A Quality Aware Anycast Routing Protocol for Wireless Mesh Networks

Amitangshu Pal and Asis Nasipuri
Electrical & Computer Engineering
The University of North Carolina at Charlotte
Charlotte, NC 28223-0001
E-mail:{apal,anasipur}@uncc.edu

***Abstract-* In this paper we consider anycast routing for multi-gateway wireless mesh networks to maximize the overall quality of communications. For such networks, anycasting provides an effective mechanism to reduce problems due to congestion and interfence by appropriate selection of gateways, particularly at heavy traffic conditions. However, as proved in this paper, the optimal gateway selection problem is *NP-hard*. Hence, we propose a heuristic for route selection that tries to perform gateway and route selection to minimize interference. Simulation results show that our proposed anycasting scheme performs better than other well known anycasting protocols.**

***Keywords:* Wireless mesh networks, on-demand routing, anycasting, QoS.**

I. Introduction

A wireless mesh network (*WMN*) is a collection of mesh routers that enable mesh clients to communicate over dynamically established multihop routes. *WMNs* are emerging as a promising technology for providing ubiquitous network connectively in enterprises, campuses and metropolitan areas. A small fraction of these routers may have wired connection to the Internet and serve as gateways to the rest of the network. Thus, *WMN*s provides a cost-effective solution for extending the reach of Internet access points. If required, *WMNs* can also be scaled up easily by installing additional routers to increase geographical coverage and service. Consequently, there is an increasing interest of using mesh networks.

Anycasting allows a source node to transmit packets to one of a group of destination nodes. It is a routing model that can increase service scalability and provide efficient load distribution. Our anycast based architecture is depicted in Fig. 1, where all the gateway nodes $(G_1, G_2, G_3, G_4, G_5, G_6)$ are connected and collaborate with each other. Using anycasting in *WMNs* has several advantages. First, it reduces the congestion at one gateway, thus improving the network performance. Secondly, as shown in Fig. 1, if any link of the path $X{\rightarrow}Y{\rightarrow}G_5$ is broken then also X can reach the Internet through G_4 by choosing $X{\rightarrow}Z{\rightarrow}G_4$. But among all the gateway nodes, choosing the optimal gateway is a difficult and challenging problem. Some existing works [3] propose the selection of the gateway from which the first route reply packet *RREP* is received by the source, which may not give good performance. As shown in Fig. 1, in the presense of a traffic $A{\rightarrow}B{\rightarrow}G_1$, the nearest gateway from *C* (i.e. G_1) may not be the best gateway; rather G_2 may be the better gateway from *C*. This paper proposes a *gateway selection and quality aware routing protocol (GSQAR)* to select the best gateway node (destination) and the corresponding route to maximize the overall quality of communication paths in the network. We present performance results obtained from simulations to show that *GSQAR* performs better than *random gateway selection scheme* or *nearest gateway selection scheme*.

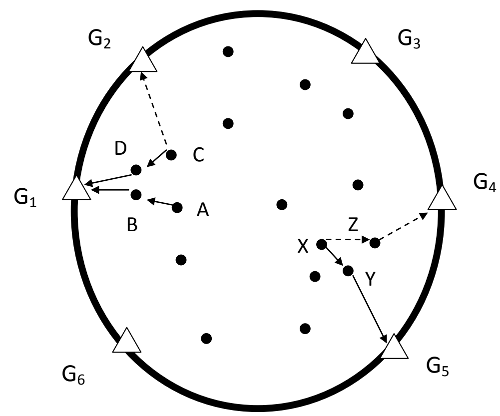

Fig. 1. Wireless mesh network architecture with multiple gateways

The rest of the paper is organized as follows. In section II, we discuss the design of our anycasting based scheme in *WMNs*. Section III describes our proposed *GSQAR* routing protocol. In section IV, we present performance evaluations of *GSQAR* and its comparison with a popular shortest-path based routing protocol (*AODV*) and another QoS based routing protocol *QoSBR* [2] with random gateway selection. Conclusions are presented in section V.

