PERFORMANCE IMPROVEMENT OF AUTOMATED ADDRESS ASSIGNMENT FOR PATH CLUSTER WSN USING 2-LEVEL ROUTING

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ABSTRACT

Although wireless sensor network have been extensively researched, their deployment is still a main concern. Observe that many monitoring applications for WSNs have adopted a path-connected-cluster (PCC) topology, where regions to be monitored are deployed with clusters of sensor nodes. Since these clusters might be physically separated, paths of sensor nodes are used to connect them together. Call such networks PCC-WSNs. PCC-WSNs may be widely applied in real situations, such as bridge-connected islands, street-connected buildings, and pipe-connected ponds. Show that the address assignment scheme defined by ZigBee will perform poorly in terms of address utilization. Then propose a systematical solution, which includes network formation, automatic address assignment, and 2 Level routing. Proposed system contributes in formally defining the PCC-WSN topology. Also, proposed a formation scheme to divide nodes into several paths and clusters. Then a two-level ZigBee-like hierarchical address assignment and routing schemes for PCC-WSN would be conducted. The proposed automated address assignment scheme assigns each node both level-1 and level-2 addresses as its network address. With such a hierarchical structure, routing can be easily done based on addresses of nodes. Also show how to allow nodes to utilize shortcuts. With proposed design, not only network addresses can be efficiently utilized and the spaces required for the network addresses can be significantly reduced, but also the network scale can be enlarged to cover wider areas without suffering from address shortage.

Keywords: PCC, Zigbee, WSN.

I. INTRODUCTION TO WIRELESS SENSOR NETWORKS

Wireless Sensor Network is a heterogeneous network composed of a large number of tiny low-cost devices, denoted as nodes, and few general-purpose computing devices referred to as base stations. The general purpose of wireless sensor network is to monitor some physical phenomena (e.g., temperature, barometric pressure, light) inside the area of deployment. The basic units of WSN are nodes (sometimes called motes). These nodes are equipped with communication unit, mostly the
radio transceiver, processing unit, battery and sensors. Due to the size and expected costs of the nodes, they are constrained in processing power and energy. The number of nodes deployed in WSN can vary from tens to tens of thousands depending on the particular application. Nodes can be deployed, for example, by precise placing one by one into predefined positions or by dropping from the plane. Their positions can be static or mobile. Networks with nodes in static positions are more common.

Nodes have to be autonomous and the network itself has to be self-organizing. They are also prone to failures, thus the topology of the network changes very often. Beside resource limited nodes, the wireless sensor network includes one or more base stations (sometimes called sinks). These base stations have more resources and capabilities than the nodes. Assume base stations might have laptop capabilities. They act as gateways between the sensor network and other networks, e.g. Internet. They can also somehow coordinate the nodes. In most common application schemes, the nodes collect measured data and send them to the base stations, which forward them to the consumer.

