A Zone Networking Architecture based on Zone Masters for Mobile Ad-Hoc Wireless Networks*

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ABSTRACT

This paper describes a zone networking architecture based on zone masters for enabling wireless nodes to communicate with each other through intermediate nodes. Especially, we focus on the design of scalable routing protocol for deploying relatively large and densely populated Mobile Ad-hoc Networks (MANET). In MANET, scalability is one of the most difficult challenges. Moreover, the communication over MANET only relies on mutual and cooperative routing functionalities of nodes without any specific relaying devices such as router or base station. To overcome such challenges, we propose to use the zone master which is a supplementary device having high computing and battery power. A zone master gathers routing information and distributes it to nodes within his zone so that the nodes can discover and maintain a route in an efficient manner. We also show that the control overhead of the proposed approach is lower than those of previously proposed protocols.

Keywords: MANET, Zone based ad-hoc networking, Zone master, Zone master routing protocol, Scalability

1. INTRODUCTION

MANET is a self-organizing and self-configuring multi-hop wireless network. It is intended to allow mobile nodes to communicate with each other without any support of centralized network infrastructures [1]. The nodes, therefore, should be able to relay packets of other nodes for maintaining a multi-hop connectivity. To form MANET properly, we should consider several challenges that include the mobility of nodes resulting in frequent topology changing, scarce network resources, low computing power and limited energy of nodes, and difficult handling in scalability and reliability. The most difficult challenge, in particular, comes from the fact that the communication over MANET only relies on mutual and cooperative routing functionalities of nodes without any specific relaying devices such as a router in a wired network. Consequently, it is difficult to directly employ conventional routing protocols used in wired networks into MANET.

To overcome these problems, lots of routing protocols have been proposed in the literature. These routing protocols are generally categorized into three [2]: reactive, proactive, and hybrid routing protocols. In reactive (often called on-demand) routing protocols such as Ad-hoc On-demand Distance Vector (AODV) [3] or Dynamic Source Routing (DSR) [4], the route to the destination is discovered only when the source node has a packet to send. The main shortcoming is the route discovery delay because the routes are not available when the source wishes to send the packet.

On the contrary, proactive (table-driven) routing protocols such as Destination-Sequenced Distance-Vector (DSDV) [5] or Optimized Link State Routing protocol (OLSR) [6] allow a node to transmit packet instantly since the node always maintains the latest routing information of network in a similar way to the one used in wired routing protocols. To do this, all nodes are required to update routing tables whenever the network topology is changed.

Reactive routing protocols introduce relatively lower overheads than proactive routing protocols in a limited scale of MANET [7]. However, there still exist severe performance degradation when the network size (the number of nodes and its mobility) increases. Therefore, it is necessary to find a scalable routing protocol for a large scale and densely populated MANET. Support of good scalability is more and more desired in many potential applications [8].

In this paper, we propose a zone based network architecture that is well suited for a large scale MANET. Moreover, a novel routing protocol is given to allow a mobile node to discover and maintain a feasible route in a scalable manner. The proposed routing protocol, named Zone Master Routing Protocol (ZMRP), borrows the

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fundamental concept of the cluster based routing algorithm. The main difference is that there is no highly expensive processing to elect a cluster head. Instead, each cluster (referred to as a zone in this paper) has a Zone Master (ZM) of which role is similar to those of a cluster head. That is, a ZM gathers routing information and distributes it to nodes within his zone so that the nodes can discover and maintain a route in a low cost. As a result, we can dramatically reduce lots of overburden of nodes and flooding of control packets necessary to maintain a cluster and its head.

This paper is organized as follows. In the next section, we first discuss previously proposed routing protocols and its drawbacks in terms of the scalability. Then, in section 3, we propose the zone networking architecture based on ZM to overcome such drawbacks. Section 4 presents the proposed ZMRP. We then evaluate the performance of the proposed protocol using network simulation in section 5. Finally, in section 6, we conclude this paper.

2. SCALABLE ROUTING PROTOCOLS

Scalable routing protocols in MANET are categorized into two [2]: one is cluster based hierarchical routing protocols such as Zone Routing Protocol (ZRP) [9] or Clusterhead-Gateway Switch Routing (CGSR) [10] and the other is geographical location based routing protocols such as Location-Aided Routing (LAR) [11] or Geographic Addressing and Routing (GeoCast) [12]. In the former, a MANET is logically partitioned into a set of clusters; thereafter routing procedures are performed in each cluster separately to manage a large scale of MANET. On the other hand, the latter utilizes geographical position information for routing under the assumption that all nodes are equipped with Global Positioning System (GPS) modules available for getting location information. In real world, therefore, the former seems to be more suitable for MANET since it is more or less impractical for all nodes to be equipped with such a module at the moment.

