Multi-path Routing Protocol with Optimum Routes Finding Scheme in Wireless Sensor Networks

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Abstract

Finding an energy efficient route is one of the very important issues in the wireless sensor networks. The route scheme should consider both of the energy level of sensor nodes and the number of hops at the same time. First of all, this paper proposes an optimum routes finding scheme (ORFS), which could be used in the sensor network routing protocols. The scheme uses an optimum value for the path with the considerations of both the minimum energy level of a path and the number of hops at the same time. After that, this paper proposes a routing protocol based on the ORFS for how it could be used for the multipath directed diffusion with data aggregation (MDD-A), to get the better energy efficiency. The analysis result shows that the proposed routing protocol could lengthen the network life cycle about 18.7% compared to the previous MDD-A related protocols.

Keywords:

Wireless Sensor Network; Routing Protocol; Energy Efficiency; Directed Diffusion

1. Introduction

Sensor networks differ from traditional networks in several ways : sensor networks have severe energy constraints, redundant low-rate data, and many-to-one flows. Among them, one of the main challenges raised by sensor networks is the fact that they are usually power constrained [1]. Thus, energy conservation is of prime consideration in sensor network protocols in order to maximize the network's operational lifetime. To find energy efficient routes, most of routing protocols uses one of common three schemes : considered with just hop counts, considered with energy level of sensor nodes, and considered with an average energy level [2]. However, the route finding scheme should consider both of the energy level of sensor nodes and the number of hops at the same time.

Thereby, first of all, this paper proposes an optimum routes finding scheme (ORFS), which could be used in the overall sensor network routing protocols. The scheme uses an optimum value for the path (OV_{path}) with the considerations of both the minimum energy level of a path ($MinEnergy_{path}$) and the number of hops ($Hopcount_{path}$) at the same time by using the equation, $OV_{path} = MinEnergy_{path} / Hopcount_{path}$. By using this equation, the scheme could get a shortest path with the consideration of the energy in that path. After that, this paper proposes a routing protocol based on the ORFS for how it could be used for the multipath directed diffusion with data aggregation (MDD-A), to get the better energy efficiency. The analysis result shows that the proposed routing protocol could lengthen the network life cycle about 18.7% compared to the previous MDD-A related protocols.

2. Related Works

This section describes the basic schemes related with the proposed schemes. At first the previous route finding schemes are described with the analysis of the problems in them. Then flat-based schemes with data aggregation are abbreviated for the later comparison with the proposed scheme.

2.1 Route Finding Scheme

To find energy efficient routes, most of routing protocols uses one of common three schemes, i.e., using a path with minimum hop counts (Scheme 1), a maximum path within the minimum nodes energy remainder levels (Scheme 2),

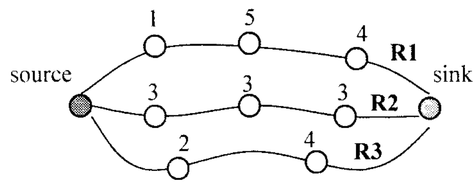

Figure 1 – An example to establish routes

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and a path with the maximum of average energy remainders (Scheme 3) [2]. Figure 1 shows an example to illustrate how these schemes work. Scheme 1 is usually used in the wireless networks and the wireless ad hoc networks and it does not consider the energy remainders. The scheme would choose the route R3 as shown in Table 1. Scheme 2 chooses the route R2 which is for the extension of network life cycles by choosing a maximum path within minimum energy levels of nodes. However, there is a detouring problem because of without considered with the hop counts. Contrast with that Scheme 3 will choose the route R1 due to it considers both of the energy remainders and the hop counts. The scheme seems like it uses routes in the overall energy considerations and chooses somewhat shortest paths in the perspective of the hop counts. However, there are network partitioning problem or sensing hole problem in scheme 1 because the chosen route R1 has a node with energy remainder with 1. If the scheme uses the route R1, a node with the energy remainder of 1 will exhaust its energy and dies forever. Thereby, the first purpose of this paper is proposes an improvement of these schemes by considering both of the energy remainders and the hop counts.

Table 1 – Properties in each route

Path	Hop count	Minimum Energy Level	Average Energy Level
R1	3	1	3.3
R2	3	3	3
R3	2	2	3

2.2 Flat-based Routing Scheme with Data Aggregation

This sub-section describes the basic schemes to understand our paper and these schemes are used to analysis the proposed protocol. The proposed scheme is based on directed diffusion so it is first abstracted and then some protocols based on it but considered with the data aggregation are described in a little bit detail [3-5].

