Impact of Guard Time Length on IEEE 802.15.4e TSCH Energy Consumption

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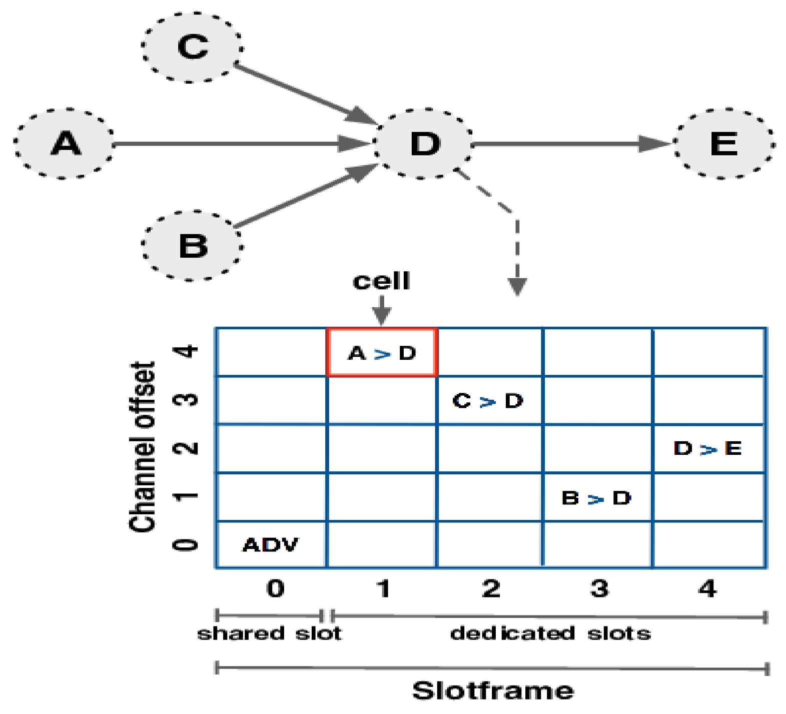
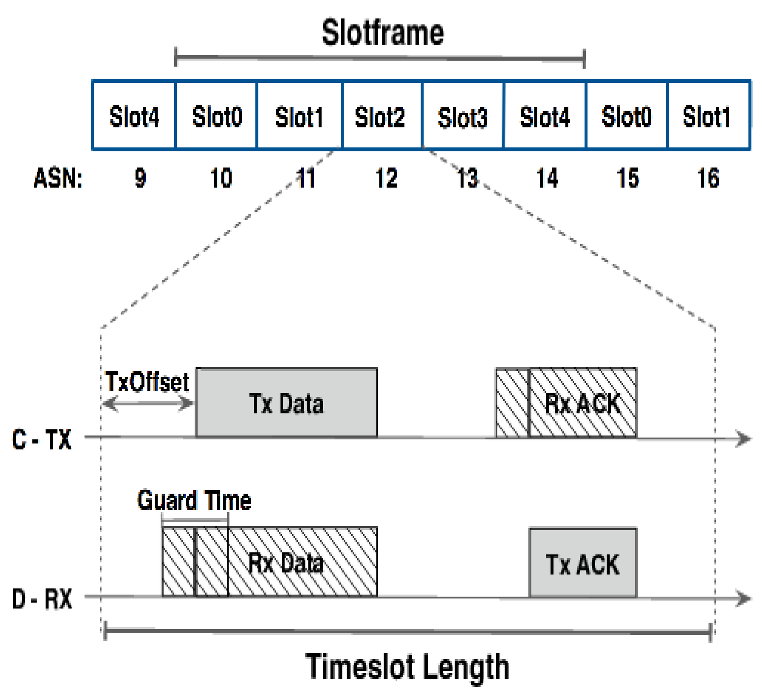
Introduction

In 2016 the IEEE 802.15.4-2015 standard [1] was published to offer a certain quality of service for deterministic industrial type applications. Among the operating modes defined in this standard, Time-Slotted Channel Hopping (TSCH) is a medium access scheme for lower-power and reliable networking solutions in Low-Power Lossy Networks (LLNs). Indeed, it is adopted by major industrial-oriented standards such as WirelessHART and ISA100.11a. At its core, TSCH implements a channel hopping scheme to defeat noise and interference, and consequently to enable high reliability [2], while it employs time synchronisation to achieve low-power operation.