In cluster based routing protocols, a cluster head node is elected autonomously for each cluster by predefined algorithm. The cluster head node binds ordinary nodes in his cluster to perform routing procedures that include management of cluster members, routing information distribution, and communication management.

2.1 Problem statements

Cluster based algorithms introduce high overhead because all nodes must exchange information to elect a cluster head in addition to the routing procedure itself. Furthermore a cluster head should be reelected whenever the network topology of a cluster is changed. In some scenarios, the topology is frequently changed by the mobility of nodes in MANET, thus it results in very high overhead [13]. This is because lots of information should be transmitted from the previous cluster head node to the currently selected one in addition to the control packets conveying information for head election. Moreover, in cluster based protocols, every node sends packets to a cluster head whenever he has packets to send. Thereafter the cluster head sends the packets to the gateway nodes. This requires higher energy consumption of a cluster head node than other nodes.

To reduce overhead, cluster based routing protocols restrict the radius of a cluster by one hop. But, if a small cluster in size is used, it is hard to take benefits from clustering when a scale of MANET is large because lots of clusters are composed. Moreover, there exists a problem of a single point of failure caused by tuning down or disappearing of a cluster head suddenly. In general, MANET node has a limited amount of battery. A cluster head consumes much energy than other nodes because the head has to do concentrative computing. Thus, the power of head node dries up fast or a user may be turn off its power. If a cluster head is disappeared abnormally, all nodes in a cluster can not communicate with each other during some periods of time.

2.2 Zone routing protocol (ZRP)

ZRP is also one of cluster-based routing protocols. The main difference between ZRP and other protocols is that ZRP does not require any procedures for electing a cluster head [9]. In ZRP, each node becomes a head and forms a localized routing region defined as a zone. The size of a zone is predefined as the number of hops to each node. ZRP does not specify a certain protocol but rather it applies a proactive routing protocol for nodes within a zone and a reactive routing protocol for nodes belonging to different zones in a hybrid manner. Thus, ZRP takes advantages of both proactive and reactive routing protocols. The main purpose of the hybrid approach is to maintain valid routing tables without high overhead even though the network topology is rapidly changed by the mobility of nodes.

ZRP is a combined protocol consisting of three different sub-protocols as illustrated in Figure 1; intra-zone routing protocol (IARP), inter-zone routing protocol (IERP), and bordercast resolution protocol (BRP) [9]. As the name said, IARP and IERP are routing protocols that are used for nodes within a zone and outside a zone respectively. BRP is triggered when a node who has a packet to send can not find the destination in his IARP routing table. A route request (RREQ) packet is broadcasted only via the nodes on the border of the zone, namely nodes locating at overlapping region of two different zones, so the protocol is called selective bordercasting.

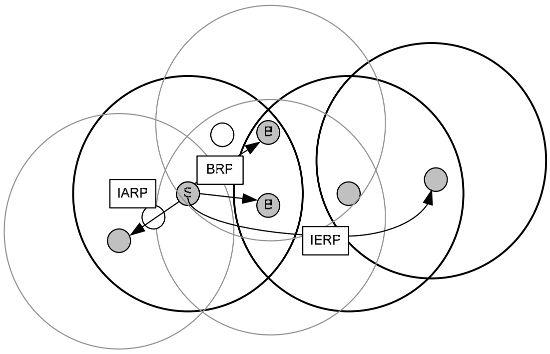

Figure 1 : Three components of ZRP

3. PROPOSED ARCHITECTURE

In this section, we discuss a zone master based networking architecture as illustrated in Figure 2. We consider a relatively large and densely populated MANET.

