On the Impact of Beacon Collisions in Co-located IEEE 802.15.4-based Networks

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***Abstract*—IEEE 802.15.4 has become the de-facto standard in many areas of wireless communications including wireless sensor and body area networks in industrial automation and healthcare domains. Such pervasive usage will involve multiple networks with overlapping transmission and interference areas, operating uncoordinated. IEEE 802.15.4 defines a node synchronization strategy using beacons for achieving robust low energy communication. Nonetheless, collisions are inevitable as some packets, e.g., the synchronization beacons are sent without carrier sensing. Consequently, co-located networks may substantially suffer from beacon collisions. We present early performance evaluation results involving multiple co-located networks. In an extensive set of simulation experiments, we found that the number of lost beacons is independent of the amount of superframe overlap, but is a major cause of performance degradations. We conclude that distributed coordination is necessary. Therefore, our ongoing work includes the development of adaptive inter-network beacon coordination schemes.**

I. Introduction

IEEE 802.15.4 [1] defines a standard for Low-Rate Wireless Personal Area Networks (LR-WPANs) for both the MAC and the physical layer. The practicality of this LR-WPAN technology will enable a multitude of additional use cases. Thus, the deployment of multiple Wireless Personal Area Networks (WPANs) operating on the same channel within the same transmission range will soon become unavoidable (in the scope of this paper, we call these *co-located* WPANs). As some packets are sent without carrier sensing, the existence of co-located WPANs that are independent and unsynchronized will result in collisions and, subsequently, an overall degradation of those WPANs' performance.

There has not been much work focusing on beacon collisions in co-located WPANs. Kim et al. [2] studied a scenario where the superframes of multiple co-located WPANs are scheduled within the inactive period of other WPANs. The work mainly focused on the effect of complete overlapping of WPANs where all nodes are within each other's range. They did not analyze scenarios where only parts of the involved WPANs are overlapping. The IEEE Task Group 15.4b proposed a solution called the *beacon-only period* approach where all superframes start at the same time and a portion of time at the beginning of all superframes is dedicated for beacon transmissions which contain information on each WPAN's starting time. However, as mentioned in [3] and [4], there are still outstanding problems such as an inadequate inactive period or a beacon-only period that may get too long if the number of co-located WPANs gets too high. This can be overcome by either (i) synchronizing the co-located WPANs while avoiding beacon overlapping, thus enabling all nodes in the WPANs to equally compete for access, or (ii) changing the WPANs' parameters to take advantage of the inactive period. Nonetheless, if mobility is involved, both strategies will suffer as WPANs will no longer be able to coordinate among themselves.

In this paper, we aim to better understand the effects of multiple co-located WPANs. Our work forms the preliminary part of ongoing work to develop adaptive beacon strategies and coordination techniques for WPANs.

II. Performance Issues in Co-located WPANs

We simulated three scenarios. First, we evaluated the impact of beacon collisions in a two-WPAN scenario. We used two networks, each consisting of two nodes; a WPAN coordinator sending beacons and a node sending data to the coordinator. Secondly, we used three nodes per network which allows us to study different collision scenarios. Thirdly, we enabled WPAN 2 to move past WPAN 1 at normal walking speeds of 1.5 m/s and 2.5 m/s while still applying the time overlaps. This scenario reflects a typical body area network configuration where multiple persons carrying their own networks spontaneously get into interference range when meeting each other.

We used the OMNeT++/INET simulator with the IEEE 802.15.4 model developed by Chen et al. [5]. We chose the beacon-enabled mode as we want to understand the losses due to corrupted beacons. We configured a duty cycle of 50 % using a BO/SO combination of 7/6. All other key parameters were taken from [5]. We assumed that all child nodes belong to only one WPAN and the associations with their own coordinators were predetermined. The starting times for both WPANs were varied with WPAN 1 starting at 0 s and WPAN 2 starting at $0\,\mathrm{s} + n/16$ of the superframe length as depicted in Figure 1. This allows us to analyze the effect of different degrees of superframe overlaps. Each simulation was run for 30 min and the results shown were taken over 5 runs.

We start by discussing results for the first scenario. As a baseline, we evaluated the performance of two independent WPANs (data not shown). As expected, 100 % of the beacons were successfully received. The resulting goodput showed the well known stochastic behavior. However, when there was a time overlap of the WPANs' superframes, collisions resulted in loss of beacons and data packets. As the overlap was increased in increments of $1/16$th the superframe size and the duty

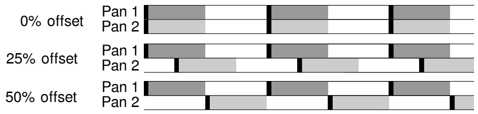
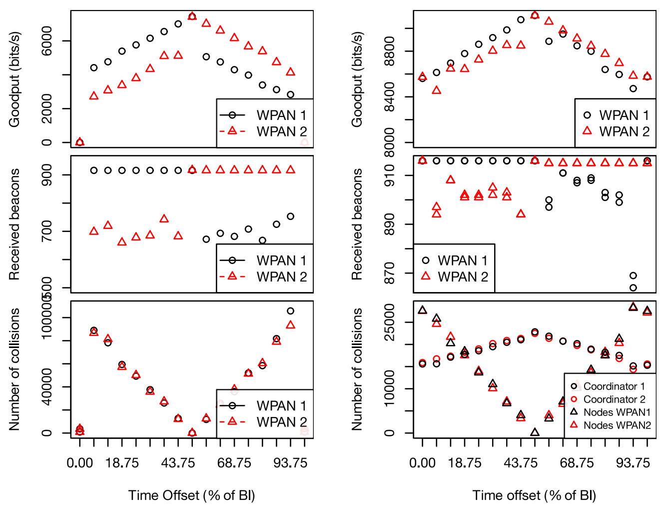


