Location-based Support Multi-path Multi-rate Routing for Grid Mesh Networks

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Abstract

We introduce a location-based routing model applied for grid backbone nodes in wireless mesh network. The number of paths with nearest distance between two nodes is calculated and used as key parameter to execute routing algorithm. Node will increase the transmission range that makes a trade off with data rate to reach its neighbors when node itself is isolated. The routing model is lightweight and oriented thanks to the simple but efficient routing algorithm.

1. Introduction

Wireless Mesh Networks (WMNs) are believed to be the promising solution to build self-organized network in places where wired network's deployment is not available or costly, and serve as broadband wireless access to the internet [1].

The Fig. 1 shows our bi-level infrastructure. The backbone-level includes Mesh Routers (MRs) as relay nodes and several Gateways (GWs) to connect to Internet. The client-level contains wireless devices (laptop, PDA, Smart Phone...) which can only communicate with MRs or even can directly communicate with others (in ad-hoc mode). Backbone-level uses proactive routing thanks to unlimited energy and higher capacity to reduce routing delay, while client-level uses reactive routing to reduce overhead of periodically exchange routing information messages.

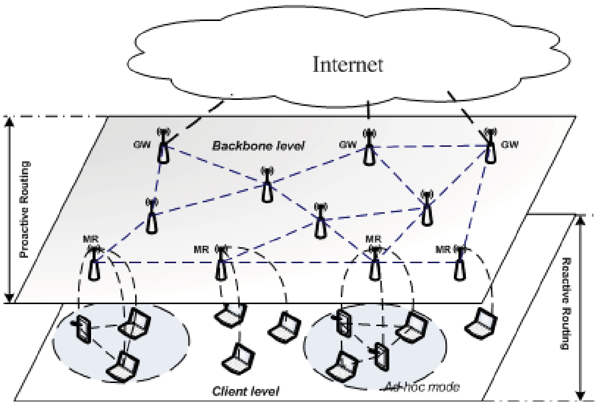

Fig. 1: Bi-level Mesh Architecture

We consider the backbone nodes which are deployed as grid network due to the following specific characteristics that distinguish them from pure ad-hoc networks. First, the positions of different nodes of a WMN are relatively fixed. This substantially reduces the need for routing packet overhead. Indeed, such routing packets are likely only needed at initialization and when traffic volume is sufficiently low that a node cannot be sure that its neighbors is still present, as opposed to having crashed. Second, the nodes will typically have access to a power source, and so power consumption is not a critical issue. Third, unlike pure ad-hoc networks, where the traffic flows between arbitrary pairs of nodes, in WMN, all traffic is either to or from a designated gateway, which connects the wireless mesh network to the Internet. The relevance of this point is that the traffic may be split over multiple gateways, so as to reduce the load within any given portion of the network. Finally, such systems can be created within a single domain of authority, and so many security issues present in ad hoc networks are no longer relevant. For those reasons, the most commonly used topology for wireless mesh networks is a grid layout. Each node should adjust its transmission range that is able to reach its four direct neighbors, and works on relative data transmission rate. Each node has its generated local packets and relay packets from its neighbors to and from the gateway.

In our paper, we give a location-based model to find the shortest paths between two communicating nodes. The number of path can be exactly calculated and the relative location between two nodes can be achieved by relative coordinate *xy*-axis without the need of exact location such as GPS system. This is simple but amazingly effective routing mechanism applied for grid mesh networks. The remaining of paper will solve network maintenance and we propose a solution for a node to reach other intermediate nodes by adjust transmission rate to gain further transmission range. Finally, we give some discussions and conclude our work.

2. Location-based routing model

In WMN with this grid topology, we presume that each node communicates with its direct neighbors to eliminate the interference among nodes. For example, a node *(x, y)* has direct neighbors *(x-1, y)*, *(x+1, y)*, *(x, y-1)*, *(x, y+1)*. Each node performs packet forwarding for its neighbors to and from the gateway.

Packet delay is caused by various reasons such as collision, different routing and different scheduling algorithms, etc. However, the most critical reason for packet delay in WMN is path length. Under the same traffic intensity, a smaller number of hops would lead to less packet delay. For two nodes, $S(x_S, y_S)$ and $D(x_D, y_D)$, in a grid network, their shortest distance is given by:

$$l_{SD} = |x_S - x_D| + |y_S - y_D| \quad (1)$$

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If there are more than two paths available and satisfy the requirements of network QoS such as bandwidth, to minimize packet delay we usually use the shortest path. However, this must be done in the context of minimizing collisions causing by packet forwarding, packet buffering, and different scheduling algorithms, since highly-contended paths that are shortest are not necessarily ideal [2].