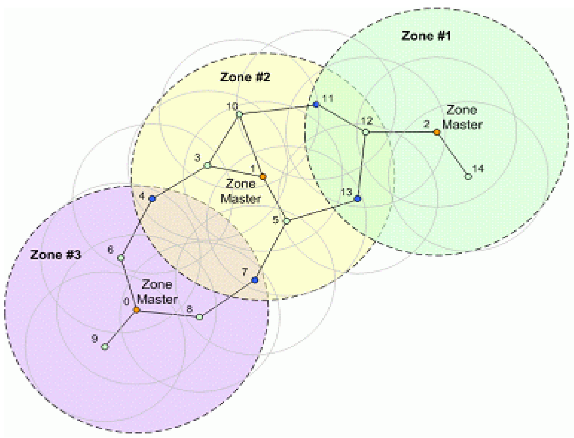

Figure 2: Zone master based MANET

The proposed architecture utilizes ZM, instead of a cluster head of a cluster based routing protocol, as a routing assistant infrastructure to solve problems discussed in section 2. As a result, we can reduce lots of overhead necessary to elect a cluster head whenever the topology is changed; we can remove the single point of failure problem caused by energy exhaustion of a cluster head node; and we can save resources in energy and data processing of ordinary nodes in MANET by maximizing the role of zone master.

Based on the proposed architecture, we also propose a scalable routing protocol, ZMRP, which is an extension to ZRP (see section 4 in details). Therefore, ZMRP can be smoothly deployed into MANET without high impact on the underlying MANET routing protocols.

3.1 Zone Master

MANET is divided into several routing zones in which a ZM is assigned as shown in Figure 2 (here, ZM are node 0, 1, and 2.). Nodes within a predefined zone radius, which is measured by the number of hops from the ZM, are referred to as member nodes of the zone. Unlike member nodes, ZM has high computing power and robust electrical power as a super node to assist member nodes in routing at MANET.

A ZM maintains consistent and up-to-date routing information for his member nodes so that a member node does not need to follow the changing of network topology. That is, highly expensive computing to generate and maintain a routing table is performed only by ZM. Therefore, ZM allows nodes of MANET to decrease computational overhead to discover a route to the destination and also enhances the scalability of MANET. Further, as an additional benefit from using ZM, a node can recognize some location information of the target node approximately since the ZM, which covers the target node, has its own identifier and its location information can be obtained by a network administrator. Such a property can be used very efficiently in some scenarios such as emergencies and natural disasters without any support of GPS or satellite based service.

3.2 Virtual wireless backbone

In order to achieve a high connectivity among nodes and zones as well, ZM may be allowed to adjust his transmitting power differently (namely, different radio level). The signal power for transmitting data among ZMs should be higher than those for sending data to member nodes.

The virtual wireless backbone formed by such a linked ZMs provides robustness against a scenario where no boarder nodes that play a role in relaying a packet between zones exist in an overlapping region. Figure 3 shows an example, where ZMs use two different powers (i.e. f_{node} and f_{ZM}) so that packets can be transmitted via the wireless backbone without relaying of boarder nodes.

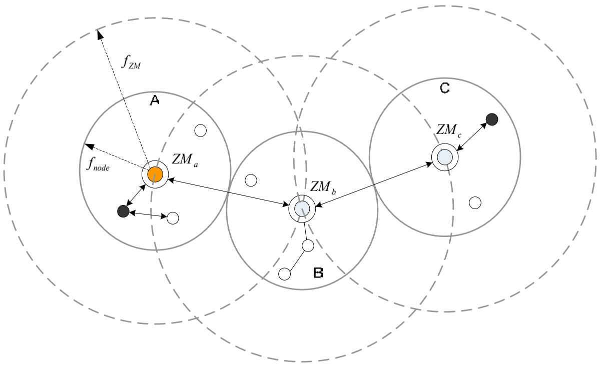

Figure 3 : Virtual backbone formed by ZMs

3.3 Remark on defining a routing zone

The size of a zone highly affects the performance of MANET in zone based routing protocols. Nevertheless, it is difficult to define an optimal size of a zone because it may vary in cases depending on situations. Larger size of a zone gives more benefits to the case where the mobility of nodes is very low (e.g. MANET for conference room), while increased mobility of nodes requires a small size of zone to take advantage of reactive routing protocol.

A routing zone can be defined in two different manners in the proposed architecture. One is the same way to other cluster based routing protocols on one hand. In this way, a zone is defined by the number of hops (often called radius of a zone) from member nodes to the ZM.

