Fast Forwarding Schedule Function for Multi-hop 6TiSCH Networks

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***Abstract*—The architecture of Internet of Things gradually mature and has been applied in many fields. The variety of sensors has been transmitted to the Internet through the wireless sensor network. The IoT technology has been popular topic discussion and extended to the industrial network. The IETF proposed 6TiSCH (IPv6 over the TSCH mode of IEEE 802.15.4e) integrates IPv6 and IEEE 802.15.4e TSCH protocol which is suitable for IWSNs(Industrial Wireless Sensor Networks) environment. The main purpose of this research is to enhance the performance of Multi-hop 6TiSCH network by using the FFSF (Fast Forwarding Schedule Function). According to the simulation results, the proposed FFSF increases the overall transmission efficiency with lower end-to-end transmission delay than the original 6TISCH SF0 mechanism.**

Keywords—6TiSCH , SF0 , 6top , IEEE 802.15.4e

1. INTRODUCTION

In Internet of Things, a large number of sensors needed to communicate in the same areas, is bound to be affected with the ISM 2.4GHz frequency interference. IEEE 802.15.4e [1] TSCH MAC layer protocol proposes a time slots channel hopping technology which is combine with TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access) to reduce the co-channel interference. However, the TSCH lacks the overall channel management in the multi-hop wireless sensor networks due to the random channel hopping.

IETF proposed 6TiSCH [2] mainly used in IPv6 wireless sensor network, through RPL [3] deployment for a large number of network, a tree topology is used to establish multi-hop network based on RPL routing algorithm. Thus, IETF 6TiSCH introduce a 6top [4] sub-layer which responsible for the adjacent node monitoring and management nodes scheduling for IEEE 802.15.4e TSCH network architecture. In this paper, we conducted simulation analysis based on OpenWSN [5] which is an open source wireless sensor network simulation. We has analyzed the effectiveness between the original 6TiSCH SF0 [6] and the proposed FFSF. The simulation result shows the proposed FFSF has lower end-to-end transmission delay than the original 6TISCH SF0 mechanism. The remaining part of this paper is organized as follows; related works are discussed in section 2. The section 3 describes the original 6top SF0. In section 4, we compare the transmission performance between the original 6TiSCH SF0 and the proposed FFSF. Finally, section 5 concludes this paper along with future directions.

2. 6TISCH ARCHITECTURE AND RELATED WORKS

The IEEE 802.15.4 standard operates in ISM 2.4GHz frequency band and extensive use in wireless sensor network. The IEEE 802.15.4e-2012 standard defines a MAC amendment to the existing IEEE 802.15.4-2006 standard. Time-Slotted Channel Hopping (TSCH) is one of the MAC operation modes for IEEE 802.15.4e-2012 standard. The TSCH (Time-Slotted Channel Hopping) is one of the MAC operation modes, which reduces the influence of co-channel interference by using random channel hopping in each slots. However, this random channel hopping pattern in TSCH mode lacks a complete hopping management mechanism to operate for multi-hop wireless sensor network environment.

In addition, IETF proposed 6TiSCH architecture, which integrates with IETF 6LoWPAN [7] and ROLL [8] and 802.15.4e TSCH. In the 6TiSCH architecture, CoAP and UDP are used for upper-layer communication and a scheduling mechanism is used to manage available timeslots The 6top is a new sub-layer of 6TiSCH stack, which sub-layer is responsible for maintaining the link status, statistical information and provides the node schedule. The timeslot scheduling of 6TiSCH starts communication after pairing between receiver and transmitter. The cells are scheduled into one cycle called a slotframe. In [9] and [10], authors conform the structure of 6TiSCH and implement the related applications under IPv6 network.

The RPL (IPv6 Routing Protocol for LLNs) is a Distance Vector IPv6 routing protocol for low-power lossy networks to compute the 'best' route path in multi-hop networks. In RPL, the parent node sends DIO messages and children nodes feedback the DAO message to build a DODAG (Destination Oriented Directed Acyclic Graph) tree topology. In addition, the node can send the DIS message to know the status of neighbour nodes to establish the stably connection to the parent node. In [11], authors solve a single network load balancing by using the proposed LB-RPL method to improve the overall WSN node network life cycle.

