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Path Recovery Mechanism in 6LoWPAN Routing

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Abstract— **The feature of 6LoWPAN is the capability of the dynamic assignment of 16-bit short addresses. Hierarchical routing (HiLow) algorithm that uses dynamically assigned 16-bit unique short address as its interface identifier has an advantage of memory saving. The 16-bit unique short address is assigned to a 6LoWPAN device during an association operation with a neighbor node which is also called parent node in HiLow. Besides reducing the overhead of maintaining routing table, HiLow also supports for larger scalability. However, previous research did not deal with the path recovery when sensor nodes in HiLow are failed. The node failure may be due to the battery lifetime of the 6LoWPAN device. This kind of failure will cause the expiration of the association event and make the previously assigned 16-bit short address of the child node from the failure parent node become invalid within PAN. In this paper, a new path recovery mechanism so-called step parent node (SPN) algorithm is proposed to conventional HiLow to reassign the valid 16-bit short addresses for the child nodes of the failure parent node and provide the path robustness. The child nodes of the failure parent node will broadcast a step parent node request message (spn_request) to the neighbor nodes. The neighbor node whose child nodes do not exceed the maximum child value will act as a step parent node of the new child nodes. It enhances the reliability of conventional hierarchical routing mechanism.**

Keywords- 6LoWPAN; HiLow; 16-bit address; path recovery; step parent.

I. Introduction

Wireless sensor network (WSN) is one of the fastest growing segments in the ubiquitous networking today [1]. In order to morph WSN from Personal Area Network (PAN) into Low power Personal Area Network (LoWPAN), IEEE standard 802.15.4 is introduced [2]-[4]. The standard specifies the wireless medium access control (MAC) and physical (PHY) layer for low-rate wireless personal area network as defined in [5].

Currently some sensor network protocols have non-IP network layer protocol such as ZigBee, where TCP/IP protocol is not used. However, future WSNs consisting of thousands of nodes and these networks may be connected to others via the Internet [1]. Hence, IPv6 over Low power Wireless PAN (6LoWPAN) is defined by Internet Engineering Task Force (IETF) [6] as a technique to apply TCP/IP to WSN [1], [7]. 6LoWPAN provides a WSN node with IP communication capabilities by putting an adaptation layer above the 802.15.4 link layer for the packet fragmentation and reassembly purpose [1], [2], [8]. The 6LoWPAN devices are the devices conform to the IEEE 802.15.4 and characterized by short range, low bit rate, low power, low memory usage and low cost [9]-[12].

Due to the constrained resources of 6LoWPAN devices, routing protocols in 6LoWPAN environments make the choice from existing pool of routing schemes very limited [13]. Routing per se is a two phased problem that is being considered for 6LoWPAN. First is the routing of packets in the PAN. Second is the routing of packets between the IPv6 domain and PAN. Therefore, there are two routing scheme categories in 6LoWPAN: the mesh-under and the route-over. Figure 1 shows the mesh-under and route-over routing at the 6LoWPAN protocol stack layer respectively.

The mesh-under approach performs its routing at adaptation layer and performs no IP routing within LoWPAN whereby it is directly based on the IEEE 802.15.4 MAC addresses (16-bit or 64-bit logical address). On the other hand, the route-over approach performs its routing at network layer and performs IP routing with each node serving as an IP router [14] - [16]. The globally unique IP address of each node is created automatically by appending its interface identifier (either 16 bits or 64 bits) to the IPv6 prefix that received via router advertisement (RA). This is known as stateless auto-configuration method which is one of the 6LoWPAN features [17].