On the other hand, alternatively, a zone can be regulated by adjusting the signal strength (i.e. transmission power) of the Zone Master. The stronger power results in the larger size of a zone. It is impractical to apply such a way to other cluster based protocols owing to the heterogeneous signal strength of nodes. However, in our architecture, we can adjust the power of ZM simply to form a zone. The main advantage of such a way is the capability to adjust a routing zone dynamically according to the network conditions (e.g. node densities or mobility of nodes). The challenge of the second way, however, is that large transmission coverage may increase the probability of local contention because of the nature of shared MAC.

In ZRP, each node forms its own zone resulting in a large number of overlapping of nodes (see Figure 1). This leads to increased control overheads even though a larger number of neighbors per node are required for robust connectivity. The proposed scheme reduces such an overlapping by means of ZM. In addition, if the second way can be used to form a zone, the proposed scheme enhances the connectivity well.

4. ZONE MASTER ROUTING PROTOCOL

In this section, ZMRP is given under the assumption that a zone is defined by the pre-specified number of hops.

4.1 Intra-ZMRP

Zone master broadcasts an Integrated Link State (IntLS) packet to member nodes periodically. IntLS packet, which is variable in size, contains time-to-live (TTL) value, border node identifiers (BN-IDs), link information of the zone and neighbor lists for each node. The TTL value is used to restrict a broadcasting region of IntLS packets within a zone. BN-ID indicates nodes that belong to two different zones. In other words, the nodes are located at the overlapping region of two different zones. The border nodes play an important role in performing the inter-zone routing. Link information of a zone might be used differently from case to case depending on the policy of the network. If the main requirement of the network is to discover energy efficient routes, for example, electrical power of each node can be included as a factor of the link information in addition to hop counts. Finally, the neighbor lists field of the IntLS packet tells each node which nodes can be reached directly. Figure 4 shows Intra-ZMRP that is performed proactively in a zone.

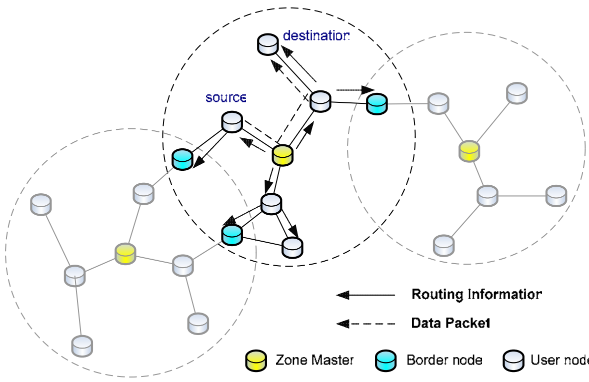

Figure 4 : Intra-zone master routing protocol

A zone master recognizes his member nodes by two phases. In the bootstrapping phase, a zone master broadcasts a IntLS packet containing only TTL value which is the equivalent to the radius of the zone (e.g. TTL=2 in Figure 4.). In the second phase, member nodes of the zone reply to the IntLS. The replied IntLS conveys link information of each node. After that every member node takes IntLS packet containing integrated routing information of the zone so that each node can communicate with each other that belongs to the zone.

4.2 Inter-ZMRP

A node first checks his routing table once he has a packet to send. If there is no information in the routing table, the destination may belong to other zones or be newly moved into the zone just before the arrival of IntLS packet at the source. The source sends a route request packet to his zone master to discover a route to the destination. A zone master that takes a route request packet checks whether the destination is within his zone. If the zone master finds the node, he broadcasts a newly updated IntLS packet including information of the new member node to his member nodes. Otherwise, the zone master unicasts a route request packet to border nodes. Figure 5 shows the route discovery procedures as an example.