The number of paths available is then determined according to the following theorem.

Theorem: *For any two given node S (x_S, y_S) and D (x_D, y_D) in a grid network, there exists* $\binom{|x_S - x_D| + |y_S - y_D|}{|x_S - x_D|}$ *different paths that have shortest distance l_{SD}, given in Eq. 1.*

Proof: Without loss of generality, assume $x_S \le x_D$ and $y_S \le y_D$.

+ From $S(x_S, y_S)$ to (x_S, y_S+1), there is only one path; Likewise for $S(x_S, y_S)$ to (x_S+1, y_S). The number of shortest paths between $S(x_S, y_S)$ to (x_S+1, y_S+1) is 2, which is a summation of the above 2.

+ Suppose from S to intermediate node $I(x_I, y_I)$ with $x_S \le x_I$ and $y_S \le y_I$, the number of shortest paths is

$$\binom{x_I - x_S + y_I - y_S}{x_I - x_S}$$

+ From S to (x_I+1, y_I), the number of shortest paths can be calculated recursively as

$$\frac{(x_I - x_D + 1 + y_I - y_D)!}{(x_I - x_D + 1)!(y_I - y_D)!}$$

From S to (x_I, y_I+1), the number of paths is

$$\frac{(x_I - x_D + y_I - y_D + 1)!}{(x_I - x_D)!(y_I - y_D + 1)!}$$

Therefore, from S to (x_I+1, y_I+1), the paths are a sum of the above two, because the paths must go through either (x_I+1, y_I) or (x_I, y_I+1). That is

$$\frac{(x_I - x_D + 1 + y_I - y_D + 1)!}{(x_I - x_D + 1)!(y_I - y_D + 1)!}$$

which is equal to

$$\binom{x_I - x_S + 1 + y_I - y_S + 1}{x_I - x_S + 1}$$

By induction method, the theorem is proofed.

The total number of shortest paths from node S to node D is illustrated in Fig. 2. We can easily figure out that for the nodes in the same ordinate (x-axis or y-axis) with S, there is always exist 1 shortest path between them. The number of shortest paths between S and other nodes follow the theorem. For example, between S and D there are $C_8^4 = \frac{8!}{4!4!} = 70$ shortest paths with the distance 8-hops far from each other.

Each node knows its relative location *(x,y)* values and location of other nodes through updated hello messages that being sent only if there is a node in or out of service in the network. For mesh network, the topology is stable as discussed in previous section. So that this update messages are rarely exchanged and inconsiderably affect network performance. When a node wants to communicate with other node, it will send a RREQ with its location and destination location. The neighbors will perform the following routing algorithm to find the best path out of multiple shortest paths above.

```
Initial
Step 1: send RREQS to neighbor nodes;
check node's availability & location
(x,y);

Step 2: for intermediate node I
if lSD > lID
  {forward the RREQS to its neighbor;
   use lID instead of lSD for the next
step}
else: discast the RREQS
Step 3: repeat step 1 until lID = 0
//node I is the destination.
end.
```

The routing algorithm is lightweight and oriented to the destination. It means that suppose $x_S \le x_D$ and $y_S \le y_D$, only nodes have location (x_i, y_i) that $x_i \ge x_S$ and $y_i \ge y_S$ will evolve in route finding process. Other nodes will discast the RREQ, so that the broadcasting messages are limited and delay is minimized. Note that there are always only 2 out of the whole number of shortest paths can guarantee node disjoint path. This claim can be proofed easily, because for example, there are only 2 neighbors of node S that have the location nearer destination D than location of node S. So that following the routing algorithm, only those two nodes will forward the RREQ. Based on the need of data transmission, a single path or multiple paths can be used simultaneously to achieve throughput and reduce delay, which is discussed in our previous work [3].

For network maintenance, when an intermediate node is malfunction or out of service, the previous node will send back the route error message and source node will choose another node or other found paths already exist in routing table in the previous step. In the next section, we will give a solution for isolated node in the worst case that all 4 neighbors of this node are out of service by increasing the transmission range (or reducing the data rate) instead of increase transmission power.

