A Novel Multi-Path Routing Protocol in Wireless Sensor Networks

Li-Ming He
School of Information Engineering
Chang’an University
Xi’an, China
Email: limhe08@yahoo.com.cn

Abstract—In wireless sensor networks (WSNs), multi-path routing can find multiple paths from source node to sink node for achieving high reliability and high energy-efficiency. However, the existing multi-path routing protocols in the literature construct multiple paths with long latency and high overhead [11] [12] [13]. In this paper, a novel multi-path routing protocol in WSNs is proposed, which can discover multiple paths with short latency and low overhead. Performance analyses and simulation results show that our proposed protocol has much better performance than the existing ones in terms of both latency and overhead.

Keywords - multi-path routing, wireless sensor networks

I. INTRODUCTION

In recent years, a special type of ad hoc networks, wireless sensor network (WSN), has attracted much attention of researchers [1]. WSNs consist of a large number of tiny low-power devices capable of performing sensing and communication tasks. In WSNs, wireless devices are usually called nodes, which spontaneously form a network without the need of any infrastructure so that a multihop wireless network is constructed. The main task of a WSN is to sense, collect, process and transmit data including physical parameters and events to a central base station where the collected information can be used for various purposes. The applications of WSNs are quite numerous, for example, emergency applications, environment monitoring, information gathering in battlefields, operating indoors for intrusion detection and so on.

In addition to the common characteristics of traditional wireless networks like mobile ad hoc networks, WSNs have some specific ones, such as very limited energy and bandwidth resources, high density of node deployment, and cheap and unreliable sensor nodes which are prone to failures. Due to these inherent characteristics that distinguish WSNs from other networks, routing issue in WSNs is very challenging. For example, as the number of sensor nodes is relatively large, it is impossible to build a global addressing scheme for all the nodes. Thus, traditional IP-based protocols may not be applied to WSNs. Recently, intensive research efforts have been focused on designing routing protocols specifically for WSNs, such as [2-10].

Of these routing protocols in the literature, some can find multiple paths from source node to sink node. Sensing data will be delivered along these paths at the same time. Two main benefits can be achieved by multi-path routing: First, as the transmission load is balanced among multiple paths, the energy of nodes is burned more equitably. Thus, energy-efficiency is increased and the network lifetime is prolonged. Second, multiple paths provide redundancy for data transmission, which increases the reliability of delivery.

C. Intanagonwiwat et al. proposed a popular data aggregation paradigm for WSNs called Directed Diffusion [11], which can find multiple paths from source node to sink node for transmitting the data at lower rate. In [12], D. Ganesan et al. proposed a novel braided multipath scheme, which results in several partially disjoint multipath schemes. In [13], B. Deb et al. proposed a multipath protocol called ReInForM to support information awareness in sensor networks.

However, the existing multi-path routing protocols in the literature construct multiple paths with long latency and high overhead, which greatly decreases the applicable value of them. In this paper, a novel multi-path routing protocol in WSNs is proposed, which can discover multiple paths with short latency and low overhead. Our proposed protocol is composed of three phases: double routing trees construction, route discovery, data transmission.

The rest of this paper is organized as follows. Section II proposes the system model. Our proposed protocol is presented in Section III. Performance evaluations are given in Section IV. Finally, the conclusion is made.

II. SYSTEM MODEL

In this paper, the following assumptions are made. The WSN is composed of a base station (BS) and a set of sensor nodes which are scattered in an area A. The network is data centric.

Each sensor node is energy constrained and has the knowledge of its energy. Each node has a unique identifier (ID) and can directly communicate with its immediate neighbors. A link layer protocol ensures this communication. Every link between two nodes is bidirectional.

III. OUR PROPOSED ROUTING PROTOCOL

The proposed multi-path routing protocol is composed of three phases: double routing trees construction, route discovery, data transmission.
A. Double Routing Trees Construction

Double routing trees construction phase constructs two trees: query tree which is rooted at sink node and search tree which is rooted at source node. At the time when the construction of two trees begins, sink node broadcasts query messages and source node broadcasts search messages. Once one node receives a query message, it enters the query tree. And once one node receives a search message, it enters the search tree. The construction of two trees ends at the same time. The period of construction is preassigned, which determines the size of two trees, i.e. the number of nodes in two trees. After two trees have been constructed, there are some nodes which belong to both of two trees, called shared nodes. The longer the construction period of two trees is, the more the shared nodes are.

