IJE TRANSACTIONS A: Basics Vol. 27, No. 1, (January 2014) 33-38

International Journal of Engineering

Journal Homepage: www.ije.ir

LEBRP- A Lightweight and Energy Balancing Routing Protocol for Energy-constrained Wireless Ad Hoc Networks

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P A P E R I N F O

Paper history:
Received 30 April 2013
Received in revised form 31 May 2013
Accepted 22 August 2013

Keywords:
Ad-hoc Network
Routing Protocol
Energy Balancing
Wireless Network

A B S T R A C T

A wireless ad hoc network typically refers to any set of wireless networks where all devices have equal status on the network and are free to associate with any other wireless ad hoc network devices in their range. Due to their nature, these networks commonly do not have external power supplies, and each node has a limited internal power source. In this paper, we put forward a new routing protocol that is light enough for energy constrained networks, and find routes on the basis of remaining power of each node. Besides, we have also taken some other factors into consideration. These factors include the ratio of remaining power of a node to the distance of the node from next receiving node and the ratio of the remaining power of current node to the average remaining power of the whole network. This protocol puts emphasis on routing in such a way that the network stays heterogeneous in terms of remaining power of nodes. This homogeneity brings on a longer network lifetime. In addition, the presented protocol does not impose a high computational load on the network. Hence, it is lightweight enough to be used in networks with low computational power and constrained power resources.

doi: *10.5829/idosi.ije.2014.27.01a.05*

1. INTRODUCTION

Wireless Ad-hoc networks are composed of small self-powered devices which are capable of communicating with each other, and also other wireless devices [1, 2]. These networks are different from other networks in some ways. In these networks each node is configured with the same peer-to-peer networking protocol, thereby allowing a group of nodes to form a self-configuring network. But the biggest and the most important feature to pay attention to, is that they are commonly energy constrained. Considering this constraint, we should search for parts that consume energy in ad-hoc networks. The biggest part of energy consumption is concerned with computation and transmission, in which transmission has higher priority. So, we should think about a mechanism which helps the network to transmit data, using lowest possible amount of energy.

The traditional approach, enshrined in the family of link-state protocols, is to tell everyone [3]. However, as a network grows, the requirement of universally communicate and act on each topology change can become problematic, since plenty of network energy would be lost [4-6]. Therefore, we should devise a protocol which does not waste the network energy. The protocol should also consider energy balancing issue, as well as the remaining power of the network. In this paper we have proposed a protocol that considers these factors in addition to some other factors such as homogeneity of the network. The motivation of this study is to devise a low complexity and lightweight routing protocol which increases lifetime of constrained power source networks, and surmount energy management problems of the protocol which only consider remaining power of nodes or are not light enough for energy constrained networks.

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2. RELATED WORKS

In the last decade, many energy efficient network routing protocols have been proposed for ad-hoc networks. Previous routing schemes [7] involve direct communication protocols which facilitate direct communication between the source node and the base station. Therefore, for scenarios where the base station is quite a distance away from the source node, there is excessive usage of energy resources, which ultimately results in a complete drainage of power. Such routing schemes are successful only where nodes are near enough to a base station. The routing protocols proposed require each node to act as a router and route data from the source node to the base station through a set of selected intermediate nodes [8, 9].

These protocols differ from each other in terms of methodology and the algorithm used to select the intermediate nodes which are included in the route between the source and the destination. The main disadvantage of these kinds of protocols is that sometimes nodes which lie near the station are included in the routing path, therefore causing their energy resources to drain off quickly. This inclusion affects the overall power efficiency of the wireless network adversely [5].

Two protocols in the category of ad-hoc networks are proposed for wireless sensor networks which are based on clustering technique and involve dividing the nodes into a set of clusters, then each of them selects a cluster head [10, 11]. Rather than transmitting data directly from the node to the base station, each node transmits the data to the cluster head which, in turn, sends data to the base station. However, as pointed out in [12], the cluster heads need to be selected based on a random rotation to make sure that the energy load is distributed evenly among all nodes. This selection leads to additional overheads [13].

A substantial amount of work has also been done on cross-layer architecture in the last couple of years. A significant portion of such work has focused on cross-layer interaction between the MAC sub-layer and the routing layer. Researchers focused on both power efficiency and scheduling, attempting to solve the problem of power efficiency and Quality of Service (QoS) [8]. Their proposed approach reduces the energy used to transmit and guarantee a certain level of bandwidth for the desired QoS. The main drawback of this approach is that it is a centralized approach where algorithms are executed by central agents having information of the network. Such an approach is more suited to those kinds of wireless networks in which infrastructure support is available to the network. The proposed routing protocol has achieved its security goal, but the main drawback of this protocol is that it is not scalable and does not support data diffusion [14].

