Power-Efficient and Path-Stable Broadcasting Scheme for Wireless Ad Hoc Networks

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Abstract – The simplest broadcasting scheme in the mobile ad hoc networks (MANETs) uses *flooding* which may result in the *broadcast storm problem*. The MultiPoint Relays (MPR) is another broadcasting scheme for solving the broadcast storm problem. In MPR, the mobile hosts (MHs) use a greedy algorithm to find a connected dominating set (*CDS*) by the exchange of 2-hop neighbor information. In order to reduce the size of CDS, the greedy algorithm used by MPR usually selects the farthest nodes from the source called the border nodes as the forwarding nodes. Since the border nodes have a higher probability of moving out the transmission range, the routing paths in MPR from the source to some destinations may be unstable. In this paper, we propose a broadcasting scheme called Dynamic Power-aware and Stability-aware MultiPoint Relays (DPS-MPR) which avoids selecting the border nodes as the forwarding nodes. As a result, the transmission range of MHs can be reduced for saving energy and the negative impact of unstable forwarding nodes can also be reduced. In addition, we use a range buffer to further enhance the stability of the forwarding nodes. We evaluate the performance of the proposed DPS-MPR by using NS2 and compared it with the existing schemes. The experimental result shows that DPS-MPR saves 20%~25% of energy and increases the lifetime of forwarding nodes by several seconds.

Keywords: Ad hoc networks, Broadcasting, Multipoint Relays, Energy-efficient, Path-stable.

1. Introduction

In mobile ad hoc networks (MANETs), a person that carries a Mobile Host (MH) can move to a location arbitrarily or communicates with another MH for data transmission by multi-hop routing protocols. Routing protocols can be classified into main two classes: Table driven and On-demand. Under table driven routing, each MH exchanges the routing tables with its neighbors when the network topology is changed. Under on-demand routing, when a MH wants to communicate with another one, it creates routing path to the destination. Due to the concern of energy consumption and limited wireless bandwidth, on-demand routing protocol is preferred to be used in mobile ad hoc networks.

An on-demand routing protocol contains *route discovery phase* and *route maintenance phase* for data transmission. In the route discovery phase, the source broadcasts route of request message to the MHs in the covered area of the source. When an MH first receives the route of request, it re-broadcasts or replied the message if it is the destination. When a routing path is broken, the route of error message is generated and replied to the source. The source re-invokes the route discovery phase to find another routing path to the destination when it receives the route of error message. In such a broadcasting scheme (usually called *"flooding"*), all MHs will re-broadcast once they want to communicate with other MHs. This leads to the serious redundancy, contention, and collision of messages when the node density is high. The energy of MHs and the bandwidth of wireless network will be used up quickly. This condition called the *"broadcasting storm problem"* [1]. In the last decade, researchers have developed different broadcasting scheme [2-4], [6-19] to reduce the negative impacts of "*broadcasting storm problem*".

The MPR [3] is a popular broadcasting scheme for solving the broadcasting storm problem. A greedy algorithm is used to find a connected dominating set (CDS) by the exchange of 2-hop neighbor information. The CDS is selected from 1-hop neighbors and can cover entire 2-hop neighbors. In order to reduce the size of CDS, the greedy algorithm usually selects the farthest nodes from the source called the border nodes as the forwarding nodes. Since the border nodes have a higher probability of moving out the transmission range, the routing paths in MPR from the source to some destinations may be unstable.

Therefore, in this paper, we propose an improved MPR scheme called Dynamic Power-aware and Stability-aware MultiPoint Relays (DPS-MPR) which avoids selecting the border nodes as the forwarding nodes. As a result, the transmission range of MHs can

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be reduced for saving energy and the negative impact of unstable forwarding nodes can also be reduced. In addition, we use a range buffer to further enhance the stability of the forwarding nodes.

The rest of the paper is organized as follows: Section 2 reviews the ralated broadcasting schemes. Section 3 presents the proposed Dynamic Power-aware and Stability-aware MultiPoint Relays (DPS-MPR). The experimental results are shown in Section 4. Section 5 concludes the paper.

