Utilizing Directionality Information for Power-Efficient Routing in Ad Hoc Networks*

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Abstract— **Recently, the need for designing power-aware routing protocols for ad hoc networks has been stressed. In this paper, we present a new energy-efficient algorithm for routing in such networks. The proposed algorithm is called as "Directionality-based Power Efficient Routing (DPER)" since it explores directionality information when determining energy-efficient routes. The use of directional information towards a destination can produce a gradually approaching route to the destination, and thus maximally utilize the saving in the power consumption of the existing power-aware routing approaches that often create an unnecessarily longer path. Our simulation results show that considering this directionality metric in power-aware routing protocols may limit the number of nodes evaluated during the routing process, and therefore can reduce the average consumed power significantly over the existing algorithms.**

Keywords— **Mobile Ad Hoc Networks, Power-Efficient Routing, Directionality Information, Wireless Communication.**

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) are wireless networks where a collection of mobile nodes communicate with each other, in the absence of a fixed infrastructure [1, 2]. A routing problem for ad hoc networks has been extensively researched in the past years [3-9], and the approach for developing a power-aware routing protocol has been stressed more recently [10,11,14]. One common method in these power-aware routing algorithms is to reduce the transmission range of a sender as much as possible, so total energy consumption can be saved by minimizing each sender's transmit power consumption that is in proportion to square of a distance from the sender to receiver. In most existing protocols, minimizing the sender's transmission range is achieved by each sender's decision for selecting an appropriate intermediate node to forward its messages for the receiver. This intermediate node selecting decision is mainly done *locally* since, in general, the closest node from the sender becomes the intermediate node among all its neighbors — More details about how to select such intermediate nodes will be explained in the following section.

We observe that such a local decision made by each sender may produce unnecessarily longer routes between sender and receiver as the decision is made without considering the directionality information of neighbors towards a destination. To solve this problem and to further improve the energy performance of existing power-aware routing protocols, we propose a new algorithm, DPER (Directionality-based Power Efficient Routing). Using the proposed DPER algorithm, each sender can select the intermediate node through which the overall route is gradually approached to the destination. It also results in the decrease of the number of nodes unnecessarily involved in a routing process.

The remainder of this paper is organized as follows. In the next section, we discuss related work on the existing power-aware routing algorithms. In section 3, we describe the DPER. Section 4 presents the results of our simulations where we demonstrate the use of new proposed routing algorithm. Finally, Section 5 summarizes the main results.

II. RELATED WORKS

In this section, we briefly summarize some of existing power aware routing algorithms in multi-hop wireless ad hoc networks. We then motivate our work by pointing out some problems in these algorithms.

First of all, [10] proposed PARO (power-aware routing optimization) to minimize the transmission power needed to forward packets between wireless devices in mobile ad hoc network. PARO elects intermediate nodes called *redirectors* to forward packets on behalf of source-destination pairs; thus reducing the aggregate transmission power consumed by wireless devices. In [11], the authors proposed an approach to control transmission power to improve the performance of energy consumption. They also considered the effect of transmission power range. Their proposed protocol can get the high connectivity and capacity by

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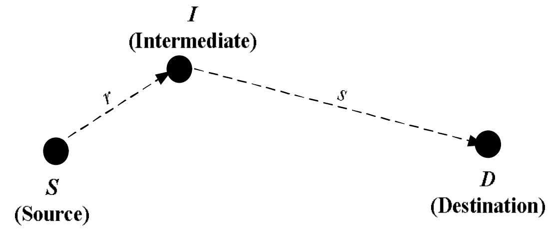
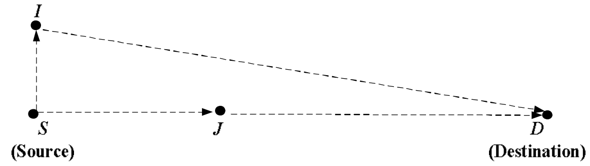
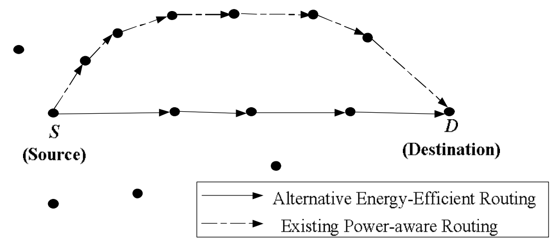


Fig. 1. An example of selecting the intermediate node I in [14]



(a) Intermediate node selecting by S



(b) Overall route between S and D

Fig. 2. Routing decision in existing power-aware algorithm

controlling the transmission power of each node according to the network topology.

