An Efficient Power-Aware Multicast Protocol for Mobile Ad Hoc Networks

C. N. Kao+ S. F. Hwang* Y. Y. Su† C. R. Dow*
Department of Information Engineering and Computer Science
Feng Chia University, Taichung, Taiwan
+Email: {m9018380@knight.fcu.edu.tw}
*Email: {sfhwang, crdow@fcu.edu.tw}
†Email: {pioneer.su@msa.hinet.net}

Abstract

Ad hoc wireless networks are organized by a collection of wireless devices. Any pre-established wired or wireless infrastructures and the centralized administration are unnecessary. Due to the mobile hosts can move arbitrarily and the resources of mobile devices such as the network bandwidth, and power consumption of mobile hosts are limited, to design multicast routing protocols becoming more challenging. However, there are many applications achieved by multicasting such as video conference, distance learning, etc. How to deign an efficient multicast routing is very important. In this paper we will propose an efficient and power-aware multicast routing algorithm in ad hoc networks. Simulation results show our approach has better performance in packet delivery ratio, number of alive nodes, number of alive members, throughput than ODMRP, MZR, HMP, E2MRP.

keyword：ad hoc wireless network，multicast routing，power consumption，single-source multicast

1. Introduction

Recently, technology of mobile computing and wireless communication is widely used. Users are expected to access Internet at anytime and anywhere, without the need to wire their laptop or PDA to browse Internet. The multimedia services keep users sending/receiving stream/data in a wireless environment. Mobile node (the laptop or PDA) is a peripheral that are found very versatile to handle the mobility. The advancement of this technology has moved a step further. Mobile ad hoc network (MANET) is introduced to perform greater mobility service. Thus, one of the most important aspects that need to be considering in order to achieve this greater mobility is the routing protocols for MANET.

This research was supported in part by the National Science Council, ROC, under Grant NSC 92-2213-E-035-018

A mobile ad hoc network, MANET, is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. MANET platform consist of mobile nodes that act as routers in the network. Therefore, the mobile node is searching and working to find its own route to send data packets or messages. MANET has some characteristics that need to be studied in order to understand it and as a guide line for designing routing protocols, such as the dynamic topologies, energy constrained operation, limited of security and bandwidth constrained with variable capacity links.

Multicasting is an important research area because of the widely applications. Multicast techniques that are tailored from static networks do not work well in ad hoc networks as the multicast trees formed are constantly restructuring and fragile. Additionally, the communication requires exchanging large amount of information as needed by static multicast techniques based on distance vector and link state could be prohibitively expensive owing to the low bandwidth wireless links, processing overhead and the dynamic network topology.

Most of the multicasting protocols can be further divided into four categories: tree, mesh, location, hybrid schemes. In the typical wired network, tree topology is usually used in multicasting. One of the characteristics of tree scheme is that there is only one path between source and receivers. When the path is broken, it must be reconstructed, such as the MAODV[10] (Multicast operation of the Ad hoc On-demand Distance Vector routing protocol), CBT[2] (Core-Based Tree). Mesh scheme is also used by many multicast routing protocols. It has multiple redundant paths between source and receivers. It usually has high packet delivery ratio with high control overhead, especially when the number of receivers is very large. ODMRP[4] (On-Demand Multicast Routing Protocol), CAMP[6] (The

Core-Assisted Mesh Protocol) are examples of mesh scheme. ODMRP relies on creating a mesh of nodes, which is known as the forwarding group. The forwarding group is responsible for forwarding the multicast packets within the mesh. The protocol is an on-demand protocol as it maintains only soft-state for group maintenance but maintaining the entire route information.