Time Slotted Channel Hopping (TSCH)

TSCH is a scheme aiming to guarantee network reliability by keeping nodes time-synchronised at the MAC layer. The latter is accomplished by scheduling, therefore nodes must remain time synchronised throughout the network deployment's life-time. To this end, nodes periodically exchange Enhanced Beacon (EB) packets. Synchronisation does not need explicit EB exchange, data packets may also be utilised to compute clock drifts. [2] Typically, an EB contains time and channel frequency information, as well as information about the initial link and slotframe for new nodes to join the network. New nodes may join a TSCH network by "hearing" an EB frame from another node. Below the TSCH slotframe is illustrated with a leaf and a sink node. At its core, TSCH implements a channel hopping scheme to defeat noise and interference, and consequently to enable high reliability [2], while it employs time synchronisation to achieve low-power operation.



Clock Drift and Guard Time

TSCH incorporates a `guard time` to account for loss of synchronisation. To account for both positive and negative clock drift, the receiver wakes up before the expected end of the `TxOffset` and keeps the radio on for τ seconds or until a frame preamble is received. The guard time τ is equally spaced around the end of the `TxOffset`. Thus, for a certain guard time, τ, the maximum synchronisation error, ϵ_τ, that can be tolerated is:

$$\epsilon_\tau = \frac{\tau}{2} - \tau_p \,, \tag{1}$$

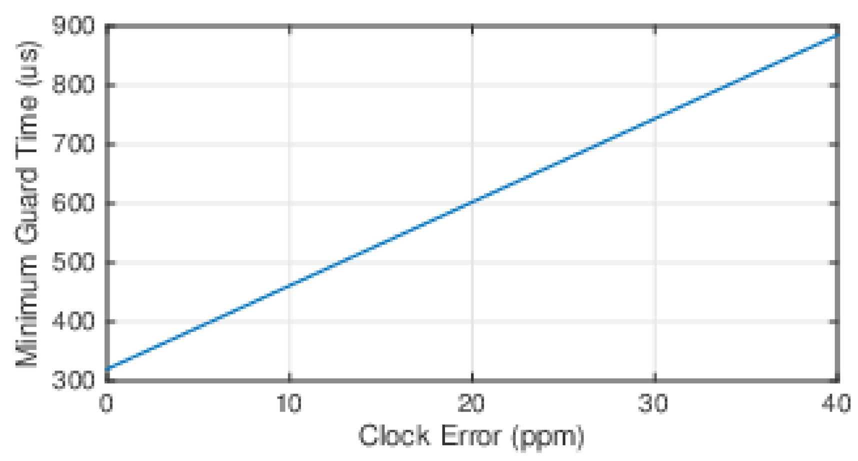
where τ_p is the time required for the reception of the frame preamble. Let us consider the use of clocks with an error of $\pm e_f$. The synchronisation error accumulates over time. The worst case scenario for synchronisation is right before a synchronisation event (EB frame), when the error is:

$$\epsilon_T = T\left(\frac{1}{1-e_f} - \frac{1}{1+e_f}\right) , \tag{2}$$

where T is the period of synchronisation events. By equating (1) and (2), we calculate a minimum guard time required to achieve zero packet losses due to loss of synchronisation (τ_m):

$$\tau_m = 2T\left(\frac{1}{1-e_f} - \frac{1}{1+e_f}\right) + 2\tau_p \,. \tag{3}$$

