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Mesh Routing Schemes for Wireless Sensor Networks[1]

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Abstract

In this paper, we survey mesh routing algorithms for wireless sensor networks. In wireless sensor networks, there exist two kinds of mesh routing approaches: layer 2 routing and layer 3 routing. In layer 3 routing, mesh functionality is in network layer while the functionality is embedded in data link layer in layer 2 routing. Standardization activities have shown that layer 3 routing can be implemented based on the tree-based and AODV routing algorithms while layer 2 routing uses meshed adaptive tree scheme. For both cases, we qualitatively provide their advantages and disadvantages, and conclude that layer 2 routing provides better adaptability and scalability for increasing network nodes.

1. Introduction

Wireless sensor networks are usually formed in mesh topology which has very attractive features [1] such as (1) extension of network coverage without increasing transmission power or receiving sensitivity, (2) enhanced reliability via route redundancy, (3) easier network configuration, and (4) longer device battery lifetime. There are two types of mesh nodes in wireless mesh networks (WMNs): mesh routers and mesh clients. A mesh router provides network access for clients, and also forwards packets to other nodes. WMNs are dynamically self-organized and self-configured. Thanks to these capabilities, WMNs are expected to provide a large number of potential applications in the near future.

To keep pace with the rapid growth of WMNs, standardization organizations have developed specifications for WMNs based on IEEE 802.11, 802.15, and 802.16. For wireless personal area networks (WPANs), IEEE 802.15 published two specifications for high data rate (task group 3 [2]) and for low data rate (task group 4 [3]). For wireless sensor networks, specification for only task group 4 (IEEE 802.15.4) among all IEEE 802 family can be utilized. Recently, ZigBee alliance [5] has been formed to provide any higher layer functions for IEEE 802.15.4 MAC/PHY. ZigBee stack provides mesh routing functionality in network layer for reliable multipath communication. More recently, task group 5 has also been chartered to determine the necessary mechanisms in physical and MAC layers of WPANs to enable mesh networks to be interoperable, stable, and scalable. The task group also considers necessary modification for IEEE 802.15 standards [2, 3]. IEEE 802.15.5 utilizes a fully distributed MAC without any central coordinator. Logical groups are formed around each device to facilitate contention-free exchanges while exploring medium reuse over different spatial regions.

In this paper, we survey the above mesh routing algorithms for wireless sensor networks with emphasis on qualitative features such as advantages and disadvantages. In section 2, we provide conceptual overview of wireless mesh network. Then, we explain the mesh routing approaches in section 3, followed by comparisons in section 4. Finally, we conclude this paper in section 5.

2. Wireless Mesh Network

There exist, in general, a large variety of network topologies for different network infrastructure. They can be categorized by three types of topologies: (1) star, (2)

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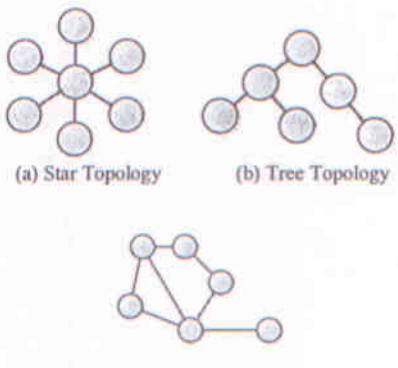

Fig. 1. Three topologies for wireless connection

tree, and (3) mesh as in Fig. 1. A star topology consists of a central node with a point-to-point link in a 'hub' and 'spoke' fashion. The hub (or the central node) transmits its data to the spoke nodes (or nodes that are attached to the central node) or relays the data coming from a spoke node to another.

A tree network topology has a central node which forms a star topology with other nodes that are connected to it. The central node can be considered as a parent while the other nodes are taken as children nodes. The child node can recursively take a new set of other nodes as its children to form a tree topology. A node that does not have any parent is called a root of the tree while a node that does not have any children is referred to as a leaf node. In the tree topology, there is only one path between a parent and a child.