Some multicast routing protocols utilize GPS to get location information of receivers in order to decrease control overhead of route discovery, such as LBM[8] (Location-Based Multicast Scheme), MHMR[1] (Mobility-based Hybrid Multicast Routing). LBM is a multicast extension of LAR[9]. It utilizes location information to reduce overhead. Location information used in LBM may be provided by the GPS. LBM defines the Multicast Region and the Forwarding Zone. The nodes in Multicast Region are the multicast group members. Forwarding Zone is used to limit flooding area of control packet. In other words, only the nodes in the Forwarding Zone would forward data packets to the multicast group members. After data packets reach the Multicast Region, LBM utilizes flooding method to transmit data packets. MHMR utilizes GPS to form several clusters. The formation of the cluster is according to the individual mobility and group mobility of each node. MHMR utilizes mesh topology to do multicasting and the nodes in the mesh are the clusterheads of the clusters.

Some multicast routing protocols combine the following two methods: proactive and reactive, to adapt the different network condition, such as HMP[3] (Hierarchy-based Multicast Protocol) and MZR[5] (Multicast routing protocol based on Zone Routing). HMP elects some nodes to become cores which establish the local shared tree(LST) to manage the receivers. Then, the source node discovers the multicast paths to all the cores. The source node transmits data packets to the receivers after the multicast paths are found. MZR is a hybrid tree-based multicast routing protocol. It utilizes the concept of ZRP[7] to construct and maintain a tree topology. E2MRP[11] (Energy-Efficient Multicast Routing Protocol) is a modification of ODMRP which take the power consumption in to consideration. Since it also uses the concept of forwarding group to forward the data packets, the multicast efficiency(number of packets transmitted per data packet delivered) is still poor.

In this paper, we propose a Power-Aware Multicast Protocol(PAMP). We employ the tree-based structure because of the high efficiency and low control overhead compares to the mesh-based one. We also use a hybrid scheme, which uses table-driven for intra-LST routing and on-demand approach for inter-LST routing, to achieve our multicast routing protocol. A weight function is used to construct the LST by calculating the weight of each node and selecting the proper cores. Besides, the PAMP is also power-aware. We consider the energy consumption to select the cores, build the LST and the multicast paths.

The rest of this paper is organized as follows. Section 2 discusses our power-aware multicast routing protocol. Section 3 shows the experimental results and analysis. Finally, we conclude this paper in section 4.

2. Power-Aware Multicast Protocol (PAMP)

This section is divided into several subsections to introduce our power-aware multicast routing protocol. First, we introduce the selection of cores. Then, the construction of the local shared tree(LST) and the multicast paths are discussed. The multicasting is explained in section three. Finally is the maintenance of core, LST, and the multicast path.

2.1 The selection of cores

The selection of cores will directly affect the efficiency of the multicast. Y.-S. Chen[13] although proposed a good core select algorithm, but the algorithm does not consider the power consumption. So our aim in this subsection is to select some nodes as cores, to manage its local receivers and reduce the total power consumption. First, we define a weight function such that the cores can be chosen easily. We must define some notations. For each node x, let $Ni(x)$ be the set of the i-hop neighbors of x. And the weight function of x, $w(x)$, be $4s + 2t + 3$ (x is a member), where s and t are the numbers of members in $N1(x)$ and $N2(x)$-$N1(x)$, respectively, and [p] is 1 if p is true, and is 0 otherwise.

When a node x gets its 2-hop neighbors information, it will calculate its weight, and then compares to its 2-hop neighbors. The node y with the maximum weight (>0) in $N2(x)$ will become a core, that is, $w(y) = \max_{z \in N_2(x)} w(z)$.

If there are two nodes with the same weight, the node which has more residual power will become the core. For example, in figure 1, the weight of each node is: A=2, B=8, C=2, D=13, E=19, F=13, G=9, H=16, I=8, J=9, K=7, L=7. The maximum value is 19(E), so node E will be elected as a core.

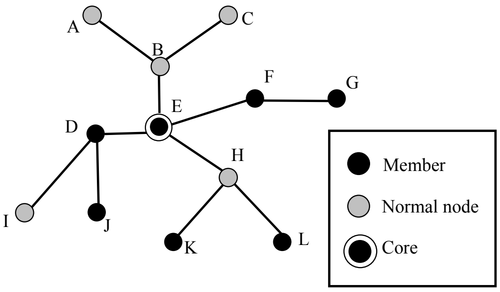

Figure 1. The selection of core.

