

Energy Efficient Clustering Technique for Multicast Routing Protocol in Wireless Ad Hoc Networks

I-Shyan Hwang and Wen-Hsin Pang

Department of Computer Science and Engineering, Yuan-Ze University, Taiwan, 32026.

Summary

Energy efficient communication in mobile ad hoc networks (MANET) is a very stringent issue due to the power-constraint of battery in each mobile node. Therefore, designing a suitable energy efficient multicast routing protocol to conserve power as much as possible while still achieving good system performance is a challenge. This paper proposed an energy efficient clustering technique (EECT) for multicast routing protocol, which each node uses weight cost function based on the transmission power level, residual power and node speed to form cluster in the neighboring area and the node with the minimum weight value is selected as the clusterhead. The EECT can alleviate the energy consumption because the communication between clusterhead and member is adjustable with appropriate power level. The tree-based MAODV and the mesh-based ODMRP ad hoc multicast routing protocols are adapted to the EECT being executed on the each clusterhead. Simulation results demonstrate the adaptation of MAODV and ODMRP using EECT have better system performance than MAODV and ODMRP in terms of total energy consumption, mean end-to-end delay, mean hop count, packet delivery ratio and percentage of alive nodes for different multicast group size and mobility.

Key words:

Mobile ad hoc networks, Energy efficient, Cluster technique, MAODV, ODMRP.

1. Introduction

A Mobile ad hoc network (MANET) is a collection of wireless communication nodes that dynamically self-configures to form a network without any fixed infrastructure or centralized administration. The network topology may dynamically change frequently in an unpredictable manner since nodes are free to move [1]. Each node participates in this network as a router as well as an end host. Without the inherent infrastructure, the connection between any two nodes is a multi-hop path supported by other nodes and must be willing to forward packets for other nodes.

Multicasting is the transmission of datagram to a group of hosts identified by a single destination address and hence is intended for group-oriented computing [2]. Multicasting can efficiently support a variety of applications that are characterized by close collaborative efforts and data transmission. Using the multicasting

techniques can be considered as an efficient way to deliver the data packet from the source node to any number of client nodes. In MANET, the mobile nodes usually communicate with each other in groups, so multicasting plays a very important role. The work [3] mentioned the power control problem. How can battery life time and the network life time be maximized? The existing multicast routing protocols concentrate traffic on a single node such as source-based and core-based approaches. The main goal of these protocols is to maintain a robust multicast structure but do not take the problem of energy consumption into consideration. These protocols assume that the node transmission is fixed and no power control is used. In MANET, because the most of nodes are battery operated, it becomes a very important issue to find energy efficient algorithms that reduce the use of the battery power and increase the lifetime of wireless networks. This paper concentrates on the problem of power control for multicast over the MANET.

2. Problems Formulation

The primary goal of the conventional multicast routing protocols in MANET is to reduce the propagation delay since most multicast applications tend to be delay sensitive. Recently, attention has been given to design multicast routing protocols that are energy efficient because of the limited battery power supply of mobile nodes. Energy consumption of a mobile node in MANET can be either "useful" or "wasteful". Useful energy consumption can be (1) transmitting/receiving data, (2) processing requests, (3) forwarding data/request to neighboring nodes. Wasteful energy consumption can be (1) idle listening to the media, (2) retransmitting due to packet collisions, (3) overhearing, (4) generating/handling control packets. Our objective is to reduce and balance the useful energy consumption for multicast algorithms with power control among all participating mobile nodes, and to maximize the lifetime of the networks.

2.1 Related Works

In order to alleviate useful energy consumption, several energy efficient multicast routing protocols have been proposed, which can be categorized into tree-based [7], mesh-based [8], hybrid-based [9] and cluster-based [10-13].

Clustering is a well known technique for grouping nodes that are close to one another in a network and it has the unique potential to reduce useful energy consumption. The concept of clustering is to divide the geographical region to be covered into small zones. The essential operation in mobile node for clustering is to select a set of clusterheads among the nodes in the network, and the clusterheads are responsible for coordination with their clusters (intra-cluster), and communication with other clusterheads (inter-cluster). Any node can become a clusterhead if it has the necessary functionality, such as processing and transmission power. Node registers with the nearest clusterhead and becomes a member of that cluster. Clusters may change dynamically, reflecting the mobility of the underlying network. In multicast and broadcast operations, it is natural to use clustering so that nearby nodes can be reached with a single transmission. Adopting the clustering approach can make fewer connections existing between different zones in the network and hence make access being controlled, and bandwidth being allocated so that the overall energy consumption and interferences can be reduced. The work [11] proposed a greedy method to form clusters for multicast routing protocol and the nodes in a cluster take turns to be clusterhead by round robin schedule or energy threshold. A problem might happen that transmission will be broken due to the lack of battery power of the selected clusterhead with little residual power.

