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Power-Aware Routing for Energy Conserving and Balance in Ad Hoc Networks *

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Abstract – *In this paper, we proposed an energy conserving routing protocol in mobile ad hoc network. The goal of our protocol is to reduce power consumption in transmission and hence to increase the lifetime of the whole network. To achieve energy conservation, the transmission power is controlled to the minimum level that packets can be correctly received. To find a proper route, we take into account both the transmission power and the remaining energy of the mobile hosts along the path. We also proposed a route caching strategy to increase the cache efficiency. Simulation results show that our protocol can conserve 10% to 20% more energy than dynamic source routing does. Also, our protocol also have not only longer network lifetime but also lower standard deviation on remaining energy among hosts.*

Keywords: Dynamic source routing, energy balance, network lifetime, power control.

1 Introduction

A *mobile ad hoc network* (MANET) is formed by a cluster of mobile hosts without any pre-designed infrastructure of the base stations. Many routing protocols have been proposed for MANETs [2, 4, 5]. Most of them concentrate on issues like the packet deliver ratio, routing overhead, or shortest path between source and destination. In fact, energy-constraints represent an equally important issue in MANET operations. Each mobile host that operates in a MANET has a limited lifetime due to its limited battery capacity. Failure of one mobile host may disturb the whole MANET. Thus, battery capacity should be considered to be a scarce resource and an effective energy-conserving technique must be found to extend the lifetime of a mobile host and, hence, the whole MANET.

Energy conservation for a mobile host can be done either in transmission mode or in idle mode. In this paper, we concentrate on issues of reducing power consumption in transmission mode. There are two ways to achieve this purpose: (i) using a proper route and power to transmit, and (ii) reducing routing overhead by increasing the cache efficiency. The former addresses how to find a power-efficient route and to decide the best transmission power to next hop. While the latter addresses how long a route can be maintained in the cache. A correct route in the cache will eliminate a lot of route discovery overhead thus can reduce the power consumption of a mobile host.

Several studies have addressed energy-constraints. In [7], instead of choosing a route with minimum required hops, the authors proposed five metrics to choose a route: minimize energy consumed per packet, maximize time to network partition, minimize the variance of each node's remaining energy, minimize cost per packet, and minimize the power consumption of the node that has the maximum cost in a route. However, the routing protocol proposed in [7] does not consider the mobility and considers only one metric when choosing a route. The protocol proposed in [1] considers two metrics: energy consumed and remaining energy of a host. The authors intend to maximize the lifetime of the whole MANET by evenly distributing the power consumption to each host and minimizing the overall transmission power for each connection. The transmission power in [1] is not fixed, each host uses different power to transmit according to the distance to the destination and the interference around it. Two different hosts that have the same remaining energy may have different remaining lifetime, so it is not suitable to choose a route by the remaining energy of the hosts. Michail et al. [10] proposed a method to find a route according to a cost function combined with transmission power and the remaining energy of a host. Each host computes its cost, according to the cost function, and then broadcast it. The minimum cost route will be chosen at destination. A similar strategy can be found in [9]. The work in [6] considers three metrics to find a route: the transmission power, the remaining energy, and the load of a host. The routing protocol collects above-mentioned information in route discovery phase and then calculates the cost according to the collected information to choose a route which has the minimum cost.

Besides the energy conserving protocols, the use of cache can also help to reduce the power consumption in route discovery process. Marina et al. [8] focus on cache strategy and proposed several algorithms to improve cache efficiency. However, they do not consider the transmission power and the remaining transmission time of a host.

In this paper, we propose a *power control source routing protocol* (PCSR) based on the dynamic source routing (DSR) [2]. The PCSR do not need the whole network topology during route discovery phase. When choosing a route, the PCSR considers both the transmission power

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Table 1: Relationship between received signal strength and used transmission power.

