Fully autonomous scheduling for heterogeneous traffic through opportunistic transmissions

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I. Background

A. TSCH

The Time Slotted Channel Hopping (TSCH) medium access control has garnered significant attention in the wireless sensor network research community. It combines channel-hopping, to increase resilience against wireless fading events, with contention-free allocation of time-slots. It is selected as the MAC in IETFs ongoing work on 6TiSCH - an IPv6-enabled stack for industrial wireless low-power networks [1].

B. Scheduling

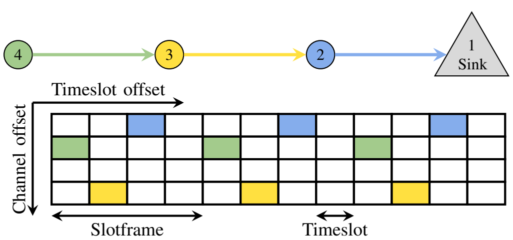

Fig. 1. Simple wireless network topology with example TSCH schedule

Nodes in a TSCH network operate according to a schedule implemented as one or more *slotframes*. These repeat over time and dictate if a node is allowed to transmit or receive. Figure 1 shows an example network with an accompanying schedule. Time is divided into timeslots on the horizontal axis, while the available channels are shown in the vertical. A *cell* is defined by a pair of timeslot- and channel-offset coordinates, and it allows for transmitting or receiving one frame with an optional acknowledgment.

Key in TSCH is the establishment and maintenance of the slotframe content, i.e. how cells are allocated among nodes in the network. This is achieved by a *scheduler*, which may operate in a centralized, collaborative or autonomous fashion. With an autonomous scheduler, nodes create their schedules independently without any information exchanged between schedulers on the nodes.This simplifies the configuration, avoids signalling overhead, and increases the fault tolerance since no signalling is needed to utilize new links.

The current state-of-the-art autonomous scheduler Orchestra [2] lets nodes utilize their own and neighbor IDs to allocate cells. When setup in a contention-free configuration, Orchestra maps each node ID to a unique cell used by the given node to transmit. For nodes wanting to receive, they simply add a RX cell matching the transmitter ID. The coordination is obtained through a routing protocol such as RPL.

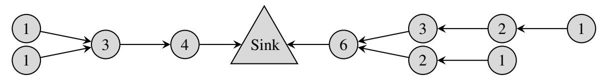

Fig. 2. Funneling effect, number indicates cumulative offered traffic

II. Problem statement

Typical autonomous schedulers statically assign a fixed amount of resources to each node and does not adapt to variations in traffic intensity. This leaves it vulnerable to e.g. applications with heterogeneous traffic intensity, differing link qualities yielding a varying demand for retransmissions, and convergecast applications where traffic intensity increases close to the destination, as illustrated in Figure 2.

III. Related Work

A survey on autonomous scheduling in [3] lists three which focus on traffic adaptations: TESLA [4], PAAS [5] and e-TSCH-Orch [6]. However, all of these require exchange of information which 1) Increases complexity, making it more difficult for operator to understand the network operations, i.e. the "visibility problem" [3], and 2) introduces possibility for scheduler-convergence periods and de-synchronization (TODO confirm for the mentioned), thus reducing some of the key benefits of autonomous scheduling.

IV. Proposal

	Channel						
Orchestra	2	Node 1	Node 2	Node 3	Node 4	Node 5	
Possible extra TX	3		*Node 1*	*Node 1*	*Node 1*	*Node 1*	
	4			*Node 2*	*Node 2*	*Node 2*	
	5				*Node 3*	*Node 3*	
	6					*Node 4*	

	Channel						
Orchestra	2	Node 3	Node 1	Node 4	Node 3	Node 2	
Possible extra TX	3		*Node 3*	*Node 3*	*Node 3*	*Node 3*	
	4			*Node 1*	*Node 1*	*Node 1*	
	5				*Node 4*	*Node 4*	
	6					*Node 3*	

Fig. 3. Orchestra application slotframe with potential extra transmissions in italics. Slotframe at ASN n on top, slotframe at ASN $n + SF_{length}$ at bottom