A Wireless sensor network (WSN) usually needs to configure itself automatically and support ad hoc routing. A lot of research works have been dedicated to WSNs, including power management [1], routing [2], data gathering [3], [4], sensor deployment and coverage issues [5], and localization [6]. On the application side, habitat monitoring is explored in [7], wildfire monitoring is addressed in [8], healthcare system is proposed in [9], and navigation is studied in [10]. To form a WSN, two most important issues are addressing and routing. Strict per-node addressing is expensive in a dense network, because not only the address space would be large, but also these addresses would need to be allocated and managed according to the topology change. Allocation of addresses in a dense network is a problem which is often underestimated [11]. On the other hand, routing is to discover paths from source nodes to destination nodes based on their network addresses. Path discovery in a dense network could incur high communication overheads. Therefore, designing a light-weight addressing and routing protocol for WSNs is very important. Recently, ZigBee [12] has been proposed for addressing and routing on WSNs. It supports three kinds of network topologies, namely star, tree, and mesh networks. A ZigBee coordinator is responsible for initializing, maintaining, and controlling the network. Star networks can only cover small areas. For tree and mesh networks, communications can be conducted in a multi-hop fashion. The backbone of a tree/mesh network is formed by one ZigBee coordinator and multiple ZigBee routers. An end device must associate with the coordinator or a router. In a tree network, routing can be done in a stateless manner; a node can simply route packets based on nodes’ 16-bit short addresses, which are assigned based on the tree structure. In fact, a mesh network also has a tree inside to serve as its backbone; routing can go directly along the tree without route discovery or go along better paths if a node is willing to conduct route discovery first. In this, most works have assumed that a ZigBee network grows in an arbitrary manner. Recently, the long-thin topology has been proposed for applications where sensor deployment is subject to environmental constraints [13]. The use of long-thin network ranges from leakage detection of fuel pipes [14], [15], [16], tunnel monitoring, street lights monitoring [17], flood protection of rivers [13], debris flow monitoring [18], barrier coverage [19], and in-sewer gas monitoring [20]. Proposes system further extend the long-thin topology to a path-connected-cluster (PCC) topology, where regions requiring intensive sensing are deployed with clusters of sensor nodes and these clusters, which are physically separated, are connected by long paths for occasional communications. Call such topologies PCC-WSNs. PCC-WSN has an application for habitat monitoring in a wildlife park. Sensors for different habitat zones form different clusters. Data from these clusters is collected through paths connecting them. Such “sometimes fat, sometimes slim” topologies would worsen the orphan problem [21], which states that the ZigBee address assignment may not allow some nodes (called orphans) to join the network even if there are available addresses elsewhere. Although ZigBee supports address-based routing through its distributed addressing scheme, it could incur a lot of orphans or result in waste of address space [21]. The virtual coordinate addressing schemes in [22] try to provide stateless routings directly from nodes’ addresses. However,
additional GPS devices or localization mechanisms should be involved. Moreover, these schemes still need a lot of address spaces. Address assignments for WSNs are studied in [11], [23]–[26]. These works all focus on compact assignment of addresses to sensor nodes, but they need additional routing protocols to deliver packets because they do not support address-based routing. The work [11] allows network addresses to be reused to conserve address space, but it only supports many-to-one communication.

II. PROBLEM DEFINITION

Proposed work an automated address assignment and 2 level routing protocol for PCC-WSNs. Approach is based on the principle of ZigBee address assignment, but leads to much more compact address usage than the original ZigBee’s design, thus significantly alleviating the orphan problem in PCC-WSNs. Furthermore, based on addressing, routing still incurs low communication overheads. Proposed work contributes in formally defining the PCC-WSN topology. Given a PCC-WSN, present a formation scheme to automatically separate paths from clusters in a distributed manner. Then propose a ZigBee-like automated address assignment scheme for a PCC-WSN. In particular, design different addressing strategies for slim parts (paths) and fat parts (clusters) of a PCC-WSN. Proposed design allows us to conduct automated address assignment and 2 level routing. Although this requires slight modification to ZigBee specification, and finding the leads to quite efficient communications.

ZigBee Address Assignment and Tree Routing

In ZigBee, network addresses are assigned to devices in a distributed manner. To form a network, the coordinator determines the maximum number of children per router (Cm), the maximum number of child routers per router (Rm), and the maximum depth of the network (Lm). Note that children of a router include child routers and child end devices. So Cm ≥ Rm and up to Cm – Rm children of a router must be end devices (an end device cannot have children). Addresses are assigned in a top-down manner. The coordinator takes 0 as its address and divides the remaining address space into Rm+1 blocks. The first Rm blocks are to be assigned to its child routers and the last block has Cm – Rm addresses, each to be assigned to a child end device. The similar approach is adopted by each router to partition its given address space. From Cm, Rm, and Lm, each router at depth d can compute a Cskip(d) value, which is the size of one address block to be assigned to a child router:

\[
C_{\text{skip}}(d) = \begin{cases} 
1 + C_m \times (L_m - d - 1), & \text{if } R_m = 1, \\
1 + C_m - R_m - C_m R_m^{L_m - d - 1}, & \text{otherwise}.
\end{cases}
\]