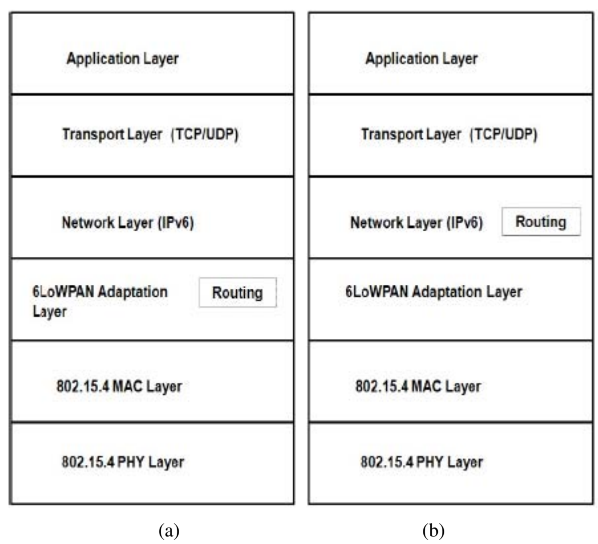


Figure 1. Routing schemes in 6LoWPAN (a) mesh-under and (b) route-over.

There have been a few developments on routing protocols for 6LoWPAN. The Ad-hoc On-Demand Distance Vector (AODV) is the most widely used routing protocol for mobile ad-hoc networks and has been considered as a strong candidate for 6LoWPAN because of its simplicity for finding routes. AODV uses a destination sequence number for each route entry to help a requesting node to choose the route with the greatest sequence number to a destination. It is also used to ensure the loop freedom within the routes [4], [18]. In order to achieve a more lightweight protocol that maximizes bandwidth efficiency in 6LoWPAN, the 6LoWPAN Ad-Hoc On-Demand Distance Vector Routing protocol (LOAD) has been proposed in [19]. It is a simplified on-demand routing protocol based on AODV. Instead of using destination sequence number, LOAD utilized the Link Quality Indicator (LQI) of the 6LoWPAN physical layer in the routing decision. It is in order to reduce the size of the control messages and simplify the route discovery process. For ensuring loop freedom, only the destination of a route should generate a Route Reply (RREP) in LOAD [19], [20].

To obtain a globally unique address for preventing address conflict, both AODV and LOAD use IEEE 64-bit address as devices' interface identifiers for building on demand multi-hop routing table. However, because of its length, the IEEE address is not scalable and inefficient when used in the 6LoWPAN [21]. Therefore, hierarchical routing (HiLow) that use dynamically assigned 16-bit unique short address as device's interface identifier is proposed in [22]. It has an advantage of memory saving. The 16-bit unique short address is assigned to a 6LoWPAN device during an association operation with a neighbor device (or router) which is also called a parent node in HiLow. Besides reducing the overhead of maintaining routing table, Hilow also support for larger scalability [7], [22], [23].

However, the previous researches did not deal with the path recovery when the sensor nodes in HiLow are failed. The routing path between source and destination nodes becomes unavailable when intermediate nodes are failed. The node failure may be due to the battery lifetime of the 6LoWPAN device. This kind of failure will cause the expiration of the association event and make the previously assigned 16-bit short address of the child node from the failure parent node become invalid within PAN. In this paper, a new path recovery mechanism so-called step parent node (SPN) algorithm is proposed to the conventional HiLow. In this algorithm, the child nodes of the failure parent node will broadcast a step parent node request message (spn_request) to the nearest neighbor nodes. The neighbor node whose child nodes did not exceed the maximum child value will be assigned as the step parent node for these child nodes. Hence, the valid 16-bit short addresses for these child nodes can be reassigned to avoid the addressing conflict between nodes. It enhances the reliability of conventional hierarchical routing mechanism.

This paper is organized as follows. Section II presents the overview of 6LoWPAN. The various routing protocols used in 6LoWPAN are discussed in Section III. The proposed SPN algorithm with some new features for path recovery in conventional HiLow is described in Section IV. This paper is concluded in Section V.

II. 6LOWPAN OVERVIEW

A. *Brief introduction to 6LoWPAN*

6LoWPAN is a simple low cost communication network that allows wireless connectivity in applications with limited power and relaxed throughput requirements [6]. 6LoWPAN provide IPv6 networking over IEEE 802.15.4 networks [22]. Figure 2 shows the 6LoWPAN architecture. Figure 3 describes the reference model of 6LoWPAN protocol stack. It adopts IEEE 802.15.4 standard PHY and MAC layer which are specified in [5] and [6] as its bottom layers while chooses IPv6 in its network layer.

