

An Industrial IoT MAC Protocol Based on IEEE 802.15.4e TSCH for A Large-Scale Network

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Abstract— IEEE 802.15.4e TSCH MAC is widely used for the industrial market, which require ultra-high reliability and ultra-low power. However, the significance of the TSCH is missing, which is a management function to build and maintain the communication schedule. We address several limitations for IPv6 over IEEE 802.15.4e TSCH in a large-scale network and propose an enhanced scheme which deals with the configuration of Slotframes, Linkset slots, EB(Enhanced Beacon) management and scheduling information. It supports a dynamic schedule management based on observed resource usage, which achieves industrial-grade performance in terms of jitter, latency, scalability, reliability and low-power consumption.

Keywords—TSCH(Time Synchronization Channel Hopping), Slotframe, Linkset Slot, Enhanced Beacon.

I. INTRODUCTION

The 802.15.4e standard [1] is suitable for low-rate, low-power, and low-cost Personal Area Networks (PANs), to address embedded industrial applications. The standard [1] defines different MAC behavior modes. In this paper, we focus on the Time Slotted Channel Hopping (TSCH) mode, which guarantees determinism on channel access and enhances resilience to channel interference. In the TSCH, the network's communication schedule instructs each node what to do in each time slot: send to a particular neighbor, receive from a particular neighbor, or sleep. Channel diversity is obtained by specifying, for each send and receive slot, a channel offset. The same channel offset is translated into a different frequency on which to communicate at each iteration of the Slotframe.

However, the significance of the TSCH is especially pointed out by the IETF 6TiSCH Working Group (6TiSCH WG), which promotes its adoption in a future standardized communication stack for the Internet of Things [2][3].

First of all, TSCH does not define the mechanism to build and maintain the communication schedule which sets up and controls the topology of the network. For example, network formation in a TSCH network involves the transmission of

Enhanced Beacons (EB). EBs include information for joining nodes to be able to synchronize and set up an initial network topology. It is important for each node to need to periodically synchronize its network clock to another node, and it also provides its network time to its neighbors. However, it does not specify how the period of EBs is configured, and rules.

In addition, it misses the schedule the resources allocated between neighbor nodes to the data traffic flows, which matches that schedule to the multi-hop paths maintained by the Routing Protocol for Low Power and Lossy Networks (RPL) [4].

It is also required for TSCH to be designed to allow optimizations and strong customizations, simplifying the merging of TSCH with a protocol stack based on IPv6, 6LoWPAN, and RPL. This should consider various kinds of QoSs depends on routing metrics, topological information, energy consumption and latency requirements in a large-scale network.

Therefore, we propose an enhanced scheme for the configuration of Slotframes, a Linkset slot, EB management and scheduling information to achieve industrial-grade performance in terms of jitter, latency, scalability, reliability and low-power consumption.

The proposed technique enables internal TSCH queuing configuration, size of buffers and packet priorities to mitigate fragmentation and buffer management in a multi-hop Networks. It also provides an efficient EB management which leads to not only avoid the message collision but also reduce the energy consumption. Finally, depending on traffic requirements, it support a dynamic schedule management based on observed resource usage.

The rest of the paper is organized as follows. We describe the proposed enhanced scheme for the TSCH in detail in section 2. In section 3, the related work is discussed. Finally, we conclude this paper and suggest future work in section 4.

II. AN ENHANCED SCHEME FOR THE TSCH

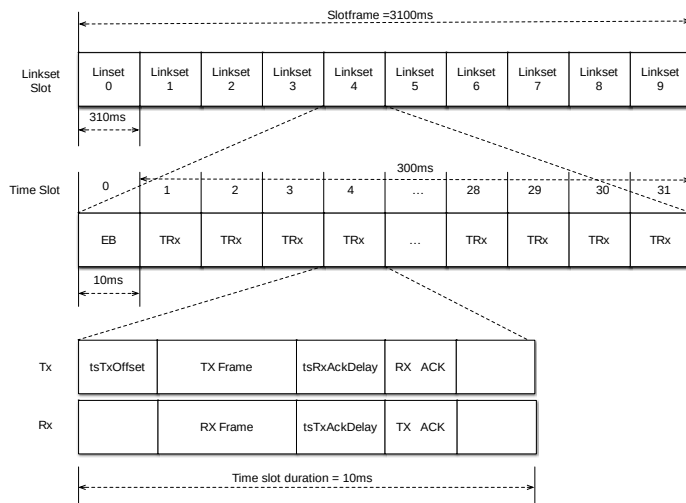


Figure 1. Slotframe and Linkset Slot Structure.

In the TSCH, only the small amount of data packet (127byte) can be transmitted within a time slot period(10ms) in a Slotframe. Due to the IPv6 default minimum MTU size (1280 bytes), an unfragmented IPv6 packet is too large to fit in an IEEE 802.15.4e frame [2]. Therefore, we propose a bundle of time slots, called a Linkset slot. Utilizing the Linkset slot we minimize the packet loss caused by the buffer overflow without fragmentation and reduces the end-to-end delay between nodes. In other words, it enables internal TSCH queuing configuration, size of buffers and packet priorities.

