Role-based Broadcasting Algorithm in Wireless Sensor Networks

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Abstract

In application-driven environment of wireless sensor networks, the role-based designing is a very important method to realize dynamic application, and role-packet broadcasting is a challenging problem. For large-capacity role-packet, the biggest problem is that there is too much cost in broadcasting. A role-based broadcast algorithm for wireless sensor networks (CRD algorithm) was presented, which use context information to calculate the relying cost function in order to reduce redundancy broadcast cost. On the basis of fully analyzing node's broadcast cost, the CRD algorithm optimizes the relaying cost function according to the requirements of application services and the around environment information of a node. Simulation and performance evaluations were down about broadcast rate, arrival rate, energy consumption. The results showed that the algorithm had high performance advantages in broadcasting the large-capacity role-packet.

Keywords: Wireless Sensor Network, Roles, Broadcasting, Cost Function

1. Introduction

Broadcasting is the most important communication mode in wireless sensor networks. For example, a gateway node can broadcast query messages to the entire networks. The feature of flooding broadcast algorithm is very simple. It needn't to maintain the nodes topology information. All network nodes forward packets to their neighbors directly. It is real-time, low time and space complexity degree, and it can ensure coverage. But that will cause excessive broadcast redundancy, enormous energy consumption[1], and broadcast storms. It is not very suitable for the power-sensitive wireless sensor networks.

In application-driven environment of wireless sensor networks, role design[2] is a very important method in realizing dynamic applications. Each node depends on the application requirements (Objective, Requirements) and dynamically maps the roles (Task, Specifications) in the networks. To meet the requirements of application services, every node need to finish own role-task. In order to get the roles assigned, the dynamically updated application services need to broadcast the application-mapped roles to network nodes.

Role-code is an executable abstract program that can satisfy the requirements of application services. Nodes dynamically analyze the role-code to complete the corresponding role-task. Role broadcasting as a special way of broadcast algorithm has its own characteristics. As role is the program abstraction, the data packet of role-code is larger than the usual packet. Therefore, when the gateway node broadcasts this role packet, we need to take some other strategies. Otherwise the entire network can easily result in excessive energy consumption and reduction of network lifetime. Roles-container is defined as the set of the roles which have mapped to the applications. When application services are updating, gateway needs to broadcast roles-container to each node in time.

2. Related Work

In order to reduce the broadcast redundancy, some improved algorithms is proposed by using the strategy of reducing the number of relay nodes[3-5]. However, they could not guarantee broadcast coverage, and there were still a few redundancies in some relay nodes.

In order to reduce energy consumption, centralized broadcast algorithm (BIP)[6] was designed to construct a spanning tree. Local nodes can automatically add their neighbor nodes into the spanning tree. While it just need to broadcast data to the remote nodes of the spanning tree once, the other nodes...
of the spanning tree can also receive the data, significantly save energy. For the nodes in the wireless sensor network, constructing such a spanning tree structure need to know the entire network topology information. This will increase too much cost and complexity, and practicality is not strong.

In distributed broadcast algorithms[7],[8], each node maintains at least 1 hop local topology information. With this topology information, we can complete the entire network broadcast and extend the network lifetime.

But such algorithm needs to maintain the neighbor tables. In these scenarios, network topology information changes quickly and node density is high, this would cause much cost and reduction of efficiency and accuracy. In addition, above algorithms are only suitable for those networks with small broadcasting packets. They are not appropriate for the large-capacity packets networks.

FRANK C in [9] proposed a generic role assignment algorithm. It combines the context information to assign a suitable role to the node which meets the conditions. However, it did not consider the role-code updating methods when application changes dynamically. Broadcasting such a large roles-container packet with the common broadcast algorithm can easily cause serious link conflict, resource competition and energy consumption. It is not suitable for broadcasting roles.

The ordinary control message packets are much smaller than the role packets. So in this paper, we use context-aware method and control message dynamically learn the state information of the neighbors and the attributes of itself. By judging the type of the application, the network nodes are divided into role relay-nodes and non-relay-nodes. Then establish the relaying cost function and broadcast selectively according to it. We proposed a Role-based broadcasting algorithm in wireless sensor networks (CRD). Broadcast the roles-container to the network by using some strategies. Nodes use the request-response mode to get neighbor states information and calculate the relaying cost in order to determine whether to relay or not. So we can reduce the broadcast redundancy and save energy cost.