II. Problem Formulation And GSQAR Design

The problem of optimal gateway selection can be formulated as follows. Consider a case of n sources $\{S_1, S_2, ..., S_n\}$ and a group of m gateways $\{G_1, G_2, ..., G_m\}$ where $1 \leq m \leq n$. The problem is to assign the n sources to m gateways so that the total quality of the network is maximized. The problem can be formulated as a *0-1 integer programming problem* as follows:

$$Maximize \sum_{i=1}^{n}\sum_{j=1}^{m} q_{S_iG_j} x_{S_iG_j} \quad (1)$$

subject to

$$\sum_{j=1}^{m} x_{S_iG_j} = 1 (1 \leq i \leq n) \quad (2)$$

$$x_{S_iG_j} = 0 \text{ or } 1 \ (1 \leq i \leq n) \ (1 \leq j \leq m) \quad (3)$$

where $q_{S_iG_j}$ is the quality of the best route between S_i and G_j and $x_{S_iG_j}$ is a binary variable used for gateway selection: if the best gateway chosen for S_i is G_j, then $x_{S_iG_j}$ =1; otherwise $x_{S_iG_j}$ =0. Constraint (2) states that S_i can only transmit all its packets to one gateway only.

A. Time Complexity of Optimal Gateway Selection

The complexity of *GSQAR* is proved using reductions from the *3-PARTITION* problem. The *3-PARTITION* problem is to decide whether a given multiset of integers can be partitioned into triples that all have the same sum. More precisely, given $\{a_1, a_2, ..., a_{3p}\}$ integers, does there exist a partition $\{A_1, A_2, ..., A_p\}$ of $\{1, 2, ..., 3p\}$ such that $\mid A_i \mid$=3 for $i = 1, ..., p$ and $\sum_{j \in A_i} a_j$= $\sum_{j \in A_k} a_j$, for any $1 \leq i, k \leq p$.

From an instance of *3-PARTITION*, we construct an instance of *GQSAR* as folows: Choose $n = 3p$, $m = p$, $\sum_{i=1}^{n} x_{S_iG_j} = 3$ for each i and set q_{ij}=a_j, $j = 1, 2, ..., n$; $i = 1, 2, ..., m$. Since *3-PARTITION* problem is *NP-complete*, from our reduction it folows that *GSQAR* is also *NP-hard*.

B. Design of GSQAR

As the problem of optimal gateway selection is *NP-hard*, we propose a heuristic solution to solve this problem. Our solution is centralized, where we assume that the set of gateway nodes communicate with each other (possibly over some infrastructured network) and determine the optimum routes for the network. The proposed scheme is illustrated in Fig. 2, where we assume three sources S_1, S_2, S_3 and two destinations D_1, D_2 and the network is assumed to be a grid structure. Each small box represents a node and each box is assumed to be a unit square. We define *rect(S_i, D_j)* as the rectangular region whose diagonal is the line connecting S_i and D_j. The scheme follows the following steps:

- First, we consider costs associated with routing over each box, which are initialized to zero. For each source S_i and destination D_j, the scheme chooses a route inside *rect(S_i, D_j)*, which minimizes the cost. The route cost is entered in each box in this rectangular region, which is equal to the distance between S_i and D_j (distance is measured as the sum of horizental and vertical distance in Fig. 2). Initially, each source considers routes to all destinations and marks the costs in the boxes. The costs for multiple destinations are superimposed on all boxes. For instance, in Fig. 2(a), all the boxes in the right of S_1 is set to *6*, which is the distance between S_1 and D_1. Similarly, the boxes on the left of S_1 are assigned to *3*. The column that consists of S_1 is assigned to $6 + 3 = 9$ where two regions (*rect(S_1D_1)*) and (*rect(S_1D_2)*) overlap. Similar process is continued for S_2 (Fig. 2(b)) and S_3 (Fig. 2(c)).
- Among all the boxes consisting of $\{S_1, S_2, ..., S_n\}$, the box with minimum cost is chosen first. Then path selection is based on traversing along neighboring boxes of minimum cost, i.e. comparing the costs of the boxes to the right/left/up/down of the current box, until any destination is reached. We cannot move to the boxes that have a cost of zero. The nodes that are visited to reach the destination gives the route from source to destination. If we move up, we cannot move down again. The same rule applies in the down-up, left-right and right-left directions. If more than one box in left/right/up/down of the current box have minimum cost, the box that leads to the nearest gateway is selected. Once the route between any S_i and D_j is found, all the costs of boxes in *rect(S_i, D_k)* ($k \neq j$) are decremented by the distance between S_i and D_k. Next, all the unvisited boxes in *rect(S_i, D_j)* are decremented by the distance between S_i and D_j. Once the route from S_i is found, S_i is marked as a *visited_source*. For instance, in Fig. 2(d), the box consisting of S_2 is of minimum cost. So, we start with S_2 and follow the boxes with minimum cost until we reach destination D_2. After that all the boxes in *rect(S_2, D_1)* are decremented by 7. All the unvisited boxes in *rect(S_2, D_2)* are also decremented by *6*.
- After the route from a source S_i and destination D_j is found, all the boxes that are in the interference range of any node in the new route are interferered. Thus we increment the cost of these boxes by the distance of S_i and D_j. In Fig. 2(d), all the boxes in the interference range of the new route are incremented by 6.
- Next, boxes consisting of *unvisited_sources* are searched and the box with the minimum cost is selected. Then the same technique is repeated until and unless all $\{S_1, S_2, ..., S_n\}$ get a route towards any destination. This is depicted in Fig. 2(e) and Fig. 2(f).

The above scheme does not depend on the order of the flows. But in a real network, flows come one after another and that may create a problem. Let us assume in Fig. 2, S_3, S_1 and S_2 are activated in sequence. First S_3 chooses gateway D_1 and then S_1 chooses D_2. Next when S_2 becomes active, according to the scheme, S_1 should switch to D_1. But this switching degrades the network performance. For more number of sources the number of switching increases, thus making the scheme inefficient. To avoid this, the overall quality (the quality is calculated based on the quality metric from our earlier work in [2]) of all the routes before and after switching is calculated. *If the improvement after switching is significant*, only then the sources switch the gateways.

The algorithm of gateway selection is depicted in Algorithm 1. Although we explain in the gateway selection scheme in a uniform grid structure, the scheme can be applicable to any kind of topology by using a non-uniform grid.

After gateway selection, we have all the *(S_i, D_j)* pairs. But the above gateway selection scheme gives only one route from S_i to D_j. When *RREQ* of S_i reaches D_j, D_j gets a lot of routes from S_i to D_j. Among all these routes and the route

Algorithm 1 Our gateway selection scheme

INPUT
G=set of gateways; S=set of sources; T=neighbor connectivity graph
OUTPUT
a set of paths from each source to one gateway
for each vertex $v \in V$ **do**
draw a horizental box around v
draw a vertical box around v
end for
for each vertex $v \in V$ **do**
cost(v)=0;
put 0 in all the boxes
end for
$S^/$=S
for $each S_i \in S^/$ **do**
for $each G_i \in G$ **do**
d_{ij}=distance(S_i, G_j)
$cost\_box(v)$=$cost\_box(v)$+d_{ij}
put $cost\_box(v)$ in all rectangular boxes in region $[(S_{ix}, S_{iy}), (S_{ix}, G_{jy}), (G_{jx}, S_{iy}), (G_{ix}, G_{jy})]$
end for
end for
sort $S^/$ according to $cost\_box(S_i)$
while not_empty($S^/$) **do**
while current_node $\notin$ G **do**
n_i=minimum(S)
move to right, left, up or down based on which box has minimum cost
if previous move is right **then**
do not move left
end if
if previous move is left **then**
do not move right
end if
if previous move is up **then**
do not move down
end if
if previous move is down **then**
do not move up
end if
if among right, left, up or down more than one boxes have minimum cost **then**
follow the path that leads to the nearest destination
end if
record the nodes in $visited\_node(n_i)$
end while
$S^/ = S^/ \backslash n_i$
end while
for each $S_i \in S$ **do**
choose the path to the gateway which is the nearest from nodes $\in visited\_node(S_i)$
end for