2. Related work

2.1 Broadcasting schemes

"*Broadcasting*" is an important data transmission scheme used in MANETs to disseminate public messages and topology information of the network. J. Wu [12] proposed a generic distributed broadcast scheme. The approach is based on selecting a small subset of nodes as the forwarding nodes to carry out the broadcast process. Williams et al. [2] classified the *"broadcasting"* schemes into four catalogs: *simple flooding*, *probability-based*, *area-based* and *neighbor knowledge* scheme. Due to the limitation of space, we briefly introduce MPR (Multipoint Relays) [3] and PAB (Power Adaptive Broadcasting) [4].

2.2 Multipoint Relays (MPR)

In MPR [3], each MH uses the localized 2-hop neighbor information to select the set of forwarding nodes, called MPR set. The MPR uses a greedy algorithm to select MPR set from the 1-hop neighbors. A MH which receives a broadcasting packet will not re-broadcast if it is not in the MPR set. Thus, the MPR scheme can reduce the number of re-broadcast significantly.

MPR sets form a connected dominating set (*CDS*) to cover the entire MHs in the networks. The routing path is consisted of the nodes which are in the *CDS* between the source and the destination. The proposed greedy algorithm uses maximum transmission range to exchange neighbor information and then selects a minimal set of 1-hop neighbors to cover the entire 2-hop neighbors. Therefore, the border nodes of 1-hop neighbors are usually selected to be included in the MPR set because the border node usually has higher probability to cover most 2-hop neighbors. This greedy algorithm is finished until the entire 2-hop neighbors are covered.

The greedy algorithm is operated as follows: Each MH-x maintains 2-hop neighbor information. $N(x)$ is the set of 1-hop neighbors and $N^2(x)$ is the set of its 2-hop neighbors of MH-x. The heuristic can be stated as:

1. Start with an empty multipoint relay set, $MPR(x)$,
2. First select those 1-hop neighbor nodes in $N(x)$ as multipoint relays which are the only neighbor of some node in $N^2(x)$, and add these one-hop neighbor nodes to the multipoint relay set $MPR(x)$
3. While there still exist some node in $N^2(x)$ which is not covered by $MPR(x)$:
   (a) For each node in $N(x)$ which is not in $MPR(x)$, compute the number of nodes that it covers among the uncovered nodes in the set $N^2(x)$.
   (b) Add that node of $N(x)$ in $MPR(x)$ for which this number is maximum.

When MH-x selects v as a forwarding node, MH-x put v in $MPR(x)$. Until $N^2(x)$ can all be covered by nodes in $MPR(x)$. Two papers [7],[19] proposed several extensions of source-independent MPR to generate a smaller CDS using complete the 2-hop neighbor information to cover each node's 2-hop neighbor set.

The MPR does not sufficiently take into consideration the effect of the routing maintenance needed for data communication. Routing maintenance is invoked when the routing path is broken due to the movement of MHs. The nodes which are selected by the greedy algorithm easily move out the transmission range because the forwarding nodes are usually border nodes. If a node moves out the transmission range of the routing path, the source must re-broadcast for finding a new routing path to the destination, which results in the *"broadcast storm problem"*.

2.3 PAB (Power Adaptive Broadcasting).

There are mainly two groups of approaches for developing energy efficient broadcasting: *fix/dynamic power control*. In the first one, the nodes use a fixed power level for transmissions, and in the second one nodes use the a power adaptive approach. Chen proposed a Power Adaptive Broadcasting (PAB) algorithm [4] which uses 2-hop neighbor information that can be obtained by exchange of "*Hello*" messages to adjust the transmission range. Each forwarding node adjusts the propagation power instead of maximum transmission power to save energy, but it does not have any policy to select the forwarding node and reduce the re-broadcasts.

3. DPS-MPR (Dynamic Power-aware and Stability-aware MultiPoint Relays)

3.1 Notations and network model

The definition of notations in DPS-MPR protocol is explained in Table 1. We model the MANETs environment as a graph $G = (V, E)$, where V represents the set of mobile hosts (MHs) in the network, and E is the set of links. An edge $e = (u, v) \in E$, where $u, v \in V$, exists if and only if u is in the transmission range of v and vice versa.