Using weight-based techniques to form clusters were proposed in recent literatures. The weight function [12] is combined with the neighbor nodes, border nodes and node degrees. The work [13] considered four parameters for each mobile node in the clusterhead election procedure, which are degree-difference, sum of the distance with all neighbors, average moving speed, and clusterhead serving time. The sum of the distance of all neighbors is not a suitable factor to select clusterheads because the distance between two nodes will change frequently, especially when nodes are in high speed. The clusterhead serving time cannot guarantee a good assessment of energy consumption because the number of packets of each clusterhead delivered is different and unpredictable.

In this paper, the clustering technique using weight-based for multicast routing protocol is proposed, which nodes use weight cost function based on the transmission

power level, residual power and node speed to form clusters and choose a clusterhead in each cluster.

The rest of paper is organized as follows. In Section II, an energy efficient clustering technique (EECT) for multicasting routing protocol is proposed. The Section III presents the simulation results of effect of different combinations of weight values and the performance of the adaptation of MAODV and ODMRP using EECT compared with original MAODV and ODMRP, respectively. Finally, the conclusion and future works of this paper is presented in Section IV.

3. Problem Solution

This section introduces the weight cost function, the proposed energy efficient clustering technique (EECT) and the cluster maintenance.

3.1 The Weight Cost Function

- Power level: The different transmission power levels, n , and the pre-defined threshold of the number of neighbors to be covered, σ , are assumed in this paper. A node is suitable to be a clusterhead when it can use lower transmission power level to cover the number of neighbors σ .
- Residual power: The clusterheads consume more power than ordinary nodes since clusterheads have extra responsibilities to carry the packets to its members and the other clusterheads. A node with more residual power is suitable to be clusterhead.
- Speed: A stable cluster is needed since the end-to-end delay and the packet delivery ratio of multicast traffic are tightly coupled with the frequency of cluster reorganization. If a clusterhead is in high speed, the topology of cluster will change frequently. Therefore, a node with lower speed is better to be a clusterhead.

3.2 Energy Efficient Clustering Technique

Table 1: The notations in the EECT algorithm

P_u	Transmission power level of node u .
n	Transmission power level.
P_{min}	Specified minimum power level.
P_{max}	Specified maximum power level.
$D_u(n)$	Number of neighbors of node u when power level is n .
σ	Pre-defined threshold of the number of neighbors.
R_u	Residual battery power of node u .
F_u	Full charge battery power of node u .
S_u	Speed of node u .
W_u	Combined weight of node u .

The system notations are defined in Table 1. The energy efficient clustering technique (EECT) consists of four main phases and is described as following, as shown in Fig. 1.

● Beacon Phase

Each node sends a beacon with the highest transmission power level and receives ACKs from other nodes. Each node can determine the number of its neighbors and the corresponding distance via signal strength.

● Counting Weight Phase

(A) Each node u increases its transmission power level, n , one level at a time and computes its corresponding number of neighbors $D_u(n)$, where n is from P_{\min} to P_{\max} ($P_{\min} = 1$ and $P_{\max} = 3$ are assumed in this paper). Each node will select its power level factor $P_u = n$ such that the $D_u(n)$ is greater than or equal to the pre-defined threshold σ (note that if several transmission power levels meet this requirement, and then the smallest n is chosen).

(B) Each node u computes residual battery power factor R_u .

(C) Each node u monitors its speed. If a node u locates at (x_{t_1}, y_{t_1}) at time t_1 , and then moves to (x_{t_2}, y_{t_2}) at time t_2 . The speed factor S_u is calculated as:

$$S_u = \frac{1}{t_2 - t_1} \sqrt{(x_{t_2} - x_{t_1})^2 + (y_{t_2} - y_{t_1})^2}$$

(D) Each node u computes the combined weight $W_u = w_1 P_u + w_2 (F_u - R_u) + w_3 S_u$, where w_1 , w_2 and w_3 are the weight values for the corresponding weight factors and $w_1 + w_2 + w_3 = 1$. Different weight values of w_1 , w_2 and w_3 will result in different system performance. How to choose a suitable weight values will be discussed in the Section 3.

● Cluster Building Phase

Node u sends a clusterhead election message including its own W_u to its neighbors using the transmission power level P_u . All nodes listen to the messages from its neighbors and choose the node with smallest W_u as the clusterhead. These messages are assumed to be received correctly in finite time. Once a node has chosen a clusterhead and joined a cluster, it is not allowed to participate in the clusterhead election procedure.