The author has presented a cluster base routing protocol which hierarchically forwards data toward the destination [15]. The main disadvantage of this protocol is that it is fairly complex to be implemented in a resource constrained network like WSN.

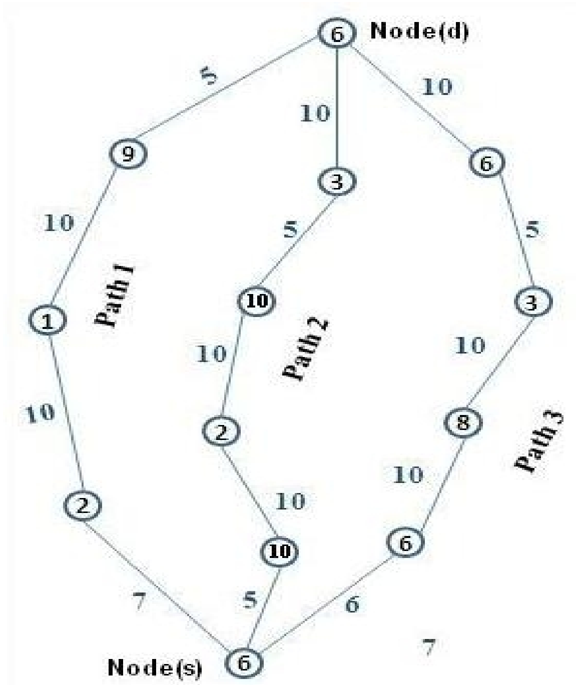

Figure 1. Remaining power of each node, and data transmission cost between nodes

3. PROPOSED METHOD

In our proposed method we use three main factors to select a path. These factors are the cost of energy, the amount of remaining power of the nodes in a route, and the standard deviation of the remaining power in a route. Consideration of these three factors leads to a reasonable judgment about which route to choose. Energy cost factor helps to know about the average amount of energy each route consumes to transfer data. So, less costly routes can be determined as more suitable routes.

The second factor, which is the remaining power of nodes, makes the process of routing more reasonable because of the fact that a less costly route in terms of energy is not always a better route, due to the power problem it may encounter.

A route may have a low energy cost, but not enough remaining power. So it fails to survive until the end of data transmission. The third factor deals with the homogeneity of the route found. This factor considers a situation in which the average remaining power of a route is not low, but some nodes in the route have critical power level, while it can not be recognized by other factors. This factor helps to lower the priority of these routes. The main idea of homogeneity factor is that a chosen route should be homogeneous in terms of remained energy.

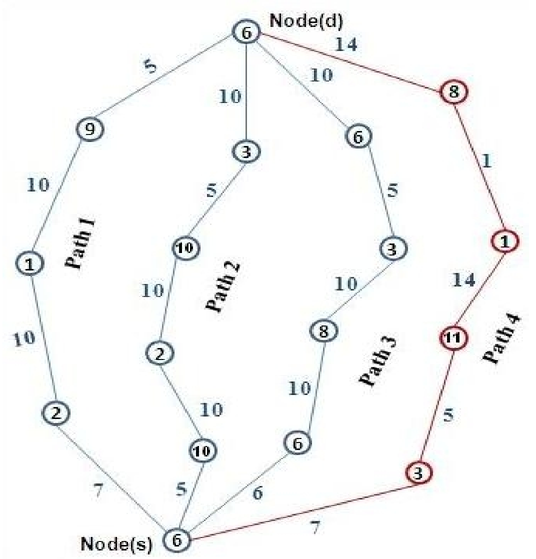

Figure 2. A forth path toward destination with different remaining powers and transmission costs

3. 1. How It Works Energy cost of a path is calculated as follow:

$$EC_{\#X} = \sum_{i,j \in Path\ X} EC_{i,j} \quad (1)$$

in which $EC_{\#X}$ represents the total energy cost of $path_x$, and $C_{i,j}$ is the cost of data transmission between $node_i$ and $node_j$, while $node_i$ and $node_j$ are two adjacent nodes. The path cost shows the amount of energy consumed while data transmission in $path_x$. The second factor to be taken into the consideration is the level of remaining power. So, we add this factor to formula (i) in such a way that it considers the remaining power as well.

$$LocC_{\#X} = \sum_{\substack{i,j \in Path\ X \\ i\ is\ connected\ to\ j}} \frac{EC\ i,j}{RPi} \quad (2)$$

where $LocC_{i,}$ is the Local cost of using $path_X$ to transmit data between $node_i$ and $node_j$. The word local implicates that the calculated value has not considered the entire network condition which will be discussed later. RPi means the remaining power of $node_i$. By applying this formula, lower remaining power brings about higher path cost. The standard deviation of remaining power of each path will be calculated separately.