2.2 The construction of local shared tree (LST)

When the cores are elected, they will construct the basic topology-local shared tree. First, the core issues the LST RREQ (route request) to its 2-hop neighbors. When the members in 2-hop neighbors of the core receive the LST RREQ, they will reply the LST RREP (route reply) to the core. After all members replied the LST RREP to the core, the local shared tree is established.

For stability, the residual power of each node must be considered in the construction of the local shared tree. In other words, the residual powers of the intermediate nodes in the local shared tree must be larger than a given threshold value α.

When the member receives two or more LST RREQs from the different cores, it will choose the nearest one to reply the LST RREP and join it. If the distance of both cores is the same, then choose the core which has larger residual power to join the local shared tree. Figure 2 is an example of the local shared tree construction. In Figure 2(a), node E issues the LST RREQ packet to its 2-hop neighbors. After the members in the 2-hop neighbors receive this packet, they reply the LST RREP packet back to node E. Thus, the local shared tree is constructed as figure 2(b).

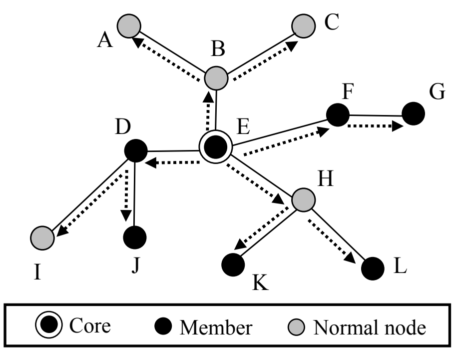

Figure 2 The construction of a local shared tree
(a) LST RREQ

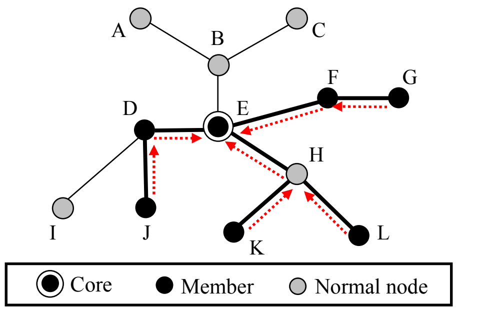

Figure 2. The construction of a local shared tree.
(b) LST RREP and construction.

2.3 The construction of multicast path

The path construction between the cores is implemented with an on-demand approach.

The multicast paths construction is divided into two phases: the multicast request phase and the multicast reply phase. In the multicast request phase, the core of the source node will broadcast MREQ (multicast request) to other cores in the network. In the multicast reply phase, as a core receives the MREQ, it will select a route with maximal lifetime (the residual power of the route is maximal), and reply MREP (multicast reply) to the core which issues the MREQ control packet. After multicast request and multicast reply phase are completed, the multicast paths are constructed. Although the number of the constructed multicast paths is not large, they are still reliable due to the power consideration. To evaluate the lifetime of the path P, from the core of the source Cs to another core Ct, we give a power function T_P for P as follows.

$$T_P = \min_{n \in P} residual\ power \quad (n)$$

Then, choose the path with the maximum T_P as the multicast path between Cs and Ct. This criteria is similar to MMBCR[12]. Figure 3 shows the construction of multicast path. Source node issues MREQ packet, only four cores C1, C2, C3, C4 will reply MREP packet.

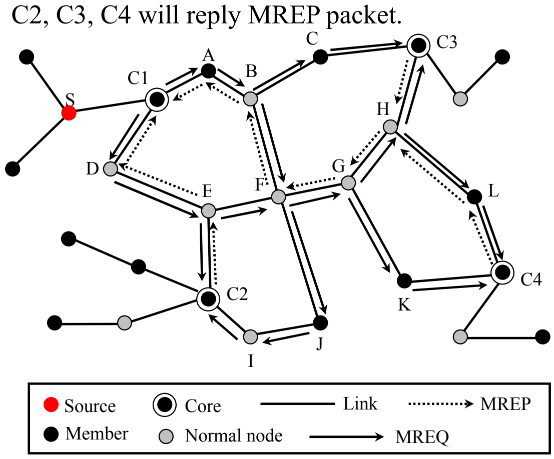

Figure 3 The construction of multicast paths

2.4 Multicasting

Our multicasting will be done by the local shared trees and the multicast paths. We use proactive approach in intra-LST multicasting, and use reactive approach between LST and LST. In our method, only the core nodes need to maintain 2-hop information. If the members in the local shared tree want to find a route, they can request the core which manages them to find a route. Thus, we can save lots data storage space and the flooding of multicast route request packets. The details are as follows.