There have also been some recent works on defining power consumption models in wireless communication devices. Rodoplu and Meng [12] proposed a general model for the power consumption between two nodes, $u(d) = d^{\alpha} + c$, where d is the two nodes' distance and, α and c are some constants. They adopted the model with $u(d) = d^4 + 2\times 10^8$ for their experiments. Heinezelman et al. [13] also presented a simple energy consumption model, where the power consumed by sender and receiver can be divided into two parts: the power for transmission (T) and the power for reception (P). Thus, in their model, the energy needed between two nodes at distance d is defined as $u(d) = T + P = (E + d^2) + E = 2E + d^2$.[1]

The models described above were more generalized to $u(d) = ad^{\alpha} + c$ by [14][2]. Note that both models presented in [12] and [13] (also, referred to as HCB-model and RM-model in [14], respectively) can be represented using this expression. For instance, in the RM-model $\alpha = 4$, $a = 1$, $c = 2\cdot 10^8$ while in the HCB-model $\alpha = 2$, $a = 0.1$, $c = 2E_{elec}/10^{-9}$. In [14], it was also shown that the power needed for direct transmission (i.e., the value of $u(d)$ above) would become optimal if the distance d between the source S and the destination D is equal to or less than some value of $(c/(\alpha(1-2^{1-\alpha})))^{1-\alpha}$. In other words, when $d > (c/(\alpha(1-2^{1-\alpha})))^{1-\alpha}$, power saving can be obtained by selecting some intermediate node for retransmission between S and D pairs. More precisely in such cases, the maximum power saving can be obtained when $n-1$ nodes are equally spaced and located in between S and D — n is the optimal equal subdivisions and calculated as the nearest integer to the Eq. (1) below.

$$n \cong d\left(\frac{a(\alpha-1)}{c}\right)^{\frac{1}{\alpha}} \tag{1}$$

In that case, the total power consumption is computed as follow:

$$v(d) = \left(c\left(a\frac{\alpha-1}{c}\right)^{\frac{1}{\alpha}} + da\left(a\frac{\alpha-1}{c}\right)^{\frac{1-\alpha}{\alpha}} \right) nJ/bit \tag{2}$$

For $\alpha = 2$, the above equation would be $v(d) = d(ac)^{1/2}$ (These equations will be used in our paper as well). With these basic concepts, [14] proposed a new power-aware localized routing algorithm, in which each sender needs to select one of its neighbors as the next forwarding intermediate node so that the total power consumption can be minimized. Fig.1 illustrates how such intermediate node is selected in [14]. In the figure, the source node S will determine the intermediate node I which will minimize the Eq. (3),

$$P(S,D) = u(r) + v(s) \qquad \text{where } r = |SI|,\ s = |ID| \tag{3}$$

The preceding equation (3) can be refined as follows.

$$P(S,D) = u(r) + v(s) = ar^2 + c + 2s(ac)^{1/2} \tag{4}$$

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1 The model presented in [8] is further detailed as $u(d) = 2E_{elec} + \varepsilon_{amp} \times d^2$, where the radio dissipates $E_{elec} = 50nJ/bit$ to run the node circuitry and $\varepsilon_{amp} = 100pJ/bit/m^2$ for the transmit amplifier to achieve an acceptable E_b/N_0.

