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A Summary of Multicast Routing Algorithms in Wireless Mesh Networks

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Abstract

Wireless Mesh Network (WMN) presents us a key emerging technology which can construct the next generation wireless multi-hop network. It combines the advantages of both mobile ad-hoc network (MANET) and traditional fixed network. The applications of WMNs also attract significant industrial and academic attentions. As a vital function of network communication, multicast is normally applied to transmit data for high-definition video and gaming in WMNs. Therefore, the multicast routing algorithms are very important to the performance of group communication in WMNs. In this paper, we review a list of existing multicast routing algorithms in WMNs. Based on the findings, we also point out the open issues of multicast routing algorithms.

Keywords: *multicast routing algorithms; comparison of wireless mesh network*

1. Introduction

Wireless Mesh Network (WMN) is now one of the major wireless communication technologies for the next generation wireless networks. Compared to traditional networks, WMN brings the revaluation of using basic radio frequency physics to provide a robust, flexible, standard-based architecture, offers instant, highly flexible, and low-cost mobile broadband communications to different communities through the readily attainable multi-hop connection. Moreover, instead of using optical fibre cable, wireless radios are applied in WMNs. With above advantages, WMNs have been already deployed to construct wireless broadband networks in some developing areas worldwide [1] especially in some isolated islands [2].

A WMN converges the characteristics of both fixed network and MANET. The communication inside a WMN is similar to MANET, client nodes are self-configured and self-organized while the routes are selected by using certain routing algorithm and each client node has to relay other's packets. For accessing the backbone internet, the packets are forwarded through internet gateway to the fixed network by fixed cable links.

Multicast is a key technology for a group communication while this technology sends information from one or multiple nodes to multiple nodes in the network. Packets are delivered over each link only once, and copied in the replicator nodes. In comparison, the source node should send packets to multiple receivers for multiple transmissions by unicast for the same result. Multicast can reduce the communication cost, consequently, conserve bandwidth, and reduce latency and network congestion. It overcomes the shortcoming of sharing the same wireless channel as well as the bandwidth scarcity condition of many applications and services, such as service discovery, video conferencing, distributed gaming, *etc.* Therefore, multicast technology is applicable for future wireless multihop networks to provide efficient data communication among a group of nodes for the purpose of group communication. However, existing multicast

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protocols for wireless multihop networks [3-6] cannot be applied to WMNs for efficient multicasting. These multicast routing algorithms are primarily designed to be suitable for energy-constrained mobile nodes from MANETs. In contrast, besides energy and mobility issues, multicast routing algorithms are required to fulfil the new characteristics of WMNs, such as gateway involvement, low node mobility *etc*., so as to provide high communication quality to end users.

In this paper, we first review a list of existing multicast routing algorithms [3,8,11,13]. We also describe the possible open issues remaining in the current design of multicast routing algorithms in WMNs.

The rest of this paper is structured as follows. In Section 2, the network model of Wireless Mesh Network is presented. Both feasible multicast routing algorithms for MANET and WMN are reviewed and studied in Section 3. And in Section 4, we point out the open issues of existing multicast routing algorithms through comparing the algorithms of Section 3. Section 5 concludes the paper and shows the future work direction.