● Cluster Forming Phase

All the elected clusterheads send a cluster forming message to its member(s). Note that some nodes will form a single cluster and uses maximum transmission power

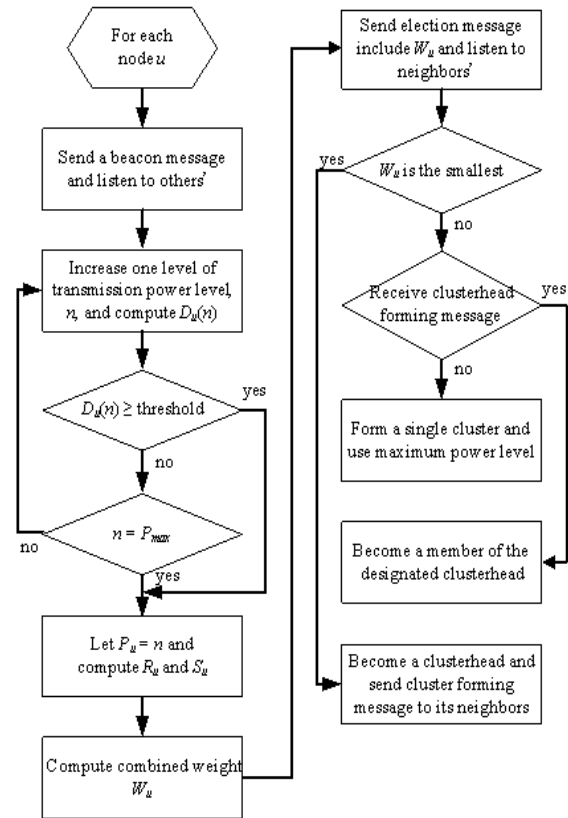


Fig. 1 The flowchart of the EECT.

level to reach other clusterheads if they did not receive any cluster forming message at the end of this phase.

3.3 Clustering Maintenance

The flowchart of cluster maintenance is shown in Fig. 2. The clusterhead periodically broadcasts a member message and the member replies a message back to its clusterhead in order to maintain the membership of a cluster. Three possible conditions are considered and described in the following.

- If a member does not receive the message from its original clusterhead but from other clusterheads, it will join a new cluster with the shortest distance to the new clusterhead. The new clusterhead will update its member entry and the original clusterhead will delete it.
- If a member goes into a region not covered by any clusterhead, it will execute the EECT algorithm and a new cluster will be formed.
- If a clusterhead has not received any message from its member, it will use the maximum transmission power level to reach other clusterheads.

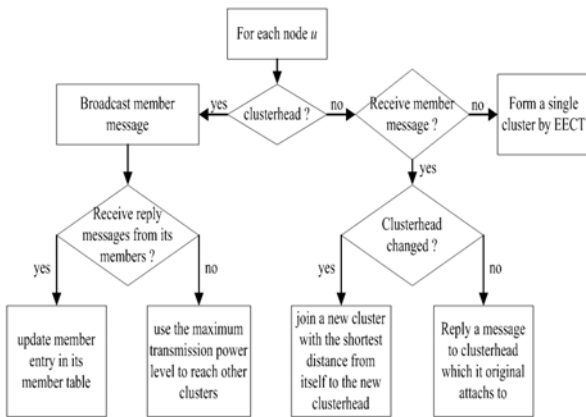


Fig. 2 Flowchart of cluster maintenance.

3.4 Adaptation of MAODV and ODMRP

In this section, the adaptation of MAODV [4] and ODMRP [5] using EECT will be shown. Three major steps are in the adaptation scheme: (1) form clusters using EECT; (2) execute MAODV or ODMRP on each clusterhead; (3) forward multicast packets to multicast receivers through their respective clusterheads. The clusters are communicated via the clusterheads. Each clusterhead that received the multicast packets will check if there are any multicast receivers in its cluster. The clusterhead will transmit the packet to the members if they are multicast receivers. When a member of a cluster wants to join multicast group, it will send a message to its clusterhead and the clusterhead has to find the route for the member. The advantage of EECT is that any modification of MAODV and ODMRP is not needed.

3.5 Performance Evaluation

In this section, the performance of the proposed energy efficient clustering technique (EECT) is evaluated via simulation. The performance of the adaptation of MAODV (ODMRP) using EECT is compared with the original MAODV (ODMRP). The adaptation of MAODV using EECT is represented by the term EECT-MAODV and so does EECT-ODMRP.