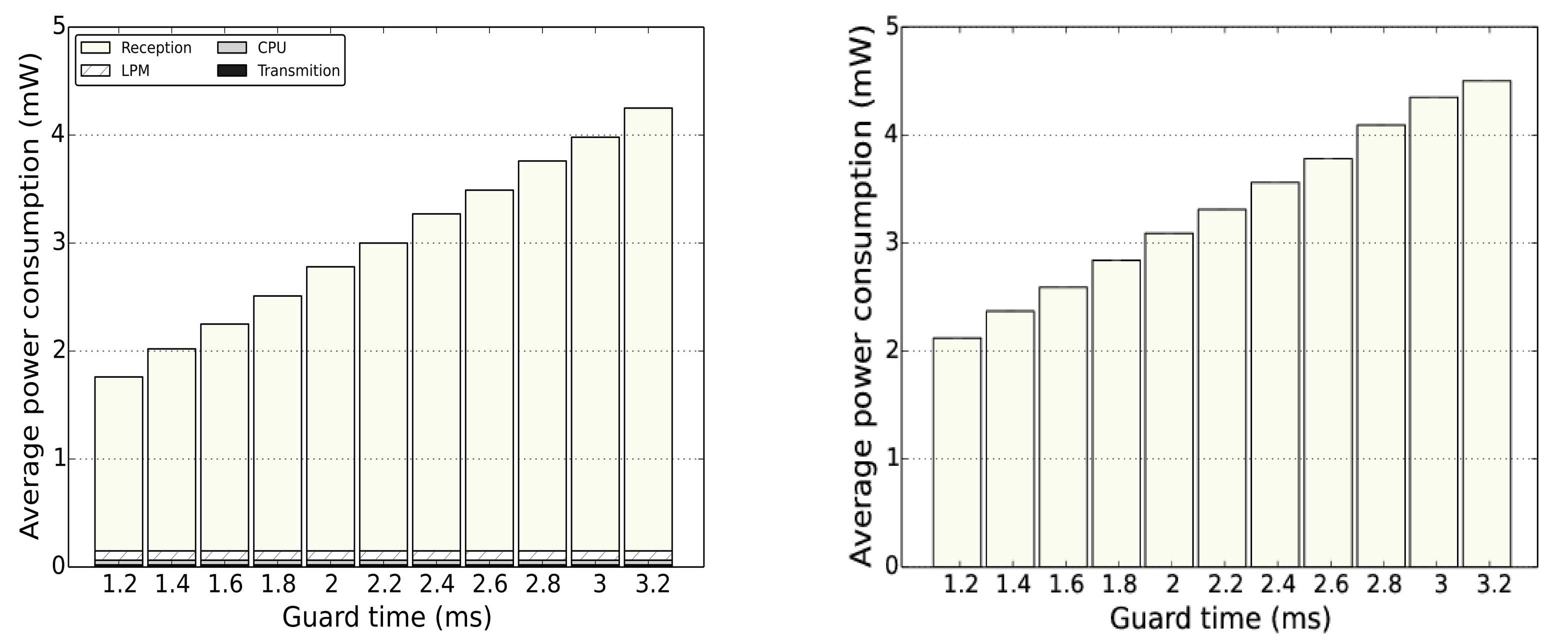
It can be observed that in the ideal case where the clock error is $e_f = 0$ ppm, the minimum acceptable guard time is $\tau_m = 2\tau_p$. The figure below plots the minimum guard time for various clock drifts ($\tau_p = 160$ us, $T = 3.5$ s) demonstrating a linear behaviour.



Minimum guard time for operation without packet loss due to loss of synchronisation.

Performance Evaluation

We deployed two scenarios; the first scenario is low contention in which two nodes, leaf transmitter and sink receiver, respectively, are positioned at a distance of 20 m. The second scenario (high contention) consists of 9 nodes, including the sink station, in a star topology. All 8 nodes are symmetrically distributed around the sink in an area of 20 x 20 m, and 1-hop communications take place among the sensor nodes and the sink. By employing the RPL protocol [3], each node is able to construct a Directed Acyclic Graph. Below the figures depicts the average power consumption both to the sink and the leaf nodes.



Average power consumption for a single transmitter in line topology (left) and for 8 transmitters in star topology (right), respectively.

Conclusions

In this work, we investigated the behaviour of TSCH under different guard time configurations. More specifically, we analysed the impact of the guard time duration to the network reliability and energy consumption. Our thorough performance evaluation results demonstrate that the guard time length has a straightforward impact on energy dissemination. It is shown that fine-tuning the guard time can result into significant savings in energy consumption without compromising the reliability of the network. Our ongoing work consists of further investigating this lead under various realistic clock drift configurations.

References

[1] "IEEE Standard for Low-Rate Wireless Personal Area Networks (LRWPANs)," April 2016.

[2] T. Chang, T. Watteyne, K. Pister, and Q. Wang, "Adaptive Synchronization in Multi-hop TSCH Networks," Computer Networks, vol. 76, pp. 165–176, 2015.

[3] T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, J. Vasseur, and A. R., "RPL: IPv6 Routing Protocol for Low- Power and Lossy Networks," IETF, RFC 6550, 2012.