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Multipoint Relay with Energy Awareness for System Data Sharing in WSN

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Abstract

In this paper, a multipoint relay with energy awareness (EA-MPR) is proposed for a system data-sharing protocol, abbreviated as EAMPR-SDS. It adopts a system data-sharing concept which combines broadcasting routing with data fusion so that data exchange between wireless sensor nodes can be easily realized in the real world. Owing to the energy constraint of WSN, the proposed protocol employs EA-MPR to improve the transmission efficiency and extend network lifetime. Unlike some broadcasting optimizing mechanism such as self-pruning, it assigns a sending node to decide which of its neighbors should forward the shared data on the basis of the neighbors' rest energy as well as the neighbor information. Therefore, instead of all the nodes in the network, only a subset of nodes needs to forward the shared data while still guaranteeing complete network connectivity. The simulation results prove that in comparison with the existing system data-sharing protocol and self-pruning, EAMPR-SDS can significantly reduce the redundant broadcasting and its corresponding power consumption.

1. Introduction

The wireless sensor network is widely used in many applications. Because of the limitation of the calculation and communication capabilities of the wireless module, WSN needs very simple transmission protocols to realize data exchanging among the nodes. System data sharing is a transmission style with low complexity proposed for mobile WSN applications, wherein each node can share data with all the others [1]. In WSNs, broadcasting can serve as an efficient solution for sensors to share their local measurements among each other, owing to the robustness and the low complexity of the protocol. Broadcasting routing process and data fusion [2] concepts are combined into system data sharing. Broadcasting is a special routing process of transmitting a packet so that each node in a network receives a copy of this packet. Data fusion causes a node to select the newest received data to forward to the network. It can also improve transmission efficiency by integrating the data from different source nodes for one broadcast.

Figure 1: Related works of system data-sharing protocol

The synchronous dynamic multihop data-sharing (S-DMDS) protocol [1] and on-demand dynamic multihop data-sharing (On-Demand DMDS) protocol [3] were proposed for system data sharing in WSN, as shown in Figure 1. A regular broadcasted data sharing frame (DSF) was adopted as the interface to realize node data sharing, as shown in Figure 2. However, S-DMDS instructed each node to broadcast the whole DSF regularly so that a certain amount of redundant data is forwarded through the network when there is not much data that needs to actually be shared. Then, the On-Demand DMDS protocol is presented, in which the node to broadcast DSF is assigned according to the real demand. When the broadcast time slot arrives, instead of broadcasting the whole DSF, an on-demand mechanism will be used to detect if any new shared data needs to be broadcast as well as to decide how much data needs to be broadcast. In this way, the On-Demand DMDS protocol can constrain the source node from generating redundant data. S-DMDS is proved to be the worst case of On-Demand DMDS [3]. However, On-Demand DMDS protocol neglects the forwarding by intermediate nodes, and consequently, each node must forward the received shared data. It also leads to the consumption of much unnecessary energy. Therefore, the protocols proposed in [1] and [3] lead to high data redundancy and power consumption, which limit them to energy-restricted applications of WSN.

Some broadcasting optimization strategies, such as self-pruning [4], can reduce the redundant broadcasting by using neighbor information. Self-pruning can help the node decide whether to retransmit a particular packet or not. Although self-pruning is simple and low cost (it only needs one-hop neighbor information), it is not so efficient since only those

Figure 2: DSF structure in EAMPR-SDS protocol

Figure 3: Example of optimized broadcasting with energy awareness

nodes very close to the sender or at the endpoints can satisfy the self-pruning condition.

In this paper, multipoint relay with an energy-awareness (EA-MPR) mechanism is proposed for the system data-sharing protocol. It can reduce redundant rebroadcasting and extend network lifetime. Unlike self-pruning, it instructs the sending node to decide which of its neighbors to forward the shared data on the basis of the neighbors' rest energy as well as the neighbor information. Therefore, intermediate node forwarding becomes more energy efficient.

This paper is organized as follows. In Section 2, the EAMPR-SDS protocol is elaborated. In Section 3, the performance of EAMPR-SDS is analyzed. Then, the simulation results are compared and provided in Section 4. Finally, the conclusion is summarized in Section 5.