3.6 Simulation Environment

The simulation environment, multicast traffic pattern and energy model are depicted in detail.

- The simulated environment consists 50 wireless mobile nodes which are randomly distributed in a square area of 1000m × 1000m.
- The MAC protocol is IEEE 802.11 and its data rate is 11 Mbps.

- The radio transmission range is 200 meters. When a node executes EECT, three power levels can be chosen and its corresponding transmission range is 100m, 150m and 200m.
- Two kinds of speed, low and high, are adopted. The low speed is varied from 0 to 2 m/s. and high speed is varied from 0 to 20 m/s.
- Mobile nodes are assumed to move randomly according to the random waypoint model [5] and the pause time is between 0 and 10 seconds.
- Each simulation executes for 100 seconds.

3.6.1 Multicast Traffic Patten

- One multicast group with a single source is simulated. Multicast source sends packets every 200 milliseconds and the size of each packet size is 512 bytes.
- The multicast receivers are randomly selected. Nodes join the multicast group at the start of the simulation and remain as members throughout the simulation.
- The numbers of multicast receivers are varied from 5 to 40 nodes to see the effect of the group size on the system performance.

3.6.2 Energy Model

- Each node has the same initial energy.
- The radio model is based on [14]. The free space (d^2 power loss) channel models are used, depending on the distance between the transmitter and receiver.
- To transmit an m -bit packet and distance is d , the radio expends: $E_{TX}(m, d) = mE_{elec} + m\epsilon_{free-space}d^2$. To receive this packet, the radio expends $E_{RX}(m) = mE_{elec}$. The energy parameters are: $E_{elec} = 50 \text{ nJ / bit}$, $\epsilon_{free-space} = 10 \text{ pJ / bit / m}^2$.

3.6.3 Performance Metrics

The performance metrics used in EECT evaluation are defined as below.

- **Total energy consumption:** This is the sum of the power consumed at each transmitting and receiving node in the network.
- **Mean end-to-end delay:** This measure shows that how long is the duration time for a packet being generated by multicast source to it being received by the individual receiver, which includes route discovery latency, retransmission delays, etc.
- **Mean hop count:** It is defined as the mean number of hops for a packet successfully transmitted from the source to individual receiver.

- **Packet delivery ratio:** The ratio of the number of packet delivered to the multicast receivers to the number of packets supposed to be delivered to multicast receivers.

Table 2: The combinations of weight values

w_1 (power level)	w_2 (residual power)	w_3 (speed)
1/3	1/3	1/3
0.6	0.2	0.2
0.2	0.6	0.2
0.2	0.2	0.6

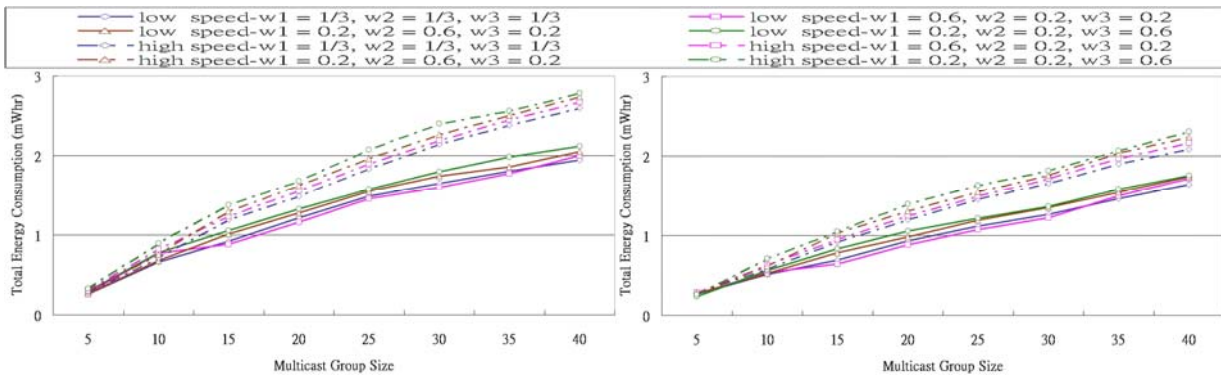
3.6.4 Effect of Combinations of Weight Values

The effect of different combinations of weight values with different number of nodes in low speed and high

threshold of the number of neighbors (σ) is fixed and equal to 5 for the entire simulation.

The total energy consumption is higher in high speed for both EECT-ODMRP and EECT-MAODV in all cases because the more control packets need to be rerouted. Moreover, the packet delivery ratio is degraded since the link between two nodes breaks frequently in high speed.

