무선 Ad-hoc 네트워크환경에서 전송지연과 에너지소비를 고려한 라우팅 알고리즘

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Delay and Energy-Aware Routing Algorithm For Energy-Constrained Wireless Networks

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요 약

무선 Ad-hoc 네트워크에서의 배터리 고갈에 의해 발생하는 노드 실패는 네트워크 전체의 성능에도 큰 영향을 미치므로 에너지소비를 고려한 라우팅 알고리즘은 매우 중요하다. 본 논문에는 전송 시 노드에 의한 에너지 소비뿐만 아니라 노드의 잔여 에너지와 경로 재설정 시 소요되는 지연까지도 고려한 라우팅 (DEAR; Delay and Energy-Aware Routing) 알고리즘을 제안하였다. 성능분석결과 DEAR알고리즘은 충분한 잔여 에너지를 보유한 노드로 경로를 설정함으로써 에너지 비율에 따라 균형 있게 에너지를 소비할 수 있었다.

ABSTRACT

Wireless Ad-hoc networks may contain nodes of various types of which many can have limited power capabilities. A failure of a node due to energy exhaustion may impact the performance of the whole network hence, energy must be conserved. In this paper, we propose a Delay and Energy-Aware Routing (DEAR) algorithm a multiple metric path cost routing algorithm which considers not only the energy consumed by the node during transmission and reception but as well as the residual energy of the node and the delay incurred during route discovery. Based on our results, DEAR algorithm performs well and maximizes network lifetime by routing flows to nodes with sufficient energy such that the energy consumption is balanced among nodes in proportion to their energy reserves.

키워드

Ad-hoc networks, energy-aware routing, routing metrics, network lifetime

I. 서 론

Wireless Ad-hoc networks are becoming popular as they provide users access to information and communications anytime and anywhere. These types of network are useful in any situation where temporary network connectivity is needed. However, implementing Ad-hoc wireless networks poses many technical challenges due to the constraints imposed by the environment. Also, the devices in these networks are generally battery-powered hence energy should be conserved in order to maximize the life of the devices and the network itself.

If power control is implemented between links, i.e. the transmit power used is the minimum energy required just to

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reach the destination node, the energy consumption rate per unit information transmission would depend on the choice of the next hop node or simply the routing decision. Hence, routing plays a significant role in maximizing system lifetime. As node sends, receives or forwards packets, the energy of a node is reduced and once the energy level falls below a threshold, the node suffers shutdown and eventually die. Hence, energy related metrics should be taken into consideration in designing Ad-hoc routing protocols.

Routing under energy constraints is a significant design challenge too since the exchange or routing of data consumes precious energy resources. Most papers dealing with routing consider only the minimum energy path regardless of the delay associated when transporting data while some papers deal only with end-to-end delay which leads to finding the shortest-hop path ([1] and references herein.). In this way, one or more nodes in the shortest-hop path are heavily loaded and nodes will tend to have widely differing energy consumption resulting to an early death of some nodes.

In this paper, a delay and energy-aware routing (DEAR) algorithm which considers multiple metrics is proposed. It includes the energy consumed by the nodes during transmission and reception, and the delay incurred during route discovery which is a function of residual energy of the nodes. The paper is organized as follows: Section II presents the related works while Section III discussed the proposed routing algorithm. Numerical analysis of the proposed routing metric is presented in Section IV and Section V concludes this paper.

Ⅱ. Related Works

In wireless Ad-hoc networks, nodes have limited initial amount of energy which is consumed in different rates depending on the transmit power level and the distance from intended receiver. Hence, the path to be selected must consider the energy reserves of the nodes such that nodes with depleted energy reserves do not lie along many paths. In wireless Ad-hoc networks, nodes have limited initial amount of energy which is consumed in different rates depending on the transmit power level and the distance from intended receiver. If all traffic is routed through the minimum energy path to the destination or if same node is selected as a route for packets going to every other node, the nodes in that path will run out of batteries quickly and would result to an early network partition [2]. Hence, the path to be selected must consider the energy reserves of the nodes such that nodes with depleted energy reserves do not lie along many paths. Traffic should use routes with sufficient remaining energy to maintain balance in the network.