As seen in the Figure 1, a Linkset slot(310ms) consists of one-time slot(10ms) for EB transmission and thirty-one time slots(300ms) for data transmission. A bundle of thirty time slots is consecutively assigned for the IPv6 packet transmission, which mitigates fragmentation and buffer management in a multi-hop Networks. Ten Linkset slots build a repeatable communication cycle, called a Slotframe(3100ms). The Linkset slot also reduces the time delay between the nodes which are two or more hops away. Because an aggregation node can optimize the bundle schedule, which is multiple Linkset slots scheduled to the same neighbor, as modifying the amount of resources allocated between neighbors.

Since the standard does not specify any algorithm for advertising EB in order to announce the network presence, we have defined a simple advertisement algorithm. Although each node has a chance to broadcast EB at the first time slot in Linkset slot, only node which has an associated Linkset slot with a parent can announce EB during the that period. Therefore, a child node has an ownership only if it has the schedule with a parent. This leads to not only avoid the message collision but also reduce the energy consumption as minimizing the slot to transmit and listen to the EB for every neighbor.

As seen in the Figure 2, EB contains Sync IE (ASN, Join Priority), Timeslot IE (timeslot template, slot length and timing in the slot), Channel Hopping IE (Channel Hopping template), and Slotframe and Linkset IE (Slotframe and Linkset information). These IE fields indicate that for each scheduled (transmit or receive) Linkset slot, the address of the neighbor

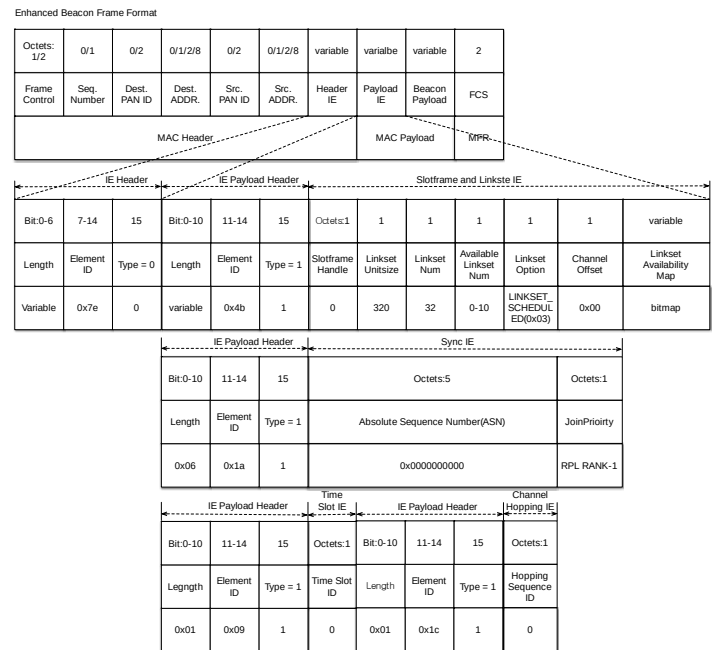


Figure 2. Enhanced Beacon Structure.

with which to communicate, and the frequency to communication on.

The Slotframe and Linkset IE specifies the Slotframe structure and the allocation status of the Linkset slot. As a parent node describes whole Linkset slot allocation information with Linkset Availability Map(bitmap), a child node can acquire an ownership of a Linkset slot with a parent node dynamically and quickly. Whenever a node receives an Enhanced Beacon, it should update its schedule if there is a difference regarding to the cells used for synchronizing with the advertiser of the Enhanced Beacon.

Since the TSCH can announce only few numbers of time slots to do associate a link, it is hard for a child node which already has occupied with several descendent nodes to assign a new Linkset slot dynamically. Depending on traffic requirements, the Linkset Availability Map(bitmap) can guide 6top to add or delete a number of cells scheduled to a particular neighbour every beacon interval. The links may be changed dynamically.

A parent and child node negotiate the schedule with 6p message defined by 6TiSCH WG [3]. The Figure 3 is a sequence diagram which illustrates this exchange. Here, node A requests 2 Linkset slots to node B. It sends a 6P ADD Request to node B indicating it wishes to add 2 Linkset slots, and specifying a list of 3 candidate Linkset slots from which node B can choose (the "LinksetList" value). Each Linkset slot in the LinksetList is a tuple with the (Linkset slotOffset, channelOffset) coordinates of the candidate Linkset in the TSCH schedule. Node B selects 2 of the 3 Linkset slots in the LinksetList of the 6P ADD Request, and sends a 6P Response back to node A specifying the Linkset slots it selected from the specified container (e.g Slotframe, Chunk, etc ...). This allow nodes A and B to add those two Linkset slots to their schedule.