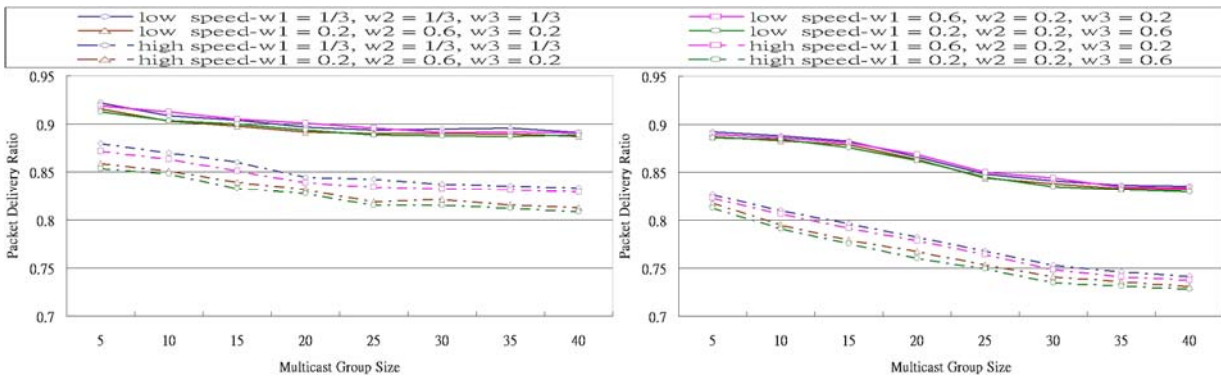
The system performance when w_1 , w_2 and w_3 are equal to 1/3 outperform than other combinations in most cases, especially in high speed. The results infer that the weight factors of transmission power level, residual power and node speed are equally important in the EECT algorithm. In general, the higher w_1 and w_2 , the less energy consumption and the higher packet delivery ratio. When the w_3 is the largest, the performance is worse for



(a) Total energy consumption of EECT-ODMRP.

(b) Total energy consumption of EECT-MAODV.

Figure 3. Total energy consumption of adaptation of ODMRP and MAODV using EECT.



(a) Packet delivery ratio of EECT-ODMRP.

(b) Packet delivery ratio of EECT-MAODV.

Figure 4. Packet delivery ratio of adaptation of ODMRP and MAODV using EECT.

speed are shown in Fig. 3 to 4, respectively. The objective is to see the impact of different weight values on the system performance in terms of total energy consumption and packet delivery ratio in this section. The four combinations of weight values are shown in Table 2. The

both EECT-ODMRP and EECT-MAODV. The reason is the topology will change more frequently since the members with higher speed will move out the cluster easily.

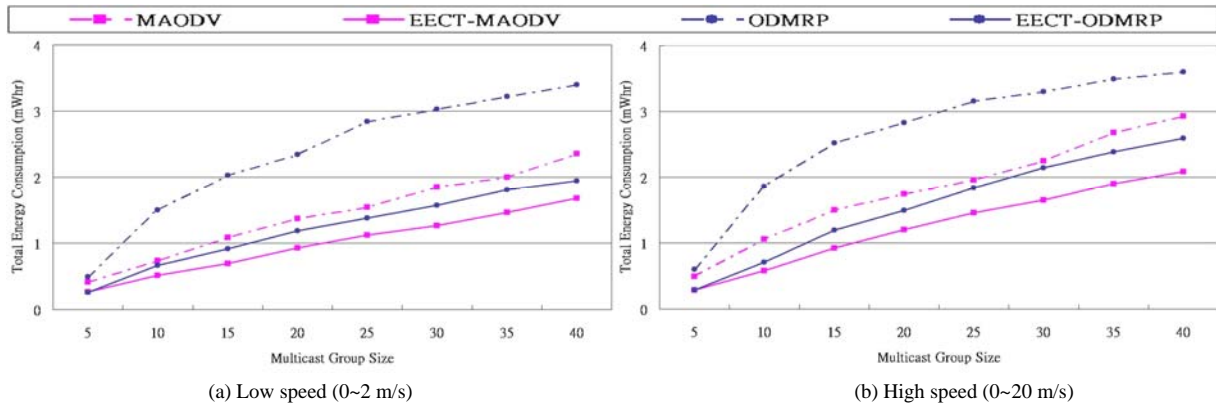


Figure 5. Total Energy Consumption in different speeds.