![Figure 1: An example ZigBee tree network](image-url)
The value of \( d \) is 0 for the coordinator and is increased by one after each level. For example, given an address block, a router at depth \( d \) will take the first address for itself, reserve \( R_m \) blocks, each with \( C_{\text{skip}}(d) \) addresses, for its child routers, and reserve \( C_m - R_m \) addresses for its child end devices. Fig. 1 shows an example of ZigBee address assignment. Clearly, in Fig. 1, the value of \( R_m \) is at least 3 for supporting 3 router children. Note that ZigBee network address is 16 bits. Even though set \( L_m \) to 9, \( B \) and \( C \) still cannot associate with the network. Even worse, such address assignment would work poorly in a PCC-WSN because of its “sometimes fat, sometimes slim” nature. With the above address assignment, ZigBee supports very simple address-based routing. When a router receives a packet for \( A_{\text{dest}} \), it first checks if it is the destination or one of its children is the destination. If so, it accepts the packet or forwards this packet to its child whose address block contains \( A_{\text{dest}} \). Otherwise, it relays the packet to its parent. Assume that the depth of this router is \( d \) and its address is \( A \). This packet is forwarded to its child \( A_r \) which satisfies \( A_r < A_{\text{dest}} < A_r + C_{\text{skip}}(d) + 1 \) such that \( A_r = A + 1 + \frac{A_{\text{dest}} - (A + 1)}{C_{\text{skip}}(d)} \times C_{\text{skip}}(d) \). If the \( A_{\text{dest}} \) is not a descendant of \( A \), this packet will be forwarded to its parent. Note that in a mesh network, nodes are also assigned addresses following these rules. This means that address-based routing can coexist with a mesh routing.

### III. PROPOSED SYSTEM

Given a PCC-WSN, propose a low-cost, fully automated scheme to initialize it, assign addresses to nodes, and conduct ZigBee-like tree routing. First, a distributed network formation procedure will be launched by the coordinator \( t \) to divided nodes into two sets \( C \) and \( P \). Then, a two-level address assignment scheme is conducted to assign a level-1 and a level-2 addresses to each node. A level-1 address is to uniquely identify a path or a cluster. A level-2 address is similar to ZigBee addressing but is confined within one cluster/path. For simplicity, assume that all nodes are router-capable devices. Finally, show how to conduct routing based on proposed system two level addressing. Also, address how proposed system protocol can adapt to changeable topologies.

#### Network Formation

Given a PCC-WSN \( G = (V, E) \), the network formation process has three goals:

(i) to partition \( G \) into clusters and paths,

(ii) to assign a group ID (GID) to each cluster/path, which should be known to each member in that cluster/path, and

(iii) to identify an entry node for each cluster/path, which is the one nearest to \( t \) in terms of the number of clusters/paths if travel from \( t \) to the entry node (as a special case, \( t \) will serve as the entry node of its cluster).

#### Automated Address Assignment

A two-level addressing.

It has two purposes:

(i) To reduce address space and

(ii) To support ZigBee like stateless routing.

In level-1 addressing, regard each cluster/path as a supernode and use ZigBee-like addressing to assign an \( m \)-bit address to each supernode.

In level-2 addressing, again apply the ZigBee-like addressing on each individual cluster/path to assign an \( n \)-bit address to each node.

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IV. PERFORMANCE EVALUATION

Proposed System simulate some PCC-WSNs that are generated by a systematically method which has been developed in NS2 Simulator. An SxS m² rectangle region is simulated, on which n sensor nodes are randomly deployed. The field is divided into grids, each size of sg x sg m². In order to form a PCC-WSN in a systematic way, impose a fail probability of Pf on each grid. If a grid is determined to fail, all sensor nodes inside the grid fail. This would partition the network into multiple subnetworks when Pf is sufficiently large. The successful and adjacent grids will be grouped into the same cluster by proposed system simulator. Then apply a minimum spanning tree algorithm to build paths between clusters. Simulator generates sensor nodes at every distance of d on each path. The coordinator is at the left-top corner. Hence, make the left-top grid always be not failed. Fig. 2 shows an example of a random generated PCC-WSN. All simulation results are from the average of 50 runs. As Fig.2 shows, protocol can partition the network nodes into 2 sets accurately. Also, each node can successfully connect to the network by automated addressing assignment. Based on the same determination principle of Cm, Rm, and Lm, ZigBee addressing can still make all nodes connect to the network as well. However, the address space conducted by ZigBee is excessively larger than that conducted by protocol. Larger transmission range will result in smaller address space. This is because larger transmission range will decrease the value of Lm. Moreover, the address space conducted by protocol is smaller than that conducted by ZigBee addressing up to 10100. The address space is mainly influenced by the values of Cm and Lm. Below, Proposed system limit the address space. Mainly consider the number of orphans as proposed system performance metrics.