Received signal strength(P_r)	Used transmission power	Region
$P_{r1} < P_r \le P_{r2}$	$P_{t1} = P_{txmax}$	1
$P_{r2} < P_r \le P_{r3}$	$P_{t2} = P_{t1} - (P_{r2} - P_{r1}) + P_{sec}$	2
$P_{r3} < P_r \le P_{r4}$	$P_{t3} = P_{t1} - (P_{r3} - P_{r1}) + P_{sec}$	3
$P_{r4} < P_r \le P_{r5}$	$P_{t4} = P_{t1} - (P_{r4} - P_{r1}) + P_{sec}$	4
$P_{r5} < P_r$	$P_{t5} = P_{t1} - (P_{r5} - P_{r1}) + P_{sec}$	5

and the remaining transmission time (instead of remaining energy) of a host. A route request packet is sent to the destination to collect such information in order that the destination can decide which route is the best one. A route maintenance algorithm is proposed to prevent unnecessary energy consumption because of broken routes. The proposed protocol operates well in a mobile environment since transmission power can be adjusted according to the received signal strength of the mobile host during transmission. We also propose a cache strategy which predicts the lifetime of a route according to the variance of the received signal strengths. Simulation results show that the PCSR achieves the energy conservation without much performance degradation and has not only longer network lifetime but also lower standard deviation on remaining energy among hosts.

2 Preliminary

Instead of using maximum power to transmit all the time, the PCSR adjusts transmission power according to received signal strength. A host uses suitable power to transmit can not only conserve its energy but also reduce the interference to others. To decide a proper transmission power between two hosts, say host A and host B, host A will first use the maximum transmission power (P_{txmax}) to send a packet to host B. Host B receives this packet with received signal strength P_r and decides which region it belongs to according to P_r as shown in Table 1. The corresponding transmission power will be used by host A and host B for further communication. We define logical regions to represent the hosts that have similar received signal strength. For example, when the received signal strength of a particular receiver is between P_{r1} and P_{r2}, we say this receiver is in region 1 (with respect to the sender). The values of $P_{r1}, P_{r2}, ...,$ and P_{r5}, in increasing order, are the boundary signal strength for each region. The value P_{r1} is the minimum received signal strength that receiver can correctly receive a packet. A packet will be dropped if the received signal strength is below P_{r1}. Since the relationship between received signal strength and the distance to the corresponding host is not linear, and we hope that the range of each region is equally sized, the range of the values ($P_{r2} - P_{r1}, P_{r3} - P_{r2}, ..., P_{r5} - P_{r4}$) are not the same. The exact values of P_{txmax}, P_{t2}, P_{t3}, P_{t4}, and P_{t5} will be shown in Section 4. The value P_{sec} in Table 1 is used to insure that the receiver can correctly receive the packets. We can use a larger P_{sec} value for a severely interfered environment and a smaller one for a lower interference condition. By adjusting the transmission power according to the received signal strength, the PCSR solves the host mobility problem without the help of a positioning device, such as a GPS receiver.

Next, we introduce the cost function to find a route between the source and the destination. Let P_{ij} be the transmission power used by host H_i to send packets to host H_j, $B_i(0)$ be the initial energy of host H_i, and $B_i(t)$ be the remaining energy of host H_i at time t. The remaining energy ratio for the host H_i, Rb_i, is thus given by $B_i(t)/B_i(0)$. When choosing a route, we want to find the one which consumes the least energy and extends the network lifetime most. Thus, the cost function for the route from i to j is defined as follows.

$$cost = \frac{1}{Rb_i} \times P_{ij} \qquad (1)$$

The factor Rb_i can be viewed as the "intention" for host H_i to transmit. More cost has to be paid to ask a low-intention host to transmit.

The cost of a route from source to destination is the summation of the costs along the route. If we always choose a route with minimum cost, it is possible that we may select the route with minimum cost but several hosts in this route have little remaining transmission time. Then we may drain the remaining energy of these hosts soon so that we need to find another route during transmission. It is obvious that always choosing the route with minimum cost is not the best choice. Thus, we further consider to choose a route according to the hosts' minimum remaining transmission time. The remaining transmission time for host H_i with respect to the route from H_i to H_j is defined as $B_i(t)/P_{ij}$, where P_{ij} is the transmission power from H_i to H_j. If the remaining transmission time of this host is greater than a pre-defined threshold, T_{hold}, we choose the route with minimum cost. Otherwise, we pick the route with the maximum remaining transmission time. The use of the threshold T_{hold} is intended to select the route with higher reliability. We will explain our mechanism more detail in Section 3.

