Energy-Balanced Broadcasting Scheme for Mobile Ad Hoc Networks

Yeim-Kuan Chang, I-Wei Ting and Min-Yuan Tsai
National Cheng Kung University, Tainan, Taiwan
{ykchang, p7893113}@mail.ncku.edu.tw

Abstract

The simplest broadcasting scheme is "Flooding" for data transmission in mobile ad hoc networks (MANETs). However, it results in substantial redundancy, contention and collision of transmitted messages. Connected Dominating Sets (CDS) scheme is proposed to calculate the CDS nodes and form a virtual backbone for broadcasting data. In this paper, we propose a novel source independent broadcasting scheme called Extended CDS (ECDS), which calculates multiple CDS according to the mobility, degree and remaining energy of mobile hosts (MHs). Our goal is to solve the problem of imbalance of the power consumption by broadcasting data in single CDS. We also explain how to update and rotate among multiple CDS for data transmission. As a result, the messages can be broadcast in different CDS. Therefore, the power consumption is to be more balanced among the MHs and the life time of each MH is prolonged. The simulation results show the average life time is increased compared with the traditional CDS scheme.

Keywords: Broadcasting, Connected dominating sets, Energy-balanced, Mobile ad hoc networks, Power consumption.

1. Introduction

Mobile ad hoc network (MANET) is a special type of wireless network formed by a cluster of MHs with wireless network interfaces. Due to the constraint of transmission range of transceivers, two MHs may communicate with each other either directly, if they are close enough, or indirectly, by involving other intermediate MHs relay their messages. A working group called MANET [11] has been formed by the Internet Engineering Task Force (IETF) to stimulate research in this direction [12]. Issues related to MANET have been studied intensively [6][7][12][13].

Broadcasting of communication technology is expected to be more frequently used to a particular MH, to find an MH, or alarm all MHs in MANETs. "Flooding" mechanism can achieve the high broadcasting coverage because all MHs receives the broadcasting messages will re-broadcast to their neighbors once in order to avoid that certain MHs do not receive the messages. However, it will result in substantial redundancy, contention and collision of transmitted data when the node density is high, which is referred as the "Broadcast Storm Problem" [13]. Connected Dominating Set-based broadcasting [21] is proposed to broadcast message based on the concept of connected dominating set (CDS) in graph theory [19]. That a set is a dominating (forwarding) set if every node not in the set is adjacent to at least one node in the set. The main idea is to limit the broadcast process to a sub-graph induced from the dominating set. Also, the dominating set should be connected for the ease of the broadcast process. Thus it calls such approach CDS broadcasting. Note that, vertices in a CDS are called CDS hosts while vertices that are outside a CDS are called non-CDS hosts. The main advantage of CDS broadcasting is that it simplifies the decision of retransmission. Only CDS hosts need to relay the broadcast packet. Non-CDS hosts are prevented from retransmitting, this mechanism reduces power consumption, redundant retransmission and the network contention caused by the "Flooding" broadcasting.

The most related works for CDS broadcasting is usually to find the minimum size of CDS hosts. Little attention has been given to the effect of the mobility or energy consumption. Although they can find the near minimization of CDS size, the movement and energy consumption of selected forwarding nodes may easily lead to the disconnection, i.e. partition the entire network into two or more sub-networks. MHs in the CDS also consume more energy to handle various bypass traffics than other MHs that outside the CDS. Therefore, the MHs in the CDS consume more energy easily.

In this paper, we propose an improved source independent CDS for selection of dominating sets, called Extended Connected Dominating Set (ECDS), which calculated multiple CDS to extend the life time of each MH and the network by balancing the power consumption in the network system. Also, we design algorithms to deal with the way to rotate the role of each CDS to be responsible for the backbone of the network. Note that saving overall power consumptions do not necessarily prolong life time of a particular individual host. ECDS balances the energy consumptions by multiple CDS, to retransmit the broadcast packet. In additionally, in order to maximize the life time of all MHs, ECDS dynamically selects CDS to be the backbone of the network. Specifically, in the selection process of a CDS-host, we give preference to an MH with a higher energy level, an MH with few neighbors and an MH with low mobility. The effectiveness of the proposed scheme in prolonging the life time of the network is confirmed through simulation.

The rest paper is organized as follows: The related work for varied broadcasting schemes are reviewed in section 2. Our proposed ECDS is presented in section 3. Simulation results are shown in section 4. The conclusion is presented in section 5.