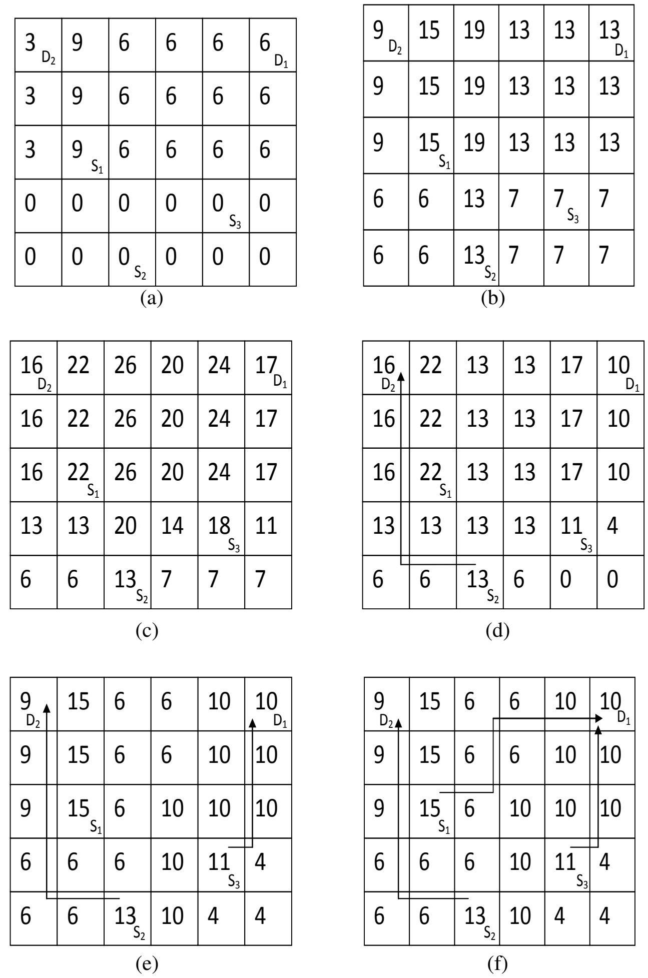

Fig. 2. Proposed gateway selection scheme in grid environment

given by the gateway selection scheme, D_j chooses the route that maximizes the overall quality.

III. GSQAR Routing Protocol

When a source does not have a route to any gateways, it sends route requests (*RREQ*) for all gateways. After getting the *RREQ* packets, the destinations collaborate with each other to obtain the best gateway for each source by applying Algorithm 1. Then only the best gateway sends the *RREP* towards source, that consists of all the intermediate nodes from source to destination. All intermediate nodes update their routing table based on this *RREP* packet. When the source receives *RREP*, it starts transmitting *DATA* packets to the best gateway. When there is any route switching, the gateway informs the source about the switching. The source then route *DATA* packets based on that route only.

IV. Performance evaluation of GSQAR

We next present the performance of the proposed *GSQAR* routing protocol in comparison to *AODV based nearest gateway selection based scheme*, which is a popular ad hoc routing protocol, and the *QoSBR based random gateway gateway* *selection based scheme* presented in [2]. We use the *network simulator–2 (ns2)* [1] to measure the performance of different protocols. For our performance evaluations, we consider a grid network consisting of 30 nodes placed in a uniform grid. We choose two gateways and keep them fixed. The sources are selected randomly. Each flow runs *UDP* with a transmission rate of 65 KBps. Each flow is alive for 200 seconds. We have averaged the results over 10 such simulations. The parameters used in the simulations are listed in Table I.

