Design of the Energy Efficient Virtual Backbone Construction in the Zigbee Network

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ABSTRACT

In wireless sensor networks (WSNs), one challenging issue is to construct a virtual backbone in a distributed and localized way while considering energy limitation. Dominating set has been used extensively as core or virtual backbone in WSNs for the purposes like routing and message broadcast. To ensure network performance, a good dominating set construction protocols should be simple and avoid introducing extra message. In addition, the resulting dominating set should be small, connected, and take into account the energy level at each node. This paper studies efficient and simple virtual backbone construction protocol using defer time in IEEE 802.15.4- based WSNs (e.g. Zigbee). The efficiency of our proposed protocol is confirmed through simulation results.

KEYWORDS

Wireless sensor network, Zigbee, EEE 802.15.4 Virtual backbone, Connected dominating set, Defer timer

I. 서론

At present, there are several standard and proprietary devices that support sensor networks. IEEE 802.15.1 (Bluetooth) [1] and IEEE 802.15.4 (Zigbee) [1] are the most promising standards for wireless sensor networks because Bluetooth and Zigbee devices are generally inexpensive and consume relatively little power. Among them, Zigbee
present the next great challenge for WSNs, built on the IEEE 802.15.4 standard [1]. Zigbee is wireless communication standard created to satisfy such requirements; a limited amount of delay, a low energy consumption, and a low data rate in a multi-hop mobile environment.

To take full advantage of wireless sensor networks, many research issues such as virtual backbone construction [2, 3, 4], a mesh routing [5, 6, 7], and message broadcasting [8, 9, 10] remain to be addressed. Among these issues, virtual backbone construction is considered one of the most important issues limiting wireless sensor networks. In addition, virtual backbone should be able to deal with real-world problems such as energy consumption, nodal mobility, scalability, and mesh connectivity in WSNs to improve network performance.

Dominating set has been used extensively as core or virtual backbone in WSNs for the purposes like routing and message broadcast. To ensure routing performance, a good dominating set construction protocols should be distributed, simple, and adapt to energy constrain. In addition, the resulting dominating set should be small and connected.

In this paper, we present a Timer-based Connected Dominating Set construction Protocol for virtual backbone in WSNs. In our protocol, each node sets up a defer timer based on the number of uncovered neighbors and determines whether or not to join the dominating set when the timer expires. Unlike other dominating set construction protocols, the node in our protocol obtains the necessary information strictly through the exchanges of extended beacons with its immediate neighbors.

II. Background

The IEEE 802.15.4 Astandard [1] is initially developed by the Zigbee alliance. Zigbee is a new technology for wireless sensor networks. It is designed to support low data rate, low power consumption, and low cost wireless communications. The primary applications of Zigbee include automation and remote control. It supports a data rate of 250 kbps using 2.4 GHz unlicensed bands within a range of 10 to 75 m. Based on IEEE 802.15.4, the Zigbee protocol stack is shown in Figure 1. The physical layer and the media access control (MAC) layer adopt the IEEE 802.15.4, while the Zigbee Alliance specifies the standards for network and application layer.

![Zigbee Protocol Stack](image)

The defer timer is a countdown timer at each component. In general, before a defer timer expires, a component is forbidden to perform a certain set of events. By controlling the defer timer for each component, it is thus possible to determine the order of events. The concept of the defer timer has been used in many network protocols. For instance, in the end-to-end communication protocols, the (defer) timer is used to guarantee the safe delivery of the packet and is normally set to be a constant [11]. In an IEEE 802.11b wireless LAN [12], a station listens to the wireless medium and ensures the medium is available before it transmits anything. This medium access control mechanism is referred to as carrier sensing multiple accesses with collision avoidance (CSMA/CA). The (waiting) time a station listens to the channel before it transmits is defined as its inter frame spacing (IFS).

III. Virtual Backbone Construction

A wireless sensor networks is represented as an undirected graph \( G=(V,E) \), where \( V \) is the set of all stations in the WSN and \( E \) is the edge set with \( (u,v) \in E \) if and only if \( u \) and \( v \) are within each other's transmission range.

If \( G \) is connected, a set \( DS \subseteq V \) is called a dominating set
if for every vertex $v \in V - DS$, there exists a vertex $v \in V - DS$ such that $(v,w) \in E$.

A dominating set is said to be connected if its induced graph in $G$ is connected.

A node $u \in V$ is said to be in the state of $inDS$, covered(by$DS$), or uncovered (by $DS$) according to the following:

- $inDS$: if $u \in DS$;
- covered: if $u \notin DS$ and there is an edge $(u,v) \in E$ for some $v \in DS$;
- uncovered: if $u \notin DS$ and there is no edge joining $u$ to any node in $DS$;

There are four possible states for a node, namely uncovered/initial, initiator, covered, and $DS$. The state transition diagram is shown in Figure1.