2 Since DPER is based on the protocol presented in [14] in many ways, we now present some more details about [14].

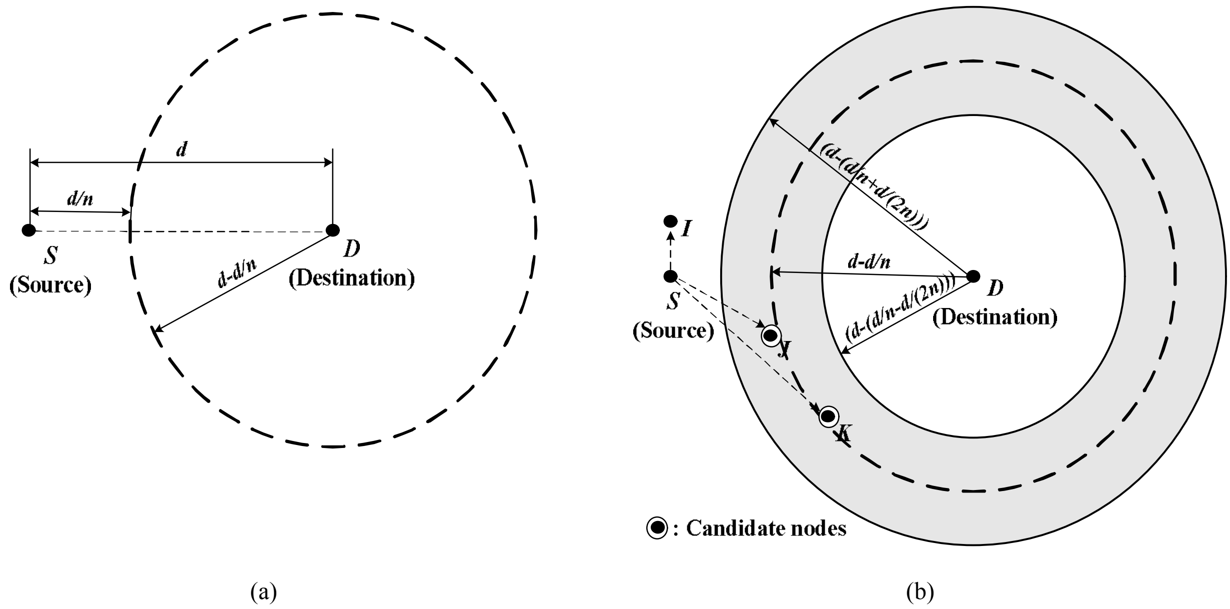


Fig. 3. Candidate node selection phase

where $\alpha = 2$ as in the HCB-model. This refined equation implies that a distance from S to I much greatly impacts the total power consumption than a distance from I to D. Therefore, the sending node using above power formula always selects the *closest* neighbor to send a message. Consider Fig.2(a) as an example. Here, node S will select node I rather than J because I is very close to S, but J is not.

When using the above algorithm, observe that such a localized path selection made by each sender may result in seceding from a path toward destination (for instance, as shown in Fig.2(a), selecting node I becomes more distant to D compared to node J). If the algorithm proceeds until the destination is reached, it may be possible that unnecessarily longer path with more number of nodes is created (see Fig.2(b) — the alternative energy-efficient path exists). Clearly, the more number of nodes are involved in a routing process.

We believe this problem is caused because the existing power-aware routing algorithms including [14] do not take into account the directionality information of neighbor nodes' location towards a destination. In this paper, we suggest a protocol to create the routing path that is gradually approached to the destination (but still energy-efficient); every-time the next forwarding node is selected. Thus, we attempt to reduce the number of nodes unnecessarily participated in the power-aware routing process by utilizing directionality information. There are approaches to solve routing problem using zone information [15, 16]. These algorithms always fix the zone and use the concept of zone for routing. However in our approach, node can use the concept of directional to reduce the energy consumption in routing.