TABLE I
SIMULATION ENVIRONMENT

Parameter	Values used
Maximum node queue length	200
Data packets size	1000 bytes
Propagation Model	Two Ray Ground
Transmitter antenna gain	0 dB
Receiver antenna gain	0 dB
Transmit power	20 dBm
Noise floor	-101 dBm
SINRDatacapture	10 dB
SINRPreamblecapture	4 dB
PowerMonitor Threshold	-86.77 dBm
Modulation scheme	BPSK
Traffic Generation	Exponential

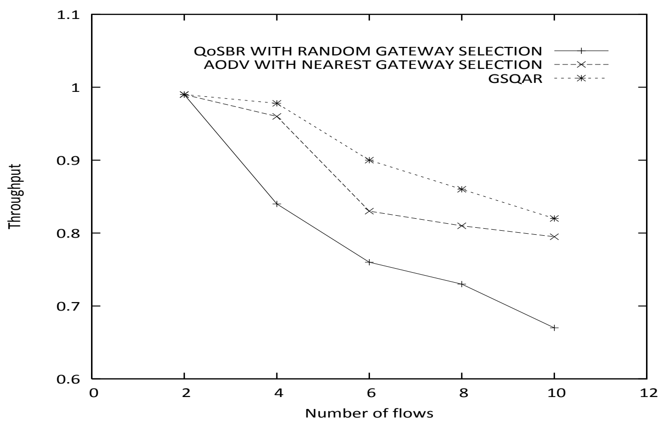

Fig. 3. Comparison of Throughput

We vary the number of flows and measure the average throughput, delay and jitter of the data flows using the three different routing protocols. The results are shown in Fig. 3–5. It is observed that *GSQAR* performs better than both *QoSBR based random gateway selection scheme* and *AODV with nearest gateway selection based scheme* in terms of throughput, delay, and jitter. This is because the shortest path and nearest gateway does not anycasting with the best overall quality. If all the sources choose the shortest path to reach the gateway, the shortest paths gets congested, which results in increased delay and packet loss. It can be also observed that *QoSBR based random gateway gateway selection based scheme* performs worse than *AODV with nearest gateway selection based scheme* because of the random nature of gateway selection, without taking into account any metric to select the gateways.

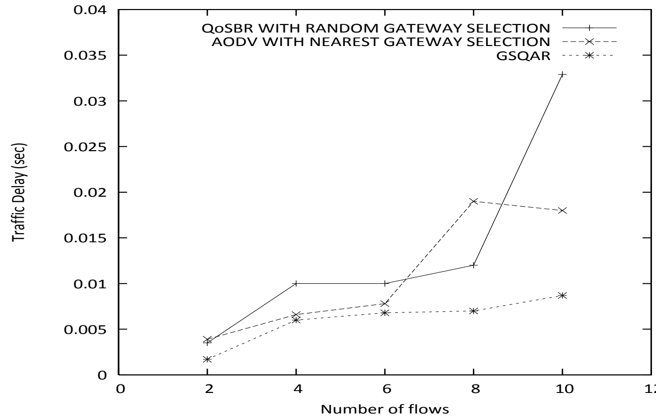

Fig. 4. Comparison of Delay

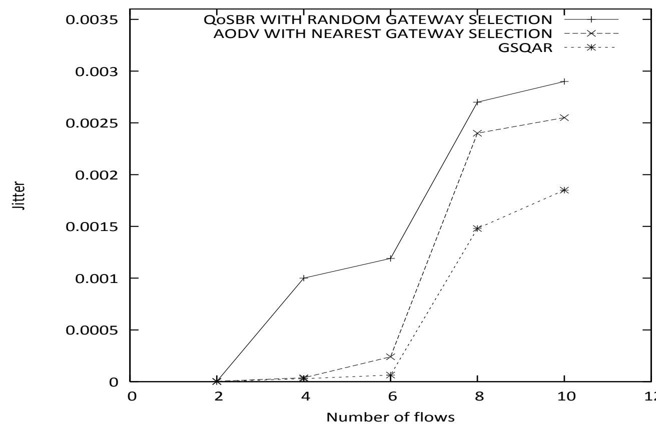

Fig. 5. Comparison of Jitter

V. Conclusion and Future Work

Mesh networks are a promising approach to wireless Internet connectivity for mobile users. However routing in mesh networks remains a major concern because of the complexity. In this paper, we have developed *GSQAR*, a novel *QoS* aware anycast routing protocol for wireless mesh networks. Our *QoS* based gateway selection and routing scheme achieves encouraging results in terms of overall performance. In future, we plan to apply our *QoS* based anycast routing approach to incorporate multiple channels with multiple radios for each mesh router to reduce co-channel interference.

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