A Fuzzy-Routing-Zone-Based Multicast Routing Protocol for Bluetooth MANET

Chenn-Jung Huang, Chih Cheng Chang
Institute of Learning Technology
National Hualien Teachers College
cjhuang@mail.nhltc.edu.tw

Wei-Kuang Lai, Sheng-Yu Hsiao
Dept. Computer Science and Engineering, National Sun Yat-Sen University
wklai@cse.nsysu.edu.tw

Abstract

In this paper, a routing protocol which utilizes the characteristics of Bluetooth technology is proposed for Bluetooth-based mobile ad hoc networks. The routing tables are maintained in the master devices and the routing zone radius for each table is adjusted dynamically by using a fuzzy inference system. Observing that there existing some useless routing packets which are helpless to build the routing path and increase the network loads in the existing ad hoc routing protocols, we selectively use multiple unicasts or one broadcast when the destination device is out of the routing zone radius coverage of the routing table. Based on the proposed routing protocol, a source-initiated multicast protocol is developed to transmit packets to a group of nodes. The simulation results show that the dynamic adjustment of the routing table size in each master device results in much less reply time of routing request, fewer request packets and useless packets compared with two representative protocols, Zone Routing Protocol (ZRP) and Dynamic Source Routing (DSR), and is well suited for the multicast applications in a Bluetooth MANET.

Keywords: fuzzy logic, bluetooth scatternet, multicast, reactive routing, proactive routing.

1. Introduction

Bluetooth is mainly pictured as a cheap technology enabling peer-to-peer communication between a central terminal and peripheral devices. The characteristics of low-power consumption and high security make Bluetooth a good choice for a Mobile Ad Hoc Network (MANET) deployment. There exist some differences between Bluetooth-based mobile ad hoc networks and traditional ad hoc networks. Firstly, the connection range is smaller in a Bluetooth MANET due to the low power of a Bluetooth device. Secondly, the number of neighboring nodes for a device is limited since the piconet scenario in a Bluetooth-based ad hoc network consists of one master device and up to seven slave devices each. Thirdly, a large routing table is inappropriate in most Bluetooth devices due to their limited storage spaces. Fourthly, it is common that a moving Bluetooth device is out of connection with the joined piconet since communication range is short in a Bluetooth MANET.

Although many ad hoc routing protocols have been reviewed in [1], they are not well suited for Bluetooth scatternets, which consists of two or more piconets each. Among them, Dynamic Source Routing Protocol (DSR) is a reactive routing protocol based on source routing, and each packet will determine a routing path to the destination itself. Zone Routing Protocol (ZRP) is a hybrid reactive/proactive routing protocol. On one hand, ZRP limits the scope of the proactive procedure to the node's local neighbors only. On the other hand, the searching through the network is adopted when a device cannot find the destination within the scope of proactive routing. Recently, Prabhu *et al.* [2] presented a routing protocol to achieve more gain in network life time, the issues of reducing routing request reply time and request packets and lower down useless packet path length are still not addressed.

To address these challenges, we present a self-adaptive zone routing protocol (SAZRP) for bluetooth scatternets in this article. The proposed algorithm builds a limited routing table in every master device, while keeps the size of routing table adjustable based on the computation result of a fuzzy inference system. We also present a multicast routing protocol based on the SAZRP. Simulation results show that the SAZRP needs less routing request reply time, and generates fewer request packets and useless packets compared to other representative routing protocols used in ad hoc networks. Moreover, the multicast routing protocol also performs well in a Bluetooth MANET. The remainder of the paper is organized as follows. In section 2, we will show the details of SAZRP. Section 3 presents the framework of proposed multicast routing protocol. Section 4 reviews the simulation results and comparisons. Conclusions are made in Section 5.

2. Self-Adaptive Zone Routing Protocol (SAZRP)

After observing the Bluetooth-based ad hoc networks, we find several characteristics which are different from traditional ad hoc networks.

(1) The number of neighboring devices is limited and small. For other ad hoc networks, the neighboring devices may be large. However, in Bluetooth-based ad hoc networks, a master device connects up to seven slave devices, and a slave also connects to limited master devices.