All links in G are bi-directional, i.e., if u is in the transmission range of v, v is also in the transmission range of u. Assume v_x is a mobile host in network of G. The network is assumed to be in a connected state. If it is partitioned, each component is treated as an independent network.

3.2 Assumption

The main idea of DPS-MPR algorithm is first to measure the *"distance"*, *"speed"*, and *"direction"* of neighbors and then selects the MPR set for creating

Table 1: Notations in DPS-MPR algorithms.

N(x)	The set of v_x's 1-hop neighbors.
N(x, v)	The neighbor information of a neighbor v_v, where $v_v \in N(x)$.
N(x, v).dist	The distance from v_x to v_v.
N(x, v).speed	The speed of v_v.
N(x, v).dir	Inward or outward. The movement direction of v_v to v_x.
N(x, v).nb-list	The neighbor list of v_v.
N(x, v).time	The time of recording this information.
$N^2(x)$	The set of v_x 's 2-hop neighbors. $N^2(x) = \bigcup_{i=1\sim n} N(x, v_i).nb\_list - N(x) - \{x\} = \{u_1, u_2, \ldots, u_n\}$.
Signal(x, v)	The value of signal strength that v_x received from neighbor *v*.
H(x)	The Hello message is sent by v_x.
H(x).nb_list	The 1-hop neighbor list of *x* is attached in ***H(x).***
Dist(signal-strength)	The function of switching received signal strength to distance from the sender.
P(signal-strength)	The function of calculating how much transmission power is needed to propagate to the neighbor with this signal strength.
$R_t(x)$	The transmission radius of v_x.
DPS-MPR(x)	The set of forwarding nodes are selected by v_x
B_packet	A broadcasting packet.
B_packet.DPS-MPR	The DPS-MPR set attached in *B*_packet.

routing path. Therefore, we have some assumptions as follows.

1. The MHs have hardware-support or software-support to measure the distance of neighbors from the received signal strength. The MHs also can control the transmission power for adjusting the transmission range.
2. The wireless interference is not considered. It means if the received signal strength from the neighbor is weak; the node is far away from the neighbor. The node speed is uniform for the wireless environment.

3.3 DPS-MPR

DPS-MPR scheme contains four algorithms: *Algorithm_Hello*, *Algorithm_Adjust*, *Algorithm_Select*, and *Algorithm_Expand*. The Algorithms are executed to select MPR set when a MH receives a broadcasting packet. In order to give a clear description of the proposed algorithms, we use the view of the forwarding node v_x to describe the operation of the algorithms.

3.3.1 Algorithm_Hello

Algorithm_Hello maintains the localized 2-hop neighbor information by exchange of *"Hello"* messages which are sent locally in each MH. These messages are sent periodically as a *"Keep-Alive-Signal"*. In this way, each MH knows who its 1-hop neighbors are. To obtain the information of 2-hop neighbors, each MH adds their own 1-hop neighbors in their *"Hello"* messages. Therefore, MHs can independently calculate their 1-hop and 2-hop neighbors with the received *"Hello"* messages. Generally, we obtain the *k*-hop neighbor information by piggybacking the *(k–1)*-hop neighbor information in

```
Algorithm_Hello ( H(v) ){
// Input: H(v), Hello message from neighbor v_v and get the
signal(x. v).
// Output: Updated N(x) and N^2(x) of v_x.
01  IF ( v_x receives "Hello" message from v_v first time. ) {
02    Increase v_v into 1-hop neighbor list;
03    N(x, v).dist = dist(signal(x, v));
04    N(x, v).speed = 0;          //initial speed
05    N(x, v).dir = inward;       //initial direction
06    N(x, v).nb_list = H(x).nb_list;
07    N(x, v).time = Current_Time;
08    N^2(x) = (N^2(x) ∪ H(x).nb_list) - N(x)-{x};
09  }
10  ELSE {  // Update the neighbor information
11    N(x, v).speed= (dist(signal(x, v)) - N(x, v).dist) / (Current_Time - N(x, v).time);
12        IF( ( dist(signal(x, v)) - N(x, v).dist ) > 0 )
13            N(x, v).dir = outward;
14        ELSE
              N(x, v).dir = inward;
15    N(x, v).dist = dist(signal(x, v));
16    N(x, v).nb_list = H(x).nb_list;
17    N(x, v).time = Current_Time;
18    N^2(x) = ( N^2(x) ∪ H(x).nb_list ) - N(x)-{x};
19  }}
```

Figure 1: The detail of Algorithm_Hello.