2.2.1 Directed Diffusion

Directed diffusion (DD) is an important milestone research in the flat-based routing [3]. DD aims at diffusing data through sensor nodes by using a naming scheme for the data. Figure 2 shows the routing establishment scheme.

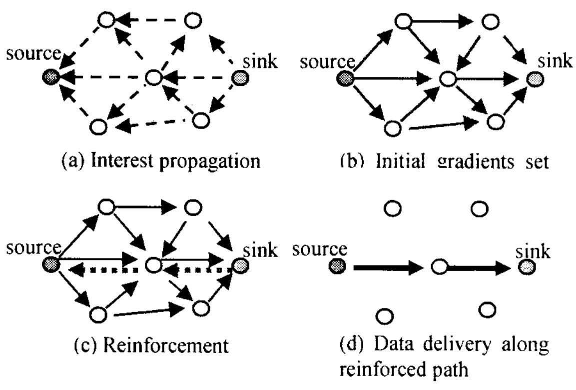

Figure 2 – A simplified schematic for DD

A sink floods interests for named data. Nodes which received the interests establish routes to the sink with the considerations of gathered information from sink to that node and send back an initial data to the sink by that route. When the sink receives the data, it sends a route enhancement message to the source node by using a lowest latency route. The source node uses the route to communicate with the sink after it received the enhancement message. This scheme is adjustable to pre-established period based query and response. However, there are network partitioning problem or sensing hole problem in DD because is does not consider the nodes' energy level.

2.2.2 DD-based Routing Scheme with Data Aggregation

The DD itself is not energy efficient [4,5]. Thereby, there are some protocols which combine the DD with data aggregation. Data aggregation is used to reduce the communication costs. It means that the scheme could reduce the overall energy consumption in sensor network by reducing the size of transmitted data and the number of transmissions by aggregating data in intermediate nodes. This sub-section describes a directed diffusion greedy routing scheme and a multi path DD-Aggregation scheme in sequence.

[***Directed Diffusion Greedy Routing Scheme***] Intanagonwiwat et al. proposed a directed diffusion greedy routing scheme (DD-G) which applies data aggregation to the DD [4]. The DD-G uses an energy cost, E and an extension cost, C to set up the data aggregation point. E represents the number of hops between the source node to current node and C represents the hop counts from the source node to the pre-established path. When the DD-G establishes a path from the first source node to the sink by using the DD, the path establishment phase for the data aggregation is as follows :

Step 1 : The source node in the pre-established path sends an extension cost message to the sink if it receives exploratory data from the other source nodes.

Step 2 : The sink broadcasts a reinforcement message after it receives the incremental cost message.

Step 3 : A node with the condition of $C = E$ is pointed as the data aggregation point.

The DD-G reduces the communication costs from source nodes to a sink by aggregating data from many source nodes. However, the established path has a possibility of node energy depletion and thereby the scheme should choose an alternative path. Furthermore, there would be a tendency that the cost of data retransmission will be high due to the increment of packet loss ratio and the energy consumption would be also high for the sink node nearest nodes. Also the DD-G should consider that the size of the aggregated data would be increased by the incremental of the number of source nodes and then the data are not transmitted in a packet.

[*Multi path DD-Aggregation*] A multi-path data diffusion with data aggregation (MDD-A) is proposed to solve the deficiencies in the DD-G [5]. The MDD-A is consisted with root node selection phase, multi-path establishment phase, and data aggregation point selection phase. First of all, the root node selection phase uses equation 1 to choose root nodes.

$$N_{root} = N_{source} / N_{source\ path} \quad (1)$$

The number of root nodes, N_{root}, over a network is computed by the considerations of the number of source nodes, N_{source}, and the maximum number of source nodes in each path, $N_{source\ path}$ where is computed by the consideration of systems MTU. However, the size of the aggregated data, $L_{aggregated\_data}$, should not bigger than the maximum packet size for the data, $MTU\text{-}L_{headder}$, with the condition of equation 2.

$$L_{aggregated\_data} \leq (MTU - L_{headder}) \quad (2)$$

Ordinarily nodes near to sink are selected as the root node by considering the energy remainder level of the node. The MDD-A follows these steps to set up multi-path.