Figure 1. Time offset



(a) First scenario, WPANs with coordinator/node communication range

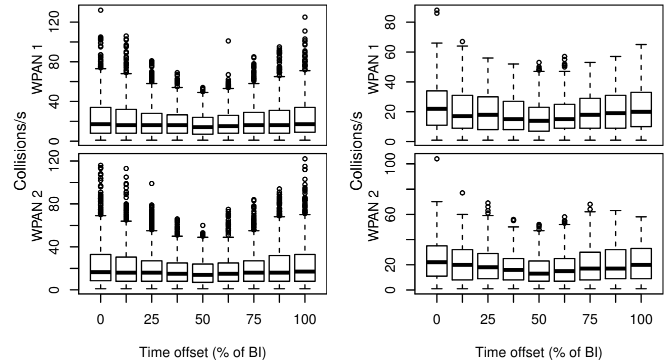
(b) Second scenario: WPANs with coordinator/node interference

Figure 2. Simulation results: in transmission range

cycle was set at 50 %, both WPANs will behave as two non-overlapping WPANs at 50 % of the offset time and achieve similar levels of goodput as seen at the 50 % point in Figure 2a. The increasing and the decreasing goodput can be attributed to the amount of overlap between the superframes belonging to both WPANs. As the overlap increases, although the number of beacons colliding does not increase in proportion with each increasing overlap, the number of successfully transmitted data packet still decreases as wider window of overlaps allow for more collisions to occur. In this setup, more beacon collisions are experienced by the WPAN that starts later as its beacons are transmitted during the active period of another WPAN. Thus, the node is unable to synchronize with its coordinator for the whole duration of the superframe and is forced to wait for the next beacon in order to gain access to the channel.

We also simulated the second scenario involving two WPANs, each comprising a coordinator and two child nodes. Here, nodes in each WPAN can interfere with nodes from the other WPAN. The results are shown in Figure 2b. As expected, collisions involving DATA-DATA coming from each respective WPAN and from the interfering WPAN occurred at both coordinators. Collisions involving ACK-DATA and BEACON-DATA took place at all nodes, similar to the previous experiments: goodput increases as the amount of overlap decreases, the maximum rate being reached at 50 %.

Results for the third scenario studying effects of mobile networks are shown in Figure 3. For each data set, a box is drawn from the first quartile to the third quartile, and the median is marked with a thick line. Outliers are drawn as small circles. The number of collisions mainly depends on the time overlap, i.e., on the configuration of both the superframe format



(a) WPAN 2 moving at 1.5 m/s

(b) WPAN 2 moving at 2.5 m/s

Figure 3. Experienced collisions

and the occasional cross-network synchronization. We found that (independent from time overlap) at 2.5 m/s the median of collisions experienced by the moving WPAN 2 does not differ much from that experienced when it is moving at 1.5 m/s. This is because faster speed allows WPAN 2 to move away quickly from WPAN 1, thus allowing it to escape from being interfered. Nonetheless we also found that, with a maximum at 0 % and 100 % as well as a minimum at 50 %, the time overlap still has a pronounced effect on the number of collisions.

III. Conclusion and Future Work

The proliferation of industrial automation and healthcare applications would increase the occurence of co-located WPANs. Both domains require them to perform in a robust manner. From our simulations, we found that that could be an issue as there is a substantial performance degradation due to beacon collisions that needs to be addressed by adaptive inter-network beacon coordination schemes. As expected, the amount of superframe overlap has an inverse effect on the goodput in co-located networks. Nonetheless, it does not have a direct effect on the beacon collisions. That is because the packets that the beacons collide with have a randomness property due to the number of random backoff slots that the nodes generate for accessing the channel. In our ongoing future work, we will validate the simulations by running actual experiments and analytically analyzing the simulated models. In addition, due to the uncoordinated and independent nature of multiple co-located WPANs, we find it essential to formulate a strategy to adaptively coordinate the multi-PANs in a distributed fashion.

References

[1] "Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs)," IEEE, IEEE Standard 802.15.4-2006, 2006.

[2] T. H. Kim, J. Y. Ha, and S. Choi, "Improving Spectral and Temporal Efficiency of Collocated IEEE 802.15.4 LR-WPANs," *IEEE Transactions on Mobile Computing*, vol. 8, no. 12, pp. 1596–1609, December 2009.

[3] A. Koubaa, A. Cunha, and M. Alves, "A Time Division Beacon Scheduling Mechanism for IEEE 802.15.4/Zigbee Cluster-Tree Wireless Sensor Networks," in *IEEE ECRTS 2007*, Pisa, Italy, 2007, pp. 125–135.

[4] J. Kim, J. Kim, and D. Eom, "Multi-dimensional Channel Management Scheme to Avoid Beacon Collision in LR-WPAN," *IEEE Transactions on Consumer Electronics*, vol. 54, no. 2, pp. 396–404, May 2008.

[5] F. Chen, N. Wang, R. German, and F. Dressler, "Simulation study of IEEE 802.15.4 LR-WPAN for industrial applications," *Wireless Communications and Mobile Computing*, vol. 10, no. 5, pp. 609–621, 2010.