3. Network Model and CRD Algorithm

3.1. The definition of the network model

A wireless sensor network is denoted by graph G(V,E): V represents network node set; E represents the set of communication links between two nodes. Assuming that each node has equal coverage, link is bi-directional and graph G is fully connected. ∀k∈V, received the network broadcast roles-container packet at time T for the first time. Take any node k for example, definition as follows:

1. Neighbor node set NB (k) is the set of one hop neighbor nodes;
2. Neighbor node n (k) is the node could communicate directly with k;
3. Forward delay Delay (k) is the interval of time between receiving and forwarding;
4. Number of uncovered node NU (t, k) is the number of neighbors that have not been covered at time t by node k, that is to say these neighbors have not received the roles-container packet;
5. Degree (t, k) is the number of the neighbors of node k at time t;
6. Node energy Energy (t, k) is the remaining energy at time t of node k;
7. Link cost Link (t, k) is the link quality status between node k and its neighbors at time t;

The broadcast role of the nodes in the network:
1. Gateway Node (GW) is the role mapping and roles container distributing node.
2. Relay Node(s) is the node satisfies the broadcast cost requirements, retains the receiving roles container packet and participates in forwarding the role packet.

   □ RNi∈N, Cost(RNi)<Limit⇒ RNi∈RelayNodes

3. Non-Relay Node(s) is the node does not satisfy the broadcast cost requirements, does not participate in forwarding the role packet but only retain the receiving roles container packet;

   □ NRNi∈N, Cost(NR Ni)≥Limit⇒ NR Ni∉ RelayNodes

3.2. Role-based broadcasting algorithm in wireless sensor networks (CRD)

CRD algorithm takes advantage of context information to calculate the relaying cost function in order
to reduce redundancy broadcast cost, energy consumption and link conflict. When the network node \( k \) at time \( t \) receives the broadcast packet for the first time, call the CRD algorithm instead of rebroadcasting directly like flooding algorithm. Firstly node \( k \) retains the packet \( P \), and then sends \text{query} \ message to its neighbors \( NB(k) \), and asks the neighbors whether they have received the roles-container packet before time \( t \). When received the \text{query} \ message, neighbor nodes query their own labeled broadcast data. The broadcast states will be forwarded to the source node of the \text{query} \ message by \text{reply} \ message. Node \( k \) will receive \text{reply} \ messages from its neighbors and then analysis neighbor broadcast state and topology information. If all neighbors in \( NB(k) \) have already received the packet \( P \), node \( k \) does not forward again. If there are some neighbors do not receive the roles-container packet \( P \), then figure out relaying cost combining with application service requirements, attributes of nodes and neighbor topology information. If relaying cost is below a certain threshold, then forward it. If not, give up. So, when received the roles-container packet \( P \), only those nodes with high-attribute values such as sufficient energy, good link state and high degree, have a big probability to forward. Meanwhile, these nodes can dynamic adjust the relaying cost function to ensure broadcast coverage degree, improve broadcast efficiency and reduce relaying times of large-capacity roles-container packets. CRD algorithm can fully consider the difference between roles-container packet and the query-reply packet, achieve a higher performance advantage but with less cost.

The CRD algorithm is designed that each node asks its neighbor relaying state information before forwarding, and then calculates the relaying cost. According to them, decide whether to rebroadcast the roles-container packet. In these occasions with large amounts of role packets, the distributed broadcast design allows less cost than existing algorithms. It can not only ensure the broadcast coverage but also reduce the broadcast redundancy. Significantly reduce the energy consumption in roles-container broadcasting and extend the network lifetime.

Algorithm is described as follows:

\textbf{Input:}\ the roles container broadcast packet \( P \); neighbor nodes set \( NB(k) \).

\textbf{Output:}\ relay or not

\textbf{Step 1:}\ Node \( k \) sends the \text{query} \ message packets to its neighbors \( NB(k) \) after receiving the broadcast roles-container packet \( P \), and wait for their replies.

\textbf{Step 2:}\ Neighbor nodes \( n(k) \) receive \text{query} \ message packet, check their broadcast states, and return this information in \text{reply} \ message packet back to the source node of query message.

\textbf{Step 3:}\ Node \( k \) analyze the broadcast state information from the received reply message packets. If some neighbors have not received the roles-container packet \( P \), then go to step 4, otherwise go to setp 5.

\textbf{Step 4:}\ Extract the QoS parameters from the broadcast roles-container packet \( P \), and get application requirements about redundancy and reliability, etc. Count all neighbor broadcast states. Calculate the relaying cost by the cost function. If \( Cost(k)<Limit \), then rebroadcast this packet \( P \), and go to step 5.

