

[6] M. C. Domingo, “Integration of ad hoc networks with fixed networks using an adaptive gateway discovery protocol,” in *Proc. IET International Conference on Intelligent Environments*, July 2006, pp. 371–379.

[7] M. Ghassemian, P. Hofmann, V. Friderikos, C. Prehofer, and A. H. Aghvami, “An optimised gateway selection mechanism for wireless ad hoc networks connected to the Internet,” in *Proc. IEEE VTC*, May 2006, pp. 782–787.

[8] C. Shin, S. H. Kim, and S. An, “Stable gateway selection scheme based on MANET with Internet,” in *Proc. IEEE ICCIT*, Sept. 2006.

[9] H. Ammari and H. El-Rewini, “Using hybrid selection schemes to support QoS when providing multihop wireless Internet access to mobile ad hoc networks,” in *Proc. IEEE QSHINE*, Oct. 2004, pp. 148–155.

[10] B. N. Park, W. Lee, C. Lee, and C. K. Shin, “QoS-aware adaptive Internet gateway selection in ad hoc wireless Internet access networks,” in *Proc. IEEE BROADNETS*, Oct. 2006, pp. 1–10.

[11] M. Wu, W. K. G. Seah, and L. W. C. Wong, “A link-connectivity-prediction-based location-aided routing protocol for hybrid wired-wireless networks,” in *Proc. ICMU*, Apr. 2005.

[12] F. P. Setiawan, S. H. Bouk, and I. Sasase, “An optimum multiple metrics gateway selection mechanism in MANET and infrastructured networks integration,” *IEICE Trans. Commun.*, vol. E92-B, no. 08, Aug. 2009.

[13] M. Ghassemian, P. Hofmann, C. Prehofer, V. Friderikos, and H. Aghvami,

"Performance analysis of Internet gateway discovery protocols in ad hoc networks," in *Proc. IEEE WCNC*, Mar. 2004, pp. 120–125.

[14] P. Ratanchandani and R. Kravets, "A hybrid approach to Internet connectivity for mobile ad hoc networks," in *Proc. IEEE WCNC*, Mar. 2003, pp. 1522–1527.

[15] T. Camp, J. Boleng, and V. Davies, "A survey of mobility models for ad hoc network research," in *WCMC*, vol. 2, no. 5, pp. 483–502, 2002.

[16] The Network Simulator - NS-2. [Online]. Available: http://www.isi.edu/nsnam/ns/

Safdar Hussain Bouk was born in Larkana, Pakistan in 1977. He received the Bachelors degree in Computer Systems from Mehran University of Engineering and Technology, Jamshoro, Pakistan, in 2001 and Masters and Ph.D. in Engineering from the Department of Information and Computer Science, Keio University, Yokohama, Japan, in 2007 and 2010, respectively. Currently he is a working as an Assistant Professor at COMSATS Institute of Information Technology, Islamabad, Pakistan. His research interests include wireless ad-hoc and sensor networks.

Iwao Sasase was born in Osaka, Japan in 1956. He received the B.E., M.E., and Ph.D. Eng. degrees in Electrical Engineering from Keio University, Yokohama, Japan, in 1979, 1981, and 1984, respectively. From 1984 to 1986, he was a Post Doctoral Fellow and Lecturer of Electrical Engineering at University of Ottawa, ON, Canada. He is currently a Professor of Information and Computer Science at Keio University, Yokohama, Japan. His research interests include modulation and coding, broadband mobile and wireless communications, optical communications, communication networks, and information theory. He has authored more than 265 journal papers and 385 international conference papers.

He received the 1984 IEEE Communications Society Student Paper Award (Region 10), 1986 Inoue Memorial Young Engineer Award, 1988 Hiroshi Ando Memorial Young Engineer Award, 1988 Shinohara Memorial Young Engineer Award, and 1996 Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan Switching System Technical Group Best Paper Award, 2008 International Symposium on Wireless Personal Multimedia Communications Best Paper Award.

He serves as a Member-at-Large, IEEE ComSoc Board of Governors (2010-2012), IEEE ComSoc Japan Chapter Chair(2011-2012), and IEICE Commnications Society President-in-Elect (May 2012-May 2013). He was the Vice President of the IEICE Communications Society (2004-2006), the Chair of the IEICE Network System Technical Committee (2004-2006), the Director of the IEEE ComSoc Asia Pacific Region (2004-2005), the Chair of the IEEE ComSoc Satellite and Space Communications Technical Committee (2000-2002), the Chair of the IEICE Communication System Technical Committee (2002-2004), and Director of the Society of Information Theory and Its Applications in Japan (2001-2002). He is a Fellow of IEICE, Senior Member of IEEE and Information Processing Society of Japan, respectively.

Syed Hassan Ahmed completed his Bachelors from Kohat University of Science and Technology, Kohat, Pakistan in 2012. During his bachelors, he published his research work in Springer and IEEE sponsored conferences. His bachelors thesis was "Sensing Activites of Different Objects with Sensorless Sensor Nodes". His research interests include wireless ad-hoc and sensor networks.

Nadeem Javaid completed his Ph.D. from the University of Paris-Est, France in 2010. Previously, he has completed Masters in Electronics from Quid-I-Azam University, Islamabad in 1999. Before going to France, he has been teaching for more than eight years in different Universities of Pakistan; such as International Islamic University, COMSTAS Institute of IT, Hamdard University, etc. His research interests include, wireless ad-hoc, sensor, vehicular, and body area networks.