A ZigBee Distributed Address Assignment Mechanism Based On Prefix Codes

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Abstract-**In ZigBee networks, a tree topology is often used to construct a wireless sensor network for data delivery applications. However, the distributed address assignment mechanism provided in the ZigBee specification make inefficient use of the address space, which may cause the orphan problem. In this paper we addressed this problem and proposed a flexible address assignment scheme based on prefix codes, which can be easily applied to construct a tree topology ZigBee network with more efficient use of the address space. Moreover, it can also achieve a low overhead when an addition or subtraction of devices occurs in the network.**

Keywords-prefix codes; distributed address assignment; zigbee

I. INTRODUCTION

ZigBee is a worldwide standard of wireless sensor network, which is low-cost, low-power, and reliable. Based on the characteristics, ZigBee technology has been widely used in intelligent sensor scenarios, such as building automation, health care, smart energy and agriculture automation [1].

ZigBee utilizes IEEE802.15.4 [2] to implement the physical (PHY) and medium access control (MAC) layers. In the network layer, each node is assigned a unique 16-bit short address dynamically with some mechanism base on different network topology. A distributed address assignment mechanism (DAAM) is employed in the tree topology, which is one of most common-used topologies.

ZigBee Alliance [3] presents an implementation of DAAM. A function called $C_{skip}(d)$ is used to calculate the size of the address space assigned by each router node at a given network depth, d. This function is expressed as the equation (1), where L_m is the maximum depth of the network; C_m is the maximum number of children per parent; and R_m is the maximum number of child routers per parent.

$$C_{skip}(d) = \begin{cases} 1 + C_m \cdot (L_m - d - 1) & , \text{if } R_m = 1 \\ \dfrac{1 + C_m - R_m - C_m \cdot R_m^{L_m - d - 1}}{1 - R_m} & , otherwise \end{cases} \quad (1)$$

For a router/end device at tree level d+1, its address A, whose parent address is Aparent, is assigned using the equation (2),where k / n is the sequential value of the router/end device under the same parent.

$$A_k = A_{parent} + C_{skip}(d) \cdot (L_m - d - 1) \quad , 1 \le k \le R_m$$
$$A_n = A_{parent} + C_{skip}(d) \cdot R_m + n \quad , 1 \le n \le C_m - R_m \quad (2)$$

Before the construction of ZigBee tree network, Cm, Rm and Lm need to be predefined. This mechanism can work well in common scenarios. However, in some cases, such as nodes non-uniform distributed networks and long-thin networks (LT WSNs)[4], the orphan problem may happen. The devices, which cannot join the network resulted from exhaustion address space arc called orphans [5]. Since the mechanism reserves many addresses that are suitable for symmetric and dynamic network establishment. The fixed values of Cm and Rm may cause wastage of network addresses, which may also limit the maximum depth of a wireless network.

In this paper, we address this problem and propose a mechanism to achieve a more efficient use of the address pool, which will expand the ZigBee technology into more application cases. Our contributions are as follows:

- We propose a novel addressing assignment algorithm based on prefix-codes, which can make more efficient use of address pool.
- The mechanism achieves a low overhead, when the devices updating occur in the network.
- A reserve coefficient is imported to increase the redundant of the address assignment mechanism, which can further reduce the overhead when an addition or subtraction of nodes in the network.

The rest of the paper is organized as follows. In Section 2, we discuss the previous literature related to our work. Section 3 gives preliminaries. Next, we introduce our address assignment scheme in Section 4. Experimental results are presented in Section 5. And finally, Section 6 concludes the paper.

II. RELATED WORK

A lot of research works have been dedicated to implement a more flexible address assignment scheme to solve the orphan problem. APS and HCWPS are two automatic parameter selection algorithms for DAAM presented in [6]. Both algorithms collected the network information before construction of the network, and then utilized the information to calculate the predefined parameters (Cm, Rm and Lm) in DAAM. These algorithms can optimize the parameters according to the current network architecture. But they cannot work well in the nodes non-uniform distributed.

Meng-Shiuan [4] proposed an address assignment and routing schemes for ZigBee-based long-thin wireless sensor networks (LT WSNs), divided nodes into several clusters, and then assigned each node with a cluster ID and a node ID, which served as the network address. Nevertheless, the LT WSN only seemed to be a special case of numerous WSN topologies and is rarely used in common applications.