Basically, the role of routing is to find the suitable route to forward data packets in multi-hop networks based on a specific metric. Since there is no infrastructure in Ad-hoc networks, every node can act either as a connection end-user or as a router for the connections of other nodes[3]. Conventional Ad-hoc routing protocols use hop count as the routing metric. However, research has shown that the shortest path is not always a good option because it could cause congestion problems and power depletion at some specific nodes. Since nodes are battery powered, it is important to reduce the energy consumption for a failure of a node due to energy exhaustion may impact the performance of the whole network.

Routing in Ad-hoc networks can be classified into two categories: Pro-active protocols (Table-driven routing protocols) and Reactive (On-Demand) protocol[4]. In Pro-active routing protocols, the routes are evaluated continuously by exchanging periodic control messages so when a data packet needs to be forwarded a route is already known. The Reactive protocols on the other hand, discover routes only when they are needed. When a source node wanted to send packets, it invokes a route discovery mechanism to find the path to the destination.

There are four multi-hop wireless Ad-hoc network routing protocols that cover a range of design choices: Destination-Sequence Distance-Vector (DSDV), Temporally Ordered Routing Algorithm (TORA), Dynamic Source Routing (DSR) and Ad Hoc On-Demand Distance Vector Routing (AODV). The DSDV protocol falls under pro-active routing protocols while TORA, DSR, AODV fall under the On-demand routing protocols category ([4] and references herein). However, table driven schemes are known to incur large routing overhead which becomes more expensive in terms of energy consumption as compared to the on-demand scheme.

To maximize network lifetime in a more balanced manner, an intuitive technique called Minimal Battery Cost Routing (MBCR) was proposed by the authors in [5]. The algorithm utilizes the node's remaining battery capacity as a cost function and selects the route that has a minimal battery cost, thereby increasing the lifetime of the network. A Maximum System Lifetime (MSL) routing algorithm suggested by Tassiulas and Chang [2] also routes traffic to nodes with sufficient energy such that the energy consumption is balanced among nodes in proportion to their energy reserves. However, their routing algorithm uses shortest-path. According to [6], a route utilizing a small number of hops (low delay) may use significantly more energy (per node and/or total energy) than a route consisting of a larger number of hops. Hence, routing protocols under energy constraints must somehow balance delay constraints, battery lifetime, and routing efficiency. In our case, we both consider delay and energy as cost and a route with minimum cost is selected such that the time before the death of a node's battery is maximized. This link cost metric will be discussed in the next section.

Ⅲ. New Routing Metric

In multi-hop networks, a number of additional metrics should be simultaneously considered for determining path cost. According to [7], there are numerous metrics used to evaluate routing protocol's performance. In our paper, we have considered network throughput, route discovery delay and network lifetime in our paper. Network throughput is the amount of data traffic the entire network carried to its destination in one second. Routing discovery delay is basically for reactive protocols, which is a measure of the effectiveness of reactive protocols, i.e. the delay between a route request being issued and a reply with a valid route being received. Lastly, network lifetime may be defined as the time until network partitioning occurs due to node failure or the time until a specified proportion of nodes fail. This indicates the protocol's energy-efficiency and load balancing ability[7].

We introduced our first step of combining a number of cost criteria into one cost link metric. One of our objectives is to find the best link cost function which would maximize the network lifetime. We have considered the energy consumption, residual energy of the nodes and the routing discovery delay to incorporate in a routing metric. Power-aware routing metrics summarized in [1], were considered in this paper; however, unlike in [1], we have combined the parameters into one function such that the life of the nodes in the network is maximized and the time before network partition is maximized. The energy expenditure e^t_{ij} and e^r_{ji} during transmission and reception of data packets over the link, respectively as well as the initial energy E_n and the residual energy $\underline{E}_n$ of the nodes are considered in the link cost.