In mesh networking, any node can be connected to any other neighboring nodes and establish multiple paths to a specific destination node, which allows continuous connections even if there are broken or blocked links by "hopping" from a node to another until the destination is reached. Consequently, mesh networks support self-healing techniques so that the network can be steadily operable. As a result, a very reliable network can be formed. The mesh network can supply back haul services to other nodes in the same network. It effectively extends a network by sharing access to a higher cost network infrastructure.

The above topologies have their own advantages and disadvantages as described in Table 1.

As described in Table 1, star topology cannot be used for extended wireless sensor network since it only extends to 2 hops. Tree topology has a significant problem of reliability became the sub tree under a parent will not operate if the parent fails. Mesh topology has substantial merits against to other types of topologies since mesh topology can resist any type of network failure by providing multiple paths for nodes to communicate each other. This impact will increase even when nodes are connected wirelessly.

Table 1. The advantages and disadvantages of tree different topologies

Star	Pros	• Relatively synchronous • Good latency control • Supports very low power operation • Possible support for QoS
	Cons	• Network at most 2 hops across • Requires reliable links with coordinator
Tree	Pros	• In beacon-oriented trees, latency can be fixed per path • Supports very low power operation • Allows multi-hop communication
	Cons	• Requires reliable tree links • Maximum network diameter if fixed • Latencies will typically be quite long if not using beacon
Mesh	Pros	• Robust, multi-hop communication that exploits multiple paths • Network diameter not necessarily fixed • Per-hop latency can be minimal
	Cons	• Path latencies are more difficult to characterize • Routers must be on all the time • Routing storage required • Route discovery required

3. Mesh Routing Approaches

We can consider two mesh routing approaches with respect to placement of mesh routing functionality. In other words, mesh functionality can be placed in network layer (referred to as Layer 3 routing) or data link layer (called by Layer 2 routing). In Layer 3 routing, mesh functionality is in network layer as normal approach while the functionality is embedded in data link layer in Layer 2 routing as shown in Fig. 2 to expedite the routing capability. In this section, we will investigate their mechanism in each subsection.

3.1 Layer 3 Routing

In wireless sensor network, sensor nodes have stringent resource constraints such as power and memory. Hence, the routing algorithm needs to be designed considering these constraints. The tree-based routing will be the simplest approaches which minimize the demands of the resources. ZigBee routing recommends tree-based routing [5], and uses Layer 3 routing. In Layer 3 routing, therefore,

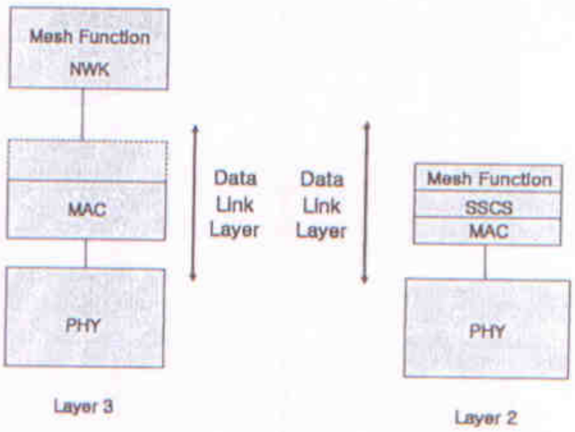

Fig. 2. The placement of mesh routing functionality

network is firstly formed by tree topology. If the sensor node has an enough resource, the node is allowed to use efficient routing algorithms to discover the best route to the destination node. AODV (ad hoc on-demand distance vector) routing can be preferred for this reason. Therefore, in layer 3 routing, we can use either tree-based or AODV routing algorithm depending on the remaining resources that the node can provide.

In the tree-based routing algorithm, each node can be assigned by a unique address using the following parameters [5]:

- δ specifies the maximum number of hops that the network may have,
- α is the maximum number of children, and
- β is the maximum number of children has routing capability.