![Figure 2: Random Generated PCC-WSN](image)

<table>
<thead>
<tr>
<th>Time in ms</th>
<th>Existing (Address Space)</th>
<th>Proposed (Address Space)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>2</td>
<td>31.87</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>4</td>
<td>32.87</td>
<td>0.15</td>
</tr>
<tr>
<td>5</td>
<td>32.88</td>
<td>38</td>
</tr>
<tr>
<td>6</td>
<td>0.12</td>
<td>0.25</td>
</tr>
<tr>
<td>7</td>
<td>0.12</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>0.12</td>
<td>0.18</td>
</tr>
</tbody>
</table>
First, in protocol, proposed system fixes $C_m$ and $R_m$ from 3 to 6 but keep $L_m$ determined by the original principle unchanged. In ZigBee addressing, limit the address space as the one determined by protocol. Therefore, based on $C_m$, $R_m$, and address pool $A$, the $L_m$ of ZigBee can be determined as $L_m = \log \left( A \times (C_m - 1) + 1 \right)/\log(C_m - 1)$. ZigBee has very poor performance due to the existence of paths. Larger $C_m$ will result in fewer orphans in protocol because it will cause larger address space. However, larger transmission range could incur more orphans. This is because larger transmission range could increase the probability of no routing capacity for a router.

<table>
<thead>
<tr>
<th>Time in ms</th>
<th>Existing (Address Utility)</th>
<th>Proposed (Address Utility)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td>0.0199</td>
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<tr>
<td>3</td>
<td>0.2</td>
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<td>4</td>
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<tr>
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<td>0.45</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0.5</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Address Utility Performance
Next, limit the address pool of ZigBee as the one determined by protocol. Then vary \( C_m \) and \( L_m \) of ZigBee to measure the orphans. Protocol does not incur any orphans. However, ZigBee addressing will result in great part of nodes as orphans. As the network nodes increase, orphans will also increase. Obviously, ZigBee addressing incurs poor performance on the existence of paths. For reducing the influence of the paths on ZigBee addressing, set \( L_m \) as the maximum depth of the network which is determined by processing a BFS scheme. By using the same address space \( A \) determined by protocol, Proposed system calculate a \( C_m \) such that \( C_m L_m + 1 - 1 < A \). Here, make the value of \( C_m \) at least as 2 even if the address space conducted by ZigBee may be larger than proposed too much.

<table>
<thead>
<tr>
<th>Time in ms</th>
<th>Existing (Delivery Ratio)</th>
<th>Proposed (Delivery Ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>1.199</td>
</tr>
<tr>
<td>2</td>
<td>0.09</td>
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<tr>
<td>3</td>
<td>0.1</td>
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</tr>
<tr>
<td>4</td>
<td>0.12</td>
<td>0.231</td>
</tr>
<tr>
<td>5</td>
<td>0.18</td>
<td>0.202</td>
</tr>
<tr>
<td>6</td>
<td>0.2</td>
<td>0.085</td>
</tr>
<tr>
<td>7</td>
<td>0.9</td>
<td>1.199</td>
</tr>
<tr>
<td>8</td>
<td>0.95</td>
<td>1.199</td>
</tr>
<tr>
<td>9</td>
<td>0.99</td>
<td>1.199</td>
</tr>
<tr>
<td>10</td>
<td>1.2</td>
<td>1.199</td>
</tr>
</tbody>
</table>

Packet Delivery Ratio Comparison

Although this method makes ZigBee addressing have better performance. ZigBee addressing still incurs many orphans. If system wants to let all nodes connect to the network and increase the \( C_m \) of ZigBee, this will result in extremely larger address space and worse address utility.

CONCLUSION

Proposed system, contribute in formally defining the PCC-WSN topology. Also, proposed a formation scheme to divide nodes into several paths and clusters. Then a two-level ZigBee-like hierarchical automated address assignment and 2level routing schemes for PCC-WSN are conducted.
The automatic address assignment scheme assigns each node both level-1 and level-2 addresses as its network address. With such a hierarchical structure, routing can be easily done based on addresses of nodes. Also show how to allow nodes to utilize shortcuts. With the proposed design, not only network addresses can be efficiently utilized and the spaces required for the network addresses can be significantly reduced, but also the network scale can be enlarged to cover wider areas without suffering from address shortage. Proposed work also verified schemes by simulation programs. In the future, it deserves to consider applying this work to real cases such as habitat monitoring in a wildlife park or structure monitoring in an amusement park.

REFERENCES