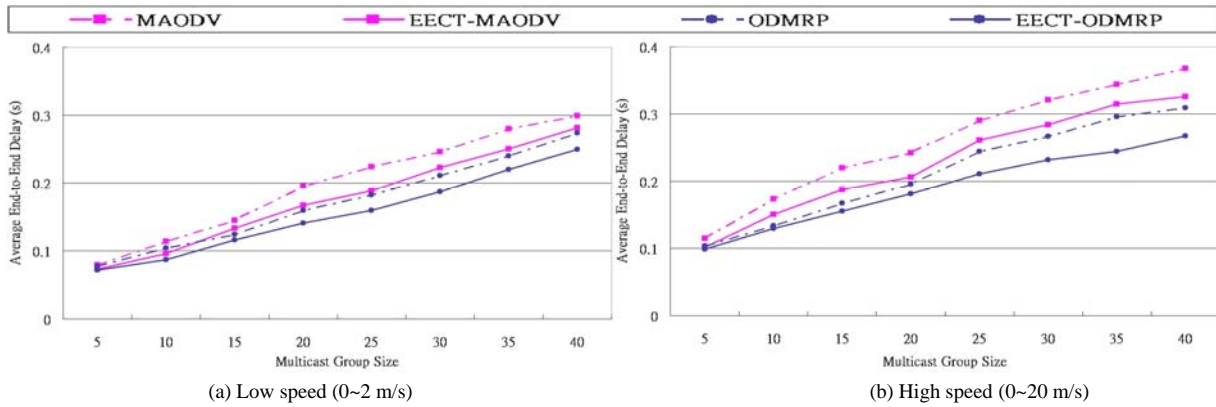


Figure 6. Mean End-to-End Delay in different speeds.

3.6.5 Simulation Results and Discussion

This section compares the system performance of EECT-MAODV (EECT-ODMRP) with the original MAODV (ODMRP) in terms of total energy consumption, energy consumption per delivery packet, mean end-to-end delay, mean hop count, packet delivery ratio and percentage of alive nodes. Other than the environment parameters are the same in the Section 3.1 and the w_1 , w_2 and w_3 are set equal to 1/3, threshold of the number of neighbors (σ) is 5 are assumed in the following simulation.

3.6.6 Total Energy Consumption

Figure 5(a) and 5(b) show the energy consumption for the tree-based and the mesh-based protocol in the low speed and the high speed, respectively. All the protocols consume more energy in high speed than in low speed. Furthermore, the proposed EECT-MAODV and EECT-ODMRP consume less energy than MAODV and ODMRP in different speeds. The two possible reasons are: first, MAODV and ODMRP broadcast the route requests to find the path when a node wants to join the multicast group. But in EECT-MAODV and EECT-ODMRP, these requests only need to be transmitted between clusterheads; second, the different transmission power levels can be used for the clusterheads to reach its members. Thus, energy consumption is eliminated.

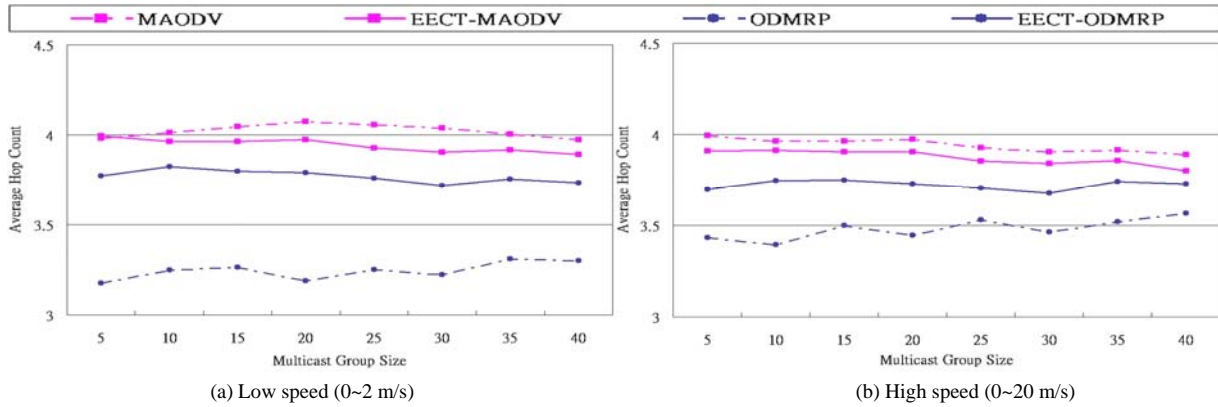


Figure 7. Mean Hop Count in different speeds.