The maximum transmission unit (MTU) for IPv6 packets over IEEE 802.15.4 is 1280 octets. However, a full IPv6 packet does not fit in an IEEE 802.15.4 frame [8]. The payload length supported by MAC in IPv6 is much bigger than one provided by 6LoWPAN bottom layer. In order to implement the seamless connection of MAC layer and network layer, 6LoWPAN working group suggested that adding a adaptation layer between MAC layer and network layer to achieve the header compression, fragmentation, reassembly and mesh route forwarding [11].

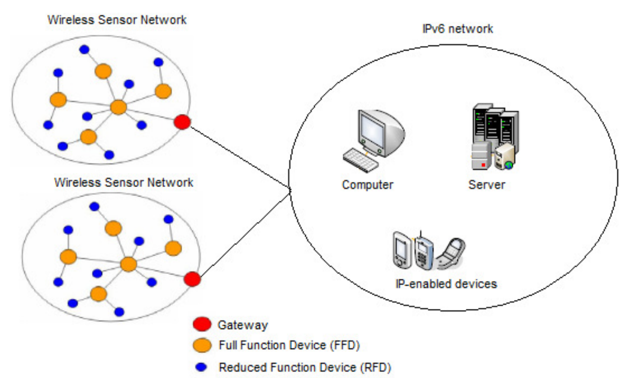


Figure 2. 6LoWPAN architecture.

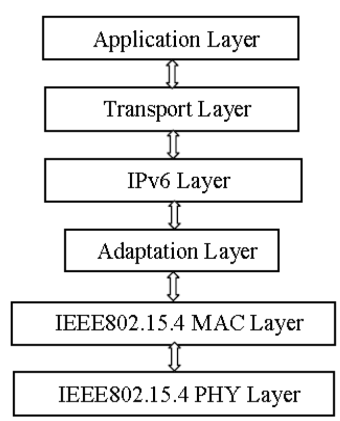
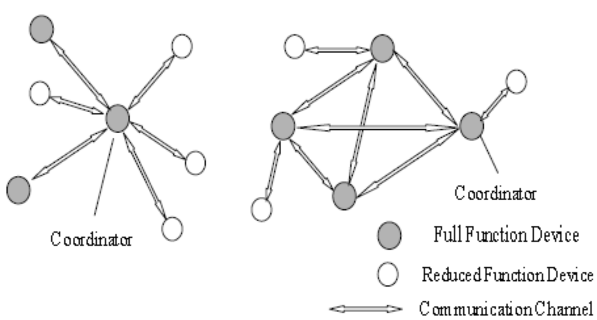


Figure 3. The reference model of 6LoWPAN protocol.

B. Features of 6LoWPAN

Since 6LoWPANs are formed by complying nodes to the IEEE 802.15.4 standard [12], the characteristics of the standard such as low power, low data rate and etc are also included in the technology [5], [6]. The main features of 6LoWPAN are listed as below:

1. Support for both 16-bit and IEEE 64-bit address: The 16-bit short addresses are unique within the PAN and are dynamically assigned after an association with the PAN coordinator or with other nodes in the PAN. The 64-bit IEEE addresses are globally unique [2], [8].
2. Support stateless address auto-configuration: The 6LoWPAN node automatically appends its interface ID to the IPv6 prefix to create its own IPv6 address. This method reduces the configuration overhead [6].
3. Support Full Function Device (FFD) and Reduced Function Device (RFD): FFD can serve as a PAN coordinator, router or an end device. It sends MAC layer beacon frame in order to indicate their presence to other FFDs or RFDs. RFD is the end device which has limited function and does not have enough power and memory space for maintaining a routing table. It unable to transmit MAC layer beacon and can only communicates with FFDs in a master/slave star topology [2], [11], [12].
4. Support both star and mesh network topology: Figure 4 shows the star and mesh network topology in 6LoWPAN. In a star network, the PAN coordinator is always one hop away from any sensor node because every node is directly connected with the PAN coordinator and there is no need of mesh header related fields in the 6LoWPAN header. However, in mesh topology, the 6LoWPAN adaptation layer needs an extra header to keep the originator and final destination address while the IEEE 802.15.4 MAC layer carries the source and destination node address that change at each hop [24].



