Building an IEEE 802.15.4e TSCH network

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***Abstract*—Most wireless sensor networks that are currently deployed use a technology based on the IEEE 802.15.4 standard. However, this standard does not meet all requirements of industrial applications in terms of latency, throughput and robustness. That is why the IEEE 802.15.4e amendment has been designed, including the Time Slotted Channel Hopping (TSCH) mode. In this paper, we focus on how to build a TSCH network and evaluate the time needed to form the network, using the NS3 simulator. A new beacon advertising algorithm is proposed for TSCH networks. A comparative performance evaluation with solutions already published is done.**

I. Context and motivation

The most frequent technologies used by the currently deployed WSNs are based on the IEEE 802.15.4 standard. Despite its advantages, this standard is unable to meet the requirements of industrial applications with regard to reliability, delays and energy. That is why the IEEE 802.15.4e amendment has been specified. Among the five MAC behavior modes proposed, the Time Slotted Channel Hopping (TSCH) [1] mode has been designed for industrial automation, process control and equipment monitoring. It supports multichannel and multihop communications and uses a slotted medium access with channel hopping on several channels.

Beacons and more precisely Enhanced Beacons are used to advertise the TSCH network. An Enhanced Beacon is a TSCH frame that contains information on synchronization, channel hopping and timeslot used in the network. However, the advertising policy is left unspecified by the IEEE 802.15.4e standard and is under the responsibility of a layer upper than the MAC one. Initially, only the CPAN is allowed to send beacons. All other nodes as soon they are powered on, remain silent until they receive a beacon. In a TSCH network, the capture of beacons is more complex due to channel hopping. Since the joining node does not know the hopping sequence, the only possibility for it is to stay on a given channel and wait until it is used by a coordinator to send its beacon.

In [2], two algorithms are presented: Random Vertical (RV) filling and Random Horizontal (RH) filling. In both algorithms, the CPAN sends its beacons in the first advertisement slot of one slotframe in the multi-slotframe, with channelOffset 0. In RV, the other nodes transmit their beacon in the same advertisement slot but with a random channel offset. In RH, the other nodes transmit their beacon with channelOffset 0 but in an advertisement slot randomly chosen in the slotframe. These two algorithms exhibit similar performance.

II. The DBA algorithm

DBA is a Deterministic Beacon Advertising algorithm that ensures that beacons are transmitted on all frequencies used by the TSCH network, regularly and without collision.

Let N_s be the number of slots in the slotframe, N_c the number of channels in the frequency hopping sequence, N_b the number of advertising slots in the slotframe and BI the beacon interval (i.e. period of beacon transmission by a node) expressed as a number of time slots. The principles of DBA are the following:

- Any beacon is transmitted in one of the N_b advertising slots of the slotframe. These N_b advertising slots are regularly spaced in the slotframe.
- The CPAN is in charge of initiating the beacon transmission in an advertising slot.
- Any advertising node, that is not the CPAN, repeats the beacon received from its association parent in an advertising slot and in a channel offset whose position has been computed during node association, to ensure the uniqueness of transmitters in this slot and over this channel offset.

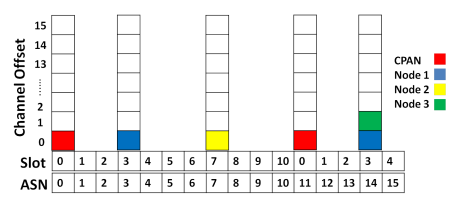

Fig. 1: Transmission of beacons in DBA.

The functioning of DBA is depicted in Figure 1 for a topology of four nodes with $N_s = 11$, $N_c = 16$ and $N_b = 3$ and $BI = N_s$. The CPAN transmits its beacon in ASN 0 with slotOffset 0 and channelOffset 0 mapped on frequency 11. Node 1 that is listening frequency 11 receives this beacon and then transmits its beacon in the next advertising slot (ASN3, with slotOffset 3 and channelOffset 0). Node 2 receives the beacon of node 1 and sends its beacon in the next advertising slot (ASN 7, slotOffset 7, channelOffset 0). In ASN 11, the CPAN sends its beacon that is received by nodes 1 and 3. Node 1 transmits in ASN 14, slotOffset 3, channel0ffset 0, whereas node 3 sends its beacon in the same slot as node 1 but with channelOffset 1.

The value of N_b must meet several requirements:

- $R1$ it should enable a quasi regular transmission of beacons close to BI.

- $R2$ it should allow each advertising node (including the CPAN) to transmit its beacon without collision.