Based on the above parameters, address of nth node A_n at depth d+1 is uniquely assigned by

$$A_n = A_{parent} + \phi(d) \times \beta + n, \qquad 1 \le n \le (\alpha - \beta) \quad (1)$$

where A_{parent} is the address of its parent, and depth $\phi(d)$ is the size of the address sub-block being distributed by each parent at depth d to its router-capable child devices at depth $d+1$, and is computed by

$$\phi(d) = \begin{cases} 1 + \alpha(\delta - d - 1), & \text{if } \beta = 1 \\ \dfrac{1 + \alpha - \beta - \alpha \times \beta^{\delta - d - 1}}{1 - \beta}, & \text{otherwise} \end{cases}$$

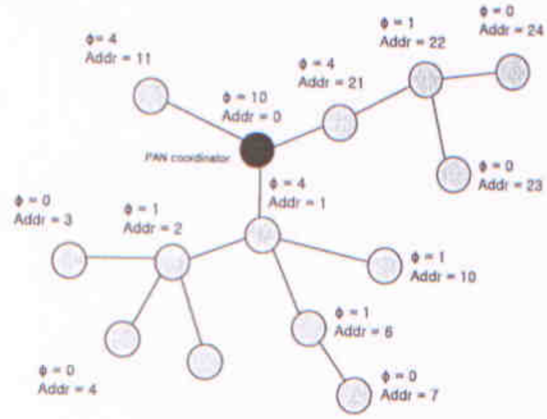

Fig.3. The diagram of address assignments (Suppose we set α= 3, β= 2, and δ=3)

The result of the address assignments using (1) is shown in Fig. 3.

Tree-based routing algorithm uses hierarchical routing. For this routing, each device has a range of addresses of its descendants. If the destination is matched with the range of addresses, the device forwards down the frame to the corresponding child. Otherwise, the device routes up the frame to its parent. However, this routing has a problem in which it could forward the frame to the destination sub-optimal path as well. It means tree based algorithm might cost much higher than expected so that we can employ AODV base algorithm.

For this algorithm, each device functioning as a router has a routing table which contains the destination address and next hop to reach the destination. When a device tries to forward a frame to the destination, it first searches the routing table. If there exist the destination address and the next hop in the routing table, it forwards the frame to the next node according to the corresponding routing table entry. If the device does not have any existing routing table for the destination, it initiates path discovery procedure to the destination. This procedure is preceded as the device broadcasts route request to its neighbors for routing information including the number of hops to the destination. After the device finds the path from route replies, it inserts the routing information to the routing table and forwards its frame according to the routing entry. If there is no space left in routing table, then the node uses tree-based routing.

3.2 Layer 2 Routing

In layer 2 routing approach [4], once again tree-based routing algorithm is used for simplicity in wireless sensor network. Unlike the layer 3 routing, the mesh functionality is embedded in the data link layer, and the mesh is formed by connecting virtual connections among neighbors. In other words, a node considers its neighbor nodes as its children, and creates meshed architecture which does not require route discovery protocol such as AODV. This is the significant difference from the layer 3 routing.

Address assignment in layer 2 routing is broken down into two stages [4]: association and address assignment. In association stage, beginning from the root, nodes gradually join the network and a tree is formed but no node has been assigned an address yet. After a branch reaches its bottom, that is, no more nodes wait for joining the network (a suitable timer can be used for this purpose), a down-top procedure is used to calculate the number of nodes along each branch and each node report to its parent. The number of children field will be set to the number of nodes along its branch, including itself. The number of requested addresses field is set to the sum of the numbers of requested addresses received from all children, plus 1 or some value larger than 1 if the node also wants to reserve some addresses.

Any node can update the number of children (the number of requested addresses) by sending another children number report frame to its parent if it has not been assigned with an address block. After the root receives the information from all the branches, it begins to assign addresses. During the address assignment stage, a top-down procedure is used. The root checks if the total number of nodes in the network is less than the total number of addresses available. If not, address assignment fails. Next, the root assigns a block of consecutive addresses to each branch below it, taking into account the number of children and the number of requested addresses. The address block assigned to each branch is specified by the beginning address field and the ending address field given in the address assignment frame sent to each branch. This procedure continues until the bottom of the tree is reached. After address assignment, a logical tree is formed and each node has a block addressing table (BAT) for tracking branches below it.