Step 1 : Each root node floods data request message with its own ID in the path. When it receives a request from other roots, it just ignores them.
Step 2 : A source node selects a route with the smallest hop counts and sends an initial data to the root node by using the selected route.
Step 3 : Root nodes with the maximized number of source nodes broadcasts a root full message.
Step 4 : The source node which received the full message sends the initial data to the second root.

The data aggregation point selection phase is the same with the DD-G but the MDD-A establish multi-path with its own root node.

The MDD-A could solve the aggregated energy consumption problem by diversifying routes and en-lengthen the overall network life cycle. However, there are potential possibilities of network partition problems and sensing hole problem due to it only consider the number of hop counts to set up multi-path.

3. A Routing Protocol based on ORFS

This section proposes a routing protocol based on an optimum route finding scheme (ORFS) for the energy efficiency. First of all, an ORFS is proposed to set an energy efficient route with the considerations of both nodes energy levels and the number of hops. After that we propose a routing protocol based on the ORFS for that how the ORFS could be used for the multi-path DD with data aggregation (MDD-A).

This paper assumes that a routing protocol uses the linear data aggregation model and the ORFS assumes that each node has an energy level within 0 ~10.

3.1 Optimum Routes Finding Scheme

The route scheme should consider both the energy level of sensor nodes and the number of hops at the same time. If a route scheme considers only energy level of nodes, it could select a long hop counts route. In contrast with that, a scheme could not support nodes energy remainders when it only considers the number of hops. To solve these problems, this paper proposes an optimum route finding scheme (ORFS). The overall routing scheme in ORFS is similar with the DD but route selection is somewhat different.

The basic idea of the ORFS is that a route scheme is good when if it could choose a route with a minimum energy remainder level of nodes and with a shortest hop counters. Thereby, when a sink floods interests, the ORFS keeps both a minimum energy level of nodes and the number of hops in a path. When a node receives the interest, it establishes routes to the sink with the consideration of both of them. Node could get the energy efficient path by using Equation 3.

$$OV_{path} = Min\_Energy_{path} / Hop\_count_{path} \quad (3)$$

, where a maximum path within the minimum nodes energy remainder levels from the sink to the source and a number of hop counts are denoted by Min_Energy_{path} and Hop_count_{path}, respectively. The ORFS chooses an optimum route among the optimum values (OV_{path}) in the equation 3

Figure 3 shows an example to establish an optimum route with the considerations of both nodes energy remainders and the number of hops.

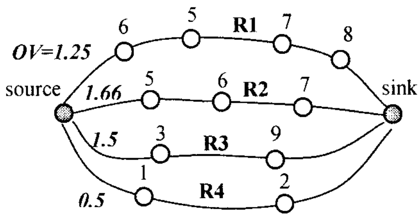

Figure 3 – An example of an optimum route selection

The optimum value OV_{R1} of the route, R1, in Figure 3 gets 1.25 from 5/4 which a minimum energy level in nodes is 5 and the number of hops is 4. From this observation, we could know that the ORFS finds an optimum OV_{path} with a maximum lower energy level and the smaller hop counts. Thereby, the ORFS chooses the route R2 in Figure 3, which has a maximum value of OV_{path}. However, the DD chooses R3 or R4 because it considers the number of hops. They look like good candidates but they do not last for long times due to the remainder energy considerations. Additionally, the most of energy efficient routing protocols would select R1 but it detours the network than R2.

Next sub-section proposes a routing protocol based on the ORFS for how it could be used for the MDD-A.

3.2 Multi-path Routing Protocol based on the ORFS

This sub-section proposes a multi-path routing protocol with data aggregation based on the ORFS (OMDD-A). The OMDD-A is a flat based routing protocol and is consisted with root node selection phase, multi-path establishment phase, and data aggregation point selection phase. The root node selection phase in the OMDD-A is same with the MDD-A. However, two different phases are different with the MDD-A in the perspective of route selections which our scheme is based on the ORFS. Thereby, this sub-section only focuses on two different phases. There are many messages that we need to abstract in the OMDD-A.