Ⅲ. PROPOSED DPER PROTOCOL

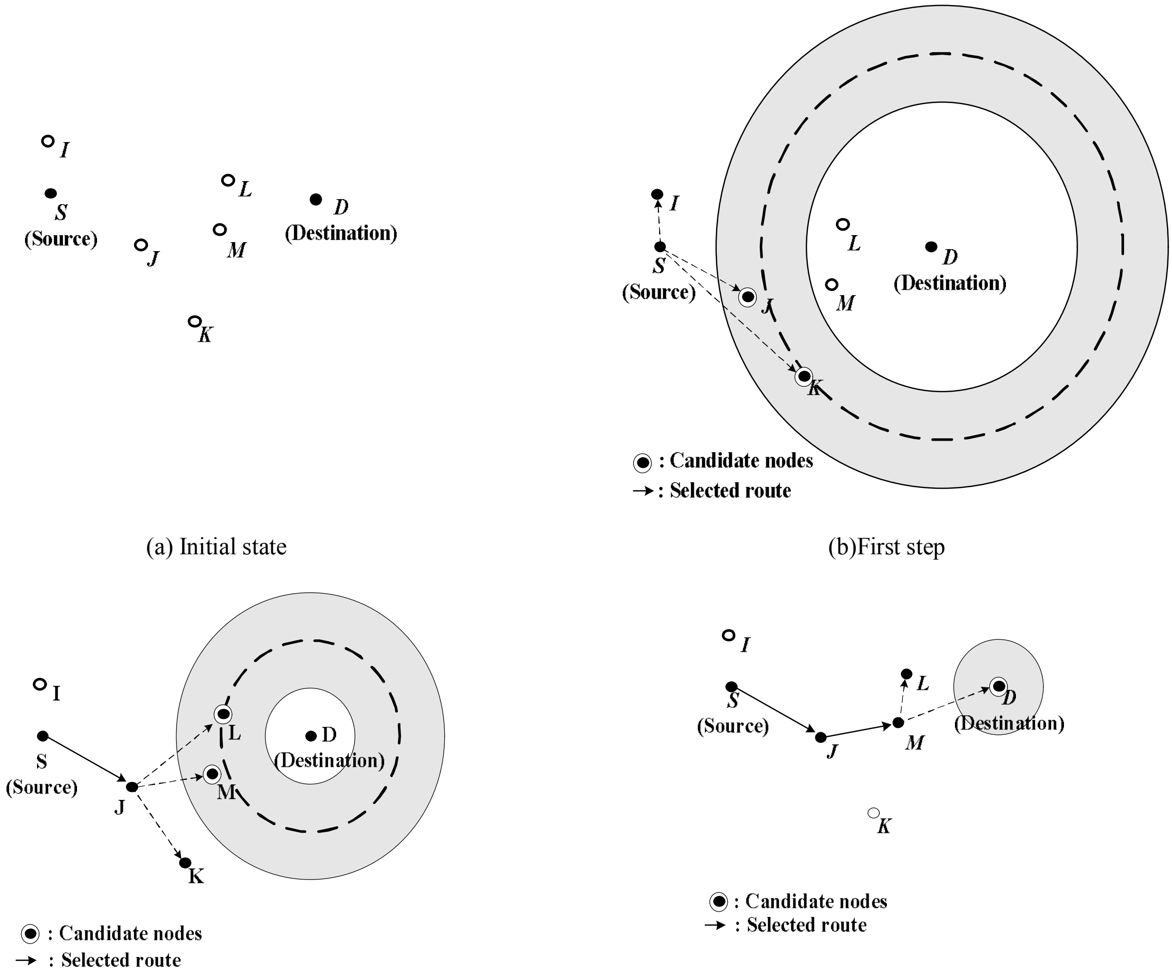
Our DPER (Directionality-based Power Efficient Routing) protocol is essentially identical to the power-aware localized routing protocol in [14], with the modification that only subset of neighbors that can guarantee the gradual approach to destination are considered as the possible candidates to forward the message[3] — therefore such a subset of neighbors is named as "candidate nodes" in this paper. As noted above, the DPER protocol uses directional information toward a destination to choose the candidate nodes.

A. Two selection phases

The power-aware routing process using DPER consists of two phases: the candidate nodes selection phase and the actual forwarding node selection phase, as discussed below.

Candidates selection phase: When a node wishes to send a packet to destination in the energy efficient manner, it first selects some of its neighbor nodes (i.e., *candidate nodes* to forward the packet). The purpose of this selection phase is to have only subset of neighbors be evaluated in the actual forwarding node selection phase, described below.