"Hello" message. Figure 1 assumes the MH v_x receives a *"Hello"* message from the neighbor MH v_v. *Lines 1-9* add the neighbor information of the MH v_v for the first time. *In lines 10-19*, the MH v_x updates the distance, speed, and direction of MH v_v based on the received "Hello" message.

Algorithm_Hello measures the information of distance, speed and direction of 1-hop neighbors by two successive received *"Hello"* message. The measurement result is obtained according to the signal strength of the received *"Hello"* messages. The process of measurement is as follows:

Distance *(lines 3 and 15):* The information of distance can be calculated with the received signal strength of *"Hello"* message. If the received signal strength is weak, the distance from the sending node is far. Otherwise, it is close to the sender. The value is recorded into *N(x, v).dist*. The measurement of distance function (*dist(signal(x, v))* refers to the two-way ground propagation model in NS2 [5].

Speed *(lines 4 and 11):* MHs also measure the speed of the 1-hop neighbor according to two successive received *"Hello"* message. The measured speed is equal to the distance divided by the time between the two received *"Hello"* messages. The detailed equation is shown in *line 11*. Note that the measured speed is not the actual speed of the MH but rather a relative speed between the observing node and the observed node.

Direction *(lines 5 and 12-13):* The direction information is also obtained by comparing the distance information of the two successive *"Hello"* messages. We measure the state of direction by subtracting "distance information in the last *Hello* message" from "distance information in the present *Hello* message". If

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```
Algorithm_Adjust ( N(x), N2(x) ) {
// Input. 1-hop neighbor list and 2-hop neighbor list.
// Output. Adjusted 1-hop and 2-hop neighbor list.
  Sort N(x) by N(x, v).dist from furthest;
  i=1;
  WHILE (i!=0){
    IF ( vi satisfies Cover(1) and Cover(2) ) {
        Mark vi as "invisible" and record in N^2(x);
        i ++;}
    ELSE {
        return N(x), N^2(x);
}}
```

Figure 2: The detail of Algorithm_Adjust

the result is negative, the state is *"inward"*. Otherwise, the state is *"outward"*. It records the state of direction into *N(x, v).dir*. Each MH knows the mobility of its 1-hop neighbors through *Algorithm_Hello*.

The 1-hop and 2-hop neighbor information are also recorded in the *N(x)* and $N^2(x)$ respectively. The information is provided to *Algorithm_Adjust* for adjusting the transmission range of MHs.

3.3.2 Algorithm_Adjust

Algorithm_Adjust modifies the original greedy algorithm in MPR [3]. The main idea of the *Algorithm_Adjust* is to reduce the probability of putting border nodes into the MPR set and also achieve full broadcasting coverage. Therefore, we define two "*Cover*" conditions to determine whether a border node can be marked as an *"invisible"* node or not. An *"invisible"* node is not put into the MPR set. The formal definitions of two "*Cover"* conditions are as follows:

Cover(1): Node v_i can be covered by other 1-hop neighbors of v_x. $\exists v_j \in N(x), v_i \in N(x, v_j).nb\_list.$

Cover(2): The 1-hop neighbors of v_i can be covered completely by other 1-hop neighbors of v_x. $\exists$ set $A=\{u_1, u_2, \ldots, u_n\} \subseteq N(x)$, $N(x, v_i).nb\_list \in \bigcup_{j=1\sim n} N(x,u_j).nb\_list$.

The algorithm heuristic checks the farthest border node if it satisfies the defined "*cover*" conditions or not. If yes, this node is marked as the 1-hop *"invisible"* node. This check is operated in turn from the farthest 1-hop neighbros until the check is false. Then, the *Algorithm_Select* selects the MPR set from the 1-hop neighbors except the 1-hop *"invisible"* neighbors by using original MPR greedy algorithm. In other words, the border nodes have the lower probability of being putting into the MPR set. Thus, a MH can reduce the transmission range and also achieve a full coverage.

The details of *Algorithm_Adjust* is shown in Figure 2. If the existing node *j* does not match *"Cover"* conditions, the actual transmission range is adjusted to cover the node *j*. In the worst-case, the maximum transmission range of the forwarding node is the distance to the farthest node in the 1-hop neighbors (as the same original greedy algorithm).

Figure 3 illustrates an example of the reduced transmission range in the view of node-*S*. The farthest

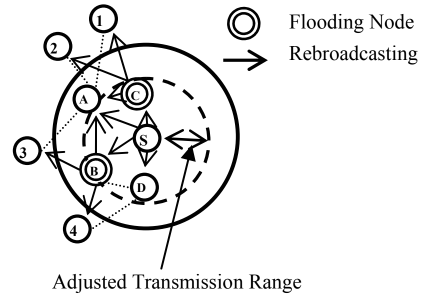

Figure 3: Illustrations of DPS-MPR broadcasting