- Interest message : Data collection request message from a root node (including a sink node) to source nodes.
- Exploratory message : Response message for the interest message from source node to root node (including a sink)
- Reinforcement message : Path reinforcement message from root node to source node
- Incremental message : Path incremental message from root node to source node
- Incremental exploratory message : When source node receives an incremental message, this message is used to find a path to be established
- Incremental cost message : When source node receives an incremental exploratory message, this message is used to find a data aggregation point

3.2.1 Multi-path Establishment Phase

The purpose of this phase is to set up multiple paths from the source to the sink. This phase is consisted with following steps.

Step 1 : Each root node floods data request message with its own ID and a minimum energy level in the path. When a node receives the request, it changes the value if its own energy level is lesser than the received energy information. After it processes the request, it just ignores messages from other roots.

Step 2 : A source node selects an optimum route by the ORFS and sends initial data to the root node in the selected route.

Step 3 : Root nodes with the maximized number of source nodes broadcasts a root full message.

Step 4 : The source node which received the full message sends the initial data to the second root.

Step 5 : Root nodes sends reinforcement message after they received the initial data and incremental message to the route.

Note that this multi-path establishment phase requires an additional step, i.e. step 5 to set up the data aggregation path establishment. Figure 4 shows the overall snapshot for the multi-path establishment phase.

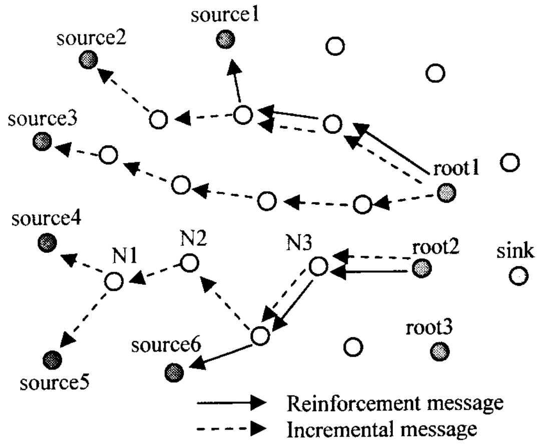

Figure 4 – An example for the multi-path establishment

3.2.2 Data Aggregation Point Selection Phase

When the ORFS chooses the data aggregation point, it uses both of the energy considerations and the hop counts. The data aggregation point selection phase follows the steps :

Step 1 : A source node broadcast an incremental exploratory message after it receives an incremental message from the root node.

Step 2 : When a node receives the incremental exploratory message, it checks and computes *OV* if the ID of its own root nodes is the same as in the message or else it just updates the minimum energy level and broadcasts to its neighbors.

Step 3 : If an source node receives an incremental exploratory message from the other source nodes, it sets its incremental cost, *C* into its *OV* and broadcasts an incremental cost message to its root node.

Step 4 : When a node receives the incremental message, it checks and sets the position as the data aggregation point if the condition $C = OV$ matches or else it updates the *OV* in the message into its own *OV* when the received *OV* is less than its own *OV*. A root node sends a reinforcement message when it receives the incremental message.

Whether a node is not the data aggregation point and receives more than two data from source nodes, it aggregates the data and sends to the next node. For example, as shown in Figure 4 if N3 is set to the data aggregation point and source 4 and 5 settled the paths with N1, N2, and N3, the data from source 5 is aggregated in N1, re-aggregated in N3 with the data from source 6, and transferred to root2. Figure 5 shows an example for the data aggregation point selection phase from source nodes with the same roots IDs.

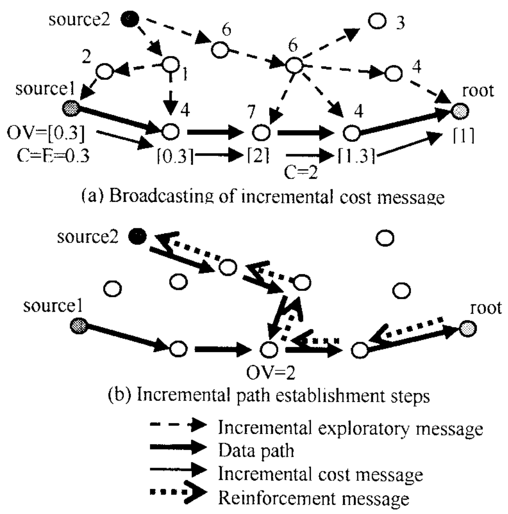

Figure 5 – An example to set up the data aggregation point

4. Analysis

This section gives analysis by performance comparisons with the DD-G, the MDD-A, and the OMDD-A [4,5]. For the analysis, we assumed the linear data aggregation model. The parameters for the analysis are the network life cycle and the latency by increasing the number of source nodes. Table 2 shows the network configurations for the performance evaluation.