In the route discovery phase, the destination will wait for a period of time, W_{req}, to collect the cost information and determine the best route to use. The value of W_{req} is related to the number of hops of the routes that will be found in the route discovery phase. We do not consider the number of hops in our cost function. Instead, we adjust the value of W_{req} to confine the hop numbers. To reflect the future energy consumption, when the best route has been chosen, the energy of the hosts along the route will be subtracted in advance by the amount they will consume during the transmission.

2.1 Power adjusting region

The idea of power adjusting region is the same as that of preemptive region proposed in [3]. This region is used

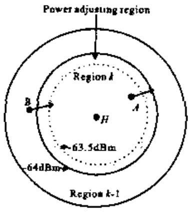


Figure 1: Power adjusting region.

as a buffer zone to make the sender to have sufficient time to adjust its transmission power before it moves out of the current region. If the received signal strength is getting smaller, which may result from the distance between the two hosts is getting longer or the interference between the two hosts is getting worse, we have to enlarge the transmission power to avoid the connection being broken. Otherwise, we can reduce the transmission power in order to save energy consumption. Let's take Fig. 1 as an example, when the received signal strength at host A from host H is getting smaller and host A reaches the power adjusting region of region k, we adjust the transmission power of host H from P_{tk} to P_{tk-1} in order to keep the connection quality. On the contrary, when the received signal strength at host B from host H is getting larger and host B reaches the power adjusting region of region k, we reduce the transmission power P_{tk-1} to P_{tk} in order to reduce the energy consumption.

The size of power adjusting region affects the performance of the routing protocol. When host A is moving away from host H as shown in Fig. 1, if the size of power adjusting region is too large, the performance in energy saving will be degraded since the host H have to change transmission power to P_{tk-1} soon; if the size of power adjusting region is too small, host H may fail to keep the connection because there is no enough time to change the transmission power to P_{tk-1}. We use -64.37 dBm, which is equal to 3.65×10^{-7}mW, as the minimum required received signal strength to assure correctly receiving. We set P_{r1} to -64dBm. In order not to degrade the performance of packet delivery ratio and end-to-end delay much when comparing to the DSR, we define the size of power adjusting region to be 0.5dBm.

3 The Power Control Source Routing Protocol

In this section, we will introduce route discovery, route maintenance, and cache strategy of the PCSR.

3.1 Route Discovery

We modified the route request and route reply packets of DSR protocol. Three fields are added in route request packet: the *total_cost* field contains the accumulated cost of the route started from the source, the Rb_i field represents the remaining energy ratio, and the *min_Rt* field contains minimum remaining transmission time along the route so far. Suppose a host A receives a route request packet and decides to rebroadcast it. The *total_cost* and Rb_i fields will be updated by host A before the rebroadcast. The *min_Rt* field is updated only if the minimum transmission time of host A is less than the *min_Rt* value in the received route request packet. With these modifications, the destination can obtain the minimum transmission time and the overall cost of this route. Such information is used as the criteria for the route selection. We add two fields in the route reply packet. The *Tx_power* field indicates the proper transmission power to next host. The *min_Rt* field is used in the cache mechanism, which we will describe in Section 3.3.

Each host also maintains a neighbor list table that records the host's neighbors and the associated transmission power to communicate with them. This proper transmission power will be carried by the *Tx_power* field in the route reply packet to next host toward the source. With the help of the *Tx_power* field of the route reply packet, each host can transmit with a suitable power without losing the connectivity.

When the destination receives a new route request packet, it must wait for W_{req} in order to collect more routes and then select the best one to use. As W_{req} is elapsed, if only one route is found, the destination will directly send a route reply packet back to the source with the information of the route attached. If several routes are found, the destination first checks the minimum remaining transmission time of each route. If all the values of minimum remaining transmission time are greater than T_{hold}, the destination will choose the route that has the minimum cost. If the values of minimum remaining transmission time of all routes are less than T_{hold}, the destination will choose the route that has the maximum remaining transmission time. If some routes (denoted as Route Group M) have minimum remaining transmission time larger than T_{hold} and others are not, the destination will choose the minimum cost route in Route Group M. The route information is transmitted by the destination to the source through a unicast route reply packet. All the hosts that receive the route reply packet will subtract the energy that will be consumed in the future, which is *(transmission power)* × *(estimated transmission time)* where the *estimated transmission time* equals *(packet length)/(transmission rate)*.