Requirement $R2$ is met by giving to each advertising node n a unique pair (slot, channelOffset) ensuring that n is the only node transmitting in this pair. This is done by the CPAN during the node association. The minimum possible value of N_b for a star topology is $N_b \geq 1 + \lceil \frac{N-1}{N_c} \rceil$.

III. Performance Evaluation

In this section, our goal is to evaluate the time needed to build the network considering a star topology with DBA, RV and RH [2].

The performance evaluation is conducted using the NS3 simulator [3]. We first implemented the NS3 modules needed to build a 802.15.4 network and then the NS3 modules for a TSCH network. To allow a fair comparison, we consider a multi-slotframe of size $N_c \cdot N_s$ with N_b advertising slots. Simulation parameters are given in Table I. Simulation results are averaged over 30 runs. We consider a number of nodes different from the CPAN ranging from 1 to 40. All these nodes are one-hop away from the CPAN.

TABLE I: Simulation parameters.

Parameter	N_s	N_c	N_b	BI	slot size
Value	1511	16	15	1511	10 ms

We evaluate the time needed by one node to detect a beacon on the frequency it has randomly chosen among the N_c frequencies used by the TSCH network. All the nodes already inserted in the network advertise the TSCH network by transmitting a beacon. Results are depicted in Figure 2. As expected, the joining time decreases when the number of advertising nodes increases. This can be explained by the fact that the probability of detecting a beacon on the frequency randomly chosen by the joining node increases with the number of its neighboring nodes. We observe that the decrease in the joining time is large up to 10 nodes, then it becomes moderate up to 20 nodes. The RV algorithm provides the worst results. This is due to the fact that collisions may occur between two nodes having selected the same channelOffset to transmit their beacon. RH is better than RV for any TSCH network with more than 2 nodes. The DBA algorithm outperforms RV and RH providing joining times that are up to 3 times less than RV.

To study the impact of the beacon period on the joining time, we consider a network of 20 nodes. Each of them advertises the network by sending beacons with the beacon interval BI. Figure 3 depicts the time needed for a node to join this network while varying the beacon interval in $\{N_s,\ 3 \cdot N_s,\ 5 \cdot N_s\}$. As expected, the joining time increases with the beacon interval. When the beacon interval is small $BI = N_s = 15s$, the joining time is small for all the algorithms tested. However, when the beacon interval increases ($BI = 3 \cdot N_s$ and $BI = 5 \cdot N_s$), the joining time increases considerably especially for the RH algorithm. But it remains small for the DBA algorithm, even for $BI = 5 \cdot N_s = 75s$ where it reaches only $33s$,

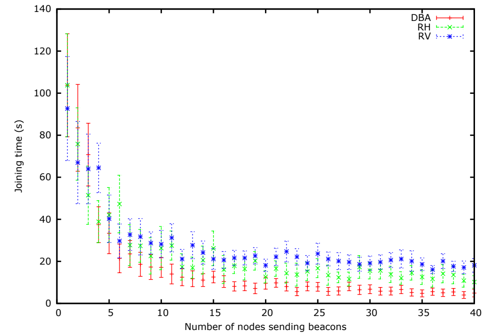

Fig. 2: Joining time.

compared with $42s$ and $71s$ for the RV and RH algorithms, respectively. The DBA algorithm provides a satisfying joining time even when the beacon interval is great and this is due to its determinism.

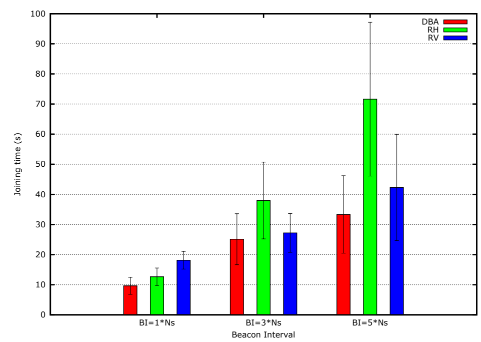

Fig. 3: Joining time in a network of 20 nodes.

IV. Conclusion

In this paper, we focus on the time needed by a node to detect a beacon sent by a TSCH network. This time is important for industrial applications where new nodes are inserted progressively, or when failed nodes are replaced. This time highly depends on the beacon advertisement policy, policy that is not specified in the standard. That is why we propose DBA, a Deterministic Beacon Advertisement algorithm that ensures a regular transmission of beacons without collisions. The performance evaluation made with the NS3 simulation tool shows that DBA clearly outperforms RV and RH solutions. In addition, DBA is able to provide the exact value of the maximum joining time.

References

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