```
Algorithm_Select ( N(x), N2(x), B_packet ) {
// Input. N(x) and N^2(x), modified by Algorithm_Adjust.
// output. DPS-MPR(x), selected forwarding node set.
 IF ( vx∈B_packet.DPS-MPR ) {
 FOR ( i=1; i≤ |N^2(x)| ; i++ ) {
      IF( ui is covered only once by 1-hop neighbor vi ) {
          DPS-MPR(x) += {vi};
          N^2(x) -= N(x, vi).nb_list;
      }
 }
 WHILE ( N2(x) != ϕ ) {
     FOR( i=1; i≤ |N(x)|; i++ )
         IF( | N(x, vi).nb_list ∩ N^2(x)| is the maximal
value) {
             DPS-MPR(x) += {vi};
             N^2(x) -= N(x, vi).nb_list;
         }
     }
 }
B_packet.DPS-MPR=DPS-MPR(x);
return B_packet.DPS-MPR;}
```

Figure 4: The detail of Algorithm_Select.

node-*A* and its neighbors can be both covered by node-*B* and node-*C*. Therefore, node-*A* is marked as an *"invisible"* node. Node-B does not match the *"Cover"* conditions. Finally, node-*S* reduces the transmission range to cover node-*B*.

3.3.3 Algorithm_Select

The algorithm selects the MPR set from 1-hop neighbors except the 1-hop *"invisible"* neighbors. The detail of *Algorithm_Select* is shown in Figure 4. The operation is the same as original MPR scheme. The detailed operation can be found in section 2.2.

3.3.4 Algorithm_Expand

Algorithm_Expand shown in Figure 5 determines whether a forwarding node needs to add a range buffer or not. It depends on the speed, direction of the farthest node in the MPR set. If the state of the direction of the node is *"inward"*, the range buffer will not be added because it will not move out the transmission range. Otherwise, the range buffer will be added (Note: the range buffer can not excess the actual maximum transmission range of MHs). In our algorithm, the size of range buffer is set to the product of speed of the node and the cycle of "*Hello*" time. Therefore, the range buffer ensures the forwarding node to be in the transmission range in a longer time period. In the best-case (forwarding node do not increase its speed), this guarantees that the forwarding node does not move out

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```
Algorithm_Expand ( ) {
// Output. Rt(x), the transmission radius for propagating.
IF ( N(x, v1).dir = inward )
    Rt(x) = N(x, v1).dist;
ELSE
    Rt(x) = N(x, v1).dist + ( N(x, v1).speed * Hello_cycle_time);
return Rt(x);}
```

Figure 5: The detail of Algorithm_Expand.

the transmission range in a cycle of "*Hello*" time. If the forwarding node moves out the transmission range, the source re-invokes the route discovery phase for creating another routing path.