$$\sigma = \sqrt{\frac{1}{n_{local}} \sum_{i=1}^{n} (x_i - \bar{X})}$$

where:

$$\bar{X} = \frac{1}{N_{global}} \sum_{i=1}^{N} x_i \quad (3)$$

We have altered standard deviation formula in a way that it compares each node in a path with the average remaining power of the whole network. To achieve this goal we use average remaining power of the whole network in the above formula instead of average remaining power of only participating nodes in a path. In the formula [3] , n_{local} is the number of nodes in a path, while N_{global} is the number of nodes in the entire network. This standard deviation helps determine in which path the power is distributed more evenly in comparison with the entire network. Considering later routings, this metric helps to determine a path which is closer to the network remaining power condition, and hence, helps keep the network homogenous. So, the total cost of a path is calculated as follows:

$$TotC_{Path_x} = LocC_{Path_x} \times \sigma_{Path_x} \quad (4)$$

Selected Path = Min(Set) , where Set is the set of total costs of all possible paths (5)

The proposed method is compared with a current technique, named as DEARP [16]. The authors have proposed DEARP method which considers only energy cost of data transmission between nodes in a path [16]. Numerical example shows how our proposed method outperforms DEARP, and why LEBRP selected routes are better than those of DEARP.

4. NUMERICAL EXAMPLE

In Figure 1, $node_s$ and $node_d$ are two nodes in the networks with a lot of nodes in between. If $node_s$ wants to send some information to $node_d$, it should choose one of three possible paths to $node_d$. the figure also shows the remaining power of each node, and the energy cost between each pair of nodes.

We apply our routing method on it to see which path is the best one to use. Regarding formula [1], energy cost of each path is calculated as follows:

$EC_{path\ 1} = 5 + 10 + 10 + 5 = 30$

$EC_{path\ 2} = 5 + 10 + 10 + 5 + 10 = 40$

$EC_{path\ 3} = 6 + 10 + 10 + 5 + 10 = 41$

The remaining power of each path is calculated as $RP_{\#X} = \sum_{i,j \in Path\ X} RP_{i,j}$. So, the remaining power of each path is as follows:

$RP_{path1} = 6 + 2 + 1 + 9 = 18$

$RP_{path2} = 6 + 10 + 2 + 10 + 3 = 31$

$RP_{path3} = 6 + 6 + 8 + 3 + 6 = 29$

Now, according to formula [2], the LocC of each path is as follows:

$LocC_{\ path1} = 5/6 + 10/2 + 10/1 + 5/9 = 16.39$

$LocC_{\ path1} = 5/6 + 10/10 + 10/2 + 5/10 + 10/3 = 10.67$

$LocC_{\ path1} = 6/6 + 10/6 + 10/8 + 5/3 + 10/6 = 7.25$

TABLE 1. Parameters of different routes in the network

	Energy Cost (DEARP)	AVG.RP	LocC	σ_{Path_x}	TotC (LEBRP)
Path 1	30	18/4 = 4.5	16.39	$\sqrt{12/4} = 1.73$	25.40
Path 2	40	31/5 = 6.2	10.67	$\sqrt{14.5/5} = 1.70$	16.53
Path 3	41	29/5 = 5.8	7.25	$\sqrt{6.5/5} = 1.14$	7.54

TABLE 2. Parameters of Path 4 in comparison with path 3

	Energy Cost (DEARP)	AVG.RP	LocC	σ_{Path_x}	TotC (LEBRP)
Path 3	41	29/5 = 5.8	7.25	$\sqrt{6.5/5} = 1.14$	7.54
Path 4	41	29/5 = 5.8	6.84	$\sqrt{15.5/5} = 1.76$	12.03

Supposing the whole network average power equals 5.5, standard deviation will also be calculated according to formula [3].

$$SD_{Path1}=\sqrt{\frac{1}{4}\,(\,(6-5.5)+(5.5-2)+(5.5-1)+(9-5.5)\,)}$$

$$SD_{Path2}=\sqrt{\frac{1}{5}\,(\,(6-5.5)+(10-5.5)+(10-5.5)+(5.5-5)+(10-5.5)\,)}$$