2.4.1 Intra-LST multicasting

As the architecture of LST is built, the core will be in charge of the maintenance of information of all nodes and link states of the LST. Thus, when a node u wants to communication with a node v in the LST, it only asks its core. The core will reply a route to the node u. Finally, the communication in the intra-LST will be achieved.

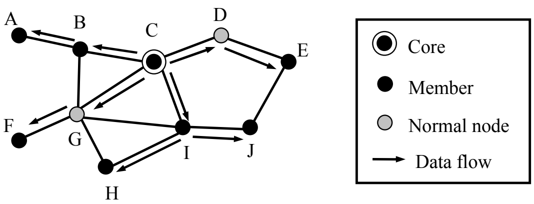

Figure 4 Intra-LST multicasting

2.4.2 Inter-LST multicasting

The multicasting between LST and LST is called inter-LST multicasting. In the inter-LST multicasting, the multicast paths are discovered by source node on-demand. After the source node sends data or messages to all cores in the network, the cores are in charge of sending data or messages to their members, as shown in figure 5. Thus, this method can avoid flooding in the network and cut down the resource consumption. Local table-driven approach also can reduce the power consumption and the overhead of updating routing information periodically.

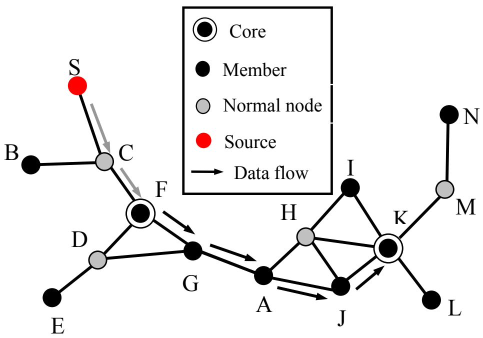

Figure 5 Inter-LST multicasting

2.5 The maintenance

The core maintenance will be divided into the following three cases.

1. Core retire: if the residual power of the core is less than the threshold value β, it must retire and elect a node with maximal weight in its 1-hop neighbors to be a new core. The members of the old core which are not be managed by the new core must find other cores to join. Otherwise, it elects itself to be a core.

2. If the distance between two cores is less than or equal to 2-hop, the core with the less residual power will give up its status. If the residual power of both cores is the same, the core with the larger id will give up.

3. If the core is moving far away from its members: when the distance between the core and its members are more than 2-hop, then the members must select a nearby core to join. If no core can be joined, executes the core selection algorithm described in section 2.1.

The maintenance mechanism of LST is to broadcast LST RREQ and RREP periodically, this is similar to the soft state of ODMRP[4].

The multicast paths between the cores of the source node and other cores are constructed by on-demand approach. So, the paths between them are maintained only when there are data packets to send. Thus, it just needs to broadcast MREQ and MREP between cores periodically.

3. Experimental Results and Analysis

In this section, we will introduce our simulation environment, parameters, and experimental results. We compare the packet delivery ratio, average hop count, number of alive nodes, number of alive members, and throughput with HMP[3], ODMRP[4], MZR[5], and E2MRP[11]. Table 1 and table 2 summarized the simulation environment parameters and the power parameters.

The simulated metrics are defined as:

Packet Delivery Ratio: The number of data packet delivered to the multicast members over the number of data packets supposed to be delivered to the multicast members.

Average Hop Count: The average path length in hop that the data packets successfully delivered.

Number of Alive Nodes: In the simulation period, at each time slot (every 50 seconds), we record how many mobile nodes are still alive (the residual power is larger than 0).