2. Related work

Broadcasting has been used widely in wired and wireless networks to disseminate data and topology information in MANETs. Many routing protocols such as Optimized Link State Routing Protocol (OLSR) [3], Dynamic Source Routing (DSR) [1] and Ad Hoc On-Demand Distance Vector Routing Protocol (AODV) [14] rely on the flooding mechanism to broadcast data and control packets throughout the whole network in order to establish route paths between each source-destination pair. Broadcasting evolves several issues than the one in wired networks for two reasons: mobility and limited system resources. Since the movement of MHs in MANETs has no regular type, there is no optimal solution to deal with the mobility. There are many methods to broadcast packets, such as flooding, spanning tree and others. Williams et al. [20] classified the broadcasting techniques into four types: Flooding Scheme, Probability-based Scheme, Area-based Scheme, and Neighbor knowledge-based Scheme.

2.1 Flooding

Most of the ad hoc routing protocols use a generally inefficient form of broadcast called *simple flooding*. In simple flooding, when an MH receives a broadcasting message for the first time, it transmits the message to all nodes within its transmission range. In a dense network, this scheme wastes the link bandwidth and node resources and cause a serious "*broadcast storm problem"* [13].

2.2 Probabilistic-based Scheme

The probability-based scheme [4][8][23] is similar to simple *flooding* except that nodes only rebroadcast with a predetermined probability. In a dense network, multiple MHs share similar transmission coverage. Thus, it randomly selects some MHs and force not rebroadcast for saving resources. In a sparse network, there is a much less shared coverage. Thus, MHs will not receive all the broadcast messages with the probability-based scheme unless the probability parameter is high. When the probability is set to 100%, this scheme is identical to simple "*flooding"* scheme.

2.3 Area-based scheme

The area-based scheme [8][13][18][23][26] assumes that MHs have a common transmission distance. An MH will rebroadcast the request message only if the rebroadcast will reach sufficient additional coverage area. An MH using area-based scheme can evaluate the additional coverage area based on all received redundant transmissions. The area-based scheme only considers the coverage area of a transmission; it does not consider whether MHs exist within that broadcasting area.

2.4 Neighbor-knowledge scheme

The neighbor-knowledge scheme maintains the state (forwarding or non-forwarding) on its neighborhood, via periodic "Hello" messages sent by each MH. All MHs in the network can obtain their *k*-hop neighbor information which is used in the decision of rebroadcast. Basically, these schemes find the smallest set of 1-hop or 2-hop neighbors set which is a set of forwarding nodes. Every MH in the network is either in the set or the neighbor of an MH in the set.

In self-pruning methods [9][15][17][21][22][25], each MH makes its local decision on forwarding status: *forwarding* or *non-forwarding*. We take the simplest one, *flooding* with self-pruning [9], for example. This protocol requires that each MH has knowledge of its 1-hop neighbors via "*Hello"* message and attaches its 1-hop neighbor list in the header of broadcast message. An MH receiving a broadcast message compares its own neighbor list with the list of broadcast packet. If all of the neighbors are covered by the list in broadcast packet, this MH will stop re-broadcasting. Otherwise, the MH rebroadcasts the message.

In neighbor-designated methods [2][10][16][24], the forwarding status of each MH is determined by its neighbors. Basically, the source MH selects a subset of nodes from its 1-hop neighbors as forwarding nodes to cover all its 2-hop neighbors. This forwarding node list is piggybacked in the broadcast message. Each forwarding node in turn designates its own forwarding node list. Most neighbor-designating methods use similar heuristics.

2.5 Connected Dominating Sets

The conception of using a Connected-Dominating-Set-based (CDS) broadcasting scheme [21] to broadcast information is that we find some MHs in the network as the forwarding hosts to cover all the MHs in the network. The hosts that been chosen as the member of the CDS (called CDS hosts) will responsible for delivering the packets and the other non-member hosts (called non-CDS hosts) do not need to rebroadcast the packets. If an MH wants to broadcasting a packet to the destination host, it will broadcast the packet to all its neighbor hosts and then all its neighbor hosts will check itself whether it is the CDS host or not. If it belongs to the CDS (i.e., it is a CDS-host), it will rebroadcast the packet. Otherwise, it will not rebroadcast the packet. Thus a source host send out the packet may need several propagations to reach the destination host.