4. Performance Evaluations

4.1 Simulation environment

We use NS-2 (2.27) [5] simulator to simulate DPS-MPR, simple Flooding, PAB [4], and MPR (original MPR) [3]. The network area is set to 1200*1200 m^2 with 20, 40, 60, 80, 100 and 120 nodes. Each node in the network has a constant transmission range of 250 m. 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 mode with no *RTS/CTS/ACK* mechanisms for all message transmissions, including "*Hello*", Data, and ACK messages in real wireless channels. The main different part of simulated model compared with previous ones is that we model the mobility of MHs. The movement pattern of each node follows the random way-point mobility model. Each node moves to a randomly selected position with a constant speed between zero to maximum speed. When it reaches the position, it stays there for a random period before starting to move to a new position. The pause time is always 10 seconds in our simulation. We experiment on the maximum speed with 0, 5, 15 and 20 meter/second. Each simulation is run in a period of 50 seconds.

The definitions of performance metrics are listed as follows:

Forwarding Rate (FR): $FR = t/r$, where t is the number of nodes that actually re-broadcast the packet, and r is the number of nodes receiving the broadcasting packet.

Expended Energy Ratio (EER) [16][18]: $EER = E_{broadcast\_scheme} / E_{Flooding}$, where $E_{broadcast\_scheme}$ is the sum of energy consumption in selected broadcasting scheme and $E_{Flooding}$ is the sum of energy consumption in Flooding.

Leaving time (L_{time}): L_{time} is used to describe the link quality between two forwarding nodes. L_{time} records the time of the link disconnected.

4.2 Experimental results

Forwarding Rate (Efficiency)

Figure 6 shows the performance of the forwarding rate under different maximum speeds of MHs. PAB is just like "*flooding*" that has no forwarding policy. So, PAB can not improve the forwarding rate. MPR reduces 39% of forwarding rate due to the selection of the connected dominating set (*CDS*). DPS-MPR can reduce the transmission range so the size of *CDS* is larger than MPR. This causes only the reduction of average 33% in the forwarding rate.

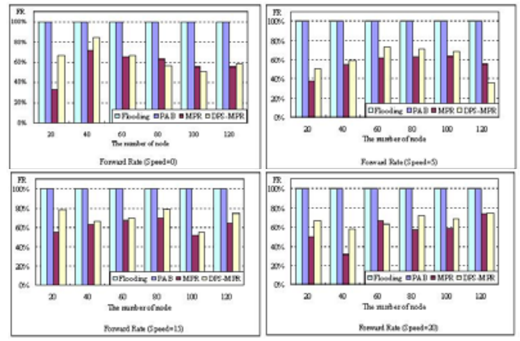

Figure 6: Forwarding Rate (FR) under four speeds.

Expended energy ratio (Power saving)

The channel model reflects the power law model [16]. In this model, the required transmission power in the media exponentially increases with the distance between the sender and the receiver. This is represented as $P_{rcv} = P_{tx}/r^n$, where P_{rcv} is the received power, P_{tx} is the transmission power, r is the distance between the nodes and n is the attenuation constant which is usually between 2 and 4. According to this formula, as the range that a node wants to cover increases, the required transmission power increases exponentially. We assume that the energy consumption of MHs is based on simple energy model, $p=r^{\alpha}$, where r is transmission range and α is a constant between 2 to 4. (We take α=4). In Flooding and MPR, the propagation range is always equal to maximum transmission range of the MH. But, MPR can save more power consumption than Flooding due to the selection of MPR set which reduces the number of re-broadcasts. PAB saves energy by dynamically adjusting transmission range but it has no selection of *CDS*. DPS-MPR saves energy by reducing transmission range and enhances the link quality by adding a range buffer. Both schems reduce the number of re-broadcasts and the number of the broken links. In Figure 7, DPS-MPR saves 20~25% of the power consumption compared with MPR and PAB in average.

L_{time} (Stability)

DPS-MPR considers the mobility of farthest node in the MPR set, and then adds range buffer according to the speed, and direction of the node. In this experiment, we set the cycle of "*Hello*" time to 4 seconds. In Figure 8, obviously, DPS-MPR has longer L_{time} (several seconds) than MPR. Thus, the link quality is improved. In other words, the life time of routing path in DPS-MPR is longer than MPR.