[3] Recall that, in the algorithm of [14], all neighbor nodes are considered when determining the next forwarding node. Thus, the power formula described in the previous section is applied for all neighbors even if only one neighbor minimizing the power consumption is eventually elected.



(a) Initial state (b)First step

(a) Second step (d) Last step

Fig. 4. The operation of DPER

Fig. 3(a) and (b) depict the process of the candidate nodes selection phase in DPER. In the Fig. 3(a), d is distance between the source S and the destination D, and n is the optimal number of subdivisions ─ recall that n can be calculated using the Eq. (1) in the previous section. We can now draw a circle of radius $(d - d/n)$, centered at the location of D. Then, node S can determine its candidate nodes based on this circle. That is, the candidate nodes, from the viewpoint of node S, are the nodes that are located in between the circle of radius $(d-(d/n-d/(2n)))$ and another circle of radius $(d-(d/n+d/(2n)))$, both centered at D.[4] For instance, in Fig. 3(b), although nodes I, J, and K are all within S's transmission range (and node I is even closer to S than J and K), nodes J and K will be selected as the candidate nodes, because node I is outside the shadow region.

Actual forwarding node selection phase: Similar to [14], the power equations - Eq. (3) and (4) in Section 2 -- are used to select the actually forwarding node. However, in DPER, this power cost evaluation procedure is applied only to the candidate nodes that are determined in the previous phase. Again, consider Fig.(3)(b) as an example. In Fig.(3)(b), nodes J and K are candidate nodes, and therefore they are evaluated in terms of the power consumption cost using Eq. (3), i.e., $P(S,D) = u(r) + v(s)$. Note that for node J, $r = |SJ|$ and $s = |JD|$ while, for node K, $r = |SK|$ and $s = |KD|$.

After that, node J now will become the next immediate node since the estimated total power of the path for S to D via node J is less than that of the $S-K-D$ path.

The formalized algorithm of DPER is presented below.

[4] If any node is located in such region, but beyond the sender's transmission range, then that node should not be selected as candidate node.

```
Simple_DPER_algorithm (S,D)

  S = Source node ;
  D = Destination node ;
  d = Distance from S to D ;
  N = Optimal division value ;
  n = Neighbors of the S is located
        between (d(N-i)/N-d(2N))
        and (d(N-i)/N+d/(2N)) ;
  B = Next node that minimize p(S,D) ;
  Ci = Set of candidate nodes ;

  i := 1 ;

  do
    if(n)
      Ci include neighbors of the S ;
    Select B among the Ci ;
    i := i+1 ;
    S := B ;
  while (i <= n)
```

B. An Example of DPER Operations

The selection procedures above continue until the final destination is reached. It is important to note that, after n-th step, the DPER can eventually reach the destination through the most energy-efficient path. Fig. 4 provides an illustration for the detailed process of DPER.

In the figure, let the optimal division, which will minimize the consuming power, be 2(n=3). Fig. 4(a) displays the initial location of nodes. In Fig. 4(b), the source node (S) selects candidate nodes J and K, which are located between $(2/3)d-(1/6)d$ and $(2/3)d+(1/6)d$ from the destination node. And then, S choose next node J, which minimize the Eq. (3) among the candidate nodes. In Fig. 4(c), M is selected as the same rules. Namely, the distance of $(d/3)$ to the destination is reduced at each step. After the final step, the destination node can be reached.

So far, we assume that at least one neighbor is selected as the candidate node. However, there is no guarantee that a path can be found consisting of the candidate nodes in the chosen shadow area. Therefore, if no nodes are selected as the candidate nodes by the sender S, our DPER protocol allows S to initiate the second selection phase (i.e., the actual forwarding node selection phase) with the all neighbors of S — thus, not limit to only the candidate node.

Ⅳ. PERFORMANCE ANALYSIS

For the evaluation purpose, the proposed DPER protocol is compared to the existing power-aware algorithm [14] (referred to as “PLR” here), by means of simulation.

A. Simulation Models

The assumptions for our simulation are as follows.