3. Proposed ECDS scheme

3.1 Constructing Multiple CDS

The single CDS has a drawback of imbalance power consumption because only CDS hosts will broadcast the messages. It easily causes that network is partitioned into some independent sub-networks in the short time when the CDS hosts have exhausted their limited battery energy. Thus, if the network has more than one CDS to broadcast data, the energy can be consumed in more balance among the MHs. As a result, the network can keep the high connectivity in a long time. In our proposed ECDS scheme, we first explain how to construct multiple CDS and also ensure the network coverage by using the selected CDS hosts. Second, we describe how to update and rotate among constructed CDS periodically.

We first use the election rule in [21] to achieve the broadcasting coverage.

Rule 1: A non-CDS host becomes a CDS host if it finds that any two of its one-hop neighbors can not reach each other directly.

The one-hop neighbor information is gathered from local broadcasting messages (i.e., *"Hello"* messages). For example, if there are two MHs y and z, they can not communicate directly with each other, where y and z are neighbors of MH x. The MH x should become a CDS host to ensure the connectivity between the MHs y and z. Although rule 1 does not lead the minimum number of CDS hosts required to merely maintain connectedness, it roughly ensures that every populated radio range in the entire network contains at least one CDS host. Packets are broadcasted through CDS hosts, the resulting dominator topology should yield good broadcasting coverage. Since the rule 1 may results in large number of redundant CDS hosts. Thus, we propose an eliminate rule to remove the redundant host in the CDS and to consider the mobility, degree and remaining energy.

Rule 2: A CDS host x becomes a non-CDS host if it has either a neighbor with high priority which dominates all neighbors of x, or more than one neighbors with high priorities which together dominate all neighbors of x.

Eliminate rule *(Rule 2)* removes all locally redundant CDS hosts from CDS by *Rule 1*. If there exist MH y, where y is the neighbor of MH x and MH x is a CDS host, that $(N(x) \subseteq N(y)) \wedge (x.\text{priority} \leq y.\text{priority})$, MH x is to become a non-CDS host. Or if there exist some MHs y and z, where y and z are neighbors of MH x and MH x is a CDS host, that $(N(x) \subseteq N(y) \cup N(z)) \wedge (x.\text{priority} \leq y.\text{priority} \wedge x.\text{priority} \leq z.\text{priority})$, MH x is to become a non-CDS host. The priority value of each MH is the output of utility function defined in the Equation as follows.

$$x.\text{priority} = \frac{(x.remaining\_power)^{W_P}}{(x.degree)^{W_D} \cdot \left(x.speed\right)^{W_S}} \quad \forall x \in V(G).$$

where the x.remaining_power is the amount of remaining power of each MH; the x.degree is the number of one-hop neighbors, i.e., $|N(x)|$; the x.speed is the $N(x,y)$.speed $(\forall y \in N(x))$; and the W_P, W_D, and W_S are all constant. The three parameters, W_P, W_D, and W_S, are weight values, we can adjust them according to different types of network. For example, if we want to make the power consumption more balance, we may let the parameter W_P larger than the other two parameters.

We explain how an MH gets the external information contains distance, speed and degree of its neighbors by the receiving *"Hello"* message. Then, the description of each parameter in utility function is also presented.

Distance: When the MH x receives a "*Hello"* message from its neighbor y, the distance between MH x and its neighbor y will be calculated by the received signal strength. In MANET, the received signal strength has an inverse proportion with the distance between any two MHs. We assume no any obstacles between two MHs. Thus, if the received signal strength is weak, the distance between these two hosts is long. On the other hand, the distance between these two hosts is short if the received signal strength is strong. Each MH will update the information of the distance between itself and its neighbors upon receive the "*Hello"* messages sending from its neighbors. Thus, the host x updates the distance between itself and host y into *N(x, y).distance* by calling the function *distance(signal(x, y))* in our assumption. Then we can use the distance to calculate the relative speed between any host pairs.

Speed: From the distance described above, we can calculate the relative between the MH x and the host y. Since we have each MH record the time into *N(x, y).time* when the MH x receive the "*Hello"* messages, MH x can compare the distance calculated this time with the distance calculate last time to get the relative speed. Then we can determine the stability (i.e., keep the topology of the network connected) of each neighbor by this information because high speed may result in high probability of host leaving the transmission range. And the host x updates the relative speed between itself and host y into *N(x, y).speed*.

