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Challenges and Evaluation of the State of the Art Routing Protocols for Wireless Mesh Networks

Shivanajay Marwaha Jadwiga Indulska Marius Portmann

The University of Queensland, School of Information Technology and Electrical Engineering and National ICT Australia (NICTA), Queensland Research Laboratory (QRL), Brisbane, Australia
{smarwaha,jaga,marius}@itee.uq.edu.au

Abstract **– Wireless mesh networks (WMNs) comprise of mobile and static nodes which communicate wirelessly. WMNs have several unique features such as self-organizing, self-configuring and self-healing and are being used in many applications such as metropolitan area networks and disaster and rescue operations etc. Routing in WMNs is challenging as the network topology and connectivity in WMN are very dynamic due to unpredictable node mobility, interference, distributed wireless channel access and limited battery power of mobile devices in WMNs. This paper describes the challenges and the state of the art in provisioning of Routing over WMNs.**

1. Introduction

Wireless Mesh Networks (WMNs) [1, 2 and 3] as shown in figure 1 comprise of "mesh routers" which are mostly static and "mesh clients" which are generally mobile.

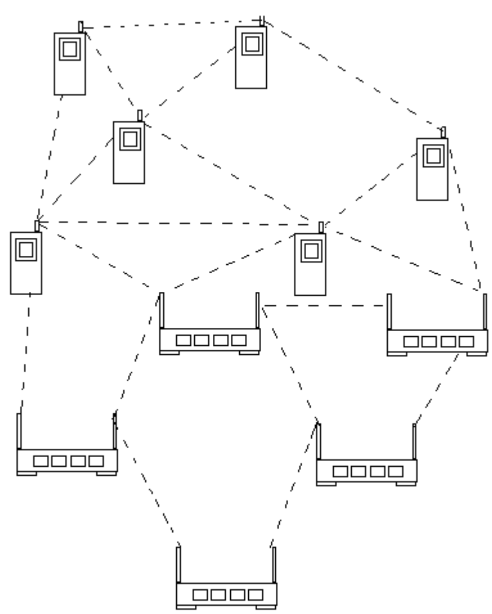

Figure 1: Wireless Mesh Network

WMNs offer numerous advantages. They can be deployed very rapidly without needing any wiring and major infrastructure support. WMNs can self-organise and self-configure in continuously changing dynamic topology and connectivity of the network. WMN also exhibit self healing characteristic. By using alternate paths, WMN can overcome route failures due to mobility, interference, congestion etc. Using multi-hop routing the range of Wireless devices can be extended in a WMN. Lastly, with the use of multi-hop routing the transmission power can be significantly reduced thereby reducing the interference in the network and increasing battery longevity of mobile nodes. Due to these and many other advantages, WMNs have been used in a variety of applications [4, 5, 6, 7, 8, 9 and 10] such as disaster relief, metropolitan area networks etc.

2. Challenges in Routing for Wireless Mesh Networks

Routing in Wireless Mesh Networks (WMNs) is quite challenging in comparison to wired networks because of various difficulties associated with these types of networks. Some of these problems have been overcome in routing for MANETs and WMNs, however many of the challenges remain unsolved. Some of the major challenges in routing for WMN include the following. Wireless bandwidth is scarce [11] and routing control packets must be used judiciously as it takes away bandwidth for actual data communication. Furthermore the wireless transmission medium is prone to interference and path loss and is not as reliable as wired transmission medium. As the client nodes in WMN are mobile, the routes often get disconnected. Routing protocol is required to maintain and reconstruct the routes as and when the routes fail. Mesh clients are also usually battery powered. The routing protocol may have to adapt to node failures resulting from battery exhaustion. Furthermore, WMN nodes have limited range of communication. Therefore, links break when nodes move and require re-routing and finding intermediate nodes to for relaying data packets. Some nodes may also temporary go out of communication range of all other nodes in the network or the network may become partitioned.

3. Routing Protocols in WMN

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This section describes and evaluates the routing protocols that have been proposed for WMNs which have been influenced by early works in Mobile Ad hoc Networks (MANET) routing protocols such as Ad hoc On-demand Distance Vector (AODV) [12] and Dynamic Source Routing (DSR) [13].