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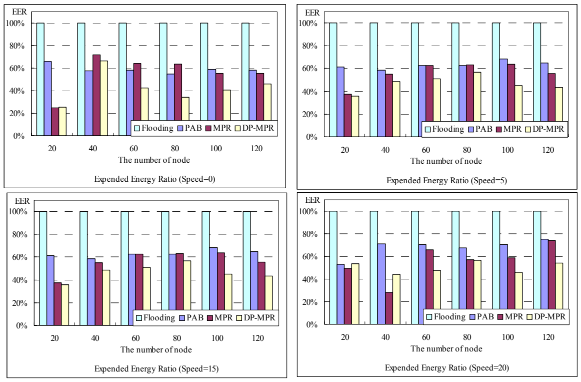

Figure 7: Expended Energy Rate (*EER*) under four speeds

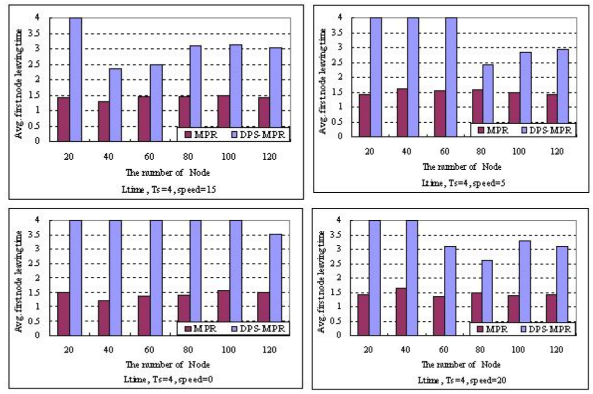

Figure 8: Ts=4, L_{time} under four speeds.

5. Conclusion

In MANETs, many existing broadcasting schemes are used to find the smaller *CDS* to reduce the number of re-broadcasts. In this paper, we enhance the link quality between the two forwarding nodes. DPS-MPR collects neighbors' information from "*Hello*" messages to make efficient forwarding decision. By two defined *"Cover"* conditions, each forwarding node can reduce its transmission range and also achieves the full coverage. The experimental results show that DPS-MPR saves 20~25% of power consumption and increases several seconds of the life time of the links.

References

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

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

[3] 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.

[4] X. Chen, M. Faloutsos, and S. Krishnamurthy. "Power adaptive broadcasting with local information in ad hoc networks". *IEEE ICNP*, November 2003.

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

[6] F. Ingelrest, D. Simplot-Ryl, I. Stojmenović. "Optimal Transmission Radius for Energy Efficient Broadcasting Protocols in Ad Hoc Networks." in *IEEE Transactions on Parallel and Distributed Systems,* to appear, 2006.

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

[8] W. Lou and J. Wu. "Double-covered broadcast (DCB): A simple reliable broadcast algorithm in manets." In *IEEE Infocom*, 2004.

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

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

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

[12] Jie Wu, Fei Dai, "A Generic Distributed Broadcast Scheme in Ad Hoc Wireless Networks," *IEEE Transactions on Computers,* v.53 n.10, p.1343-1354, October 2004.

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

[14] 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.

[15] J. Wu and F. Dai, "Broadcasting in ad hoc networks based on self-pruning,"*INFOCOM*, pp.2240-2250, March 2003.

[16] J. Cartigny, D. Simplot, and I. Stojmenovi´c. "Localized energy efficient broadcast for wireless networks with directional antennas." In *Proceedings of the Mediterranean Ad Hoc Networking Workshop (MedHocNet'02)*, Sardegna, 2002.

[17] F. Ingelrest, D. Simplot-Ryl, I. Stojmenović. "Optimal Transmission Radius for Energy Efficient Broadcasting Protocols in Ad Hoc Networks." in *IEEE Transactions on Parallel and Distributed Systems,* to appear, 2006.

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

[19] J. Wu, "An Enhanced Approach to Determine a Small Forward Node Set Based on Multipoint Relay," Proc. IEEE Semi-Ann. Vehicular Technology Conf. Fall (VTC 2003), Sept. 2003.

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