Note that, we determine the speed of MH x by averaging the *N(x, y).speed* $(\forall y \in N(x))$ in our proposed ECDS. The main reason to support this solution is that we want to get a more accurate speed of each MH for individual. Since the MHs in our assumption do not equip with a *GPS* device or any device that can measure the speed, the MHs only have the localized information of the relative speed between themselves and their neighbors. Then the best way to measure the speed, *x.speed*, is averaging the *N(x, y).speed* $(\forall y \in N(x))$. By this manner, each MH can determine its stability among its neighbors impersonally.

Degree: Degree is the number of one-hop neighbors of the MH. It can obtain from the "*Hello"* messages sent by its one-hop neighbors easily.

Priority: In ECDS scheme, we use the value of priority to eliminate the redundant host that has been selected as the dominator. Each MH can calculate its own priority value by the priority equation, and then exchange its own priority value by attaching it to the *"Hello"* messages. Thus, for the neighbor host y of MH x, it attaches the *y.priority* into the "*Hello"* messages and sends out it. And the MH x updates its neighbor y's priority into *N(x, y).priority*.

We want to prolong the life time of each MH by balancing the power consumption among the MHs in the entire network. Intuitively, it is best to broadcast packets through hosts that have sufficient remaining power (rather than through a host whose battery is on its last legs). Similarly, broadcasting packets through lightly-loaded hosts is also energy-conserving because the energy expended in contention is minimized. So we take the remaining power of each MH in the priority function. To broadcast packets through hosts that have sufficient remaining power, we make the priority of each MH has a direct proportion with its remaining power. Then the MH with high priority means it has more battery power than others.

The MHs in the CDS consume more energy to handle various bypass traffics than other MHs that outside the CDS. Thus if each MH can reduce the amounts of handling various bypass traffics, the remaining power curve may decrease placidly. For this reason, we also take the number of neighbors into account. Since the more the number of neighbors the more the power consumed to handle various bypass traffics, we wish to elect the MH with less neighbors to be a CDS host. That is to say, we want the priority has inverse proportion with the number of neighbors (i.e., degree). Thus, we make the factor of degree stay in the denominator.

In a MANET, hosts can randomly move around in the network topology. The characteristic of mobility makes MANET an unstable network; it means the links between MHs may break frequently, and then there may exists some CDS-hosts disconnect with other CDS hosts or non-CDS hosts. In order to solve the problem described above, we have to take the property of mobility into account. We already define how each MH calculates its own speed early, and we use this value to handle the problem caused by the mobility. We can observe that when an MH has high speed in the network, it has a high probability to move out its neighbors' transmission range and results in disconnection between itself and its neighbors. By this observation, we have the ideas that an MH with low speed may be stable in the network. Thus, we may let the MH with low speed as the CDS host to make the network stable.

According to the two rules: (1) Election Rule and (2) Eliminate Rule, we can construct CDS simple and distributed. We first estimate whether each MH should become a CDS host or non-CDS host by considering the rule 1. This step may result in many MHs have been elected as the CDS hosts. In fact, we do not need all these roughly decided CDS hosts as the forwarding node set. Thus, we run another eliminate rule (i.e., rule 2). In the rule 2, we eliminate the redundant host by taking the priority into account. Since we want to obtain multiple ECDS and we can only get one CDS. We make each MH reset the priority value if it has been elected as a CDS host. After resetting the priority value, each MH recursive executes the rule 1 and rule 2. The reset operation can make the other MHs (i.e., V−{x}) have high priority to be selected as CDS hosts. Note that we can not promise to find *N* disjoint ECDSs because there might exist some MHs are in vertex cut in the network. We can find *N* almost disjoint connected dominating sets in the proposed ECDS scheme if the node density is high.

3.2 Update and Rotation

In MANETs, network topology changes frequently due to the mobility of MHs. It may cause that the broadcasting area of original constructed CDS hosts can not cover all non-CDS hosts. Therefore, MHs need to update and rotate among CDS periodically. We can classify the topological changes into three categories: (1) MHs' switch on, (2) MHs' switch off, and (3) MHs' movement. Since these three operations are all unpredicted, it is better to have a mechanism to update/recalculation the CDS to prevent disconnect among MHs caused by the topology changing. We get *N* CDS of the network by the proposed ECDS scheme. In order to prolong the live time of the network, we propose the scheduling method to make rotation among these *N* CDS to achieve the load balance and also handle the problems caused by the topology changing.