3.1 Hybrid On-demand Distance Vector Routing for Wireless Mesh Networks

Hybrid On-demand Distance Vector Routing for Wireless Mesh Networks (HOVER) [14] uses the basic route discovery mechanism of AODV with the following extensions to cover multi-interface mesh nodes:

a) Preferential selection of mesh router based paths: HOVER gives preference to use Mesh Routers in creating end-to-end paths for routing data packets, as mesh routers are relatively static, have multiple radios and have longer battery life than mobile mesh clients. HOVER uses the following path cost metric as shown in Eq. 1:

Cost = (MR_COUNT*MR_COST)+(MC_COUNT*MC_COST) (Eq.1)

The parameters used in calculating the cost in Eq. 3.1 are as follows:

- *MR_COUNT* - number of Mesh Routers in the path
- *MC_COUNT* - number of Mesh Clients in the path
- *MR_COST* - 1
- *MC_COST* - 4

b) Link metric: Multiple wireless links may exist between a pair of nodes. HOVER utilizes periodic HELLO messages to measure the quality of each link using an Expected Transmission Count (ETX) [21] link metric calculated using Eq. 2:

$$ETX = \frac{1}{d_f \times d_r} \qquad \text{(Eq. 2)}$$

Where, *dr* and *df* are the delivery ratios of Hello packets for the reverse and forward direction of a link respectively, calculated *by* dividing the number of HELLO packets received by the total number of expected Hello packets in a given time window. The value of *df* is communicated back to the upstream node by piggybacking it on the RREP packets.

c) Switching to Optimal route: If multiple links exist between two neighbouring nodes in the path, HOVER utilises in addition to the ETX link quality metric other factors for example channel diversity or current channel usage, e.g. determined by the number of active flows using that channel [19] for recommending the grading of each link. The grading value is also piggybacked onto the RREP to be communicated to the upstream node.

At first HOVER establishes a potentially non-optimal path wherein the destination replies to the first RREQ it receives. This may help to minimize the initial path discovery latency. After establishing this path, the path discovery mechanism looks for a more optimal path wherein the destination keeps receiving RREQs for a limited time window. In case a better path is found (with a lower cost metric), the route is switched over to the new optimal path. Intermediate node running HOVER forward RREQ packets if they are new RREQs or if they are multiple copies of the previously forwarded RREQ, but with a lower cost metric than the previously received copy.

HOVER can lead to high control overhead as it makes use of frequent HELLO messages. Sending RREP in two phases for optimal and non-optimal paths also increases overhead as well as delay jitter experienced by data packets.

3.2 AODV-Spanning Tree

In AODV-Spanning Tree (AODV-ST) [15], the gateway acts as the root of the tree and periodically sends RREQ messages to the entire network in order to create the spanning trees. The RREQ message contains a *metric* field, which is initially set to zero by the gateway, and is updated at each intermediate node using the Expected Transmission Time (ETT) [20] metric.

Intermediate nodes receiving the RREQ, update their reverse routes if the RREQ received has a lower metric than the currently stored route. Once this is done, the intermediate node sends back a RREP to the gateway node. All the intermediate nodes on the path to the gateway can update the path to the originating node. The RREP also carries the path metric information, initially set to zero by the originating node. Access relays send a probe message to check the Round Trip Time (RTT) towards the gateways, in order to find the least congested gateway [15].

In AODV-ST, frequent use of RREQ and RREP messages for pro-actively maintaining paths may lead to higher overhead and may not work well in high mobility scenarios. AODV-ST is designed specifically for Infrastructure Mesh Networks having a Gateway. ETT calculation requires sending control packets for checking bandwidth, causing extra overhead.

3.3 AODV-Multi Link

AODV-Multi Link (AODV-ML) [16] proposes extensions to AODV routing protocol with the aim to use multiple radio links between a pair of nodes in WMN. This is accomplished by generating and sending RREQs on each interface of a node when it receives an RREQ message for route discovery. The receiving node stores reverse path information for each link on which the RREQ is received and forwards the RREQ only if it is better than the previous one. The receiving node's upstream link information may consist of previous node's address and the corresponding local network interface.

If a node observes a link failure, it can switch to another link (if there are multiple links). Similarly interference on a path can also be minimized by selecting links between nodes that have the least level of interference with upstream or downstream links. Furthermore, multiple links can also be used together for load balancing.

In AODV-ML, RREPs are combined for a pair of nodes with multiple radio links. However all the links may not have reverse link connectivity as wireless links can often be uni-directional. There is high overhead associated with sending multiple RREQs on each link between a pair of mesh nodes with multiple radio links. Changing of link may also cause end-to-end delay jitter.

3.4 IEEE 802.11s MESH NETWORKING STANDARD

The IEEE 802.11s standard is for wireless mesh networks [17] with support for wireless multi-hop routing. The network architecture of the IEEE 802.11s is as shown in figure 2.