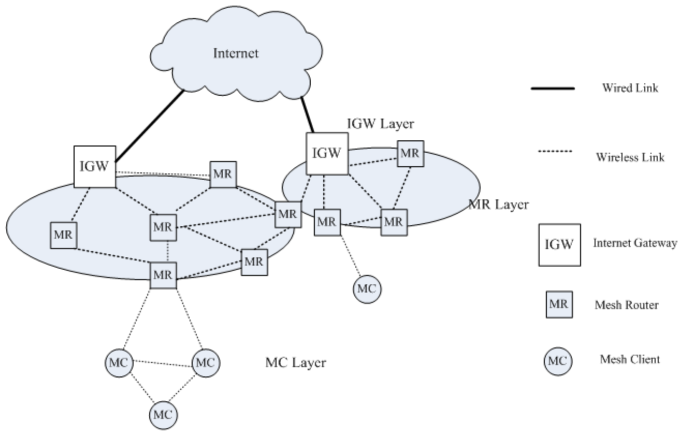


Figure 1. The Architecture of a Typical WMN

2. Network Model

WMNs are a particular type of Mobile Ad-hoc Networks (MANET). A WMN consists of mesh clients, mesh routers and gateways where mesh routers and mesh clients are designed to increase the coverage of WMNs by only using wireless radio while a gateway uses both wireless radios and fiber optic cable. Mesh clients connect to gateways through mesh routers, while mesh routers connect to a backbone network via gateways and gateways relay the message from internet to the mesh clients. There are two major differences between WMN and MANET which are gateway and mobility. Compared to MANET, most of the traffic is expected to flow between the mesh clients and the backbone network through gateways. Furthermore, in MANET, all the nodes are assumed as mobile nodes moving in the network. In contrast with MANET most of devices in WMNs are stationary or with limited mobility, where only a small portion of devices such as mobile phones, are moving in the network. In fact, most existing works on WMNs such as [14-15] *etc.*, treat WMN equally as MANET, ignoring the key gateway role of WMN in delivering application services that require a central network resource management at the provider's side. In the last few years, the demand for this kind of applications, such as group communication based applications, has significantly increased. In fact, the previous algorithms are designed with particular attention paid to the mobility of the nodes, *i.e.*, supposing most of nodes are highly mobile. Therefore, both new routing protocol and metrics are required to be designed for WMNs, and the old multicast routing algorithms also have to be re-engineered to satisfy requirements of WMNs.

3. Existing Multicast Routing Algorithms

In the design of multicast routing algorithms of WMNs, some routing schemes and ideas of multicast routing algorithms for MANETs can be borrowed. Moreover, some existing multicast routing algorithms can be applied in WMNs by re-engineering. In this paper, two feasible multicast routing algorithms of MANETs are reviewed.

3.1. MANET Multicast for WMNs

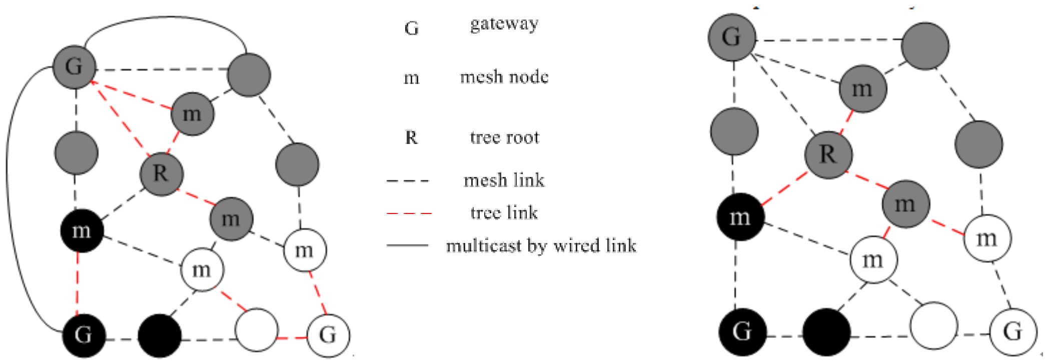
In MANETs, multicast technology has been studied in both industry and academia for more than a long while. Since mobility issue and energy consumption issue are most concerned in MANETs, most proposed multicast routing algorithms operate reactively. They aim to capture the link status of mobile nodes and eliminate the energy consumption caused by handling proactive message exchange. In the following subsections 3.1.1 and 3.1.2, we study two famous multicast routing algorithms of MANETs as with modification they are feasible to work in Wireless Mesh Networks.