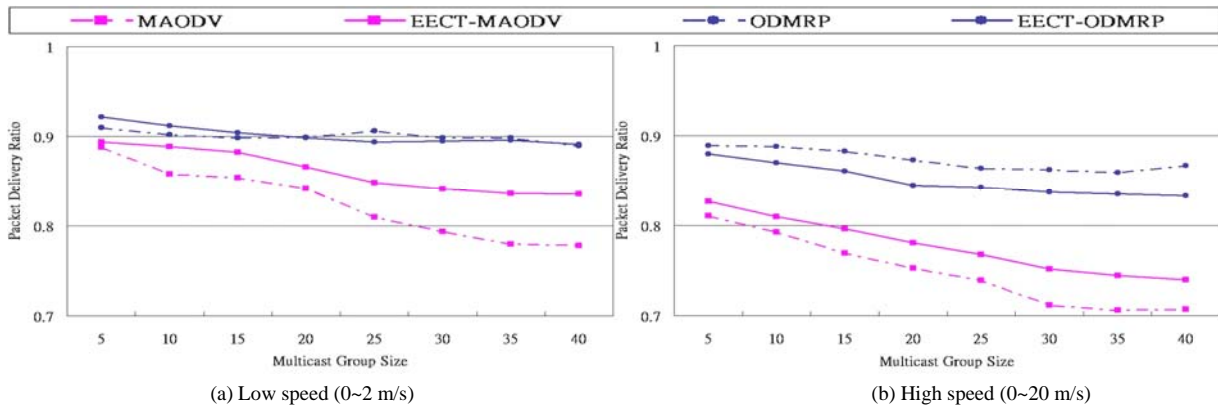


Figure 8. Packet Delivery Ratio in different speeds.

3.6.7 Mean End-to-End Delay

The mean end-to-end delay in low speed and high speed are shown in Fig. 6(a) and Fig. 6(b), respectively. Both EECT-MAODV and EECT-ODMRP outperform the MAODV and ODMRP in different speeds. The reason is MAODV and ODMRP broadcast the route requests and result in more collisions of the share channel, but EECT-MAODV and EECT-ODMRP handle these requests on clusterheads. The latency is reduced because of less contention nodes.

3.6.8 Mean Hop Count

The mean hop count in low speed and high speed are shown in Fig. 7(a) and Fig. 7(b), respectively. The mean hop count of EECT-MAODV is smaller than MAODV in both low speed and high speed. The deviation of the mean hop count between low speed and high speed is small for both EECT-MAODV and EECT-ODMRP. The mean hop count of ODMRP is the smallest among four protocols because it uses the shortest path to transmit packets.

EECT-ODMRP is slightly higher than ODMRP since if a multicast receiver is the member of a cluster, the packet is transmitted through the clusterhead and one more hop is needed. Although ODMRP has advantage of the mean hop count, it consumes more energy than other three protocols.

3.6.9 Packet Delivery Ratio

The packet delivery ratio in low speed and high speed are shown in Fig. 8(a) and Fig. 8(b), respectively. When multicast group size is large, EECT-MAODV is better than MAODV about 5% in low speed and 8% in high speed, respectively. This is because the broken probability of the links between clusterheads is degraded since EECT forms a stable network topology. EECT-ODMRP can hold good enough packet delivery ratio compared to the ODMRP in low speed. Due to the property of ODMRP, a packet can be transmitted via multiple paths, so the packet delivery ratio is higher than EECT-ODMRP in high speed.

4. Conclusion and Future Works

In this paper, an energy efficient clustering technique (EECT) for multicast routing protocol in MANET is proposed. According to the EECT, nodes use weight cost function based on the transmission power level, residual power and node speed to form clusters and choose a clusterhead in each cluster. The advantage of EECT is that the existing multicast protocol can be adapted to EECT without changing protocols. The impact of different combinations of weight values is demonstrated by simulation. When the weight values are set equal, the system performance is better than other combinations, which infer that the weight factors are equally important in the EECT algorithm. Furthermore, the simulation results show that both EECT-MAODV and EECT-ODMRP outperform the MAODV and ODMRP in terms of total energy consumption, mean end-to-end delay, packet delivery ratio and percentage of alive nodes for different multicast group size and node mobility. Multi-transmission-rate for the communication between clusterhead and clusterhead or clusterhead and member is a practical issue and will be discussed in the future work.