(2) For a master device *A* in a Bluetooth MANET, if there are other master devices within the same network, there exists at least one master device whose distance to device *A* is no more than 2 hops.

Based on the above observations, we draw some conclusions as follows.

(1) If we build routing tables in all master devices, we can cover all devices of ad hoc networks. It is not necessary to have routing tables in slave devices.

(2) When the routing table in a master device covers devices within 2 hops, the master can use this routing table to find other nearby master devices.

(3) The size of a routing table in the master is smaller than traditional ad hoc networks in general because there are at most 7 active slaves within a piconet. This leaves more room for the routing table to lengthen the routing zone radius as needed by the change of network and node behavior.

(4) If we can reduce the number of broadcasts, we can also diminish the number of nodes involved in unnecessary transmissions, which may interfere with the reply of establishing a connection. That is, we can reduce the time in finding a path to the destination which in turn alleviates the effects of topology changes due to node mobility.

Next we shall introduce the operations of the master device and the slave device of SAZRP in details. Then a fuzzy inference system is presented to adapt the routing zone radius of the routing table to a shift of the network operating conditions.

2.1 Master device

Figure 1 shows an example of Bluetooth network. There are three piconets in this example and their masters are *B*, *E* and *F*, respectively. Table 1 (a) and (b) show the routing table of master *B* and the routing table of master *F*, respectively. The routing table of master *E* can be built similarly. As shown in Table 1, the routing tables are built by link lists which comprise lists of ID-Type pairs. The first node of each ID-Type pair records those devices which is apart from the master for one hop. The second node of the ID-Type pair specifies those devices recorded in first node are masters or slaves. For example, node *C* is stored in the first node of second list in Table 1 (a). To its right, we identify node *C* as a slave node in the second node. Note that if node *C* is a master of another piconet, we identify it as a master node instead of as a slave node of master *B*. Then in the third and the fourth nodes we record those devices whose distance to the master is two hops and identify those devices as masters or slaves, respectively. Besides, if node *C* is connected to more than one master, we will use the fifth node and the sixth node for the second master, the seventh and the eighth nodes for the third master, and so on.

Source routing approach is used in SAZRP. The ROUTE REQUEST and ROUTE REPLY packets both have a type field and several routing fields which record the routing path from source to current node as shown in Figure 2 (a) and (b). When a master device receives a ROUTE REQUEST packet, it first checks if the destination is itself or a device in its routing table. If the destination is itself, then it sends the ROUTE REPLY packet to the source. The destination device will reverse the routing path in routing fields of ROUTE REQUEST to switch the roles of the destination and the source before putting them into the routing fields of ROUTE REPLY. The destination will send the ROUTE REPLY to the neighboring device according to routing fields.

If the destination is in its routing table, device will add its ID after the last routing field in ROUTE REQUEST, and then send the ROUTE REQUEST to the destination or a neighboring device of the destination. If the destination can not be found in the routing table, the master device will append its unique ID to the last routing field and send the ROUTE REQUEST to its neighboring devices via multiple unicasts or a broadcast depending on the number of neighboring devices. If the number of neighboring devices, which are masters themselves or connected to master devices, is larger than a threshold, we still use broadcast to forward the ROUTE REQUEST. On the contrary, we forward the ROUTE REQUESTs by multiple unicasts when the number of neighboring devices is less than or equal a threshold to avoid useless ROUTE REQUESTs sent to many unnecessary nodes. However, only those neighboring devices satisfying either of the following two conditions will receive the ROUTE REQUEST, (a) this neighboring device plays the master role in another piconet or (b) the neighboring device of the master has one connection to a remote master which is not in the routing fields and the master has not sent or forwarded the same ROUTE REQUEST before.

Each device except the source receiving the ROUTE REPLY in the network needs to look for routing fields and then send the ROUTE REPLY to the next specific device in ROUTE RECORD. The routing operation is complete when the source device, which is located at the last position in ROUTE RECORD of ROUTE REPLY, receives the ROUTE REPLY.