- Initially, nodes are randomly distributed in a confined space of $300 \times 300m^2$.
- Each node knows the location of other nodes using device like GPS and can calculates the distance between nodes.
- Transmission range of each node is 100 meters.

In the first simulation, the maximum transmission range is $100m$. We varied the number of nodes and the radio electronics[5] (i.e., E_{elec}). Varying the number of nodes intends to observe the effect of the number of nodes on energy consumption when the routing path is established. Number of nodes in our simulation increased from 20 to 250 by 10. And the value of radio electronics can influence the energy consumption equations, expressed in Section 2. Thus by varying the radio electronics (from 50 to 140nJ/bit in our simulation), we can see the effect of the energy consumption equations.

The optimal division of n is also varied from 3 to 8 in our simulation, in order to observe the effect of n on consumed energy. As the distance between source and destination is changed, it can bring the varying effect of optimal division. In this method, we fix the number of node as 100.

To evaluate the performance of proposed DPER, we use the following two metrics: total energy consumption on the route and number of evaluated nodes to select the next node.

Total energy consumption on the route: We evaluate the total energy consumption when the route is established. Total consumed energy is defined as summed up energy consumption when the route passed each intermediate node. To get the reasonable value, the HCB model is used to measure the energy consumed by transmission. The unit for energy consumption reported in this paper is nJ/bit.

Number of evaluated nodes to select the next node: This measurement can be achieved by aggregating the total number of evaluated nodes to select the next node on route.

Each of simulation was executed 1,000 times, and then we averaged the summed results to get the normalized value.

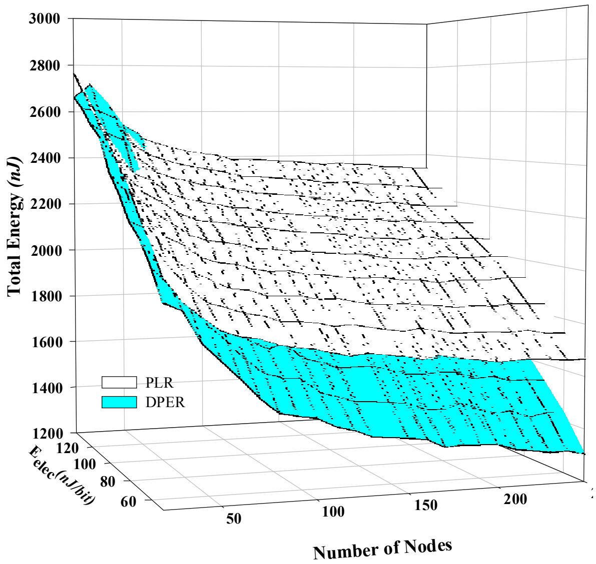
[5] In HCB-model it means that quantity of energy necessary to send or receive a 1 bit data in circuit of node.

B. Simulation Result

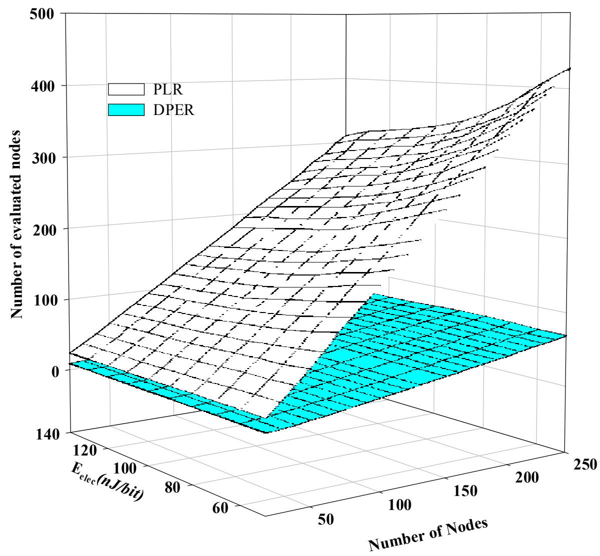
This section presents simulation results to evaluate our DPER compared to PLR. Fig. 5 shows simulation results with varying the number of nodes and radio electronics. The light gray plane expresses the existing PLR, and dark gray plane displays the DPER. Fig.5(a) shows the total energy expended in the system as the number of nodes increase from 20 to 250 and the radio electronics increases from 50 to 140(nJ/bit). When the number of nodes is 20, the DPER seems to consume more energy than PLR. This is because, with a small number of nodes, the possibility of having candidate nodes in DPER would be low. However, DPER consumes smaller energy proportional to increases of nodes than power aware algorithm passing over 30. That is, as number of nodes is increase, DPER display better performance since probability to find node in optimal position among candidates increases. As a result, by using our algorithm, the energy can be saved as density of nodes increases, because probability of node being on the optimal location is increased. Also, as you seen in figure, increment of total consumed energy occurs as radio electronics (E_{elec}) increase.