3.1.1. Multicast Ad-Hoc On-Demand Distance Vector: As a multicast extension of AODV [7], Multicast Ad Hoc On-demand Distance Vector Routing protocol (MAODV) [3] is an on-demand routing protocol in MANETs. A Route Request (RREQ) is originated if a node intends to either join a multicast group or send a message without a valid path to a multicast group. Since MAODV is a tree based protocol, the structure is composed of all group members and message forwarders. Each multicast group is identified by a unique address and a group sequence number for tracing the freshness of each group. A node broadcasts RREQ with join flag (RREQ-JOIN) messages either if it wishes to find a path to the multicast tree or it aims to become a member of the multicast group. Any node received this message may respond if it has a valid path (based on group sequence number) to the multicast group. If a node is on the tree or it has a path to the tree, it sends a Route Reply message (RREP) back to the source node unicastly. If a node intends to join a non-existent multicast group, this node becomes the leader of that multicast group. Then it is in charge of the group. As the source node receives multiple RREPs after a waiting period, it may select the best path. To maintain the multicast group, Group Hello message is used to establish the multicast group and update the routing table. Both the unicast routing table and multicast routing Table are stored for the group tree structure. This multicast routing table contains the multicast group address, the multicast group leader address, the multicast group sequence number, the number of hops to the multicast group leader, next-hop information and lifetime. There are two types of nodes in a tree structure: downstream nodes (more hops from the group leader) and upstream nodes (less hops from the group leader). Obviously, a group leader has only downstream nodes. When a member leaves the group, the pruning process is initiated to reconstruct the tree structure. When a link is broken in the multicast tree, the furthest downstream nodes send RREQ-JOIN messages to initiate the repair process. Moreover, a member node notifies the group leader if it intends to terminate the membership.

3.1.2. On-Demand Multicast Routing Protocol: On-Demand Multicast Routing Protocol (ODMRP) [4] is also an on-demand routing protocol for MANETs. In this protocol, Join Query messages are broadcasted if a mobile node intends to send packets but without a valid path to the multicast group. When receiving Join Query, each node stores the appropriate node id of the message sender and the reverse path back to the sender in the routing table. If the TTL (time-to-live) value is greater than zero, the intermediate node rebroadcasts the message. A group member broadcasts a Join Reply message if it receives a Join Query message. Upon reception of a Join Reply message, a neighbourhood node checks the join reply table to find out whether there is an existing next-hop node with the same source id. If so, the current node is set as a member of the forwarding group indicating it is on the path to source. As a mesh based protocol, there are multiple paths from sender to each receiver in ODMRP. In contrast, MAODV is a tree based protocol with only one path to each receiver. In other words, ODMRP allows a reply message back to the source node via multiple paths. These paths are stored in the source node for the future link breakage. Unlike MAODV, ODMRP is a soft state protocol. Member node can leave the group without a control message.

3.2. Current State-of-Art Multicast Routing Algorithms in WMNS

Compared to MANETs, most nodes are stationary and energy-efficient in WMNs. Therefore, existing multicast routing algorithms for MANETs cannot be directly applied to WMNs directly without any modification due to the different characteristics between MANETs and WMNs. To satisfy the new communication requirements of WMNs, several multicast routing algorithms are proposed for WMNs. In the following paragraphs, a list of multicast routing algorithms for WMNs are described and compared.



(a) With Prefix Continuity (b) Without Prefix Continuity

Figure 2. Multicast Tree Constructed with or without Prefix Continuity

3.2.1. Application of Prefix Continuity for Multicast: In [8], Ruiz *et al*. introduce the prefix continuity and the construction of Steiner tree [9]. These mechanisms enhance efficient multicast routing in WMNs. First, a discovery mechanism is applied to create default multicast paths towards the gateway on the basis of prefix continuity. Each mesh node is assigned the same prefix to existing gateway only by service provider of WMN. This guarantees a default path between a mesh node and an existing gateway with the same prefix. A mesh node without a prefix does not have the authority to register with the gateway. Similarly, to start a multicast session, source node broadcasts route request messages towards the root node. Once receiving this request, root node replies and builds the minimum spanning tree. Figure 2 shows (a) multicast tree is constructed on the basis of prefix continuity and (b) multicast tree is not constructed on the basis of prefix continuity. These examples are represented as either a shared tree or a source-rooted tree. The tree root can be either some sort of central point or source of the group. However, this work does not provide the maintenance scheme of multicast tree, which may lead to problems during the link breakage of multicast tree.