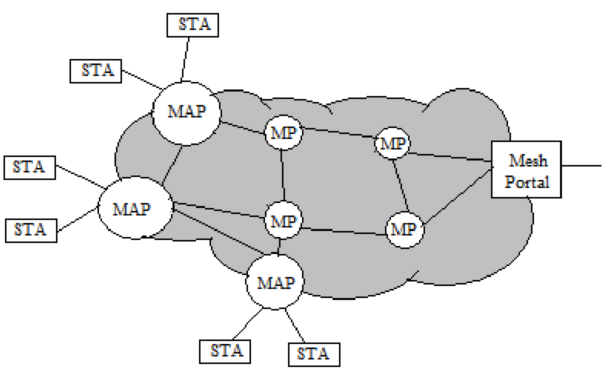

Figure 2: IEEE 802.11s Architecture

The components of the IEEE 802.11s mesh architecture comprise of the following. A ***mesh point*** (MP) is a node that has also mesh routing capabilities. Mesh points that also have capability to act as access points are called ***mesh access points*** (MAPs). IEEE 802.11 mobile clients are called ***stations*** (STA) that do not have mesh capabilities and can connect to MAPs to send their data. An MP that is connected to the wired network is called a ***mesh portal*** (MPP).

IEEE 802.11s supports both On-demand and tree based routing:

a) On-Demand Routing — With on-demand routing protocol the IEEE 802.11s MPs use expending ring search based route request (RREQ) message broadcast and corresponding route reply (RREP) messages from the destination to discover the path from the source to the destination nodes. Nodes send periodic RREQ messages on existing communication sessions for route maintenance. For added redundancy, the best path is cached for future usage in case the newly selected route fails.

b) Tree-Based Routing — The MPP in a mesh network can use proactive routing using root announcement messages. Nodes receiving the root announcement update the path metric before rebroadcasting it. For uplink routes to the MPP, the nodes send periodic RREQs towards the MPP. IEEE 802.11s [17] defines the *airtime link metric* as shown in Eq. 3 which is used for the calculation of the *airtime cost* C_a of each link.

$$C_a = [O_{ca} + O_p + \frac{B_t}{r}] * [\frac{1}{1-e_f}] \qquad \text{(Eq. 3)}$$

Summation of metrics of all individual links on that path gives the value of the end-to-end path metric. The parameters used to calculate the airtime link metric are as follows:

- O_{ca} - C*hannel access overhead*
- O_p - *MAC protocol overhead*
- B_t - *number of bits in a test frame*
- r - is the *transmission bit rate* in Mb/s
- e_f - *frame error rate*.

Periodic RREQ messages for route maintenance of ongoing sessions in IEEE 802.11s can cause high overhead. Proactive Tree Based Routing in IEEE 802.11s may not work well in a highly dynamic network environment.

3.5 Wireless Mesh Routing Protocol

Wireless Mesh Routing (WMR) [18] uses a reactive route discovery. HELLO messages are used in WMR for topology discovery. HELLO messages also carry information of the hop count between the sender of the HELLO message and the mesh router. This information in the HELLO message is termed as the distance tag. Flooding based reactive route discovery is used for nodes within the mesh group. For nodes outside the mesh group, the route discovery is restricted to the mesh groups of the source and destination nodes. Furthermore, using the distance tag information the route discovery progresses in the direction of the mesh router selecting the route with minimum number of hops to the mesh router.

As the route discovery is done based on distance tag, the HELLO messages containing the distance tag need to be broadcast very frequently. This is because new paths can form due to mobility changes in between two HELLO messages. A node with distance tag 3 may become a node with distance tag 2 or 1. Furthermore, HELLO messages cause considerable control overhead. It might also be difficult to know if the destination is in the same mesh group as the source. If the destination has moved to another mesh group, the route discovery may fail. A route discovery for a node outside the mesh group may also similarly fail, if the destination node has moved to the same mesh group as the source, since the route discovery would be distance constrained and heading towards the mesh router.

4. Discussion

Many routing protocols have been proposed for Wireless Mesh Networks. However, there are still some improvements required to achieve reliable and efficient routing in WMN. Table 1 summarizes the important properties of each of the five routing protocols reviewed in this paper for WMNs.

Table 1

Property / Protocol	Base Protocol	Metrics	Gateway Support	Multi-Link Support	Node-type awareness
HOVER	*On-demand + TREE*	*Node-type cost*	*Yes*	*Yes*	*Yes*
AODV-ST	*On-demand*	*ETT*	*No*	*No*	*No*
AODV-ML	*On-demand*	*Hop Count*	*No*	*Yes*	*No*
802.11s	*On-demand + TREE*	*Airtime Link metric*	*Yes*	*No*	*No*
WMR	*On-demand*	*Hop Count*	*Yes*	*No*	*No*

5. Conclusion

This paper presents the challenges and the state of the art in routing protocols for WMNs. Routing in WMNs is very challenging compared to routing in wired networks. It has been observed that most of the routing protocols for WMNs draw their inspiration from basic MANET routing protocols such as on-demand reactive routing. WMN routing protocols are evolving very rapidly and are also beginning to be standardized however, there are still a lot of improvements required to meet the demands of the various applications of WMNs.

6. Acknowledgments

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