In [12], the transmitter uses the On-The-Fly (OTF) [13] mechanism before data transmission to solve the bandwidth waste caused by higher or lower bandwidth and transmission rate decrease problem by using dynamic bandwidth. The results show the proposed OTF mechanism could achieve the higher reliability in the end-to-end transmission.

SF0 (Scheduling Function Zero) is a scheduling function of 6top [14] to allocate cells and the neighbor nodes' cell requirements. SF0 defines two algorithms, the cells scheduling algorithm and cells relocation algorithm. The cells scheduling algorithm defines the number of required cells between two neighbours. SF0 uses the 6P [14] messages to manage cells addition or deletion in the schedule. The relocation algorithm defines how to relocate a lower PDR (Packet-Delivery Ratio) cell in a schedule. The allocation policy of relocation algorithm monitor PDR for each allocated cell periodically to decide when to add/delete cells to a particular neighbor to meet the required bandwidth of cell. The call relocation is activated when the average PDR value of particular neighbor lower than a certain PRD threshold. Then, the relocation algorithm will select a cell randomly after 6Top negotiation to improve the cell PDR.

The LLSF fast scheduling method has been proposed in [15] which try to improve the SF0 random scheduling method in 6TiSCH. The SF0 sends an ADD cell request to the parent node to schedule a new TX cell randomly for forward packets from the previous hop. The LLSF daisy-chains the timeslots used in a multi-hop path without random schedule. The LLSF selects a cell randomly among the unscheduled timeslots in the first hop. However, this will lead to competition issues in the following multi-hop transmission. Thus, an Fast Forwarding Schedule Function (FFSF) is proposed in this paper to enhance the transmission efficiency in multi-hop wireless sensor networks. The proposed FFSF will be explained in the next section.

3. The schedule functions in 6TiSCH

3.1 Schedule Function Zero (SF0)

SF0 is scheduling function in the 6top layer, which is control the bandwidth between the nodes and maintain the link quality of cells. The transmission schedule between the parent and children nodes can be manage when the children node to send the 6P Request message on the 6top consultations. The children node will send 6P Request message to the parent node. The 6P Request message includes several random numbers of available cells, called the "cell list". The parent verifies the received cell list and then returns an available cell through 6P Response message to the children node to establish a TX/RX scheduled cells between two nodes after the RPL network topology setup complete.

We will analysis the performance of SF0 in OpenWSN network simulation which is an open source implementation of the 6TiSCH protocol stack.

Figure 1 shows the network topology of simulated multi-hop networks in OpenWSN. In Figure 2, the different color is representing the dataflow on each node. Let's consider the schedule illustrated in Figure 2. The 3 shared cells at the beginning of the slotframe, using the slot offset 0. The shared cells used for control traffic in the contention mode typically. The serialRX cells are reserved to process 6P Request and Response messages. The other cells are dedicated and only the TX cell can transmit a packet without contention. Each DODAG link has one or several cells to forward the packets to its parent. The link from node 5 to node 1 (red flow) reserved for instance 4 dedicated cells. Because the link is a four hops of forwarded path. However, 6top does not define the way to select cells efficiently. In Figure 2, the red flow (from node 5 to node 1), the incoming cell in node 3 is located after the outgoing cell. Thus, node 3 has to buffer the corresponding packet during the whole slotframe, increasing significantly the end-to-end delay. In this paper, we use the 6TiSCH stack to fast forward each flow hop-by-bop to reduce the end-to-end delay efficiently.

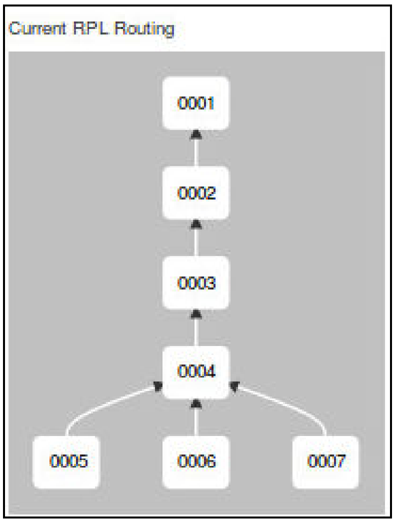


Fig 1. The Multi-hop network topology in OpenWSN

3.2 The Hidden Node Problem in Multi-hop Networks

The hidden node problem is a collision occurs if there two or more nodes try to compete for the same cell due to nodes hidden to each other and cannot listen to each other's transmissions.