The PCSR, unlike the DSR, will not discard all the duplicate route request packets in order to find the minimum cost route. A route request packet will be discarded only if we are sure that it won't become the minimum cost route. To fulfill this purpose, we change the record stored in the route request table from (*source, ID, destination*) to (*source, ID, destination, cost, min_Rt, hop_count*). The first three fields are used to identify a request while the other three fields are used for cost comparison. *Cost* is the accumulated cost of the route started from the source to the current host. *Min_Rt* is the minimum remaining transmission time along the route from source to the current host. *Hop_count* is the number of hops from source to the current host. Here we use an example to explain how a host handles a duplicate route request packet. Assume the host H_i receives a route request packet (packet B) that is a duplicate of the earlier received one (packet A). The route request packet B will be discarded by host H_i if one of the three conditions is satisfied: (i) packet B's *cost* is greater than packet A's *cost* and packet B's *min_Rt* is no more than that of A's, (ii) packet B's *cost* is

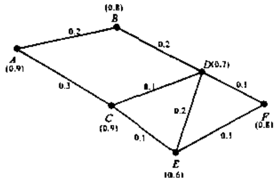


Figure 2: An example of rebroadcasting/discarding a route request packet in route discovery phase.

equal to packet A's *cost* and packet B's *min_Rt* is less than A's *min_Rt*, and (iii) both packet B's *cost* and *min_Rt* are equal to those of A's, but packet B's *hop_count* is greater than that of packet A's. All the above three situations indicates the route found by packet B is worse than the one that is discovered by packet A. Since both packet A and packet B go through host H_i, the route to the destination that is discovered by packet B must be worse than the one that is discovered by packet A. Thus, we can safely discard the packet B to reduce route searching overhead. A host will also discard a route request packet if the host finds itself in the route record of the route request packet (which means a loop is produced).

3.2 Route Maintenance

The purposes of route maintenance are twofold: to keep a route to the destination unbroken and to maintain a low-cost route. To keep the route unbroken, a host in communication will try to find an alternate route when it identifies that either its next hop host N is moving out of its transmission range or the host N is running out of its energy. For example, assume host H_i is sending packets to host H_k through host H_j. Suppose that the host H_j is moving out of H_i's transmission range. The H_j will inform H_i that the connection between them is going to break. After receiving the information, the host H_i must find an alternate route to replace the original one. The host H_i first searches its route cache to see if there exists a route that can reach the destination H_k. If a route is found in the cache, it will be used for later transmission between host H_i and H_k. Otherwise, the host H_i will try to find a new route to host H_k. Suppose the hop count between H_i and H_k in the original route is x, the host H_i will broadcast route request packet to discovery a route to H_k with TTL set to x. A new route is established if H_i receives a route reply packet from the host H_k. The host H_i must also inform the source host that the route to the destination is changed. If the host H_i does not receive any route reply packet, it will broadcast another route request packet to host H_k after a random period of back-off time with TTL set to $x+1$. The host H_i will try to broadcast the route request packet three times at most. That is, the TTL will be set to $x+2$ at most. If all the three route request packets are failed, the host H_i will send a route error packet back to the source. Once a host receives a route error packet, the route will be deleted in its cache. The source host has to discover a route to the destination when it receives the route error packet. The process is exactly the same as that in route discovery except that the erroneous route information is attached in the route request packet.

To maintain a low-cost route, the source host is always interested in finding a lower cost route to replace the original one. For example, in Fig. 2, if host A sends packets to host F through *route1* (go through hosts A, B, D, and F) and finds a new route *route2* (go through hosts A, C, D, and F). The host A will compare the *cost* and the *min_Rt* of *route1* with those of *route2* to decide if a replacement is needed. We denote X as the original route and Y the route that just being found. The route replacement will be launched if one of the following three conditions happened: (i) the *cost* of route Y is not larger than that of route X and the *min_Rt* of Y is larger than that of X, (ii) the *cost* of route Y is less than that of route X and route Y has the same *min_Rt* as route X does, and (iii) route Y has the same *cost* and *min_Rt* as route X does, but the hop count of route Y is smaller. All these three situations indicate that route Y is better than route X. The process of route replacement is similar to that of discarding duplicate route request packets as mentioned in Section 3.1. The difference is that here we want to find a better route to replace the original one, while in in Section 3.1, we want to discard the route request packets that won't produce better routes.