\textbf{Step 5:}\ End.

Context-aware role-based distributed broadcast process is shown in Figure.1, GW is the roles-distributing gateway node, the gray nodes are the role relay nodes, and the white nodes are the non-relay nodes. By controlling query-reply message communication and relaying cost calculating to reduce the number of role relay nodes.

![Context-aware role-based distributed broadcast process](Figure 1)
4. Relaying cost evaluation and performance analysis

Different application services (AS) have different real time characteristics and roles-container packet size. It should be able to design different relaying cost functions according to different service characteristics and requirements. Nodes figure out relaying cost and compare it with the upper limit (Limit). If the relaying cost is smaller than the limit, node rebroadcast it. If not, give up. In order to sense the context status information of the networks, the relaying cost function should be designed to satisfy the QoS requirements of application services such as the redundancy, reliability and so on. In addition, CRD algorithms also need to take full consideration of residual energy Energy(t, k), communication link cost Link(t, k), node degree Degree(t, k) and other indicators of node attributes. The number of uncovered nodes should be considered too. The designable relaying cost function is described as follows:

\[
\text{Cost}(k) = \frac{\alpha \times \text{Link}(t, k) \times \text{Reliability}(t, k)}{\text{Energy}(t, k)} + \frac{\beta \times \text{Degree}(t, k)}{\text{NU}(t, k) \times \text{Redundancy}} \quad (k \in V)
\]  

Where \( \alpha \), \( \beta \) are the adjustment factor, default value can be set to 1.

CRD algorithm need to send control message packets and use query-replay method to get broadcast state information of neighbor nodes. Assuming that the size of query and reply packets are all Psr. To each node I, it request the neighbor broadcast states. To each link Eij, it transmits both query message and reply message twice, so the total is 4 Psr packets. Assuming that number of links is Ecount, number of nodes is Vcount, and the size of the roles-container packet is PRC. Each node rebroadcast the role packet obeys Bernoulli probability distribution, the probability is Pt. There must be some neighbors are under non-rebroadcast states and match the relay condition: Cost(i)<Limit, otherwise do not rebroadcast. Total number of rebroadcast packet is in formula 2.

\[
P_{\text{total}} = 4 \text{Ecount} \times \text{Psr} + \sum_{i \in V} P_t(\text{Cost}(i) < \text{Limit}) \times \text{PRC} \times (1 - P_t^{\text{degree}(t,i)})
\]  

If the sizes of query and reply packet are not equal. Let the query packet size to be Ps and the reply packet size to be Pr. In addition, when the network has a high node density, that is Ecount>Vcount, node i could choose to broadcast the reply packets to all 1 hop neighbors. Then link Eij will transmit Pr packet 2 times and Ps packet Vcount times. All other condition unchanged, number of sent packets is :

\[
P_{\text{total}} = 2 \text{Ecount} \times \text{Pr} + \text{Vcount} \times \text{Ps} + \sum_{i \in V} P_t(\text{Cost}(i) < \text{Limit}) \times \text{PRC} \times (1 - P_t^{\text{degree}(t,i)})
\]  

If Pr, Ps, PRC and the network size are unchangeable, in order to make the P_{\text{total}} be minimum, we could adjust the Limit value, meanwhile we also need to ensure the network broadcast coverage. When to the Limit-threshold designing, it is necessary to take the reduction of broadcast redundancy into account, but also improve the broadcast coverage and efficiency. It is necessary to ensure the maximization of network lifetime, and meet the application service requirements. The higher threshold limit, the more likely the node rebroadcast and the higher the coverage. However, it will introduce the link conflict and energy costs. It is difficult to ensure coverage if there's a low threshold limit. Value of threshold limit depends on the specific application scenario and network conditions.

In order to simulate and get the actual results of CRD algorithm, we analyzed the energy consumption model[10] shown in Figure 2. The transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics. We used both the free space (d2 power loss) or multipath fading (d4 power loss) channel model, depending on the distance between the transmitter and receiver. If the distance is less than threshold d0, the free space model is used; otherwise, the multipath model is used. Thus, to transmit an k-bit message a distance d, the radio expends
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$$E_{TX}(k,d) = E_{TX} - elec(k) + E_{TX} - amp(kd) = \begin{cases} kE_{elec} + kE_{pd}d^2 & d < d_0 \\ kE_{elec} + kE_{mp}d^4 & d \geq d_0 \end{cases}$$ (4)

and to receive this message, the radio expends

$$E_{RX}(k) = E_{RX} - elec(k) = kE_{elec}$$ (5)