In Figure 2, the Node 3 transmits data to node 2 in slot offset 7, and node 6 also transmits data to node 4 at the same cell. Node 4 is interfered from the node 2 and it was affected by hidden node problems.

3.3 Fast Forwarding Schedule Function (FFSF)

This paper introduces a new scheduling function based on 6TiSCH protocol stack, called "Fast Forwarding Schedule Function" (FFSF). When node 5 schedules a timeslot to node 1, rather than picking the timeslot randomly, it fast forward the timeslots used in the multi-hop path. Each node knows the number of hops from RPL. In order to solve the hidden node problem, the intermediate node will forward packet after 2 unscheduled cells from the RX cell.

Let's consider the Figure 3 which illustrates a FFSF schedule with 4 hops transmission. For the path from node 5 to node 1, the outgoing cell in node 4 is located after the incoming cell with 2 cells. Thus, node 4 could fast forward the corresponding packet in the same slotframe and ensure the packet will not forward in the share cell in order to reduce the end-to-end delay.

4. Simulation Results

We implement FFSF in a 4-hop path network topology in Figure 1 and measure end-to-end delay in OpenWSN. Node 1 is the DAGroot of the network, node 5, 6, and 7 are UDP generates. All other nodes are just relaying data and do not generate their own UDP traffic. The simulation parameters were shown in Table 1. The simulation duration is 1000 seconds. In order to simulate the multi-hop network performance, we run 10 simulations and plot the average value for each slotframe length.

Table 1. Simulation parameters

Simulation duration	1000s
Number of nodes	7
Traffic model	1 packet/s , 2 packet/s
Slotframe length	25 , 50, 101
Data packet size	127 bytes
PDR	1(all link)
Channel mode	Single channel
Simulation runs	10
Retransmission	Disable