Each MH will be assigned an expiration time if it is a CDS host after finishing the procedure of the election rule and eliminate rule. We take MH *x* and MH *y* to explain. Without loss of generality, we assume that there only exists two CDS, the priority of MH *y* is less than that of MH *x* and MH *x* can be replaced by MH *y*. Thus, we may also assume MH *x* is CDS_1 host and non-CDS_2 host, and MH *y* is non-CDS_1 host and CDS_2 host. Upon each CDS been decided and assigned a valid time, T_{Period}, immediately. As illustrated in Figure 2, at time t_0 that CDS_1 and CDS_2 have been assigned a T_{Period} immediately, then the information of CDS_1 and CDS_2 are valid until Current_Time > t_1, where $t_1 = t_0 + T_{Period}$. Thus, we have two valid CDS during $t_0 \sim t_1$ in Figure 2. We want to balance the power consumption and design a mechanism called inter round-robin. We divide the T_{Period} into $\left\lceil \frac{T_{Period}}{\lambda} \right\rceil$ parts, where λ is the period each CDS works as virtual backbone or as a non-forwarding node set in each round. Thus, we can make *N* CDS to rotate the role as the virtual backbone during each T_{Period}. MH *x* has to serve as the forwarding node set during $(t_0 \sim t_0 + \lambda)$, $(t_0 + 2\lambda \sim t_0 + 3\lambda)$, and $(t_0 + 4\lambda \sim t_0 + 5\lambda)$. MH *y* has to serve as the forwarding node set during $(t_0 + \lambda \sim t_0 + 2\lambda)$, $(t_0 + 3\lambda \sim t_0 + 4\lambda)$, and $(t_0 + 5\lambda \sim t_1)$.

We make rotation among the selected *N* CDS to balance the loads and power consumption from the description above. Since the topology of the network is dynamical change in MANET, each MH has to update its status to prevent the disconnection between itself and its neighbors dynamically. Then we will introduce how to do the update / recalculation. It costs time to calculate our proposed ECDS algorithm, and we denote the time used to calculate the ECDS algorithm as $T_{Latency}$. In order to prevent the situation of that there exist no forwarding node set to forward the packets, which refers to asynchronism; each MH needs to calculate the ECDS algorithm in advance. As illustrated in Figure 2, at time t_1' that MH *x* and MH *y* have re-decide its status by

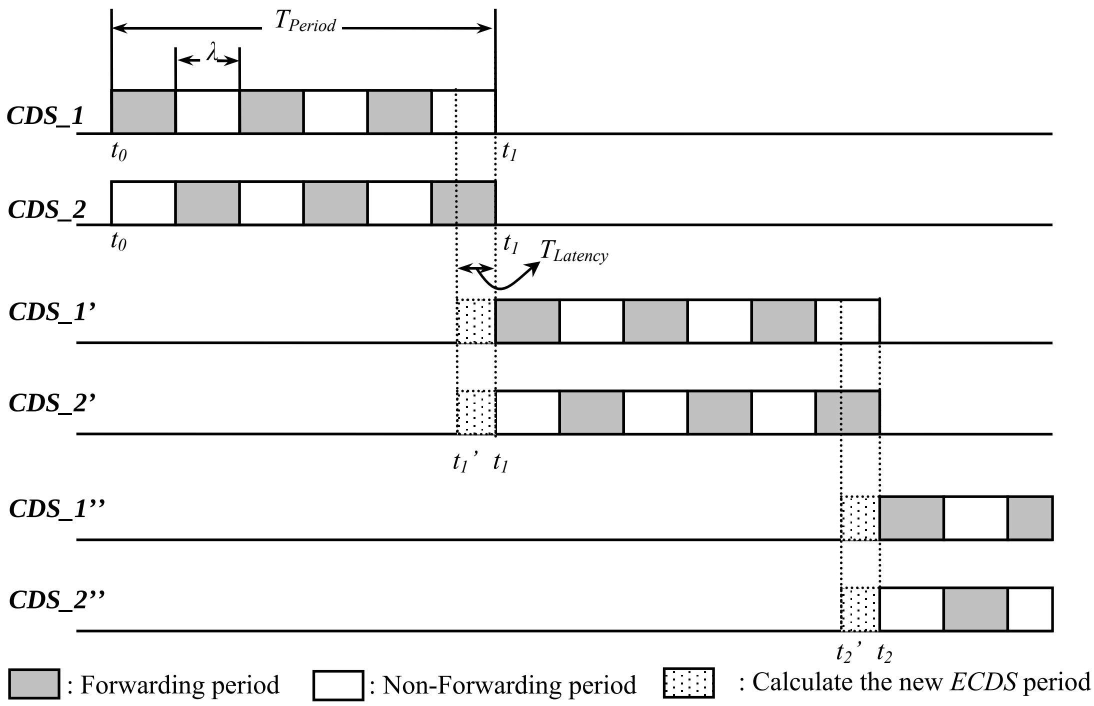


Figure 2: Global view of CDS round-robin.