(a) Star topology (b) Mesh topology

Figure 4. 6LoWPAN topologies (a) Star and (b) Mesh.

III. ROUTING PROTOCOL IN 6LOWPAN

For the routing aspect in 6LoWPAN, AODV has been considered as a strong candidate for 6LoWPAN. It enables dynamic, self-starting, multihop routing between participating mobile nodes that wishing to establish and maintain an ad-hoc network. A distinguish feature of AODV is its use of destination sequence number for each route entry as mentioned in section I. For route discovery, AODV use Route Requests (RREQs) messages and Route Replies (RREPs) messages. RREQ that broadcast by originator node contains the sequence number for route choosing purpose. RREP is to be unicast from the destination node or the intermediate node to the originator node to make the route available.

Every node maintains route entries that expire after some time if the route is not used. For each entry, there is a precursor list containing the nodes that use this one as the next hop on the path to a given destination. When there is a link break in an active route, the upstream node that detected it may try to repair the path locally, or alternatively if that is not possible, to send a Route Errors (RERRs) messages to its precursor list in order to notify other nodes that the loss of that link has occurred [18], [19].

LOAD is a simplified on-demand routing protocol based on AODV. It is defined to be operating on top of the adaptation layer instead of the transport layer and should be only run on FFDs. LOAD has several points of difference to AODV as mentioned in section I. The LQI and the number of hops from the source to the destination are the routing metrics in LOAD. A route is preferred if the number of weak links along the way is smaller (link whose LQI is worse than a certain threshold value) and less hops from the source to the destination. Besides that, LOAD does not use the precursor list of AODV in order to simplify the routing table structure. In case of a broken link happen, the upstream node of the link break may try to repair the route locally by using route discovery mechanism in LOAD whereby RREQ and RREP message are used. If the repairing node unable to repair to link, it unicasts a RERR with an error code that indicates the reason of the repair failure to the originator of the failed data message only. Thus no requiring to use the precursor list [19], [20].

Unlike AODV and LOAD that use IEEE 64-bit identifier, HiLow use 16-bit unique short address as interface identifier for memory saving and larger scalability. In HiLow, when a IEEE 802.15.4 device (or child) want to join a 6LoWPAN, it first tries to discover an existing 6LoWPAN by scanning procedures. If there is no 6LoWPAN in its personal operating space (POS), the child device becomes the initiator (or coordinator) of a new 6LoWPAN and assigns its short address by 0. Otherwise, the child device can find an existing neighbor device (or parent) of the existing 6LoWPAN and tries to associate with the parent at the MAC layer to receive a 16-bit short address. Every child node receives a short address by the following equation:

$$C = MC * AP + N \ (0<N<=MC) \tag{1}$$

where C is the child node address, MC is the maximum number of children a parent can have, AP is the address of the parent, N is the *n*th child node [23].

For the routing operation in HiLow, it is assumed that every node knows its own depth. When a node receives an IPv6 packet, it is called the current node. The current node determines first whether it is either the ascendant or descendant nodes of the destination by using (1), whereby in this case, C is the address of the current node and AP is the address of the parent of the current node. After that, the current node determines the next hop node to forward the packet by using the algorithm in [23]. However, when there is a link break in a route, HiLow does not support any recovery path mechanism as AODV and LOAD.

IV. Proposed Step Parent Node (SPN) Algorithm

In this paper, a new path recovery algorithm so-called step parent node (SPN) algorithm is proposed to the conventional HiLow. Figure 5 shows the conventional HiLow structure. In the figure, every parent node has four child nodes except node 4 which only has two child node, node 17 and node 18.

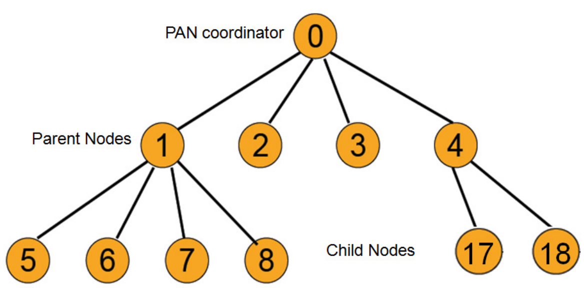


Figure 5. Conventional HiLow structure.