Similar to every existing wireless system, namely including IEEE 802.11 [12], IEEE 802.15.4 [1] and Bluetooth [1], assume each node has an unique value or identifier in the network, such as its MAC address. The following refers to a node’s unique identifier as its id. A node transmits a beacon at every fixed time interval. Before a node transmits its beacon, it encodes its own id, energy level at each node, $DS$, and current state in the header of the beacon. By doing this, each node learns its neighbors, the $DS$, energy level and the state of the neighbors without introducing extra messages.

- First, the node with the most energy is picked as the initiator.
- In cases where multiple stations have the same energy level, the one with the most neighbors is picked as the initiator.
- When multiple stations have the same number of neighbors and the same energy level, the node with the minimum MAC address is picked as the initiator to break the tie.

Starting from an initiator as the first node with the most energy in the CDS, the direct neighbors are covered as covered nodes. For each covered node, a timer is set based on the number of uncovered Neighbors (Nuncovered) and the energy level($E$) at each node to compute $\Delta T$. $\Delta T$ is calculated by multiplying Nuncovered and $E$. Nodes with more uncovered neighbors or higher energy levels are given a smaller timer value, and hence will expire earlier. When the timer expires, a node enters the CDS if it still has uncovered neighbors. The pseudo code of the proposed CDS construction protocol for virtual backbone is given in the following.

```plaintext
/* node x in wireless sensor network executes the following procedure until x has an inDS */
while (x has no inDS )
    init state :
    on receiving a signal from neighbors
    if ( x.id is smallest among its neighbors )
        then state = start
    else state = uncovered
    start state :
    start $\Delta T$
    state = covered
    uncovered state :
    on receiving a beacon from a dominator neighbor
    start $\Delta T$
    state = covered
    covered state :
    if ( x has an uncovered neighbor )
        then state = inDS
    else if ( x's inDSr is no longer a neighbor of x)
```

![Figure 2. Node's State transition diagram](image-url)
then state = init
else state = covered

inDS state:
if ( none of x”s neighbors use x as its inDS) and
(a neighbor of x, y, is a inDS)
then x”s inDS = y and state = inDS

IV. Simulation Results and Analysis

Table 1 shows a list of parameters used in the simulations, if not specified otherwise.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space</td>
<td>4 X 4</td>
</tr>
<tr>
<td>Transmission Radius</td>
<td>1</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>60-200</td>
</tr>
<tr>
<td>T_{max}</td>
<td>100</td>
</tr>
</tbody>
</table>

Nodes are generated randomly on a 4 by 4 square plane. The plane is wrapped vertically and horizontally to eliminate If the generated network is partitioned into pieces, it the effect of the edge. Each node has the same range of transmission. is discarded and a new network topology is generated to ensure the connectivity of the whole network. The value T_{max} is chosen to be 100 time units.

Similar to every existing wireless system, namely including IEEE 802.11 [12], IEEE 802.15.4 [1] and Bluetooth [1], assume each node has an unique value or identifier in the network, such as its MAC address. The following refers to a node’s unique identifier as its id. A node transmits a beacon at every fixed time interval. Before a node transmits Other than TB protocol, we also implemented two other connected dominating set protocols, namely, Wu’s protocol in [3] and Wan’s protocol [2]. All simulations were executed under the same parameters and network topology. By comparing the size of the resulting CDS and energy level for network with size between 60 and 200 nodes. We examine the network performance of our TB protocol.

In Figures 3, the x-axis represents the size of the network and the y-axis shows the size of the resulting CDS from the three different protocols. For the 4 × 4 grids, TB’s DS size ranged between 13 and 17, Wan’s protocol ranged between 20 and 25 and Wu’s protocol ranged between 20 and 27. TB thus easily outperformed the other two protocols. In Figures 4, the x-axis represents the size of network and the y-axis shows the average energy level of the stations in the resulting CDS from the three different protocols. Hence, TB able to achieve an approximately 20% higher average energy level of stations in CDS than the others for the 4 × 4 grids.

In Figures 5, the x-axis shows the size of the network and the y-axis is the minimum energy level of the stations in the resulting CDS from the three different protocols. From these figures, we can see that our energy-aware TB protocol select the stations with higher minimum energy levels than any of the others, while Wu1 selects the stations having the lowest minimum energy level. These figures indicate that the CDS created by our energy-aware TB protocol live longer than any other protocols under a static network.

V. 결론

In this paper, we presented the timer based connected dominating set protocol for virtual backbone. In our new TB protocol, the energy level at each node is taken into consideration when constructing the CDS. TB effectively constructs an energy-aware CDS that prolongs the network’s operational life under different levels of nodal mobility. The simulation results have shown that our protocols consistently generate significantly smaller CDS than those proposed in [2] and [3]. Additionally, the CDS generated by TB consistently results in stations with a higher energy level, which implies a longer lifespan for the CDS when the network is static.
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