3.3 Cache Strategy

The cache in a host is used to store the routes that have been used by the host before. Such a mechanism is designed to reduce the time that is needed in the route discovery phase. Instead of only letting the destination host to send the route reply packet, any host that has a route to the destination in its cache can send a route reply packet back to the source host. The route discovery time is saved if the cached route is still up-to-date. If it is not, much more time has to be spent on finding a new route since the source host must first identifies the cached route is out-of-date (by a route error message) and then reinitiates a route request. Thus, the correctness and freshness of the information stored in the cache has great impact on the performance. It is important to have a well-designed cache strategy in a routing protocol. Previous works on caching strategy didn't consider these issues, and a route in the cache is deleted only when a route error is occurred. In this paper, we propose a cache strategy that can predict the lifetime of the route, and limit the time a route can stay in a host's cache according to the remaining lifetime and stability of the route.

The remaining lifetime of a route, *min_Rt*, is the limitation introduced by the remaining energy of the hosts along the route. A host can obtain this information in the route reply packet. The stability of a route, T_{stable}, is defined as the time that the route can be used by the particular host in a particular region. This value represents the route lifetime limitation introduced by the host mobility and transmission power. The duration that a route can be maintained in a host's cache, T_d, is obtained by

$$T_d = min(min\_Rt, T_{stable}) \tag{2}$$

We use an example to explain how to obtain the value of T_d. As shown in Fig. 3, the source host S initiates a connection to the destination host D through hosts A and B. We consider the T_d calculation in host A. The remaining lifetime from host A to host D, *min_Rt*, can be

Table 2: The value of used parameter.

Received signal strength(P_r)	Used transmission power	P_{sec}
$-64 < P_r \leq -62.06$	P_{t1} = 24.45 dBm	x
$-62.06 < P_r \leq -59.56$	P_{t2} = 22.71 dBm	0.2 dBm
$-59.56 < P_r \leq -56.04$	P_{t3} = 20.26 dBm	0.25 dBm
$-56.04 < P_r \leq -50.02$	P_{t4} = 16.79 dBm	0.3 dBm
$-50.02 < P_r$	P_{t5} = 10.97 dBm	0.5 dBm

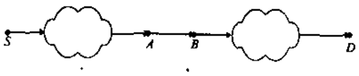


Figure 3: Host S sends to host D using a route through hosts A and B. There are one or more hosts inside clouds.

obtained from the route reply packet sent from host D. To obtain the stability of the route from host A to D, some notations must be introduced. The $P_{previous}$ is the received signal strength the host B received from the host A last time, and the P_{now} is the received signal strength the host B received from the host A now. The Δt is the duration between the last two receptions (with received signal strength $P_{previous}$ and P_{now}, respectively). Notice that if P_{now}-$P_{previous} \geq 0$, which means that host B is moving toward host A, the T_{stable} is set to the system-defined maximum value. If P_{now}-$P_{previous} < 0$, the Δ_{diff} is defined as the differential of the received signal strength, which is equal to $\Delta_{diff}= |P_{now}\text{-}P_{previous}|/\Delta t$. The stability of the route from host A to host D, T_{stable}, is defined as $T_{stable} = (P'_{now}\text{-}P_{r1})/\Delta_{diff}$. P'_{now} is the received signal strength that host B can receive when host A transmits with maximum transmission power. It means that host B will move out of the current region of host A after T_{stable}. The actual duration for the route from host A to host D is the lower one of *min_Rt* and T_{stable}. It means that we consider not only the remaining energy of hosts in the route and their transmission power but also the stability between two hosts.