There are also many studies on improving the use of the address space. SBA[7] is a segmentation-based address assignment algorithm. This is achieved by segmenting the 16-bit address space according to the maximum address predefined in the DAAM. The addresses, which is larger than the maximum address, can be assigned to the orphan nodes. However, if the predefined parameters of DAAM are improper, the spare address space is too small to utilize. Moreover, the inherent problem of DAAM, inefficient use of address space, is already existing. Furthermore, Debabrato [8] provided a unified address-borrowing scheme that can be easily employed in increasing the growth of a network beyond 16 hops and in overcoming the address exhaustion problem by borrowing an address.

Roy [9] proposed a new addressing assignment scheme to make improvements to these limitations, and derived the maximum value of the depth of the network (3). For example, if Cm=6 and Rm=4, the maximum value of Lm is 7. This means that the depth of this network cannot exceed 7.

$$L_m \leq \frac{\log_{10}(\frac{(2^{16}-1)(R_m-1)}{C_m}+1)}{\log_{10} R_m} \tag{3}$$

III.   PRELIMINARIES

Given a ZigBee network with tree topology, ND is the set of all nodes. R and E is two subsets of ND, where R is the set of routers, and E is the set of end device. The coordinator c is the root node in the network. Obviously, $ND = c \cup R \cup E$.

For each router $r \in R$, we define SR(r) as the set of sub-routers, ED(r) as the set of end devices in children.

For each node $n \in ND$, P(n) represents the parent of the node n. Noted that $P(n) \in R \cup c$ and $P(c)=\emptyset$.

For each node $n \in S$, SQ(n, S) is the sequence number of the node n in the set S, the sequence numbers start from 0. We denote ADDR(n) as the address of the node n and define ADDR(c) = 1.

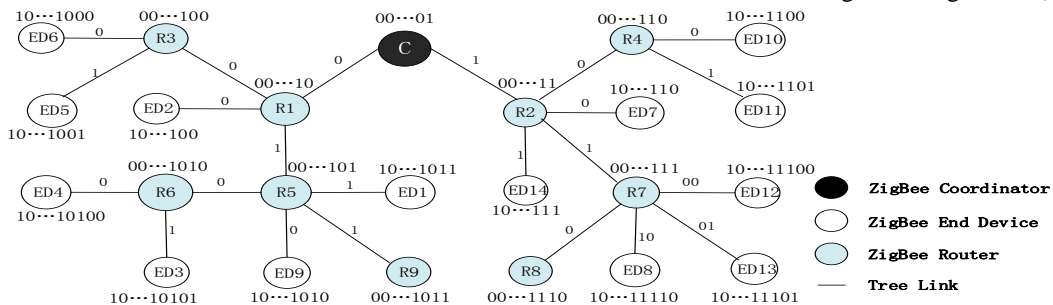### IV.   ADDRESS ASSIGNMENT MECHANISM

A. *Address Structure.*

For a ZigBee network establishment, in our mechanism, addresses are assigned using a parent-child relationship. The coordinator that forms the network is node 1 (address is 0x0001), by definition. Based on the above definitions, the address structure in our mechanism can be described as Fig. 1.
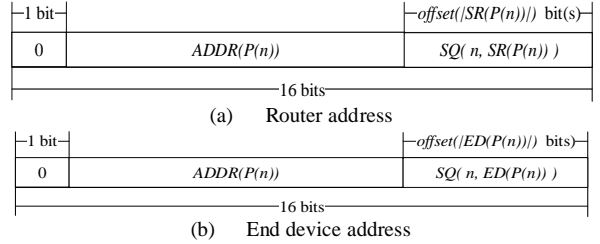

Figure 1.   The ZigBee address structure in the mechanism this paper proposed

In this structure, the top bit is used to segment the address space for different roles in the network. The top bit of the router's address is 0, and that of the end device is 1. The other 15-bit is composed of two parts. The one is the address of the current node's parent with an offset. The other is the sequence number of the node. The offset(x) is calculated by (4).

$$offest(x) = \begin{cases} 1 & if \ x \leq 1 \\ \lceil \log x \rceil & if \ x > 1 \end{cases} \tag{4}$$

This address structure has the following characteristics: (i) $\checkmark$ identification of routers and end devices using the top bit; (ii) a reference of prefix code and each device has a unique address;(iii) routers (or end devices) with the same parent device have the same prefix code;(iv) the addressing procedure between routers and end devices do not interfere with each other; (v) the subtraction or addition of an end device does not result in the reconstruction of the whole network.

B. *Address Assignment.*

By means of the above address structure, we design an algorithm for constructing a tree topology network, namely Prefix-Codes Address Assignment algorithm (PCAA).