calculating the *ECDS* algorithm to prevent the *asynchronism*, where $t_1' = t_0 + T_{Period} - T_{Latency}$. Then when *CDS_1* and *CDS_2* finish their duty at time t_1, the *CDS_1'* and *CDS_2'* are already ready for use. asynchronism, where $t_1' = t_0 + T_{Period} - T_{Latency}$. Then when CDS_1 and CDS_2 finish their duty at time t_1, the CDS_1' and CDS_2' are already ready for use.

4 Simulation Result

We use network simulator *ns-2* (version 2.30) [5] to analyze the performance of the proposed ECDS scheme. The simulation parameters are listed in Table 1. The network area is confined within 1000*1000 meter^2 and tested with 50 and 100 nodes. Each node in the network has a constant transmission range of 250 meter. We use *two-ray ground* reflection model as the radio propagation model. The *MAC* layer scheme follows the *IEEE 802.11 MAC* specification. We use the broadcast model without *RTS/CTS/ACK* mechanisms for all message transmissions, including Hello, Data, ACK messages in real wireless channels. All node InterFace Queues (IFQ) have a length of 50 packets. The movement pattern of each node follows the random way-point mobility model. Each node moves to a randomly selected destination with a constant speed between 0 to maximum speed. When it reaches the destination, it stays there for a random period and starts moving to a new destination. The pause time is always 10 seconds in our simulation. We will test the maximum speed with 6 m/s. The network traffic load also affects the performance of the protocol; we change the value of Constant-Packet-Rate (CPR) (packet per second) while each packet has a constant length of 512 bytes. In the energy model, we employ the AT&T's Wavelan/PCMCIA wireless network card that the transmission power consummation is set to 1.6W, the reception power consummation is set to 1.2W and the idle power consummation is set to 0.3W. Each node has initial energy with 600 joules. Each simulation will be run in 600 seconds.

The performance metric is *Alive Node Size Rate* (*ANSR*): $ANSR = \frac{a}{n}$, where a means the number of MHs still alive in the network, and n means the number of MHs in the network. This value can make the effect of difference schemes in the power consumption. In other words, we could measure the performance of power consumption by the metric. We compare our proposed schemes ECDS with the CDS-based broadcasting scheme [21].

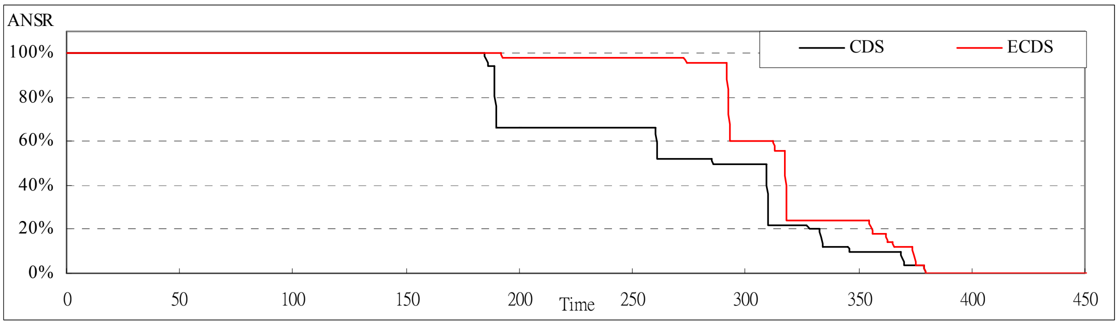
W define the effectiveness of a network; we say that a network is effective to achieve good communication among MHs if there still exists more than 60% of total MHs in the sparse network and more than 80% of total MHs in the dense network. If a sufficient number of MHs invalid (dead or leave) in the network, we could say that the network may loss the ability to make the entire MHs to communicate with each others.

Figure 3 shows the ANSR result in a low speed (6 m/s) environment. The *CDS*-based broadcasting scheme has a large number of MHs vanish about 185 seconds and *ECDS* has a large number of MHs vanish about 290 seconds and about 270 seconds. Thus, the proposed schemes ECDS could improve the live time to keep the effectiveness of the network almost 46% ~ 57%.