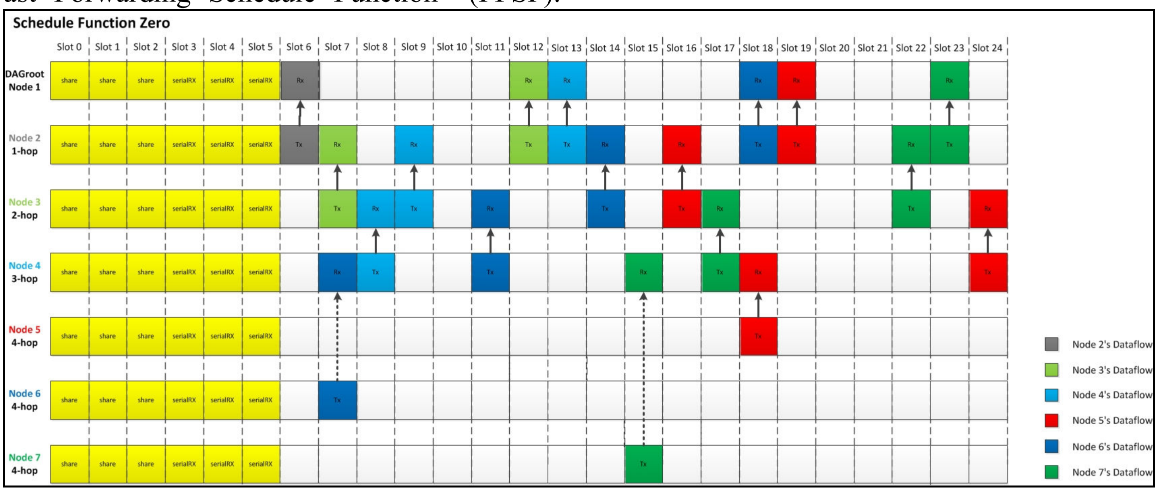


Fig 2. The schedule table of SF0 with 4 hops transmission

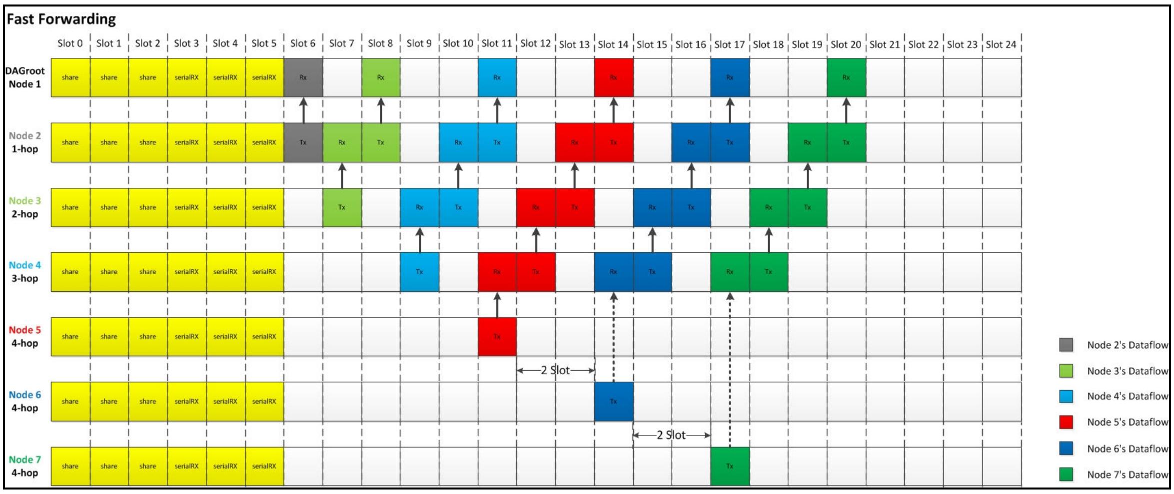
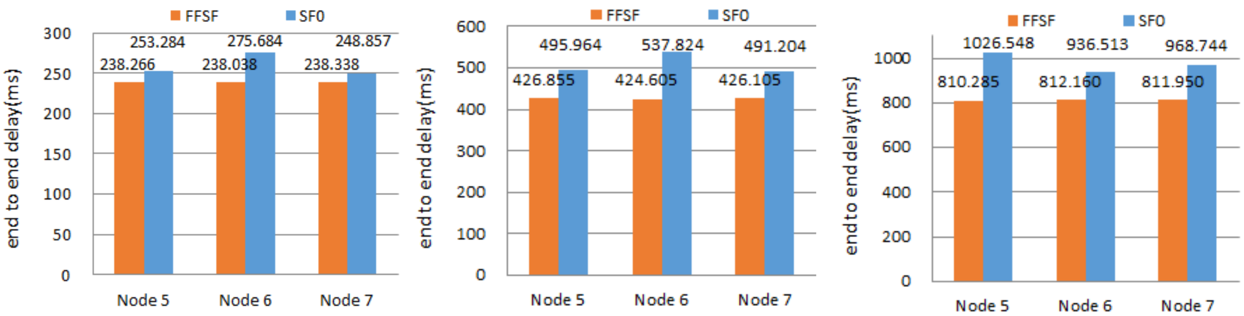


Fig 3. The schedule table of FFSF with 4 hops transmission



(a) slotframe length is 25 slots (b) slotframe length is 50 slots (c) slotframe length is 101 slots

Fig 4. The average end-to-end latency using SF0 and FFSF

In Fig.4, we measure the end-to-end delay of the SF0 and FFSF. Results show that a longer length of slotframe increases the end to end delay. In the highest slotframe length (101 timeslots), for nodes are 4 hops far from the DAGroot, the end-to-end delay of the SF0 with may reach almost 1026 ms. The end-to-end delay of the FFSF is 810ms.

5. Conclusions

In this paper proposed Fast Forwarding Schedule Function based on 6TiSCH standard. We have compared the proposed FFSF with the original SF0 in OpenWSN. From simulation results, the proposed FFSF is much efficient than the SF0.

In the future, we plan to propose mechanisms for FFSF to select best channel from TSCH to reduce co-channel interference and improve the efficiency and the reliability for multi-hop 6TiSCH networks.

Acknowledgment

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