2. Multipoint Relay with Energy Awareness for System Data Sharing

The EAMPR-SDS protocol inherits most functions of On-Demand DMDS [3] including the system data-sharing concept, TDMA access method, on-demand mechanism, neighbor table, and report mechanism.

In this paper, to alleviate the redundant broadcasting problem, the EA-MPR mechanism, which inhibits some nodes from rebroadcasting, has been proposed. Once a node wants to share its data with the network, instead of making all nodes forward data, only a subset of nodes is selected to forward the data while still guaranteeing complete network delivery. For example, a WSN is shown in Figure 3. Node S is the source node. After S broadcasts, all the other nodes need to forward the message without adopting any

optimized broadcasting strategy. This step is unnecessary and wastes the limited wireless bandwidth. A practicable solution is that after node S broadcasts, only node C is selected to forward the message while still guaranteeing reachability. Set {S, C} forms the subset of broadcasting nodes.

2.1 EA-MPR mechanism

EA-MPR is an energy-efficient broadcasting optimized strategy, which instructs the sending node to decide which of its neighbors to forward the shared data on the basis of the neighbor's rest energy as well as the neighbor information. Hence, nodes must exchange their neighbor information and their rest energy information regularly. (Neighbor table and rest energy information are attached to the DSF head, as shown in Figure 2.) A realistic example of creating a one-hop neighbor table in the system data-sharing protocol is presented in [3]. The selected nodes are called MPRs and are listed in the MPR set of each shared block, as shown in Figure 2. MPRs are selected in such a way that if they rebroadcast the shared data, all the two-hop neighbors of the sending node can receive the broadcast data. The size of the MPR set should be as small as possible. The procedures of the sending node selecting its neighbor to forward the shared data can be described as follows.

Step 1: After a node receives a DSF, it empties the MPR set of the corresponding shared block.

Step 2: To the MPR set, add the one-hop neighbors that are the only path of some two-hop neighbors. Then, remove these two-hop neighbor nodes that are covered by these one-hop neighbors.

Step 3: Try to find the one-hop neighbors that have a larger evaluation index M . M is related to the rest energy (E_{rest}) and the number of uncovered two-hop neighbors (D_2) that can be covered by this node (Eq. (1) describes the details; α and β are multiplication factors between 0 and 1). Remove all the two-hop neighbor nodes that are covered by these one-hop neighbors.

$$M = \alpha \times E_{rest} + \beta \times D_2 \quad (1)$$

Step 4: Repeat Step 3 until all the two-hop neighbors are covered.

Thus, after a node receives a DSF, it can check whether its node ID is in the MPR set of each shared block in order to decide whether to rebroadcast the corresponding shared block as the shared blocks of node 1 and node 3 shown in Figure 2. The example shown in Figure 3 can provide the details of energy awareness. If node C has enough energy, it will be selected into the MPR set because of its higher M . After the energy of node C tends to be exhausted, node A and node B will be selected into the MPR set to take the place of node C.

In this way, the redundancy of rebroadcasting can be reduced by the EA-MPR mechanism. Also, the energy cost of the nodes is balanced. Therefore, the network lifetime can be extended.

2.2 Working procedure of EAMPR-SDS

When a node reaches its broadcast time, it will calculate the MPR set for the shared blocks which will be broadcast

and create a different broadcasting DSF according to the following conditions.

- i. If a node detects the entry of a new neighbor, it will broadcast the whole DSF to the new neighbor. The purpose is to avoid the loss of data by mobile nodes [3].
- ii. If there is no new neighbor, it will adopt the On-Demand mechanism to decide whether to broadcast or how many shared blocks have new data to broadcast.
- iii. If the node detects a change in the Seq No. of some shared block, it will check each shared block's MPR set to judge how many shared blocks need to rebroadcast.
- iv. If a node has nothing to broadcast or forward, it will check whether it has been silent over $n \times \text{TDMA}$ broadcast cycles. The EAMPR-SDS protocol adopts the Report Mechanism that induces a node to broadcast the DSF head as a beacon to report its existence if the node remains silence over $n \times \text{TDMA}$ broadcast cycles. This is necessary for synchronization, neighbor table maintenance, and movement detection.