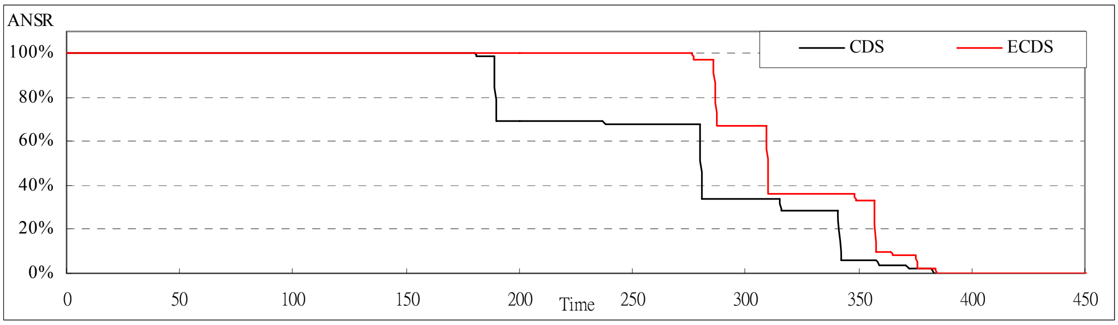
The main reason to support our simulation is that our proposed schemes could balance the power consumption among MHs. Therefore, when the *CDS*-based broadcasting scheme has a large number of MHs vanish in the network, *ECDS* could still have enough MHs to

Table 1: Simulation parameters

Simulator	*ns-2* (version 2.30)	**Network Area**	1000 * 1000 meter^2	**MAC Layer**	IEEE 802.11
Node Max IFQ Length	50 packets	**Transmission range**	250 meter	**Data packet size**	512 bytes
Bandwidth	2 Mb/s	**Simulation time (second)**	600	**Number of nodes**	50, 100
Max Speed (m/s)	6, 20	**Initial Energy (Joules)**	600	**Transmission Consume (W)**	1.6
Reception Consume (W)	1.2	**Idle Consume (W)**	0.05	**T_{Period} of ECDS (second)**	30
λ of ECDS (second)	5	**W_P, W_D, W_S**	3,1,2		



(a) 50 Nodes



(b) 100 Nodes

Figure 3: Alive Node Size Rate (ANSR) under two Environments with maximum speed = 6, $W_P = 3$, $W_D = 1$, and $W_S = 2$

take the responsibility of transferring packets to cover the entire network even though the MHs that are forwarding nodes left less power.

In most of the simulation results, we find that *ECDS* could improve the live time to keep the effectiveness of the network about 40% ~ 60%. It is thus evident that the *ECDS* has significant improvement in balancing the power consumption.

5. Conclusion

Power consumption is always an important issue in MANET since most MHs operate on battery. Broadcasting based on a connected dominating set (CDS) is promising schemes that only hosts belong to the CDS have to relay the broadcasting packets. It reduces the total amounts of power consumption upon communication between MHs. Extended Connected Dominating Set (ECDS) is proposed to extend the live time of the network by balancing the energy consumption, which calculate multiple CDSs and alternatively chose one of them to be the virtual backbone of the network. We also propose a mechanism to update and rotate among these selected CDSs. ECDS scheme constructs multiple CDS by using a utility function based on three factors: remaining power, degree, and speed. By using the utility function, we can select the forwarding node set precisely to improve the stability and power consumption.

Reference

[1] S. Alagar, S. Venkatesan, and J. Cleveland, “Reliable broadcast in mobile wireless networks,”

in Military Communications Conference, MILCOM Conference Record, volume 1, pp. 236-240, 1995.

[2] C. Adjih, P. Jacquet, and L. Viennot, "Computing connected dominated sets with multipoint relays," *INRIA, Technical Report 4597*, October 2002.

[3] T. Clausen and P. Jacquet, "Optimized Link State Routing Protocol (OLSR)," *RFC 3626*, October 2003, available: http://www.faqs.org/rfcs/rfc3626.html.

[4] Cartigny and D. Simplot, "Border Node Retransmission Based Probabilistic Broadcast Protocols in Ad-Hoc Networks." *in Proceedings of 36th International Hawaii International Conference on System Sciences (HICSS'03)*, Hawaii, USA. 2003.

[5] K. Fall and K. Varadhan, " *The NS2 manual*", *the VINT Project*, Apr. 2002, available at: *http://www.isi.edu/nsnam/ns/doc/* .