3.2.2. Probabilistically Reliable On-Demand Multicast Protocol: In [13], authors propose a multicast protocol, namely, Probabilistically Reliable On-demand multicast protocol (PROD). PROD applies a link quality based routing metric to detect the link cost, Expected Multicast Transmissions (EMT) (this routing metric is described in detail in Section 2.5.4). In PROD, all disjointed source-receiver pairs are connected in shortest path to form a temporary multicast tree. EMT measures the link cost to construct a minimal EMT tree as the Reliable Probabilistic multicast tree. During the tree construction, each node broadcasts periodic probe messages to all of its neighbours. It aims to obtain the packet deliver rate of each link to calculate EMT. PROD is a receiver-initiated multicast routing algorithm. In the multicast group, each receiver initiates the path discover procedure. It sends out JoinReq messages to the multicast tree with a minimised EMT value. Each JoinReq packet includes multicast group address, node address, sequence number, time-to-live, neighbour link quality table and link cost. In the link quality table of neighbour, the link quality of all wireless links connected to this node is stored. This allows the neighbours to obtain the backward link quality. In JoinReq packet, the path cost field is initially set to zero. Each forwarder node of JoinReq records the additional transmissions number of establishing the path to the multicast tree. This number is then stored to the field of path cost. The current multicast tree members are responsible for replying a JoinReply packet as receiving JoinReq packet. Upon reception of JoinReply messages, the joining node selects one path with the minimal cost to the multicast session among multiple replies. Then it sends a Route Activate packet unicastly to the source of JoinReply to complete the multicast join procedure. Moreover, compared with ODMRP， it was shown that PROD reduces the number of forwarder nodes [10].

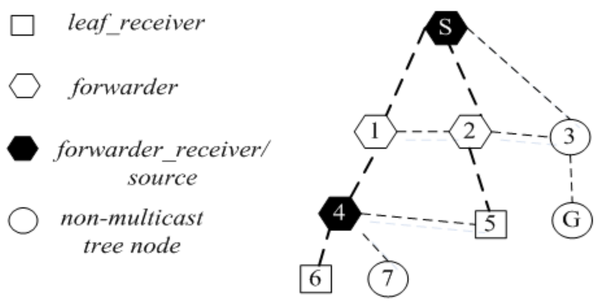


Figure 3. MGCMR Multicast Tree Construction Inside a WMN

3.2.3. Multicast Gateway Centralized Multi-Hop Routing Algorithm: In [11], authors propose a new multicast routing algorithm, namely, Multicast Gateway Centralized Multi-hop Routing algorithm (MGCMR) which facilitates the instant real time communication applications. MGCMR is known as the first multicast routing algorithm of WMN that considers both the requirements of instant applications and the capability of gateway based management in WMNs. In MGCMR, the gateway is the optimal candidate node in WMN that can play a key role in orchestrating the communication phase. Thus, in this study, to involve the gateway in managing various routing tasks, MGCMR is proposed to enhance the gateway routing capability and, thus, improve the routing efficiency of multicast communication in large scale WMNs. This is essential for the multicast based applications that require high quality management at the service provider’s side. In MGCMR, the gateway gathers information about the real-time topology of the network with ROUTE_UPDATE messages then computes routing paths for mesh nodes. Then, each node, in turn, registers with a gateway by broadcasting REQUEST to become a sender or receiver. We define the node with one-hop neighbour as a leaf node and apply the leaf-to-gateway update mechanism to maintain the network topology. The leaf nodes are chosen by the gateway to send periodic ROUTE_UPDATE packets towards the gateway. The packets follow all possible paths from the leaf nodes to the gateway. The gateway gathers the ROUTE_UPDATE packets and computes the mesh tree of this WMN. In a WMN, a non-receiver tree node is marked as forwarder. Likewise, a receiver that has at least one next-level tree node is marked as a forwarder_receiver. Both forwarder and forwarder_receiver are responsible for forwarding the data packets to the next-level node on the tree. Further, a receiver without a next-level tree node is marked as leaf_receiver. When multicast data packet arrives in a leaf_receiver, it will not be forwarded as the leaf_receiver that does not have next-level tree node. As soon as MROUTE_REPLY with notification flag message arrives at node_m, the multicast join process is completed. Figure 5.1 portrays an inner WMN multicast tree with two leaf_receivers (node_5, node_6), one forwarder_receiver (node_4) and two forwarders (node_1, node_2). In this example, node_6 and node_7 are leaf nodes to generate ROUTE_UPDATE messages. Using this tree maintenance mechanism provides a more efficient and stable networking communication environment. The results show that MGCMR significantly outperforms its counterparts, including the well-known ODMRP [4], MAODV [3] and GLBM [17] multicast routing algorithms, in terms of several performance metrics. Similar to [11,13] also applies the gateway to assist the multicast data transmission in WMNs.