References

- [1] IETF Mobile Ad Hoc Networks (MANET) Working Group Charter, <http://www.ietf.org/html.charters/manet-charter.html>.
- [2] H. Gossain, C.M. Cordeiro and D.P. Agrawal, "Multicast: wired to wireless", *IEEE Communications Magazine*, Vol. 40, Issue 6, June 2002, pp. 116-123.
- [3] C.M. Cordeiro, H. Gossain and D.P. Agrawal, "Multicast over wireless mobile ad hoc networks: present and future directions", *IEEE Network*, Vol. 17, Issue 1, Jan.-Feb. 2003, pp. 52-59.
- [4] E.M. Royer and C.E. Perkins, "Multicast operation of the ad hoc on-demand distance vector routing protocol", *International Conference on Mobile Computing and Networking*, Aug. 1999, pp. 207-218.
- [5] S.J. Lee, M. Gerla and C.C. Chiang, "On demand multicast routing protocol", *IEEE Conference on Wireless Communications and Networking*, Vol. 3, Sept. 1999, pp. 1298-1302.
- [6] J.J. Garcia-Luna-Aceves and E.L. Madruga, "The core-assisted mesh protocol", *IEEE Journal on Selected Areas in Communications*, Vol. 17, Issue 8, Aug. 1999, pp. 1380-1394.
- [7] J.E. Wieselthier, G.D. Nguyen and A. Ephremides, "On the construction of energy-efficient broadcast and multicast tree in wireless networks", *Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies*, Vol. 2, March 2000, pp. 585-594.
- [8] H. Jiang, S. Cheng, Y. He and B. Sun, "Multicasting along energy-efficient mesh in mobile ad hoc networks", *IEEE Conference on Wireless Communications and Networking*, Vol. 2, March 2002, pp. 807-811.
- [9] J. Li, and D. Cordes, "Hybrid greedy/multicasting power-aware routing protocol in ad hoc networks", *International Conference on Information Technology: Coding and Computing*, April 2004, pp. 725-730.
- [10] J.H. Ryu, S. Song and D.H. Cho, "Energy-conserving clustering scheme for multicasting in two-tier mobile ad hoc networks", *IEEE Electronics Letters*, Vol. 37, Issue 20, Sept. 2001, pp. 1253-1255.
- [11] C. Tang, C.S. Raghavendra and V. Prasanna, "Energy efficient adaptation of multicast protocols in power controlled wireless ad hoc networks", *International Symposium on Parallel Architectures, Algorithms and Networks*, May 2002, pp. 80-85.
- [12] C.C. Huang, R.S. Chang and M.H. Guo, "Weight-based clustering multicast routing protocol for mobile ad hoc networks", *IEEE Conference on Wireless Communications and Networking*, Vol. 2, March 2003, pp. 1112-1117.
- [13] M. Chatterjee, S.K. Sas and D. Turgut, "An on-demand weighted clustering algorithm (WCA) for ad hoc networks", *IEEE Conference on Global Telecommunications*, Vol. 3, Nov.-Dec. 2000, pp. 1697-1701.
- [14] W.B. Heinzelman, A.P. Chandrakasan and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks", *IEEE Transactions on Wireless Communications*, Vol. 1, Issue 4, Oct. 2002, pp. 660-670.



I-Shyan Hwang received the B.S. in Electrical Engineering and M.S. in Electronic Engineering from Chung-Yuan Christian University, Chung-Li, Taiwan, in 1982 and 1984, respectively, M.S. and Ph.D. Degrees in Electrical & Computer Engineering from the State University of New York at

Buffalo, N.Y. in 1991 and 1994, respectively. From 1984 to 1986, he served in the Chinese Navy as an instructor. From 1986 to 1987, he was an instructor in the Van-Nung Institute of Technology and Commerce, Chung-Li, Taiwan. From 1994 to 1995, 1995 to 1997 and 1997 to 2006, he was an associate professor in the Sze-Hai Institute of Technology, Van-Nung Institute of Technology and Commerce and Yuan-Ze University, respectively. Since Feb. 2007, he has been promoted as a full professor in the Department of Computer Engineering & Science at the Yuan-Ze University, Chung-Li, Taiwan. He has served many session chair and committee member, such as *PDPTA'2001*, *1st (2nd, 3rd and 4th) Photonic, Networking and Computing*, *2002 (2003, 2005 and 2006)*, *2004 and 2006 International Computer Symposium, STFOC'05 - International Conference on Photonics*, *1st (2nd and 3rd) Workshop on Wireless Ad Hoc and Sensor Networks*, *2005 (2006 and 2007)*, *2006 International Conference on High-speed and Broadband Network*, *The 2006 IAENG International Workshop on Computer Science (IWCS'06)*, *IEEE Globecom 2007 Ad Hoc and Sensor Networking Symposium*. His current research interests are High-speed Fiber Communication, Heterogeneous Multimedia Wireless networks, Fault-Tolerant Computing, VLSI Testing Design, and Loading Balancing. He is a member of *IEEE Computer*, *IEEE Communication*, *SPIE* and *ACM*.