[6] D. B. Johnson and D. A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks", *Mobile Computer*, pp. 153-181, 1996.

[7] Young-Bae Ko and Nitin H. Vaidya, "Location-Aided Routing (LAR) in Mobile Ad Hoc Netwroks", *in Proceedings of the IEEE/ACM International Conference on Mobile Computing and Networking (MOBICOM)*, pp. 66-75, 1998.

[8] J. S. Kim, D. J. Scott, and A. Yasinsac, "Probabilistic broadcasting based on coverage area and neighbor confirmation in mobile ad hoc networks," *in Proceedings of IEEE Globecom*, Nov-Dec 2004.

[9] H. Lim and C. Kim, "Multicast tree construction and flooding in wireless ad hoc networks," *in Proceedings of 3rd ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, 2000.

[10] W. Lou and J. Wu, "Double-covered broadcast (DCB): A simple reliable broadcastalgorithm in manets," *in Proceedings of IEEE Infocom*, 2004.

[11] IETF MANET Working Group, http://www.ietf.org/html.charters/manet-charter.html.

[12] J. P. Macker and M. S. Corson, "Mobile ad hoc networking and the IETF", *Mobile Computing and Communications Reviews*, July 1998.

[13] S.-Y. Ni, Y.-C. Tseng, and J.-P. Sheu, "The Broadcast Storm Problem in a Mobile Ad Hoc Network," *in Proceedings of International Conference on Mobile Computing and Networking (MOBICOM)*, pp. 151-162, 1999.

[14] C. E. Perkins, and E. M. Royer, "Ad Hoc On-Demand Distance Vector Routing," *Proceeding WMCS'99*, pp. 90-100, February 1999.

[15] W. Peng and X. Lu, "On the reduction of broadcast redundancy in mobile ad hoc networks," *in Proceedings of the ACM Interational Symposium on Mobile Ad Hoc Networking and Computing (MOBIHOC)*, pp. 129-130, 2000.

[16] A. Qayyum, L. Viennot, and A. Laouiti, "Multipoint relaying for flooding broadcast messages in mobile wireless networks," *in Proceedings of the 35th Annual Hawaii International Conference on System Sciences (HICSS'02)*, Hawaii, 2002.

[17] M. Sheng, J. Li, and Y. Shi,. "Relative degree adaptive flooding broadcast algorithm for ad hoc networks." *IEEE Transactions on Broadcasting*, vol. 51, pp. 216-222, 2005.

[18] Y.-C. Tseng, S.-Y. Ni, and E.-Y. Shih, "Adaptive Approaches to Relieving Broadcast Storms in a Wireless Multihop Mobile Ad Hoc Network," *in Proceedings of IEEE 21st International Conference on Distributed Computing Systems*, pp. 481-488, 2001.

[19] Douglas B. West, "Introduction to Graph Theory," *Prentice Hall*, 1996.

[20] B. Williams and T. Camp, "Comparison of broadcasting techniques for mobile ad hoc networks," *in Proceedings of the ACM International Symposium on Mobile Ad Hoc Networking and Computing (MOBIHOC)*, pp. 194-205, 2002.

[21] Jie Wu and H.L. Li, "On calculating connected dominating set for efficient routing in ad hoc wireless network," *in Proceedings of the 3rd ACM International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications. (DialM)*, pp. 7-14, 1999.

[22] J. Wu and F. Dai, "Broadcasting in ad hoc networks based on self-pruning," *in Proceedings of IEEE Infocom*, pp.2240-2250, March 2003.

[23] Jie Wu, and Fei Dai, "A Generic Distributed Broadcast Scheme in Ad Hoc Wireless Networks," *IEEE Transactions on Computers,* vol.53, pp.1343-1354, October 2004.

[24] J. Wu and W. Lou, " Extended Multipoint Relays to Determine Connected Dominating Sets in MANETs," *Computers IEEE Transactions*, vol. 55, pp. 334-347, Mar 2006.

[25] H. Zhang and Z. P. Jiang, "Performance analysis of broadcasting schemes in mobile ad hoc networks," *IEEE Communications Letters*, vol.8, no.12, pp.718- 720, 2004.

[26] Chunhui Zhu, M. Lee, and T. Saadawi, "A Border-aware Broadcast Scheme for Wireless Ad Hoc Network," *IEEE Consumer Communications & Networking*, Las Vegas, January 2004.