In the proposed SPN algorithm, assume that every nodes knows its MC value (MC = 4) and its depth. When there is a link break caused by a failure node, every child nodes of the failure parent node will broadcast a step parent node request (spn_request) message to the neighbor nodes in its POS as showed in Figure 6.

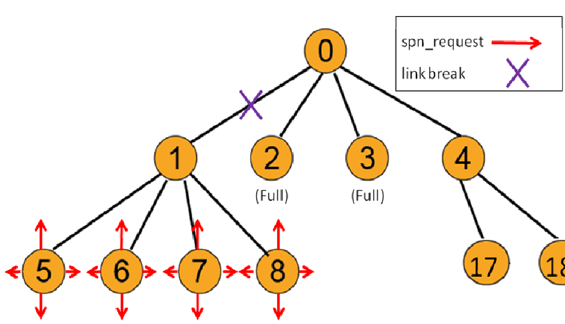


Figure 6. spn_request message broadcast.

The neighbor node that receives the spn_request will determine first whether its existing number of child nodes has exceeded the MC value or not. The neighbor node which has the existing number of child nodes that less than its MC value will unicast a step parent node reply (spn_reply) message to the spn_request sender. Figure 7 shows the spn_reply messages that unicast to the spn_request sender. Assume that in Figure 7, only node 4 does not exceed its MC value. So, only node 4 will unicast the spn_reply to the spn_request sender, node 8. Other spn_request senders such as node 5, node6 and node 7 are not discussed here to give a better understanding of the proposed SPN algorithm.

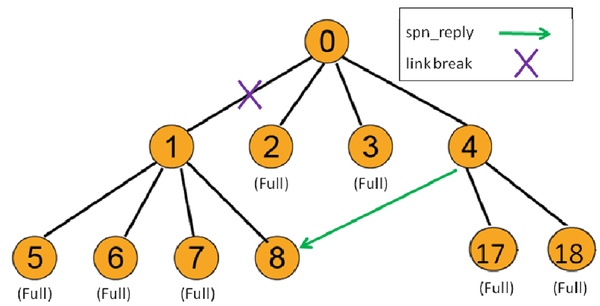


Figure 7. spn_reply message unicast

The node that receives the spn_reply message from many neighbor nodes in its POS will check the spn_reply sender's address and its path quality indication (PQI) that included in the spn_reply. The spn_request sender only makes an association event with the neighbor node that has a high PQI and is not the descending node of the sender. After the association, the neighbor node will become the new parent node of the child nodes from the failure node. Figure 8 shows the formation of new link. The new parent node, node 4 that assigned to the child node, node 8 after an association process was done. The valid 16-bit short addresses for the child node, node 8 can be reassigned by the new parent node, node 4 to avoid the addressing conflict between nodes.

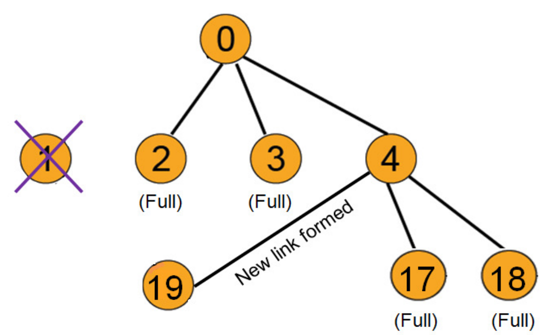


Figure 8. Formation of new link.

V. CONCLUSION

In this paper, we proposed the SPN algorithm into the conventional HiLow to solve the path recovery in 6LoWPAN system. A step parent request node message (spn_request) will be broadcast from these child nodes to the neighbor nodes. The neighbor node which has the existing number of child nodes that less than its maximum child (MC) value will unicast a step parent node reply (spn_reply) message to the spn_request sender. The robustness of proposed path recovery of SPN algorithm will provide a sustainable connection along the 6LoWPAN routing path.

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