B. Route Discovery

In this phase, multiple paths from source node to sink node will be discovered. In double routing trees constructed in the first phase, for each shared node, one and only one path can be discovered from source node to this shared node then to sink node. One shared node can determine one path. Since there are multiple shared nodes, multiple paths can be discovered.

C. Data Transmission

When source node has collected sensing data, it sends the data along multiple paths discovered in the previous phase to sink node.

IV. Evaluating Our Proposed Protocol

In the process of double routing trees construction, query and search messages are transmitted by broadcasting from sink node and source node to exterior. We assume that the delivery speed of query and search messages is the same, and that the delivery speed of the messages in diverse directions is the same. Thus, query and search messages form two circles whose centers are sink node and source node respectively. As time goes, the two circles are larger and larger. When they intersect, the shared nodes emerge. The construction period of two trees determines the size of the two circles, thus determines the number of shared nodes. The longer the period is, the larger the two circles are, and the more the shared nodes are.

Fig. 1 shows the two circles whose radius is R. The distance between two centers of them, i.e. the distance between sink node and source node, is D. The two circles intersect and form a central angle of $\Phi$. It is assumed that the density of nodes in the network is $\rho$, i.e. the number of nodes in unit area is $\rho$.

We will evaluate our proposed protocol by three parameters: the latency, the number of paths and the overhead.

A. The latency of our proposed protocol

The latency of our proposed protocol is composed of the time of double routing trees construction and the time of route discovery. First, we analyze the former, and then we evaluate the whole latency through simulation.

Figure 1. The concept of our protocol and Directed Diffusion

The time of double routing trees construction is the time during which the messages propagate from sink node and source node to the circumference and is defined as T. T can be divided into two parts: the propagation time in the space, $T_p$, and the time during which the message settles at nodes, $T_s$. So, we have:

$$T = T_p + T_s$$  \hspace{1cm} (1)

First, we calculate $T_s$. In one circle of Fig. 1, we focus on a sector whose central angle is $\alpha$. The number of nodes in this sector is:

$$n = \int_0^R \int_0^\alpha \rho \cdot r \cdot d\theta = \frac{1}{2} \rho \alpha R^2$$  \hspace{1cm} (2)

During the period of T, one message passes by h nodes, i.e. the number of nodes in one radius of the circle is h. Then, we have:

$$n = \int_0^\alpha h \cdot d\theta = h \alpha$$  \hspace{1cm} (3)

From (2) and (3), we get:

$$h = \frac{1}{2} \rho R^2$$  \hspace{1cm} (4)

At each node, the time taken by the message is divided into the receive time, $t_r$, and the send time, $t_s$. So:

$$T_s = (h-1)t_r + (h-1)t_s$$  \hspace{1cm} (5)

Now, we calculate $T_p$. The propagation speed of query and search messages in the space is defined as V. Thus, we have:

$$T_p = \frac{R}{V}$$  \hspace{1cm} (6)

Then
\[ T = \left( \frac{R}{V} + \left( \frac{1}{2} \rho R^2 - 1 \right) t_5 + \left( \frac{1}{2} \rho R^2 - 1 \right) t_5 - \frac{1}{2} \rho R^2 - 1 \right) \] (7)

As \( \rho, t_5 \) and \( t_5 \) are all fixed, \( R \) is determined by \( T \).

Through simulation, we compare the latency of our proposed protocol with that of Directed Diffusion [11] and the protocol in [12], as shown in Fig. 2. It can be seen that the latency of our protocol is shorter than that of both Directed Diffusion and the protocol in [12]. Especially, the improvement for our protocol to the protocol in [12] is very large.