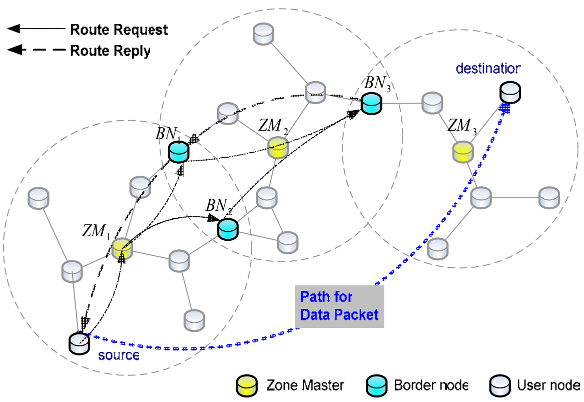

Figure 5 : Inter-zone master routing protocol

In the figure, it is assumed that the source which belongs to ZM1's zone has a packet to send to the destination in the ZM3's zone, where a zone radius is 2 hops. The source searches the destination in his routing table which is based on the information of IntLS packet. Because the destination does not exist in the table, the source generates a route request packet to send it to his zone master ZM1. The ZM1 then sends the route request packet only to boarder nodes (i.e. BN1 and BN2 in Figure 5) because the ZM1 also can not find the destination. Such a way is called as 'selective boardercasting' that can reduce the transmission overhead of control packets. After arrival of the request packet at BN1 and BN2, the packet is transmitted to BN3 since the destination does not belong to ZM2's zone as well. At last, the destination is found in the routing table of BN3. BN3 generates a route reply packet then sends it to the source via the path that was discovered by the route request packet. Now, the source can transmit packets to the destination via discovered path.

5. PERFORMANCE EVALUATION

We evaluate the performance of the proposed scheme in comparison to ZRP using the NSv2 simulator. Table 1 summarizes the parameters applied to our simulation.

Table 1: Simulation parameters

parameter	value
Mobility speed	0~3 m/sec
Pause time	0 sec
Number of nodes	50, 100, 150, 200
Packet rates	0.5 packets/sec

In simulation, AODV routing protocol is used as the underlying protocol. The moving speed of each node is selected randomly from 0 to 3 m/sec. Twenty five randomly selected sources transmit a packet of 128 bytes in size at every 0.5 second. To simulate ZMRP, four ZMs are assigned uniformly at the space of 1500x1100m in size.

The comparison results are shown in the following two figures. Figure 6 illustrates the number of control packets being sent for routing procedures in proportional to the increasing number of nodes. ZRP generates more control packets than ZMRP because, in ZMRP, only ZM node broadcasts IntLS packets to member nodes. Unlike ZMRP, each node of ZRP should broadcast its link information to other nodes.

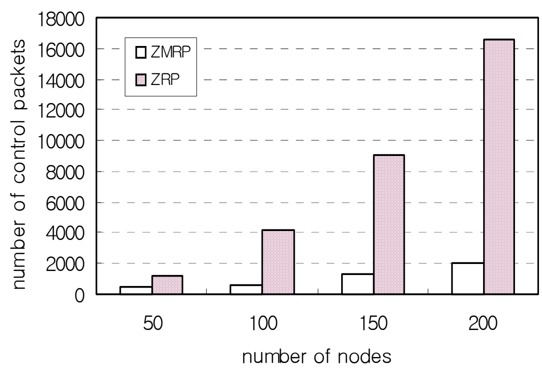

Figure 6 : Control packet overhead

Figure 7 presents that the probability of packet arrival at the destination correctly of both protocols is similar to each other. As shown in the figure, given the same size of MANET, smaller number of nodes (i.e. sparsely distributed throughout MANET) leads to worse connectivity. However, if the virtual wireless backbone of ZM is used, such a problem can be overcome (see section 3.1 in details).

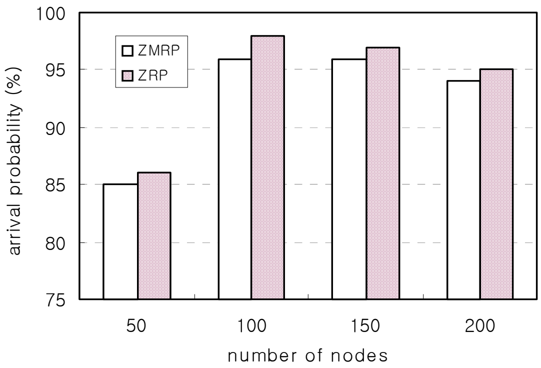

Figure 7 : Packet arrival probability

6. CONCLUSION

The fundamental question of this paper was how to reduce the scalability problem in a potentially large and densely populated wireless networks. Under the context, we discussed zone based networking architecture and scalable routing protocols. The proposed routing protocol is based on the cluster based routing algorithm but we remove highly expensive procedures corresponding to cluster head election. Instead, we propose to use an assistant node called zone master which has the similar role to the cluster head. Zone master computes routing information and distributes it to member nodes of his zone so that the nodes can discover and maintain routes without high overhead. The results of the simulation showed that our approach is very efficient in terms of performance and available for a large scale MANET as well.

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