2.2 Slave device

The slave devices do not build the routing table, so what they do is to broadcast the ROUTE REQUEST. When a slave device received a ROUTE REQUEST, it will check if the destination is itself. If it is, the slave device will send the ROUTE REPLY to the source device. If the destination is its neighboring device, the slave device will add its unique ID after the last routing field of ROUTE REQUEST, and send the ROUTE REQUEST to the destination via unicast. If the destination is not itself or its neighbor, the slave device will put its unique ID after the last routing field of ROUTE REQUEST, and then unicast the ROUTE REQUEST to all its neighboring devices one by one. The slave device which receives a ROUTE REPLY also needs to pass it to the next specific device in ROUTE RECORD.

2.3 A fuzzy routing zone radius estimation scheme

The fuzzy logic has been used to solve several routing protocols and handover problems efficiently in wireless networks in the literature [3]. There are lots of solutions on VLSI chips which allow fuzzy inferences to be hardware-computed, and high-speed low cost fuzzy chips have been introduced recently, the implementation of fuzzy logic by hardware thus becomes feasible nowadays [4]. In our scheme, a fuzzy logic approach is attempted to offer the self-tuning capability in the routing zone radius estimation mechanism. The basic functions of the components employed in the proposed fuzzy routing zone radius estimator are described as follows.

(1) Fuzzifier: The fuzzifier performs the fuzzification function that converts three types of input data from the fuzzy routing zone radius scheme into suitable linguistic values which are needed in the inference engine.

(2) Fuzzy rule base: The fuzzy rule base is composed of a set of linguistic control rules and the attendant control goals.

(3) Inference Engine: The inference engine simulates human decision-making based on the fuzzy control rules and the related input linguistic parameters. The max-min inference method is used to associate the outputs of the inferential rules [5], as described later in this subsection.

(4) Defuzzifier: The defuzzifier acquires the aggregated linguistic values from the inferred fuzzy control action and generates a non-fuzzy control output, which represents the estimated routing zone radius adapted to the new network and node conditions. The Tsukamoto defuzzification method is employed to compute weighted average of the aggregated output of the inferential rules due to its simplicity in computation [5].

Notably, the input to the fuzzifier v represents node velocity, which is a measure of network reconfiguration rate. The input n denotes the node density, which is the number of neighboring nodes of the master, and the input r stands for the route query rate observed by the master node.

The input and output fuzzy sets are correlated to establish the inferential rules of the fuzzy routing zone radius estimator which are correspondent with the observation made by Pearlman *et al.* in [6]. By way of illustration, rule 1 can be interpreted as:

IF network reconfiguration rate is "low", **AND** the node density is "low", **AND** the route query rate is "low",

THEN the weighting factor of the routing zone radius for the routing table is "low".

The non-fuzzy output of the defuzzifier is expressed as the weighted average of each rule's output after the Tsukamoto defuzzification method is applied:

$$z = \frac{\sum_{i=1}^{8} R_{z,i} \cdot w_i}{\sum_{i=1}^{8} w_i}, \qquad (1)$$

where $R_{z,i}$ denotes the output of each rule induced by the firing strength w_i. Notably, w_i represents the degree to which the antecedent part of each fuzzy rule constructed by the connective "**AND**" as shown in the above example is satisfied.

Compared with traditional ad hoc routing protocol, we can find that SAZRP has three advantages.

(1) Less number of broadcasting: In most ad hoc routing protocol, devices will broadcast route requests if they do not know the locations of destinations. Broadcast messages will keep delivering until they reach the destinations. On the other hand, a master device in SAZRP will use multiple unicasts or a broadcast if the destination is out of routing zone radius and use the selected unicast otherwise. It can greatly reduce network load since the total number of broadcasted is reduced. For instance, we assume current routing zone radius of device *B* is 2 hops and device *A* is the source and device *E* is the destination in Figure 1. In SAZRP, slave *A* will unicast a ROUTE REQUEST to master *B*. After receiving the ROUTE REQUEST, master *B* will check to see if *E* is in its routing table. Because the distance between *B* and *E* is 2 hops, the position of *E* will be recorded in the routing table of device *B*. Therefore, device *B* will unicast ROUTE REQUEST to *C*, and *C* will forward it to the destination *E*. On the other hand, in most reactive ad hoc routing protocol, such as DSR, the device *B* does not know the path to destination *E*. Thus device *B* will broadcast the ROUTE REQUEST, and both devices *C* and *D* receive it. Unfortunately, device *D* doesn't know the position of destination *E*, it also broadcasts the ROUTE REQUEST. Finally, The ROUTE REQUEST will be passed to device *F*, *G*, which adds more traffic in the network and is clearly useless.