Since most papers dealing with routing consider only the minimum energy path regardless of the delay associated when transporting data and some papers only deal with end-to-end delay which leads to finding the shortest-hop path, we have considered both energy and delay in our routing metric and characterized the trade-off between these two parameters. Similar to [3], we would explore the mechanism of discarding redundant route requests (RREQ) packets. The basic idea is that RREQs forwarded by nodes with less energy should have a higher probability to be considered as redundant or eventually discarded so that these nodes will not be used as a route. That is, each node that receives a RREQ message delays the forwarding procedure according to its remaining energy. While this mechanism of discarding RREQs forwarded by nodes with less energy balances the flows among different routes, it adds delay to the forwarding procedure. This is usually the trade off of an energy aware mechanism [3]. Hence, maximizing network lifetime is very difficult if we need to simultaneously maintain low delay and high throughput.

Yu and Lee [8] analyzed three kinds of delay functions based on the energy of the nodes. However, this was later modified by [3] in order to reduce the delay included by nodes with full energy and nodes with zero energy. Thereby, we adopt the delay function modification proposed in [3] based on Yu and Lee's work [8]. The suggested delay function is

$$d_l = \left(\frac{2D_T * E_n}{\underline{E}_n + E_n} \right) - D_T \qquad (1)$$

where d_l is the delay added to the forwarding by node *i* at time *t*, E_n is the initial energy of the node, $\underline{E}_n$ is the residual energy of the node at time *t*, and D_T is the delay threshold or the maximum delay allowed.

Based on the results in [3], the delay function reduces the average forwarding delay. The process of discarding RREQs forwarded by nodes with less energy, balances the flows among different routes and the nodes with more energy have higher probability of being chosen as route. We append this delay function (1) in our proposed routing metric where the link cost between nodes *i* and *j* is now defined as

$$\text{cost}_{ij} = (e^t_{ij})^{x_1} \left(\frac{2D_T * E_i}{\underline{E}_i + E_i} - D_T \right)^{x_2} + (e^r_{ji})^{x_1} \left(\frac{2D_T * E_j}{\underline{E}_j + E_j} - D_T \right)^{x_2} \qquad (2)$$

The non-negative weighing factors x_1, x_2 has a value either zero or one. These weighing factors help calculate the cost or change the importance of the metrics during route discovery. We scaled these factors to change our route selection scheme. In case of $x_1=0$, and $x_2=0$, the shortest hop routing will be used. If $x_1=1$, $x_2=0$, the minimum total energy path is to be used to route data. Furthermore, if $x_1=0$, $x_2=1$, our Delay and Energy-Aware Routing (DEAR) algorithm will be used. These conditions are summarized in Table 1 below.

표 1. 세 가지 라우팅 알고리즘
Table 1. Three Routing algorithms.

$F(x_1,x_2)$	Algorithm
$x_1=0$ $x_2=0$	Shortest hop
$x_1=1$ $x_2=0$	Minimum Energy
$x_1=0$ $x_2=1$	DEAR

In minimum energy routing, the link which has a minimum total consumed power for transmission and reception is being utilized. The path cost is computed as summation of the link costs on that path. Since the link cost considers not only the energy expenditure but also the residual energy of the node, this leads to maximizing node's lifetime at a tolerable delay. At the start, when all nodes have plenty of energy, the minimum energy routing could be used. As residual energy decreases, it is more important to avoid the nodes with small residual energy. To trade-off the delay incurred on the routing discovery and forwarding process, our proposed DEAR algorithm will be used. The DEAR algorithm can be implemented with the existing reactive protocols namely Dynamic Source Routing (DSR) and An-hoc On-Demand Distance Vector Routing (AODV) Algorithm.

Ⅳ. Numerical Analysis

We compare the three routing algorithms discussed in Sec. III using Dijkstra's Algorithm. The Dijkstra's algorithm finds the shortest path or the minimum cost path from a single source vertex to all other vertices in a weighted directed graph where all arc lengths or weights are non-negative. The said method is popular for solving the single destination shortest path problem with non-negative arc lengths [9], the reason why we have chosen this method for our numerical analysis.