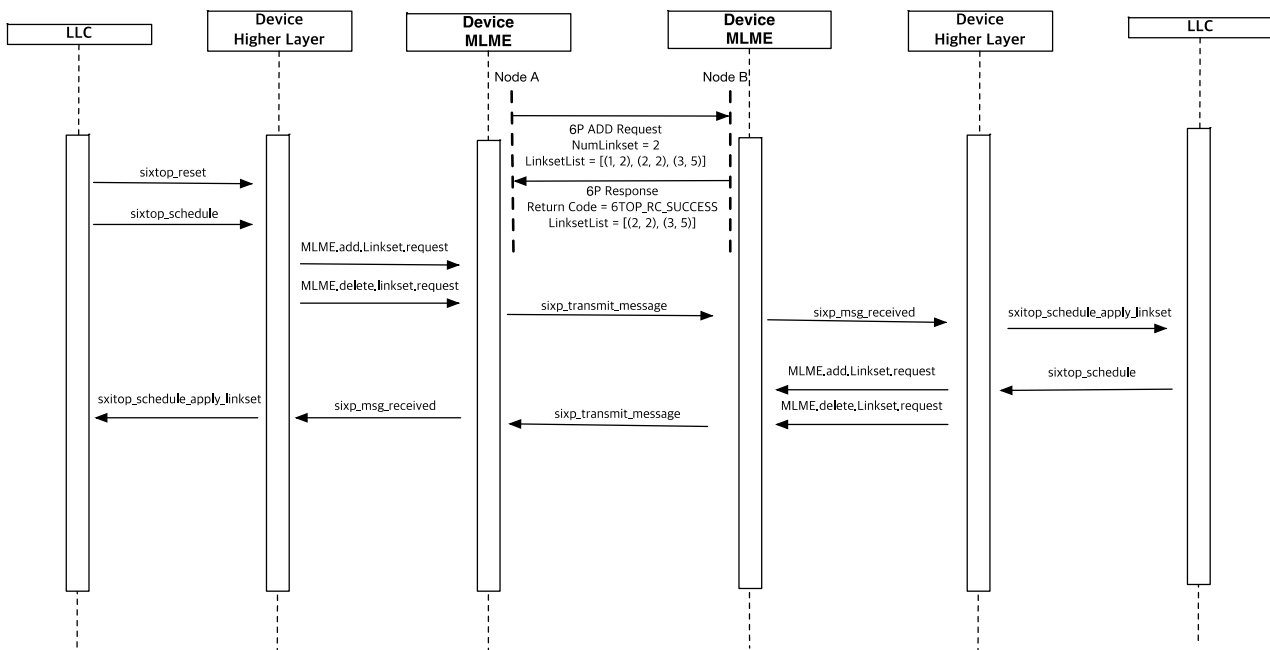


Figure 3. The Negotiation Procedure for the Linkset Slot Schdule.

III.RELATED WORK

The idea of synchronizing nodes and channel hopping to mitigate multi-path fading and external interference is established in many technologies, including Bluetooth and cellular systems. It was brought to low-power wireless networking through a proprietary protocol called Time Synchronized Mesh Protocol (TSMP) [5]. The core technology of TSMP to be standardized as WirelessHART [6], ISA100.11a [7] and IEEE802.15.4e [1].

However, the IEEE 802.15.4e standard defines the mechanism of how the TSCH MAC executes a schedule in the network, it does not specify how to build an optimized schedule. Many schedule based MACs have been proposed in the past [8], [9], [10], but they can not be directly applied to the TSCH MAC and only a handful of work is based on the IEEE 802.15.4e MAC.

Recently, traffic Aware Scheduling Algorithm (TASA) [11] is proposed as a centralized multi-hop scheduling algorithm that builds a schedule based on network topology and traffic load. However, TASA does not take into account queue congestion in sensor nodes, leading to large buffer size at these nodes.

DeTAS [12] propose a distributed traffic aware scheduling solution for IEEE 802.15.4e TSCH networks as a distributed mode of TASA [11]. In DeTAS, all nodes follow a common schedule, called macro-schedule, that is the combination of micro-schedules of each routing graph. Each micro-schedule is computed in distributed manner.

IV.CONCLUSIONS

We proposed an enhanced scheme for Ipv6 over IEEE 802.15.4e TSCH. It specifies the Linkset slot, EB management and scheduling information in a Slotframe to achieve industrial-grade performance.

Our future work includes the evaluation for the proposed scheme in a large-scale network. It requires the more detailed analysis depending the number of nodes and various kinds of QoS.

ACKNOWLEDGMENT

This work was supported by the ICT R&D program of MSIP/IITP. [1711028349, Development of integrated development solution supporting low power OS for lightweight embedded devices]

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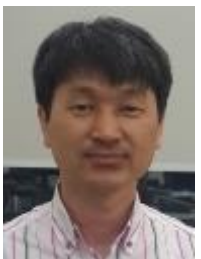
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