Number of Alive Members: In the simulation period, at each time slot (every 50 seconds), we record how many members are still alive (the residual power is larger than 0).

Throughput: In the simulation period, at each time slot (every 50 seconds), we record how many packets are received by all members.

Table 1

Item	Simulation space	Nodes	Members	Transmission range
Parameter	1000m＊1000m	50	5~40	200~250 meters
Item	Simulation time	Speed	Pause time	Movement model
Parameter	400 seconds	2~20(m/s)	10~250 secs	Random waypoint model

Table 2

Power parameters	$E_{point\text{-}to\text{-}point\ send}$	$E_{broadcast\ send}$	$E_{point\text{-}to\text{-}point\ receive}$	$E_{broadcast\ receive}$
	1.9＊size＋454	1.9＊size＋266	0.5＊size＋356	0.5＊size＋56

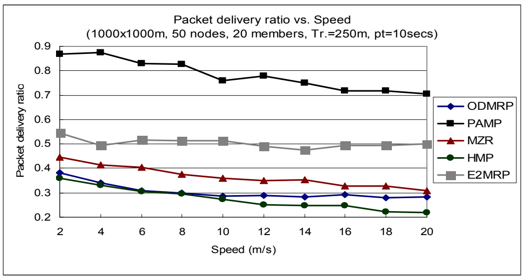

Figure 6. Packet Delivery Ratio vs. Speed

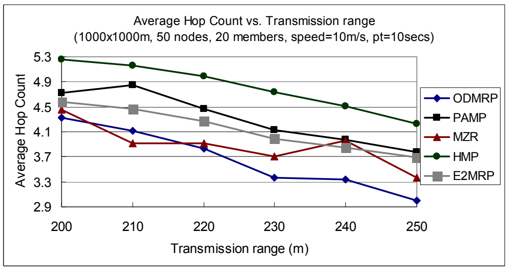

Figure 7. Average Hop Count vs. Transmission range

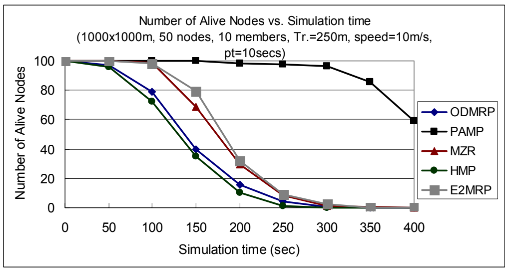

Figure 8. Number of Alive Nodes vs. Simulation time

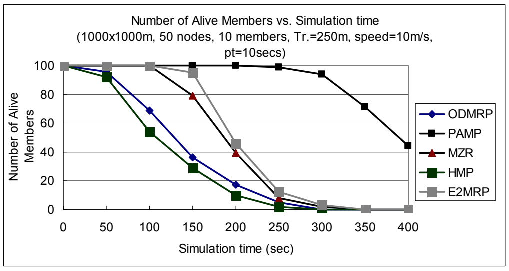

Figure 9 Number of Alive Members vs. Simulation time

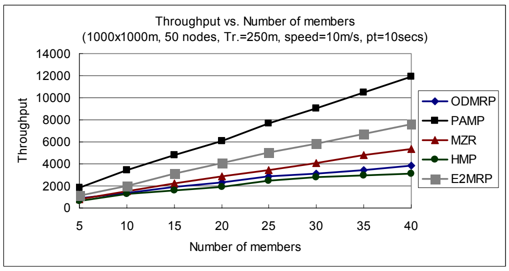

Figure 10. Throughput vs. Number of members

In figure 6, we can know that whatever the speed is fast or slow, our multicast routing protocol PAMP still keeps high packet delivery ratio. The packet delivery ratio of other multicast routing protocols is lower than PAMP. In figure 7, when the transmission range is becoming larger, the average hop count of all multicast routing protocols is becoming smaller. And PAMP is still smaller than HMP. Figure 8 and 9 show that PAMP outperforms HMP, ODMRP, MZR, E2MRP in terms of the numbers of alive nodes and alive members. Figure 10 shows that the throughput of all multicast routing protocols are increasing as the number of members increasing, and PAMP is always better than the others.