(2) Lower storage spaces: In most proactive routing protocols, each device has to build a routing table. It will be a huge cost for all devices in mobile ad hoc networks. The ZRP is better than traditional proactive routing protocols in storage spaces needed. The ZRP controls the routing table size via the routing zone radius. However, each device still needs to build a routing table in the ZRP. In the SAZRP, only master devices need to build routing tables, and each master connects up to 7 slaves. This allows the master devices to length the routing zone radius for the routing table if necessary.

(3) Shorter time for the reply of a route request: In an ad hoc mobile network, the longer a source receive a ROUTE REPLY, the more likely the path is changed when it actually transmits. The SAZRP has shorter reply time since the ZRP broadcast more ROUTE REQUEST packets and might interfere with the ROUTE REPLY and delay the time that the ROUTE REPLY arrives at the source.

3. On-demand multicast routing protocol

3.1 Multicast tree Creation

For each multicast session in a Bluetooth MANET, a multicast route entry is identified by the multicast session id, a <source, group> pair. A multicast source initiates a multicast tree creation by sending a MULTICAST REQUEST to the master of its zone if it is a slave node. Similar to the approach taken for the ROUTE REQUEST as described in Section 2, the master node will forward MULTICAST REQUEST packets to rest of its neighboring nodes and the masters in other piconets until some group member is reached.

Each device except the source receiving a MULTICAST REQUEST needs to send a MULTICAST REPLY to next upstream node of the multicast tree. In order to simplify the structure of the multicast route entry, each intermediate node only records the multicast session id, the upstream node and the downstream node(s) in the MULTICAST REPLY packet. If the downstream nodes of an intermediate node form a tree, the intermediate node lists next downstream nodes in all the corresponding tree branches. This mechanism effectively prevents the upstream node of a root for tree branches from sending the duplicate multicast packets to the downstream nodes within a tree.

3.2 Multicast tree maintenance

To keep up-to-date information at each group member in the presence of node mobility, the device which lost connection with the upstream node or the downstream node in a multicast tree will notify its upstream node and downstream node. The upstream node then sends a

MULTICAST UPDATE REQUEST packet to its new downstream node to find a new route between them and update the corresponding multicast route entries. The source and the intermediate nodes will inform their downstream nodes to remove the corresponding multicast route entries when the source finishes sending all the data for the multicast session.

4. Simulation results

We randomly generate 50 to 150 Bluetooth devices in a 5625 square meters area. The positions of devices are also produced randomly. The connection range of Bluetooth devices is 10 m. A master device can connect up to 7 slave devices, and a slave device can join up to 10 piconets. ACL link are established. After the network is constructed, we choose two devices from the network randomly to be the source device and the destination device. The source device needs to send the ROUTE REQUEST to destination and receive the ROUTE REPLY from destination in order to build a routing path. For comparison, we run a series of simulations for the ZRP, the DSR, the SAZRP, and the SAZRP with a fixed routing zone radius (FZRP). The routing radius is set to two hops for the ZRP and FZRP schemes. The simulation is repeated for 500 times and the average is computed as the final result.

Figure 3 gives the comparison of the routing request reply time for the four schemes under different node population. The reply time represents the time interval between the source sending a ROUTE REQUEST and receiving a ROUTE REPLY. It is obvious that the reply time in the SAZRP scheme is much less than the other three. We believe that this is mainly because the DSR and the ZRP both broadcast ROUTE REQUEST when devices do not know the positions of destinations. When the network is congested, the packets are delayed. Although the SAZRP and FZRP also broadcast when the destination is not within its zone radius coverage, the capability of self-adaptation on the routing zone radius results in much fewer broadcasts spread in the SAZRP scheme.