Figure 2. Radio Energy Consumption Model

Wireless communication parameters[11] are summarized in Table 1:

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Energy Consumption ($E_{elec}$)</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>free space loss of amplifiers ($\varepsilon_{fs}$)</td>
<td>10 pJ/bit/m$^2$</td>
</tr>
<tr>
<td>multipath loss of amplifiers ($\varepsilon_{mp}$)</td>
<td>0.0013 pJ/bit/m$^4$</td>
</tr>
<tr>
<td>threshold distance ($d_0$)</td>
<td>87 m</td>
</tr>
<tr>
<td>Energy consumption of data aggregation ($E_{DA}$)</td>
<td>5nJ/bit/signal</td>
</tr>
</tbody>
</table>

The CRD algorithm divides the network nodes into Relay-Nodes (RN) and Non-Relay-Nodes (Non-RN). So it is need to calculate energy consumption respectively. Relay-node (RN) receives roles-container packet from the upper layer Relay-node (RN). Then broadcast it to neighborhood. Assuming energy consumption obeys free space channel model ($d^2$ power loss), the needed energy of relay-node $K_i$ is:

$$E_{RN} = \left( P_{rc} + \text{Degree}(k_i) \times P_{m} \right) E_{elec} + \left( P_{m} + P(Cost(i) < \text{Limit}) \times P_{rc} \right) \times E_{mp} \times d^2$$ (6)

The needed energy of Non-RN $K_i$ is:

$$E_{Non-RN} = \left( P_{rc} + \text{Degree}(k_i) \times P_{m} \right) E_{elec} + P_{m} \times E_{mp} \times d^2$$ (7)

5. Simulation Results

We use OMNET++ simulation platform[12], construct the 600 × 800m communication range wireless sensor network environment, and set node signal strength to 150m. Simulate the energy consumption of the Relay-Node, rebroadcast rate and arrival rate when rebroadcast roles-container packet. Set CRD algorithm threshold Limit=6. Compare CRD algorithm respectively with flooding algorithm and edge forwarding protocol[11]. Flooding is a common broadcast method of wireless sensor networks, edge forwarding protocol is a method based on the information of 1 hop neighbors. Simulation parameters are set as follows: loss rate is $10^{-7}$, roles-container packet length is 2K byte, delay 100ms, and the data rate is 12.8Kbps.

Rebroadcast rate is the Relay-Nodes ratio in the network. In Figure 3 we can see that CRD algorithm's rebroadcast rate is directly related to the network size and the threshold Limit. The higher...
the threshold the easier to satisfy the requirements of the relaying cost function, the higher probability to rebroadcast the packets. The higher of the node density, the more number of neighbor nodes have been rebroadcast. This makes the relaying cost become larger. And reduce the rebroadcast rate and the total energy consumption of the network.

![Figure 3. The relation of broadcast rate and threshold Limit, the network size](image)

The arrival rate is defined as the proportion of receiving nodes. We compare CRD algorithm respectively with edge forwarding algorithm and flooding algorithm on arrival rate, the result shown in Figure 4. We can see that the arrival rate decrease with the increase of node density because the increase of link conflict in networks. The arrival rate of flooding algorithm is the worst because of largest link conflict. CRD algorithm use the small control message to query neighbor state, and avoid redundancy role packet broadcast, this ensures nearly 86% arrival rate when node numbers reaches 150. The CRD algorithm outperforms the other two algorithms obviously in arrival rate.

The average energy consumption of single node depends on the total energy consumption and total number of network nodes. It could be better to reflect the performance of this algorithm. Shown in Figure 5, comparing with other algorithms, the relayed probability of a node can be dynamic adaptive according to the network conditions and the knowledge provided by the neighbors. Redundant relaying significantly reduce, average energy savings of single node is very remarkable.

![Figure 4. Comparison of arrival rate](image)

![Figure 5. Comparison of Energy Consumption](image)

6. Conclusion

Roles-data packet of dynamic application has big amount of information. General broadcast algorithm can hardly meet the requirements of role-distributing due to high cost and much redundant relaying. We present a role-based broadcasting algorithm with dynamic perception for wireless sensor network. In order to avoid unnecessary energy loss, it provides context-aware and the network dynamic adaptive capacity. The algorithm can fully guarantee the arrival rate of roles-packet, and reduce the relaying probability. Using context-information and the relaying cost function, CRD effectively solves the dilemma between roles-broadcasting and energy consumption.
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8. References