4. Conclusions

Our PAMP utilizes weight function and employ the power saving scheme to construct local shared tree, then uses a hybrid routing algorithm to transmit packets to multiple receivers on-demand. Our protocol can effectively save the power consumption of the mobile hosts and extend the lifetime of the mobile host.

According to the simulation results, we know that PAMP is better in packet delivery ratio, number of alive nodes, number of alive members and throughput than HMP, ODMRP, MZR, E2MRP. Besides, the average hop count of PAMP is also better than HMP.

We will develop a power-aware multicast

routing for multiple sources environments in the future. In addition, we will extend our simulation results by adding the metrics such as end-to-end delay, control overhead, etc.

5. References

[1] B. An and S. Papavassiliou, “A mobility-based hybrid multicast routing in mobile ad-hoc wireless networks,” *Proceedings of IEEE Military Communications on Conference Communications for Network-Centric Operations*: *Creating the Information Force*, Vol. 1, pp. 316–320, 2001.

[2] T. Ballardie, P. Francis, and J. Crowcroft, “Core Based Tree(CBT) – An Architecture for Scalable Inter-Domain Multicast Routing,” In *Proceedings of ACM SIGCOMM’93*, San Francisco, CA, pp. 85-95, Oct. 1993.

[3] T.-S. Chen, Y.-S. Chen, and H.-W. Tsai, “A hierarchy-based multicast protocol for wireless mobile ad-hoc networks,” *Proceedings. Ninth IEEE International Conference on Networks*, pp. 248 –253, 2001.

[4] C.-C. Chiang, M. Gerla, and S.-J. Lee, “On-demand multicast routing protocol,” *Proceedings of IEEE Wireless Communications and Networking Conference*, pp. 1298 –1302, 1999.

[5] V. Devarapalli and D. Sidhu, “MZR: a multicast protocol for mobile ad hoc networks,” *Proceedings of IEEE International Conference on Communications*, Vol. 3, pp 886–891, 2001.

[6] J. J. Garcia-Luna-Aceves and E. L. Madruga, “The core-assisted mesh protocol,” *IEEE Journal on Selected Areas in Communications*, Vol. 17, No. 8, pp. 1380 –1394, Aug. 1999.

[7] Z. Hass and M. Pearlman, “The Zone Routing Protocol (ZRP) for Ad Hoc Mobile Networks,” in IETF MANET Draft, Jun. 1999.

[8] Y.-B. Ko and N. H. Vaidya, “Geocasting in mobile ad hoc networks: location-based multicast algorithms,” *Proceedings of Second IEEE Workshop on Mobile Computing Systems and Applications*, pp. 101-110, Feb. 1999.

[9] Y.-B. Ko and N. H. Vaidya, “Location-aided routing (LAR) in mobile ad hoc networks,” *Wireless Networks*, Vol. 6, No. 4, pp. 307-321, Jul. 2000.

[10] E. M. Royer and C. E. Perkins, “Multicast operation of the ad-hoc on-demand distance vector routing protocol,” *Proceedings of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking*, pp. 207–218, Aug. 1999.

[11] B. Sun, H. Jiang, S. Cheng, and Y. He, “Multicasting along energy-efficient meshes in mobile ad hoc networks,” *Proceedings of IEEE Wireless Communications and Networking Conference*, Vol. 2, pp. 807–811, Mar. 2002.

[12] C.-K. Toh, H. Cobb, and D. A. Scott, “Performance evaluation of battery-life-aware routing schemes for wireless ad hoc networks,” *IEEE International Conference on Communications*, Vol. 9, pp. 2824-2829, 2001.

[13] Y.-C. Tseng and T.-Y. Hsieh, “Fully power-aware and location-aware protocols for wireless multi-hop ad hoc networks,” *Proceedings of the Eleventh International Conference on Computer Communications and Networks*, pp. 608-613, 2002.