2.3 Discussion

Although EAMPR-SDS is energy efficient and it can reduce redundant forwarding in a network, it also needs some cost. For storing a two-hop neighbor table, one-hop neighbor rest energy, and the MPR set, the memory cost of EAMPR-SDS is higher than that of On-Demand DMDS, S-DMDS and self-pruning. Furthermore, since the neighbor table, rest energy, and the MPR set must be attached to the broadcasting DSF, the calculation overhead also becomes higher. Therefore, as a trade-off, higher-performance hardware is needed in terms of calculation speed and memory size. In addition, the EA-MPR is not suitable for high-mobility networks because with increasing mobility of the network, the two-hop neighbor information becomes inaccurate, which causes lower reachability.

3. Performance Analysis

In this section, we analyze and compare the performance of the EAMPR-SDS protocol in terms of transmission redundancy and power consumption. The amount of data transmitted ($K_{\text{EAMPR-SDS}}$) in a network per broadcast cycle after adopting the EAMPR-SDS protocol can be described by the following formula.

$$K_{\text{EAMPR-SDS}} = \begin{cases} \sum_{\text{MPR}} (K_{\text{DSF_head}} + \sum_n K_{\text{sharing_data}} + \sum_p K_{\text{node_id}}) + K_{\text{neighbor}^2} + K_{\text{neighbor_energy}} + \sum_s (K_{\text{DSF_head}} + K_{\text{sharing_data}} + \sum_p K_{\text{node_id}} + K_{\text{neighbor}^2} + K_{\text{neighbor_energy}}) & (0 < n \leq N) \\ 0 & (n = 0) \end{cases} \quad (2)$$

Here, $K_{\text{DSF-head}}$ and $K_{\text{sharing-data}}$ are the length of the DSF frame head and the length of the shared block in DSF, respectively. $K_{\text{node-id}}$ is the length of the node ID label, and we define $K_{\text{node-id}} \ll K_{\text{sharing-data}}$. K_{neighbor^2} is the size of the 2-hop neighbor

table and $K_{\text{neighbor}^2} \ll K_{\text{sharing-data}}$. $K_{\text{neighbor_energy}}$ is the size of the 1-hop neighbor energy table. We set each node to have the same size of the 2-hop neighbor table and 1-hop neighbor energy table in DSF. n means the number of broadcast requests per TDMA cycle. p denotes the number of node ID labels in DSF. MPR is the number of broadcasting nodes in the MPR set. s is the number of source nodes not in MPR set. From [3], we can get the amount of data broadcast in the network per broadcast cycle by adopting On-Demand DMDS, as shown in Eq. (3).

$$K_{\text{On-Demand}} = \begin{cases} \sum_N (K_{\text{DSF_head}} + \sum_N K_{\text{sharing_data}}) & (n = N) \\ \sum_N (K_{\text{DSF_head}} + \sum_n K_{\text{sharing_data}} + \sum_p K_{\text{node_id}}) & (0 < n < N) \\ 0 & (n = 0) \end{cases} \quad (3)$$

Here, N is the total number of nodes in the network. It has been proved that the broadcast data per broadcast cycle in On-Demand DMDS is less than that in S-DMDS ($K_{\text{On-Demand}} \leq K_{\text{S-DMDS}}$). The MPR size is much smaller than that of the entire node set. In addition, $K_{\text{neighbor}^2} \ll K_{\text{sharing-data}}$. It is obvious that the overhead of EAMPR is much less than the redundant broadcast data reduced by it. Then, the following equation can be satisfied.