It should be noticed that the T_d is recalculated once it is expired and the corresponding hosts are still within each other's transmission range. In such a recalculation, we must first subtract the just elapsed time T_d from the *min_Rt*. That is,

$$T_d = min(min\_Rt - T_d, T_{stable}) \quad (3)$$

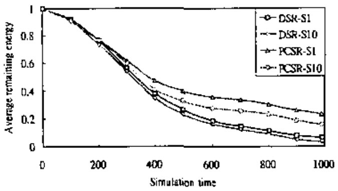
4 Simulation Results

The performance of the proposed PCSR protocol is evaluated by the ns-2 simulator (CMU wireless and mobile extensions). We modified the physical layer of the wireless transmission part, in order to transmit with different power. The power used to transmit is 281mW. The simulation runs on an area of 1000 meters x 1000 meters with 30 hosts in the area. The transmission range of a host is 250 meters and a Free Space model is used, which means the signal strength is in inverse proportion to the square of the distance. Hosts move according to the random way-point model. Two kinds of movement speeds are selected - one uniformly distributed between 0 and 1 m/s and the other distributed between 0 and 10 m/s. Each source host sends a constant bit rate (CBR) flow with one 512-byte packet per second. The CBR traffic has randomly generated a start time and a stop time. In our simulation, there are at least five sources sending packets to the corresponding destination at the same time and totally up to 30 connections during the 1000 seconds simulation time.

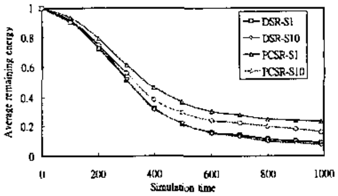
To obtain proper settings for the parameters P_{r1}, P_{r2}, ..., P_{r5}, and P_{sec}, we use the ns-2 to measure the received power of a host. We fix the position of host A, and put host B at a distance of 250, 200, 150, 100, and 50 meters away from the host A. Host A transmits packets to host B with maximum transmission power. Then we measure the received signal strength received at the host B. The measured values are -64dBm, -62.06dBm, -59.56dBm, -56.04dBm, and -50.02dBm, which are set to P_{r1}, P_{r2}, P_{r3}, P_{r4}, and P_{r5}, respectively. According to Table 1, we have P_{t2}=P_{t1}-(P_{r2}-P_{r1})+P_{sec} dBm, where P_{t1} is 24.45 dBm (the maximum transmission power which is used in ns-2 and it is equivalent to 281 mW.), P_{r2} is -62.06 dBm and P_{r1} is -64 dBm. Therefore P_{t2} is 22.51+P_{sec} dBm. Let P_{sec} be 0.2 dBm, we have P_{t2}=22.71 dBm which is also equivalent to 186.724mW. We can calculate P_{t3}, P_{t4}, and P_{t5} in the same way. When we calculate P_{t3}, P_{t4} and P_{t5}, we set P_{sec} to 0.25 dBm, 0.3 dBm and 0.5 dBm , respectively. Different values of P_{sec} are set because of different degradation. Recall that the signal strength is in inverse proportion to the square of the distance. If the received signal strength is weak, the degradation rate of received signal strength is slower compared with that when the received signal strength is strong. Thus, a smaller value of P_{sec} is enough for the packets to be correctly received. In contrast, if the received signal strength is strong, we have to set a larger P_{sec} to ensure the receiver can correctly receive packets. The value of the parameters we used is listed in Table 2.

First of all, we have to determine the values of two parameters: W_{req} and T_{hold}. We have tested several values for W_{req} and T_{hold}. Due to the strict space limit, we report our conclusion directly: W_{req} is set to 4.6 ms and T_{hold} is $0.5T$, where T is the lifetime of a full-energy host can sustain when using the maximum power to transmit.