$$SD_{Path3}=\sqrt{\frac{1}{5}\,(\,(6-5.5)+(6-5.5)+(8-5.5)+(5.5-3)+(6-5.5)\,)}$$

Table 1 summarizes these calculations. AVG.RP means the average remaining power of the path. As it is shown in Table 1, path 3 has a total cost much bigger than path1. So, DEARP chooses path 1 for data transmission, but our proposed protocol, LEBRP, chooses path 3, due to the smaller TotC value. This is logical, since although path 1 has a smaller energy cost, but the third node of the path will soon run out of energy since it has a low amount of remaining energy, but the path cost between it and the next node is very high. So, the path chain will soon tear apart and transmission by DEARP protocol will be interrupted. In other words, the remaining powers of nodes are not proportional to the transmission costs of node pairs. This case happens also for Path 2 in a milder case. Hence, although the remaining power of Path 2 is bigger than that of Path 3, and its energy cost is lower than Path 3, but in our protocol Path 2 has lower priority than Path 3, because there is a better power distribution in accordance with power costs in Path 3. So, LEBRP chooses Path 3 while DEARP chooses Path 2 which results in a heterogeneous network in terms of remaining power of nodes.

It should be mentioned that if there was another fourth path like what is shown in Figure 2, it would lose the competition since it has an inappropriate σ value, although its EC and its remaining power is totally equal to $Path_3$ and even its LocC value is smaller than $Path_3$. This preference is logical, since in a network which the average remaining power is 5.5, it is not advisable to use low power energy nodes such as second and fourth nodes in the path. As it is noticeable, the presented protocol chooses routes in a way that the network will not suffer from sudden drainage of a node in next routings. Consideration of multiple criteria has led to a longer network lifetime.

5. CONCLUSION

Wireless ad-hoc networks are a kind of network in which the nodes directly communicate with each other. This feature allows all wireless devices within range of each other to discover and communicate in peer-to-peer fashion without involving central access points. An ad-hoc network tends to feature a small group of devices all in very close proximity to each other. Performance suffers as the number of devices grows, and a large ad-hoc network quickly becomes difficult to manage. So, we should consider appropriate mechanisms for delivering data in large ad-hoc networks. Hence, proper routing protocol can help a lot. In this paper, we presented a routing protocol which tries to maximize network life time by means of energy balancing. This goal is achieved through routing on the basis of remaining power of nodes. Besides, we have also taken some other factors into consideration. These factors include the ratio of remaining power of a node to the distance of the node from next receiving node. Another factor is the ratio of remaining power of current node to the average remaining power of the whole network. Consideration of all these factors in the presented protocol has made it a suitable protocol which maximizes network lifetime and also balances the remaining power of nodes in the network. This equilibrium of remaining power of nodes makes the network a heterogeneous network in terms of energy. Such a network will never encounter the problem of sudden drainage of a node when the average remaining power of the network is in an acceptable level. Moreover, the presented protocol does not impose a high computational load on the network and is suitable for energy constrained networks.

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چکیده

شبکه بی سیم ادهاک به گونه خاصی از شبکه های بی سیم گفته می‌شود که در آن ها همه گره‌های شبکه دارای مجموعه توانمندی‌های یکسان در شبکه وبه صورت نظیر به نظیر می‌باشند. این گره‌ها دارای توان ارتباط با یگدیگر و همچنین ارتباط با سایر اجزای شبکه‌های مجاور می‌باشند. اما چنانچه طبیعت این گونه شبکه‌ها اقتضا می‌کند، به دلیل توانایی سیار بودن گره، این شبکه‌ها معمولاً به منبع تغذیه خارجی متصل نبوده و هر گره دارای منبع انرژی درونی محدودی می‌باشد. در این مقاله پروتکل مسیریابی سبکی را برای شبکه های دارای محدودیت انرژی ارائه نموده‌ایم که برای مسیریابی در شبکه فاکتورهای متعددی همچون میزان انرژی باقی مانده گره‌ها را در نظر می‌گیرد. به‌علاوه عامل‌های دیگری همانند نسبت انرژی باقی‌مانده یک گره به فاصله آن گره تا گره بعدی در مسیر، و همچنین نسبت انرژِی باقی‌مانده یک گره به متوسط انرژی باقی‌مانده در کل شبکه را در تصمیم گیری مربوط به مسیریابی دخیل نموده‌ایم. هدَف اصلی این پروتکل، مسیریابی به گونه‌ای می باشد که کل شبکه از لحاظ میزان انرژی باقی‌مانده دارای یک‌پارچگی و توازن باشد. این یک‌پارچگی و توازن انرژی نهایتاً منجر به افزایش عمر شبکه خواهد شد. به‌علاوه، این پروتکل از تحمیل بار سنگین محاسباتی بر روی شبکه خود داری کرده و به همین دلیل برای استفاده در شبکه‌های دارای محدودین منابع و محدودیت محاسباتی مفید است.

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doi: *10.5829/idosi.ije.2014.27.01a.05*