Figure 4 shows the comparison of total ROUTE REQUESTs each node receives. Every time a device receives a ROUTE REQUEST, the value of total received ROUTE REQUEST will be increased by 1. It can be seen that the SAZRP receive fewer ROUTE REQUEST packets, especially when the node population is large. This is because the SAZRP selectively use multiple unicasts or one broadcast depending on the situation of neighboring devices when the destination is out of the routing zone radius of the master. This figure further explains why the SAZRP has shortest reply time since the nodes in the network receive fewer messages and can reply ROUTE REPLY to the source faster than other protocols do.

When a source device receives a ROUTE REPLY from the destination device, the routing path is found. However, it might happen that there are still some ROUTE REQUESTs sent in network at this time. Those ROUTE REQUEST packets do not have any help to build the routing path. The reason they are still alive is that some devices do not know the routing path is found, so they still forward the ROUTE REQUESTs to neighboring devices.

In figure 5 we show the packet delivery ratio versus the maximum node speed which is varied from 0 m/sec to 30 m/sec. The packet delivery ratio refers to the ratio of the number of data packets actually delivered to the multicast group members versus the total number of data packets that were supposed to be delivered. As expected, the packet delivery ratio is high when the nodes have low mobility and goes down when the speed of the nodes increases. The performance degradation is due to frequent tree link failures.

Figure 6 illustrates how the control overhead is affected when the multicast group size is varied. The control overhead is calculated as the ratio of the control packets sent versus all the packets sent. As the control overhead is slightly improved when group size increases, we can conclude believe that our multicast protocol is very suitable for the multicast applications in a Bluetooth MANET.

5. Conclusion

We take use of some characteristics of Bluetooth technology to design an efficient protocol called the SAZRP for Bluetooth-based mobile ad hoc networks in this work. In SAZRP, we build routing table in master devices to reduce the space cost. In order to reduce the flooding of broadcast, the SAZRP uses the unicast in master devices to replace the broadcast. SAZRP also checks if the neighboring device needs to receive the ROUTE REQUEST packet. A fuzzy inference system is used to decide the routing zone radius for the routing table based on three parameters observed by the masters. Simulation results show that the SAZRP has less reply time of routing request, smaller broadcast to unicasts ratio, fewer request packets, and lower useless packet ratio, compared to the DSR, ZRP, and our scheme without the fuzzy inference system. Notably, the vector of Routing Vector Method (RVM) [7] can be incorporated into our scheme to replace the Bluetooth 48-bits address in order to further reduce overheads in networks since The RVM can reduce the size of ROUTE REQUEST and ROUTE REPLY packets. We also propose a multicast routing mechanism based on the SAZRP. The experimental results reveal that our multicast protocol is suitable for the Bluetooth MANET environment. In the future work, we will include a framework for congestion control in our multicast routing protocol and compare its performance with other representative protocols such as On-Demand Multicast Routing Protocol (ODMRP).

6. Acknowledgments

We thank National Science Council for their support for this research. The grant no. is NSC 90-2213-E-143-001.

7. References

[1] E. Royer, and C.-K. Toh, "A review of current routing protocols for ad hoc mobile wireless networks," *IEEE Personal Communications*, pp. 46 – 55, 1999.

[2] B. J. Prabhu, and A. Chockalingam, "A routing protocol and energy efficient techniques in Bluetooth scatternets," *2002 IEEE International Conference on Communications*, vol. 5, pp. 3336 –3340, 2002.

[3] Y. F. Wong, and W. C. Wong, "A fuzzy-decision-based routing protocol for mobile ad hoc networks," *10th IEEE International Conference on Network*, pp. 317 –322, 2002.

[4] M. N. Uddin, T. S. Radwan, M. A. Rahman, "Performances of fuzzy-logic-based indirect vector control for induction motor drive," *IEEE Trans. Industry Applications,* vol. 38, no. 5, pp. 1219 -1225, 2002.

[5] J. J. Buckley, E. Eslami, and E. Esfandiar, "An introduction to fuzzy logic and fuzzy sets (advances in soft computing)," Physica Verlag, 2002.

[6] M. R. Pearlman, and Z. J. Haas, "Determining the optimal configuration for the Zone Routing Protocol," *IEEE J. Selected Areas in Comm,* vol. 17, no. 8, pp. 1395-1414, 1999.