More nodes are still allowed to be added at any level of the tree after address assignment, only if additional addresses are available. Address assignment can be locally adjusted within a branch if a node runs out of addresses. For instance, a node can request more addresses from its parent. If the parent does not have enough addresses, it can try to either request additional addresses from its parent or adjust address assignment among its children. If there is a substantial change of the node number or network topology, which cannot be handled locally, the network is allowed to go through the address assignment procedure again.

After a node has been assigned with an address block, it broadcasts several hello messages to its neighbors, with the time to live (TTL) field of each hello frame set to maximum hops. By exchanging hello messages, each node will build a link state table (LST) for all its neighbors within the maximum hops count. Each neighbor's address block is logged in the LST so that the whole branches below the neighbor are routable.

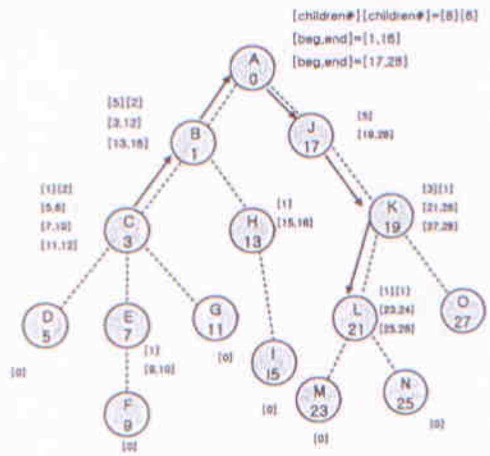

Fig. 4. Routing steps from the node C to the node L

When the node transmits a frame, it looks at the address blocks for the destination address and route the packet accordingly. If the node does not find address block, route through parent. The node C transmitted to the node L is shown in Fig. 4..

4. Comparison routing schemes for WPAN

As described in the previous section, we have shown two possible schemes for wireless mesh routing for WPAN. Layer 3 routing uses tree-based routing algorithm and AODV-based routing algorithm. Each node can be assigned hierarchical address. A node functioning as a router checks address range. If it finds address, the node forwards the frame to child node. Otherwise, the node forwards up to parents node.

Layer 2 routing is based on the meshed adaptive tree formation. A node looks at the address blocks for the destination address and route packet accordingly. If address block cannot be found, it route a frame through parent. Otherwise, it routes the frame to corresponding branch.

Layer 3 routing has a problem of fixed balanced tree architecture since layer 3 routing has a problem of fixed balanced tree architecture with three parameters α, β, and δ. These parameters are established before a wireless mesh PAN is created. Therefore, changing parameters is not possible during operation of the routing. For example, if β is chosen to a specific value (e.g. β =5), then any additional children exceeding 5 cannot join the network, Also, α and δ are fixed when network organize. In other

Table 2. Comparison Layer 2 routing and Layer 3 routing

	Layer 2 Routing	Layer 3 Routing
Routing Algorithm	Meshed adaptive tree based	Tree-based AODV-based
Flexibility	Yes	No
Address Assignment	Request & Assignment. Dynamic Assignment system,	Fixed before network organized
Topology	Star, Tree, Mesh	Star, Tree, Mesh(fixed)

words, we cannot change the depth of the tree, the maximum number of nodes which have routing function and the number of maximum children during the network operation. However, layer 2 routing gives a flexibility to organize the depth of the tree, and the number of children. This is a nice benefit for wireless sensor network. This comparison can be summarized in Table 2.

5. Conclusion

There exist two kinds of routing algorithms in wireless mesh network. Layer 3 routing algorithm uses tree-based and AODV algorithms. In layer 3 routing, mesh functionality is in network layer. Consequently, MAC layer can be replaced other MAC (medium access control) scheme. But tree addressing based on $\phi(d)$ is just not flexible enough. Often, it runs out of addresses on a particular node and the depth of the tree is sometimes too much. In layer 2 routing, meshed adaptive tree algorithm gives flexibility for network scalability and adaptability. After assigning address to nodes, other nodes can join the network.

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