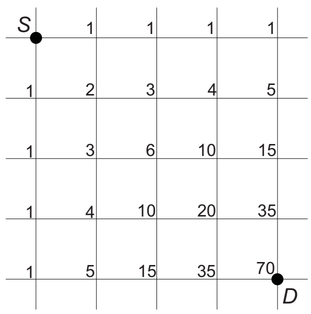

Fig. 2: The number of shortest paths from any node in the network to reference node S

3. Data Rate Adjustment for Network Maintenance

As mentioned above, when a node is isolated, for example, the geometric condition does not allow deploying grid network with equally distance among nodes; or when in the worst case, all of 4 neighbors are failure, we need to solve connectivity problem in order to deploy proposed model in reality. Many existing literatures give the solution that in case of nodes being isolated, they will increase the transmission power instead of reduce the bit rate. That argument is not applicable because most of the mesh routers or gateways are designed to work with fixed transmission power. For example, current Cisco and other well-known vendors' access points work with one transmission power and reduce the data rate when the clients move far from access point. That motivation incites us to deal with new approach of isolated node problem.

The Fig. 3 shows an isolated node as an illustration for our scenario. By default, in normal case, nodes will transmit data at the highest rate r_1. Currently, the 801.11 standard [5] supports several data rate corresponding to modulation and coding scheme as showed in Table I

Data Rate (*Mbps*)	Modulation	Coding	R_x Sensitivity (*dBm*)
06	BPSK	1/2	-82
09	BPSK	3/4	-81
12	QPSK	1/2	-79
18	QPSK	3/4	-77
24	16-QAM	1/2	-74
36	16-QAM	3/4	-70
48	64-QAM	1/2	-66
54	64-QAM	3/4	-65

Table I: Data Rate vs. R_x Sensitivity in IEEE 802.11 OFDM PHY

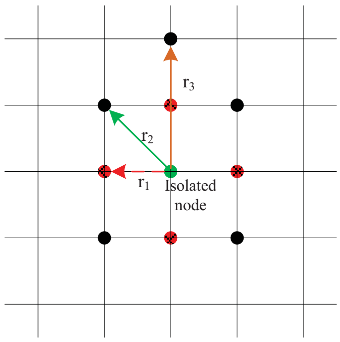

Fig. 3: Data rate adjustment to gain transmission range

According to the wireless radio propagation model, the received signal strength at a receiver *R*, which is *d* distance away from the transmitter *T*, is expressed as:

$$P_r = P_t - 20\log_{10}\left(\frac{4\pi\bar{d}f}{c}\right) - 10\gamma\log_{10}\left(\frac{R_i}{\bar{d}}\right) dBm \qquad (2)$$

where, P_r and P_t are the receive and transmit signal power in dBm, $20\log_{10}\left(\frac{4\pi\bar{d}f}{c}\right)$ is the free space path loss at a reference distance $\bar{d}$ (usually, 1m) in dBm for signal speed of *c* and frequency *f*, and γ is the path loss exponent ($1.6 \leq \gamma \leq 6$) depending on the channel condition between *T* and *R*.

For any modulation and coding scheme (for example, Table I), if the receive sensitivity P_{S_i} is required for transmission rate *i*, we can determine the transmission range R_i from (2) with $\bar{d} = 1$ and $P_r = P_{S_i}$ as:

$$R_i = 10^{\frac{P_t - P_{S_i} - 20\log_{10}(4\pi f/c)}{10\gamma}} \qquad (3)$$

From Eq. (3), when the distance increases, the data rate will be decreased within the same transmission power and sensitivity. Applied for the scenario in Fig. 3, to reach the distance $r_2 > r_1$ or even $r_3 = 2r_1$, the mesh node must reduce its data rate. By this way, we made the deployment problem in reality become possible, because there is no need for equally distributed distance.

4. Conclusions and Future Work

In this paper, we propose a simple and lightweight routing algorithm based on the relative location between nodes in the grid mesh networks. We show that when deploy a mesh network, the preferred form is grid topology and with a coordinate *(x,y)* location, the proposed routing algorithm becomes very simple but effective to find multiple shortest paths between any of two end nodes. When the node is being isolated or when the geographic condition does not allow deploying mesh node at equally distance, our solution is to reduce data rate so that increase the transmission range to reach further nodes. The relation between distance and R_x sensitivity can be calculated in the previous section.

In the future, we will integrate routing and scheduling algorithms and simulate to study wireless mesh network's performance. The number of gateways and their placement are also significant open problem, with network topology having a great impact on the final results. Also, we will utilize the multipath for simultaneous data transmission by designing new MAC scheduling scheme to efficiently work with grid mesh networks.

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