Figure 2.   An instance of network address assignment.

We can call the function PCAA(c) to assign all the address in the network. For example, in Fig. 2, the address of the router R2 is $00\cdots11$. Address $00\cdots111$ identifies R7, and the last bit 1 is the label of the link from R2 to R7. The top bit 0 means that R7 is a router. In addition, R7 has three end devices, so it needs 2 ($\lceil \log3\rceil$) bits to distinguish its children. Hence, the address of R7 left shift two bits and label 00 become a part of the ED12 address. The top bit is then placed into 1.

Algorithm 1: Prefix-Codes Address Assignment algorithm (PCAA)

Input: a coordinator in the network: $parent \in R \cup c$

Output: all the addresses in the sub-tree

```
1  begin
2      if SR(parent) ≠ ∅ then
3          for each sr in SR(parent)
4              ADDR(sr) = {ADDR(parent) << offset(|SR(parent)|)} | SQ(sr, SR(parent));
5              PCAA(sr);
6          end for
7      end if
8      if ED(parent) ≠ ∅ then
9          for each ed in ED(parent)
10             ADDR(ed) = {ADDR(parent) << offset(|ED(parent)|)} | 0x8000 | SQ(ed, ED(parent));
11         end for
12     end if
13 end
```

C. Device Join and Leave.

Sometimes a join or leave of a device may occur in the ZigBee network. In this mechanism, it is simply to leave from the network for an end device. However, a router removed can cause the network reconstruction. There are two cases when a device join the network. If the router, who is its parent, has enough spare address space, the new device can join directly. Otherwise, a reconstruction is required in the subtree. Algorithm 2 presents the Device Join Algorithm.

Algorithm 2: Device Join Algorithm (DJA)

Input: The device to be joined: x , The parent router: r

```
1  begin
2      if x ∈ R then
3          nodes = SR(r);
4      else
5          nodes = ED(r);
6      end if
7      add x into nodes;
8      if |nodes| ≤ 2^{offset(|nodes|-1)} then
9          ADDR(x) = {ADDR(r) << offset(|nodes|)} | SQ(x, nodes)
10     else
11         PCAA(r);
12     end if
13 end
```

In most cases, the addition of devices does not require an update of the network address. The worst case scenario, however, is displayed in Fig 3. As can be seen, R10 joins the network and causes the reassignment of R9's address. Likewise, the address of the end device with the same parent must be updated because of the addition of ED6.

A coefficient rev is imported to increase the redundancy of the address space, which can reduce the probability of subtree reconstruction. With the coefficient, the function offset(x) can be described as (5). This coefficient can be individually set for both router and end device, which presents the minimum number of the addresses each router reserved for router/end device addition. Noted that an improper value of rev may cause the inefficient use of address pool.

$$offest(x)=\begin{cases} 1 & if\ \ (x+rev)\leq 1 \\ \lceil \log(x+rev)\rceil & if\ \ (x+rev)>1 \end{cases} \tag{5}$$
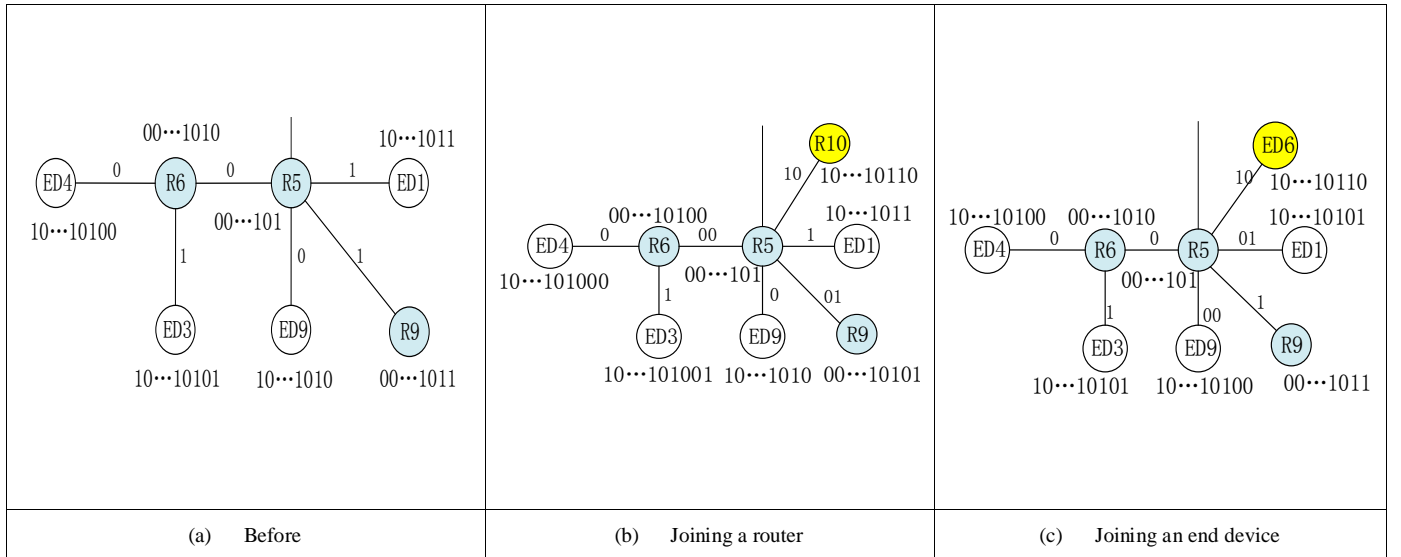