Fig.5(b) shows the number of evaluated nodes. The DPER can achieve over a factor of 3 reductions in number of evaluated nodes compared to power routing. In PLR, it evaluates the all neighbor node. However in DPER, by selecting the candidate node, it can reduce the number of evaluated nodes compared to PLR. Reducing the evaluated number of nodes means that it can reduce the computation time in node to minimize the delay. Thus, degree of delay is smaller in DPER, compared to power-routing.

The effect of varying the optimal division is shown in Fig.6. The result of total energy consumption and number of evaluated nodes are shown in Fig.6(a) and Fig.6(b), respectively. In Fig.6(a), the total energy increases. As optimal divisions are increased, the nodes that participated in routing can be increased. For this reason, PLR can cause the increment of probability to secede from path toward destination. In Fig.6(b), the DPER also shows better performance for same reason, as optimal division was increased.



(a) Consumed energy



(b) Number of evaluating nodes

Fig. 5. Performance of the DPER by varying the number of nodes

V. Conclusion

In ad hoc networking environment, saving energy for mobile devices is important as it uses battery to support mobility. This paper proposed the directionality-based power efficient routing protocol to achieve performance enhancement, compared with the existing power-aware routing protocol.

As a result of performance evaluation, the DPER shows better performance than the existing power-aware routing in most cases. When the node's density is too low, DPER shows comparable performance to the power routing because it can not select the candidate nodes near the optimal division. However, in most case DPER using directionality information show the better performance than existing power routing on both of energy consumption and number of evaluated node.

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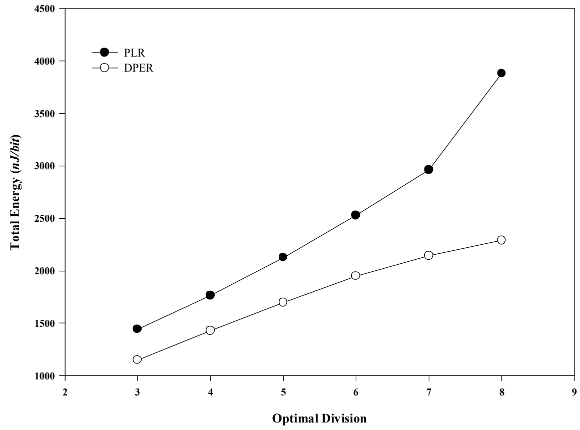
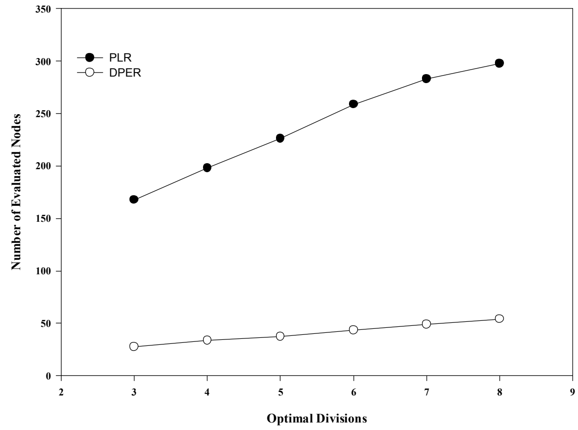


(a) Consumed Energy



(b) Number of evaluating nodes

Fig. 6. Performance of the DPER by varying the optimal divisions