The essence of the proposal is for nodes to opportunistically try extra transmissions when needed. I.e. if node 2 is scheduled to transmit in timeslot 2, it has the option to also utilize timeslot 3 and onwards for extra transmissions until its queue is empty. An overview schedule can be seen in Figure 3. This immediately creates three key challenges which we will address with a novel combination of solutions:

Firstly, how does the receiving node know that its neighbor want's to transmit in more timeslots? Here the receiver can exploit two signals:

1) The transmitting node has set the Frame Pending bit in the 802.15.4 header, indicating the node has additional packets in its queue. This behavior is according to the standard.
2) The receiver does not receive a valid packet, yet senses there is energy on the channel. This indicates a possible failed transmission attempt which induces a retransmission. (see [7]).

As long as any of these signals are true, the receiver should listen on the next timeslot. This should keep idle listening to a minimum while allowing a neighbor to transmit an arbitrary amount of additional packets. If the radio is not capable of reporting energy-levels, the Frame Pending bit can still be used alone. This would lead to the extra transmissions only being employed for queued packets, and not retransmission for failed attempts.

Secondly, since the extra transmissions are decided autonomously, there is a chance that the they will interfere with the transmissions of other nodes. To avoid this we can exploit the low band occupancy of Orchestra (only channels 0-2 are by default used) and utilize the remaining channels (or a sub-set) for extra transmissions. Thus there is no increased contention for the regularly scheduled cells. Notice how the additional transmissions in Figure 3 are in a differing channel.

This leaves the possibility of multiple nodes having extra transmissions at the same time, and also selecting the same channel, all the while being in interference range of each other. It might be that this can be mitigated by tying the channel selection to the rank, e.g. such that nodes on neighboring ranks does not interfere. However, that would increase the probability of interference within a rank. This is still an open item - although it is not unlikely that a "random" selection based on node ID yields sufficient performance (probability of collisions would depend on traffic pattern and profile, network density, and number of channels employed).

Thirdly, the cells utilized for the extra transmissions may also collide with cells already in the schedule of either the transmitter or the receiver. Consider for example if node 2 transmits towards node 3 at timeslot 2, and wants an extra transmission in timeslot 3. However, if node 3 has its own regular transmission cell in timeslot 3, it would not be able to listen for the extra transmission.

Such synchronization can be avoided by adding time as an input when calculating the timeslot offset. Instead of the timeslot being scheduled according to node id alone, it would be set by node id + time (i.e. ASN). This causes every slotframe to be unique as shown in the bottom of Figure 3. Such a technique is employed in the ALICE scheduler to avoid continuously overlapping cells. This may also be exploited to avoid synchronization in the channel calculation.

All of these techniques in combination might be sufficient for a significant increase of performance in heterogeneous scenarios compared to e.g. vanilla Orchestra or ALICE.

A. *Properties*

This proposal is a fully autonomous approach, i.e. no additional information needs to be exchanged between nodes. It can in theory be applied to any scheduler but we currently consider only autonomous schedulers. It should also be noted that the essence of the proposal is for nodes to opportunistically grab resources. Any gained knowledge from an evaluation, and the proposal itself, is probably generic such that it is applicable to any other scheduling scheme which could accommodate opportunistic extra transmissions.

The proposal involves an opportunistic addition of cells, thus the performance of these cells are probabilistic. The logical step discussed is therefore to apply it onto Orchestra or ALICE (both probabilistic), which would make it inline with PAAS, e-TSCH-Orch and TESLA (which are all based on Orchestra).

The proposal should struggle more in dense networks where a node has many neighbors. In those scenarios a node's extra transmissions would have a larger chance of colliding with other nodes extra transmissions (the second challenge mentioned above). Additionally, nodes would have more children, which would leave less room for adding extra transmissions before meeting a RX cell in its schedule (the third challenge). However, it is also in these dense networks where the funneling effect is expected to be the weakest since the network is more shallow. On the contrary, in sparse networks, where the funneling is presumed worse, the mechanism should have equally improved conditions to function.

References

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