Table 1. A Comparison of Reviewed Multicast Routing Algorithms

Protocol/Feature	MAODV	ODMRP	Prefix Multicast	PROD	MGCMR
Route discovery	Reactive	Reactive	Reactive	Reactive	Hybrid
Multicast type	Tree based	Mesh based	Tree based	Tree based	Tree based
Routing metric	Hop-count	Hop-count	Hop-count	EMT	Load-count
Reply to source	Unicast	Multicast	Unicast	Unicast	Unicast
Group maintenance	Hello message	Hello message	Prefix continuity	RouteRepair message	Leaf update message
Gateway Involvement (request handling)	No	No	Yes	Yes (only for first joiner)	Yes
Gateway Involvement (construct tree/mesh)	No	No	No	No	Yes
Gateway Involvement (data forwarding)	No	No	Yes	No	No (inner WMN) Yes (outer WMN)

4. Open issues of Multicast in WMNs

A comparison of different multicast routing algorithms is shown in Table 1. Since this paper focuses on optimising the communication performance of WMNs, existing multicast routing algorithms are concluded on the basis of the content of this section as the followings:

- Existing multicast routing algorithm cannot be directly applied to WMNs due to the differentiated networking devices and network deployment structure. In MANETs, multicast routing algorithms are designed to suit for the high mobility and energy-inefficient nodes. Therefore, in these algorithms the dynamically changing topology is discovered by broadcast. It may create overhead during the construction of multicast tree or mesh. On the contrary, in WMNs, the design of multicast routing algorithms should consider features such as the mobility level of mesh nodes and gateway involvement.
- Obviously, there is limited work on multicast routing algorithm for WMNs. Most of existing proposals are concentrated on multicast tree construction [12]. These

proposals have not clearly presented the key role of gateway in multicast communication for WMNs. In such proposals, WMNs are treated as flat network with fixed nodes. In other words, this kind of network is as same as MANETs with all stationary nodes. For example, authors abuse the term of WMN in the design of PROD [10,13]. In contrast, a WMN is hierarchical in real world. Multicast packets are relayed by the gateways between different WMNs through the Internet backbone similar to unicast packets. The gateways are responsible for managing and relaying all the multicast data. For the above reasons, there is a need to develop new multicast routing algorithms for WMNs. These new design should especially consider the gateway involvement to handle and process the routing request from the potential receivers and multicast sources.

- MGCMR [17] presents a multicast routing algorithm with applying the gateway as the central routing manager. Since MGCMR is designed for single channel multicast communication in WMNs, there is still a lack of handling multi-channel communication in such algorithm. Furthermore, other routing metrics rather than Load-count and Hop-count should be applied in this algorithm to make the communication more efficient.

5. Conclusions and Future Work

Due to the increasing demand for efficient communications, multicast routing algorithms should be improved to better work in WMNs. In this paper, we review existing multicast routing algorithms for WMNs. In addition, we also describe the remaining issues on the basis of review. In our future work, we will focus on designing efficient multicast routing algorithm in WMNs especially MGCMR with dedicated routing metrics will be studied and investigated to handle multi-channel multicast communication.

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