$$K_{\text{EAMPR-SDS}} < K_{\text{On-Demand}} \leq K_{\text{S-DMDS}} \quad (4)$$

By Eq. (4), it was proved that the transmission data of the proposed EAMPR-SDS protocol is lower than those of the previous On-Demand DMDS protocol and S-DMDS protocol. The energy consumption of a node for broadcasting a packet of K bytes at distance d is [5]

$$E_T = E_{\text{elec}} \times K + \mathcal{E}_{\text{amp}} \times K \times d^2$$

$$E_R = E_{\text{elec}} \times K \quad (5)$$

where E_{elec} is assumed to be the radio dissipation during the operation of the transmitter and receiver circuitry, and $\mathcal{E}_{\text{amp}}$ is the transmission amplifier.

$$\therefore E_{\text{EAMPR-SDS}} < E_{\text{On-Demand}} \leq E_{\text{S-DMDS}} \quad (6)$$

Above all, EAMPR-SDS has the lowest energy consumption among system data-sharing protocols. From the result of the analysis, it can be concluded that the proposed protocol has higher transmission efficiency and energy efficiency than the On-Demand DMDS and S-DMDS protocols.

4. Simulation

In this section, we evaluate the performance of the EAMPR-SDS protocol in terms of the amount of transmission data at a constant arrive rate and the network lifetime. We compare it with On Demand DMDS and self-pruning, since S-DMDS is the worst case of On-Demand DMDS [3]. The simulation is conducted in a $100 \times 100 \text{ m}^2$ 2D free space; nodes are deployed in the network initially. The physical radio characteristics were chosen to approximate the IEEE802.15.4, and can provide a maximum 250 kbps transmission rate. Table 1 shows the main network

Table 1: Simulation parameters

Parameter	Value
Network size	100×100 m ²
Number of nodes	16
Arrive rate	16 broadcast requests per TDMA cycle
Node broadcast radius	35 m
Packet size of shared data block	20 bytes
Packet size of node ID label	2 bytes
Packet size of neighbor table	2 bytes
Packet size of frame head	20 bytes
TDMA broadcast cycle	320 ms
Each node broadcast time slot	20 ms
Each node initial energy	0.1 J
Radio dissipation for running the transmitter and receiver circuitry	50 nJ/bit
Transmission amplifier	0.1 nJ/bit/ m ²
Node move speed	1 m/s

parameters and their respective values. In Figure 4, EAMPR-SDS is seen to generate less data than do On-Demand DMDS and the self-pruning mechanism under a constant arrival rate (16 broadcast requests per TDMA cycle). The total transmission data in the EAMPR-SDS protocol is approximately 52.46% of that in On-Demand DMDS, and 62.3% of that in self-pruning.

Figure 5 illustrates that the network lifetime of EAMPR-SDS is longer than those of On-Demand DMDS and self-pruning. The reason is that EAMPR-SDS can not only adjust the energy consumption according to the busy extent of the network but also reduce some redundant forwarding on the basis of neighbor information. In this paper, we define that the network is in a failure state once the first node fails. Thus, when there are 16 broadcast requests per TDMA cycle in the network, EAMPR-SDS can extend the network lifetime roughly 3.4 times and 1.73 times in comparison with On-Demand DMDS and self-pruning, respectively.

5. Conclusion

In this paper, the EAMPR-SDS protocol was proposed for a mobile multihop WSN. By adopting the system data-sharing concept, it was possible to provide a highly efficient network for each node to share data with all other nodes. In addition, the proposed method employed the EA-MPR mechanism to select a subset of nodes to forward the shared data, and it also considered the rest energy of the node as a measure in selecting the forwarding node. Therefore, redundant broadcasting can be significantly reduced and the network lifetime can be extended. The simulation result proved that the performance of EAMPR-SDS is better than those of On-Demand DMDS and self-pruning in terms of the total transmission data and network lifetime. In comparison with On-Demand DMDS and self-pruning, EAMPR-SDS can extend the network lifetime approximately 3.4 times and 1.73 times, respectively, when 16 broadcasts are requested per TMDA cycle in the network.

Acknowledgement

This research was supported by Waseda University Global COE Program, International Research and

Figure 4: Comparison of total transmission data in the network

Figure 5: Comparison of network lifetime

Education Center for Ambient SoC sponsored by MEXT, Japan, and also by funds from MEXT via Kitakyushu innovative cluster projects.

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