Figure 3.   An instance of reconstruction when device addition

V. EXPERIMENTAL RESULTS

A. Simulation Setup.

This paper used Matlab to simulate the performance of the proposed scheme. We selected a certain number of devices to form a tree topology wireless network, and then added an end device on each router. The number of devices required to update their network addresses was calculated and the average value as obtained. All experiments were repeated over 200 times and the average was attained. Furthermore, in each scenario, we compared the performance of the proposed scheme with that of the addressing scheme together with a new lightweight, table-free routing algorithm [9].

B. Effect of Updating Address with Fixed Depth.

This experiment was conducted to randomly establish a network with 100 devices, which limited the maximum depth of the network (Lm). Fig.4 shows the impact of a device addition on the number of devices updated address while reconstructing.
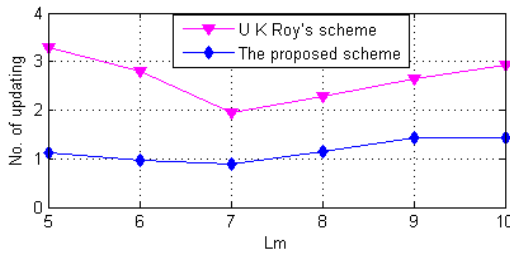

Figure 4.   Effect of Lm on the number of devices required to update addresses.

As shown in Fig. 4, the average updating value by the proposed scheme is lower than 1.5 when a device joins the existing network. In fact, the network does not require reconstructing in most cases. When Lm is 7, the number of device required to update addresses reaches a minimum value. Here the depth and breadth of the tree topology network, constructed by 100 devices, reaches a relative balance. On the one hand, a depth with a small value indicates that a small number of routers exist and that the amount of end devices linked to each router is close to saturation. On the other hand, a depth with a large value can cause an alternative chance to occur while adding an end device. These two situations both increase the result.

C. Effect of Updating Address with Different Numbers of Routers.

In the following experiment, we explore the influence of updating addresses on the number of routers in the network. It carries out by using 150, and 250d devices per group, which limited the number of children in each router (≤16). For each group, the number of routers was varied from 20 to 70. Fig. 5 shows the relationship between the number of routers and the number of devices required to update the addresses when a device joins the network. The number of

updating in the proposed scheme is much less than the one in Roy's scheme. When an addition occurs, the average number of the device's address is closed to 1.
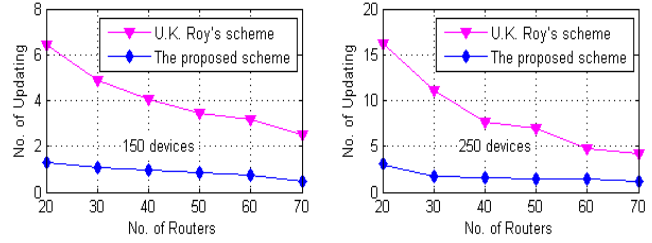

Figure 5.   Effect of the number of routers on the number of devices.

VI. CONCLUSIONS

In this paper, we proposed a new distributed address assignment mechanism based on prefix-codes to alleviate the orphan problem, which can make more efficient use of the address space. With importing a coefficient, the mechanism can provide the redundant address pool for the expansion of the network. Results show that our scheme achieves a more flexible and simple addressing assignment algorithm. The simulation results also demonstrate the low overhead when the device is updating.

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