[7] P. Bhagwat, and A. Segal, "A Routing Vector Method (RVM) for routing in Bluetooth scatternets," *1999 Mobile Multimedia Communications*, pp. 375 – 379, 1999.

[8] S.-J. Lee, W. Su, and M. Gerla, Internet Draft, draft-ieft-manet-odmrp-02.txt, Jan. 2000.

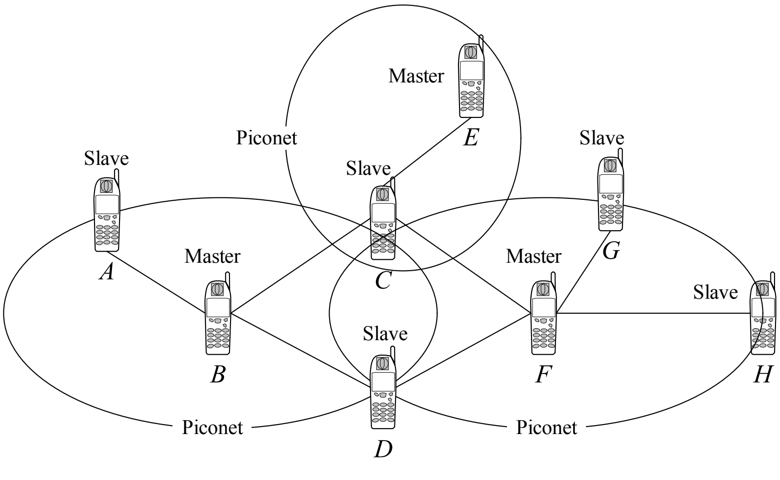

Figure 1. An example of Bluetooth MANET.

Type	Hop 1 device ID (source)	Hop 2 device ID	……	Hop n device ID

(a) Format of ROUTE REQUEST

Type	Hop 1 device ID	Hop 2 device ID	……	Hop n device ID (source)

(b) Format of ROUTE REPLY

Figure 2. Formats of ROUTE REQUEST and ROUTE REPLY packets.

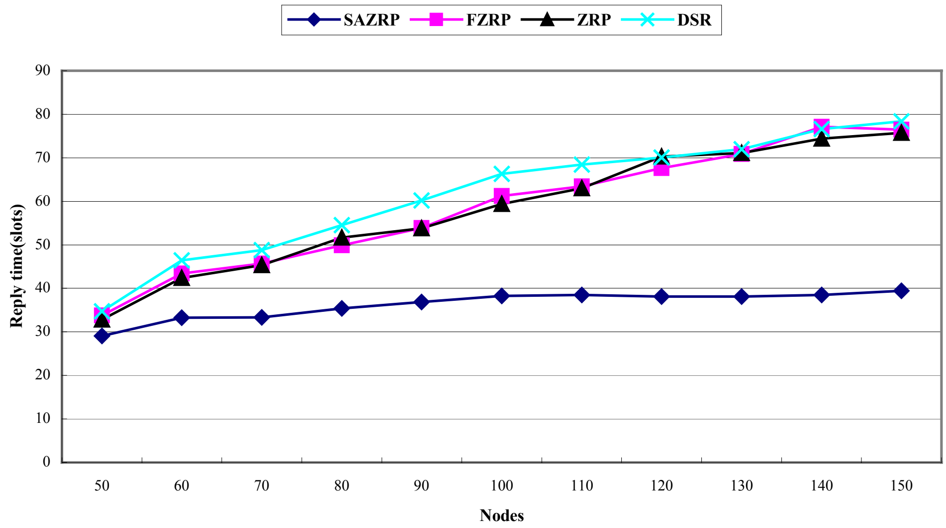

Figure 3. Total reply time of routing request under different node population.