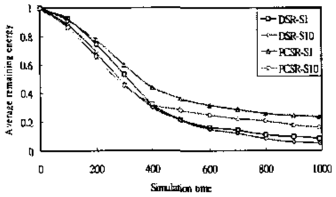
In the following, we compare the performance between the DSR and PCSR on the issue of energy consumption. As shown in Fig. 4, the PCSR consumes less energy than the DSR does in different movement speeds and pause time. The PCSR saves averagely about 15% of energy. Such savings are not as much as what we expected because we use larger transmission power, instead of the best one (the appropriate transmission power under ideal environment), in order to keep similar packet delivery ratio and end-to-end delay as what the DSR produces. In



(a) pause time = 0 second



(b) pause time = 500 second



(c) pause time = 1000 second

Figure 4: Energy consumption vs. simulation time between PCSR and DSR.

addition, there are average 10 connections in our simulations at the same time. The larger number of connections incurs larger interference. As we can see from Fig. 5, the PCSR can save most energy when only one connection is established (about 32% energy compared to DSR) because of the least interference. The PCSR can save 28% and 24% energy when the number of connections are 3 and 5, respectively. The percentage of energy saving in Fig. 5, which is defined as (the energy DSR consumes - the energy PCSR consumes)/the energy DSR consumes, is averaged in different movement speeds and pause time. As the number of connections becomes larger, the interference will increase and we have to use larger transmission power, therefore less energy is saved because of the operation of the PCSR. It is also shown in Fig. 4 that the pause time and movement speed(under 10 m/s) does not affect our routing protocol much.

5 Conclusions

How to conserve the energy consumption is an important issue in a MANET because hosts have limited battery energy. The DSR does not consider the power consumption issue and finds the route with minimum hops. Such a routing strategy makes some hosts run out of their energy very fast. We proposed the PCSR protocol to overcome the problem by considering both the cost and the remaining transmission time in route selection. Also, the PCSR adjusts transmission power according to the received signal strength in order to conserve energy consumption in transmission. Another advantage of the PCSR is its simplicity and transparency. The PCSR can be easily integrated into existing ad hoc routing protocols without affecting other layers of those protocols. Simulation results verify that the PCSR achieves better energy conservation.

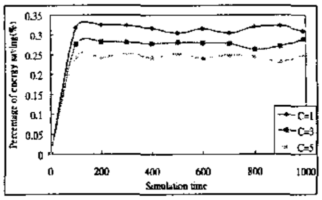


Figure 5: Energy consumption of different number of connections for PCSR and DSR.

References

[1] C. -K. Toh, "Maximum battery life routing to support ubiquitous mobile computing in wireless ad hoc networks," *IEEE Communications Magazine*, vol. 39, pp. 138-147, 2001.

[2] J. Broch, D. B. Johnson, and D. A. Maltz, "The dynamic source routing protocol for mobile ad hoc networks (Internet draft)," Feb. 2002.

[3] T. Goff, N. B. Abu-Ghazaleh, D. S. Phatak, and R. Kahvecioglu, "Preemptive routing in ad hoc networks," in *Proc. of the 7th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom'01)*, pp. 43-52, 2001.

[4] C. Perkins, and E. M. Royer, "Ad hoc on demand distance vector (AODV) routing (Internet draft)," Jan. 2002.

[5] C. E. Perkins, and P. Bhagwat, "Highly dynamic destination-sequenced distance-vector (DSDV) routing for mobile computers," in *ACM SIGCOMM Symposium on Communications, Architectures and Protocols*, pp. 234-244, Sep. 1994.

[6] N. Rous, J. -S. Pegon, and M. W. Subbarao, "Cost adaptive mechanism to provide network diversity for MANET reactive routing protocols," in *21st Century Military Communications Conference Proceedings*, vol. 1, pp. 287-291, 2000.

[7] S. Singh, M. Woo, and C. S. Raghavendra, "Power-aware routing in mobile ad hoc networks," in *The fourth annual ACM/IEEE international conference on Mobile computing and networking*, pp. 181-190, 1998.

[8] M. K. Marina, and S. R. Das, "Performance of Route Caching Strategies in Dynamic Source Routing," in *Distributed Computing Systems Workshop, 2001 International Conference*, pp. 425-432, 2001.

[9] Sojmenovic, and X. Lin, "Power-aware localized routing in wireless networks," in *IEEE IPDPS, Cancun, Mexico*, pp. 371-376, May. 2000.

[10] A. Michail, and A. Ephremides, "Energy efficient routing for connection-oriented traffic in ad-hoc wireless networks," in *Personal, Indoor and Mobile Radio Communications*, vol. 2, pp. 762-766, 2000.