B. The number of paths

The central angle of \( \Phi \) is:

\[ \phi = 2 \arccos \left( \frac{D}{2R} \right) \] (8)

The length of the chord corresponding to the central angle of \( \phi \) is derived as:

\[ L = \sqrt{4R^2 - D^2} \] (9)

Thus, the number of shared nodes, i.e. the maximum number of paths, is:

\[ S = \rho \sqrt{4R^2 - D^2} \] (10)

It is assumed that the probability for one path can’t be used is 1-p. Thus, the number of paths discovered in route discovery phase will be:

\[ Q = p \rho \sqrt{4R^2 - D^2} = p \rho D \sqrt{4 \left( \frac{R}{D} \right)^2 - 1} \] (11)

It can be seen that \( Q \) is determined by \( R \) and \( D \). Fig. 3 shows the number of paths versus \( D/R \). It is assumed that \( D=2, \rho=20 \) and \( p=0.5 \).

As \( R \) is determined by \( T \), for various \( D \), we can adjust \( T \) to fix the value of \( D/R \). Then, \( Q \) is only affected by \( D \). It is assumed that \( D \) follows normal distribution, and the mean is \( \mu \), the variance is \( \sigma^2 \). So, the mean of \( Q \) is:

\[ \mu = p \rho \mu \sqrt{4 \left( \frac{R}{D} \right)^2 - 1} \] (12)

The variance of \( Q \) is:

\[ \sigma^2 = p^2 \rho^2 \left[ 4 \left( \frac{R}{D} \right)^2 - 1 \right] \sigma^2 \] (13)

The probability density function of \( Q \) is:

\[ f(x) = \frac{1}{p \rho \sigma \sqrt{8 \pi R^2 D^2 - 2 \pi}} \exp \left[ \left( x - p \rho \mu \sqrt{4 \left( \frac{R}{D} \right)^2 - 1} \right)^2 \right] \left[ 2p^2 \rho^2 \left[ 4 \left( \frac{R}{D} \right)^2 - 1 \right] \sigma^2 \right] \] (14)

Fig. 4 shows the probability density function of \( Q \) when \( \rho=20, p=0.5, D/R=1.8, \mu=2, \sigma^2=1 \).

Figure 2. The latency versus the number of all the nodes

Figure 3. The number of paths versus \( D/R \)

Figure 4. The probability density function of \( Q \)
C. The overhead of our proposed protocol

We evaluate the overhead of our proposed protocol by the total number of messages transmitted in the network. Averagely, every node in the two circles of Fig. 1 only transmits one message. Thus, the total number of messages equals the number of nodes in the area covered by the two circles, which is defined as $N_T$ and is derived as:

$$N_T = 2\rho \left[ (\pi R^2 - \frac{1}{2} \phi R^2) + \frac{1}{2}DR \sin \frac{\theta}{2} \right]$$  \hspace{1cm} (15)$$

From (8), (9) and (15), we get:

$$N_T = 2\rho \left[ (\pi R^2 - \arccos \left( \frac{D}{2R} \right) R^2) + \frac{1}{4} D \sqrt{4R^2 - D^2} \right]$$ \hspace{1cm} (16)$$

If messages are only transmitted from sink node by broadcasting like in Directed Diffusion [11], a single circle whose radius is $D$ will be constructed, as shown in Fig. 1. We assume that every node still transmits only one message. Then, the total number of messages under this condition is:

$$N_S = \rho \pi D^2$$ \hspace{1cm} (17)$$

We compare the total number of messages in our proposed protocol and that in Directed Diffusion [11], as shown in Fig. 5. It can be seen that the number of messages increases as the D/R increases in both two protocols. But the increasing speed of our protocol is much smaller than that of Directed Diffusion [11]. When D/R is about 1.33, two lines intersect. We can adjust T to make the D/R be larger than 1.33. Then, $N_T$ is always smaller than $N_S$, i.e. the overhead of our protocol is less than that of Directed Diffusion.

V. CONCLUSION

In this paper, a novel multi-path routing protocol in WSNs is proposed to discover multiple paths with short latency and low overhead. Our proposed protocol is composed of three phases: double routing trees construction, route discovery and data transmission. Mathematical analyses and simulation results show the much better performance of our proposed protocol than that of the existing ones.

REFERENCES