Table 2 – Network configurations

Number of nodes	60 nodes
MTU of system	36 bytes
Length of header	16 bytes
Length of payload	2 bytes
Era of data aggregation	0.5 sec

The MDD-A and the OMDD-A computes the maximum number of nodes and the number of roots in each path for the network configurations. We assume that the maximum size for the aggregated data is 20 bytes and the maximum number of nodes in each path has 10. Additionally, the number of root nodes is assumed with 6.

4.1 Network Life Cycle

For the evaluation of the network life cycle, we randomly selected the number of source nodes with less than 10 nodes in each data aggregation term. Figure 6 shows the result of it. The DD-G has the lowest network life cycle but MDD-A extents its life cycle about 15.2% compared to the DD-G. The proposed OMDD-A en-lengthen about 18% compared to the MDD-A.

The MDD-A gets a better performance compared to the DD-G by diversifying energy consumption with multi-path through root nodes. However, the proposed OMDD-A enhanced the performance by using the proposed optimum route finding scheme. Note that if a node has a small amount of energy remainders in the OMDD-A, we also could guess that the overall network energy is less remained.

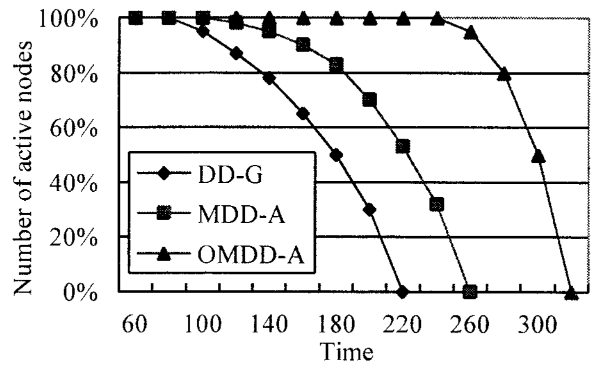

Figure 6 – Network life cycle comparison

4.2 Latency by Increasing the Number of Source Nodes

For the latency comparison, we assumed that the number of source node is increased by one by one in each 10 seconds. We start the simulation with only one source node and increases the number of source node until 20. Figure 7 shows the result. The DD-G gets the best result when the number of source nodes is less than 10 but drastically falls in more than 10 source nodes. The proposed OMDD-A gets a better latency average by increasing the number of source nodes.

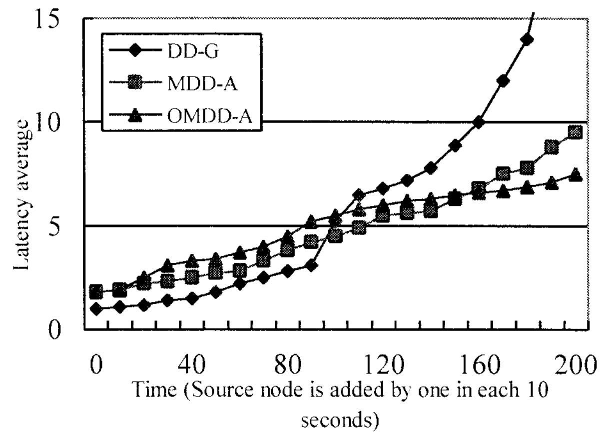

Figure 7 –Latency comparison

When the number of source nodes is less than 10, the MDD-A and the OMDD-A have a longer latency than the DD-G due to the multi-path establishment overhead. The reason that the OMDD-A gets a little bit longer latency average is that there is possibility of detouring in the OMDD-A due to the considerations of both the energy remainders and the hop counts.

5. Conclusion

Finding an energy efficient route is one of the very important issues in the wireless sensor networks. This paper proposed an optimum route finding scheme (ORFS) at first, which could be used in the sensor network routing protocols. The scheme uses an optimum value for the path with the considerations of both the minimum energy level of a path and the number of hops at the same time. After that, this paper proposed a routing protocol based on the ORFS for how it could be used for the multipath directed diffusion with data aggregation (MDD-A), to get the better energy efficiency. As we get from the analysis, the proposed routing protocol could lengthen the network life cycle about 18.7% compared to the previous MDD-A related protocols.

6. References

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