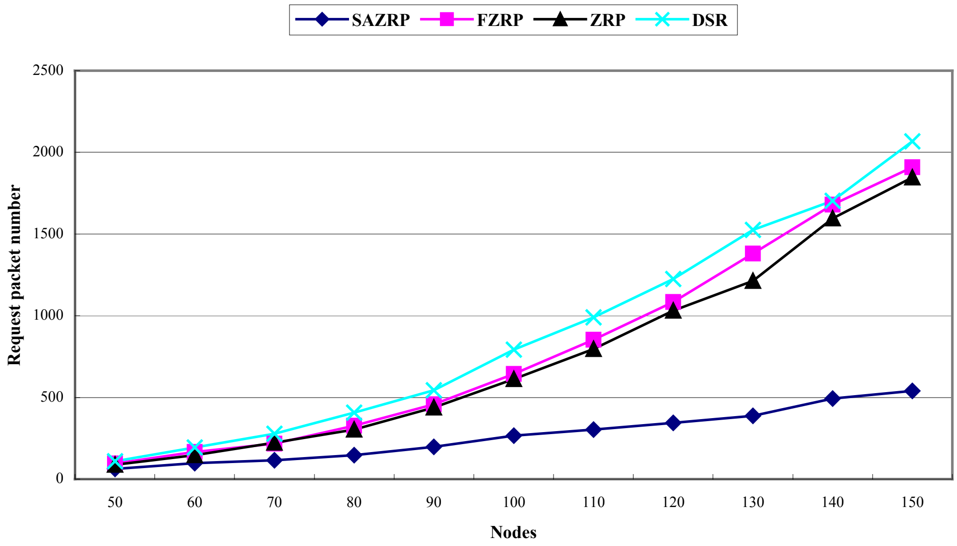

Figure 4. Total request packets comparison.

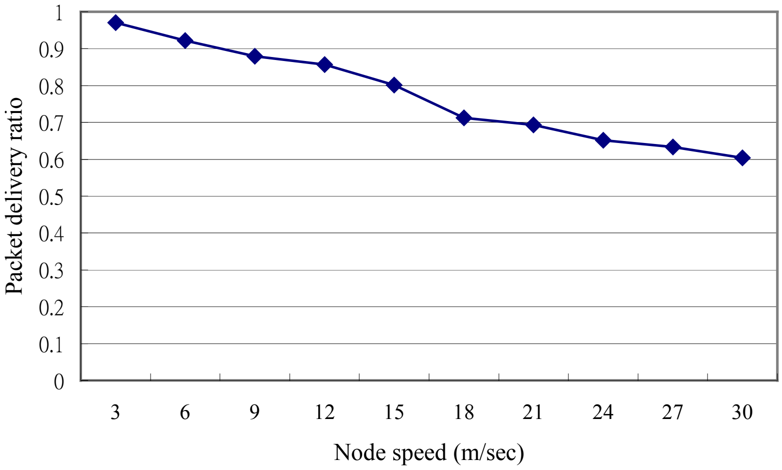

Figure 5. Packet delivery ratio as a function of node speed

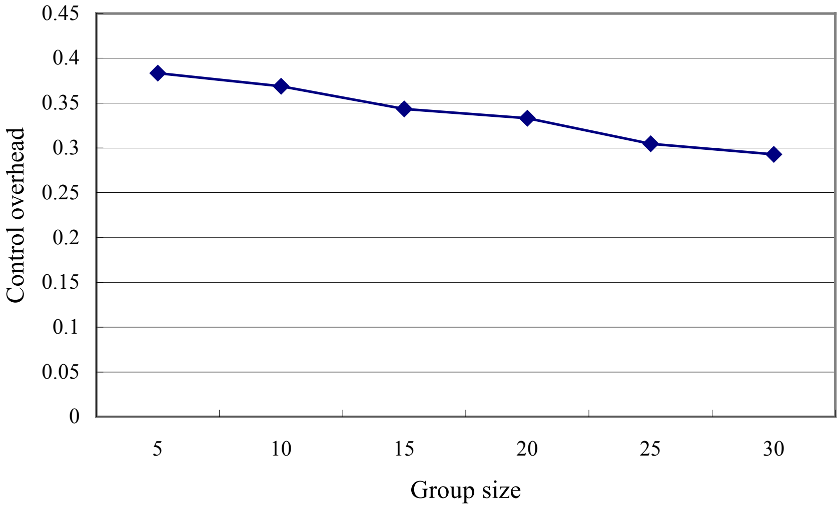

Figure 6. Control overhead as a function of group size.

Table 1. The routing table of master is built by link lists.

(a) Routing table of master B in Figure 1 (b) Routing table of master F in Figure 1