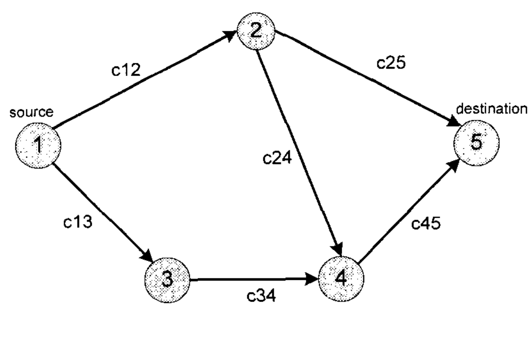

그림 1. 시뮬레이션 토폴로지
Fig. 1. Simulation Topology

Using Dijkstra algorithm, we determine the network lifetime of the network (Fig. 1) which is defined by the time the first node runs out of energy. There are three possible paths from the source node (node 1) and the destination, (node 5). The three possible paths are as follows: Path 1: $1 \rightarrow 2 \rightarrow 5$; Path 2: $1 \rightarrow 2 \rightarrow 4 \rightarrow 5$; and Path 3: $1 \rightarrow 3 \rightarrow 4 \rightarrow 5$. The pseudo code of the DEAR algorithm is illustrated by Fig. 2 below.

```
Delay and Energy-Aware Routing Algorithm

1. Find the node with the lowest residual energy.
  Let Emin be the minimum residual energy.
  Let En be the initial energy of the node
t=1
  While t < n && Emin>=0
  If Emin >= (0.80)*En
2.  Perform Minimum Energy path routing
3.  Update the cost functions. (x1=1, x2=0 in Eq. (2))
4.  Generate and update cost matrix.
5.  Determine shortest path and minimum cost via
    Dijkstra Algorithm
6.  Update energy consumption of nodes that belongs to that
    minimum path
7.  Update residual energy of nodes that belong to that
    minimum path
8.  Find the node with the lowest residual energy.
    Let Emin be the minimum residual energy.
  else
9.  Perform Delay and Energy Aware Routing Algorithm
10.  Update the cost functions. (x1=0, x2=1 in Eq. (2))
11.  Generate and update cost matrix.
12.  Determine shortest path and minimum cost via Dijkstra
     Algorithm
13.  Update energy consumption of nodes that belongs to
     that minimum path
14.  Update residual energy of nodes that belong to that
     minimum path
15.  Find the node with the lowest residual energy.
     Let Emin be the minimum residual energy.
  end
t = t+1
end
```

그림 2. DEAR 알고리즘
Fig. 2. DEAR Algorithm

In the Shortest-Hop algorithm, we let the routing cost matrix as an array of random variables. This would be equivalent to the link delay or the number of hops. For the Minimum Energy Routing algorithm, the cost matrix consists of the energy consumption of the nodes during transmission and reception as given by

$$\text{cost}_{ij} = (e_{ij}^{t}) + (e_{ji}^{r}) \tag{3}$$

from (2) while the cost matrix in the DEAR algorithm is defined by the following equation.

$$\text{cost}_{ij} = \left(\frac{2D_T * E_i}{\underline{E}_i + E_i} - D_T \right) + \left(\frac{2D_T * E_j}{\underline{E}_j + E_j} - D_T \right) \tag{4}$$

That is, for DEAR algorithm, when the residual energy of the node is above 80% of the initial energy, (3) would be used as the cost matrix but when the residual energy of the node falls below 80%, (4) would be used. Since these algorithms used matrix manipulations for the routing costs in the Dijkstra's algorithm, we used MATLAB which is a powerful tool for doing numerical computations with matrices and vectors, to compare the mechanism of the three routing algorithms.

The forwarding delay of RREQ messages is defined by equation (1) which is a function of the initial and remaining energies of the node. The value of this delay will be added to the forwarding node at time *t*. This proposed delay function [3] reduces the average forwarding delay and increases the difference of the delay added by a node with full energy and delay added by a node near exhaustion.

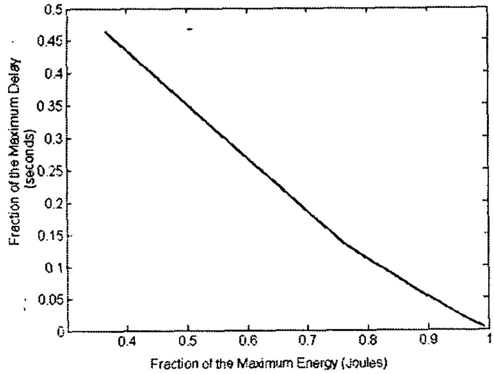

그림 3. 잔여 에너지와 지연의 관계
Fig. 3. Relationship of Residual Energy and Delay

As you can see in Fig. 3, if the node is near exhaustion, it will incur more delay especially for the routing discovery. The lower the value of the remaining energy, the higher will be the delay and the higher will be the probability that RREQs forwarded by these nodes (near exhaustion) will be discarded. Thereby, as the node comes closer to exhaustion, the added delay to the RREQs forwarding, grows faster. Thus, these nodes with exhausted energies have an aggressively small chance being used as a route.

For the simulation of Fig. 1, we used the simulation parameters given in [4] i.e. we defined that all nodes have an equal initial energy of E_n=20J, a reception energy of 150mW and a transmission energy of 165mW. From [3], we set that the maximum or tolerable link delay as 100ms for each transmission.

As you would notice from the given data in Fig. 4, the minimum residual energy of the node under DEAR algorithm is higher compared to that of the nodes in minimum energy and shortest hop algorithms. This also means that the remaining lifetime of the network is longer compared to others and this is because the DEAR algorithm balances the flow of data among the nodes in the network that prevent early network partition.

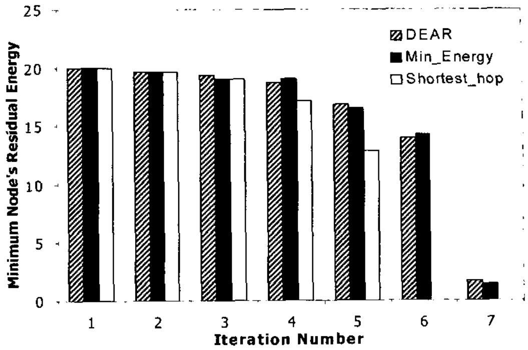

그림 4. 각 반복 당 노드의 잔여 에너지
Fig. 4. Node's residual energy on each iteration

As shown in Table 5, the DEAR algorithm alternates between Path 1 and Path 2 in routing flows from the source node to the destination node. In this way, it routes traffic to nodes with sufficient energy such that the energy consumption is balanced among nodes in proportion to their energy reserves, as well as balances the delay constraints and battery lifetime. In the case of shortest hop algorithm, a route with minimum hop or delay is selected. Based on our analysis, the shortest-hop algorithm utilizes Path 1 i. e. [1 2 5] where node 2 is always used in transmission and reception thus, consumes its battery at a faster rate compared to others. Node 2 will be dead on the 5th iteration, which is earlier compared with the other two routing protocols.

표 2. 알고리즘의 최소비용경로
Table 2. The Minimum Cost Path of the Algorithms

Iteration	DEAR	Min_Energy	Shortest Hop
1	[1 2 5]	[1 2 5]	[1 2 5]
2	[1 3 4 5]	[1 2 5]	[1 2 5]
3	[1 2 5]	[1 3 4 5]	[1 2 5]
4	[1 3 4 5]	[1 2 5]	[1 2 4 5]
5	[1 2 5]	[1 3 4 5]	
6	[1 3 4 5]	[1 2 5]	

V. Conclusion

We have proposed a new link cost metric to be used by a routing algorithm which trades off energy consumed of each node in the routing path and the delay associated on each transmission by considering them as link costs. This would maximize network lifetime at a tolerable end-to-end delay. Based on our example, our proposed Delay and Energy Aware Routing (DEAR) algorithm performs well, and maximizes network lifetime by routing traffic to nodes with sufficient energy such that the energy consumption is balanced among nodes in proportion to their energy reserves.

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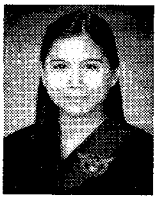
저자소개



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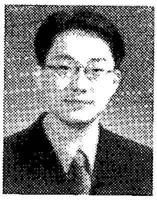

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