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Evaluation of the Ph.D. thesis by

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entitled

"Real-time Communication over Cluster-tree Wireless Sensor Networks"

Background and aims of the work

Wireless Sensor Networks (WSNs) are modern networks used in many industrial and civilian application areas. The IEEE 802.15.4/ZigBee standard is a popular technology in the area of low data rate, low cost, low power consumption, and security-oriented WSNs. Although the ZigBee standard is well designed, many features related to the WSNs are still challenging, especially for cluster-tree topologies where it is possible to achieve semi-deterministic behaviour. The author's contributions to this area are following:

1. An accurate simulation of the IEEE 802.15.4 and ZigBee protocols with focus on the Guaranteed Time Slot mechanism (GTS).
2. Creation of a methodology for solving an energy efficient cluster's scheduling problem.
3. An analysis of the interdependences among reliability, energy consumption, and timeliness.
4. Creation of a methodology for establishment of static or dynamic cluster-tree WSN.

The Thesis

The thesis begins with the introductory chapter where the main goals of the work are outlined.
In this chapter, the fact that the work is related to the soft real-time behaviour of the communication system is indirectly explained. The term "real-time" without any specific adjective (hard/soft) is usually related to the hard real-time systems (in computer science); thus, the name of the work "Real-time communication …" is little bit confusing. Also, the author's statements about the leading role of the ZigBee in the area of low cost, low data rate and, low power consumption should be referenced. This chapter is also lacking a state-of-the-art section where not only topics that must be solved should be mentioned, but also the works from different authors and workplaces that have already been presented.

Chapter two is an introduction to the IEEE 802.25.4 and ZigBee standards. The chapter is comprehensive, the cited literature is carefully referenced and a comprehensive bibliography contains all the key sources; however, this chapter should include more detailed information about the GTS mechanism as it is the key element of the following chapter. Despite the chapter's detailed information, the key information about the minimal and maximal available length of the beacon interval is missing.

Chapter three deals with a simulation model for delay/throughput evaluation of the GTS mechanism. This chapter is very well and carefully referenced; however, as the general principle of the GTS mechanism is explained neither here nor in the previous chapter, it is very difficult for the reader, who is not familiarized with this mechanism in detail, to understand to the author's user-defined attributes. The same problem is with some other user-defined attributes. For instance, the parameter *Packet Size* is related to the frame size, but it is not obvious which frame (network, data of physical) is considered and how this parameter is related to the Network Service Data Unit (if ever). It is also difficult to agree with the author's simplification that all transmissions are unacknowledged. Even the shortest frame can be affected by the interferences. The function describing the probability of non-delivering the frame is highly nonlinear (in the ISM band) and the length of the frame is just one of the parameters; thus, the author's effort to achieve comparative results with the analytical model (based on the Network Calculus) degrades usefulness of the created model. Moreover, if just one GTS and 100% duty cycle are considered, it is questionable what the purpose of the model itself is; if to compare it with the analytical one or to make new statements and results related to the entire work, i.e. about real-time communication over cluster-tree WSNs. Proposed results in terms of the optimal settings for the beacon interval that are based on the simulation results are for the selected configuration and user-defined parameters indubitably correct; however, the question stands: how is this proposal related to the real WSN configuration, where one GTS is not enough, unacknowledged transmission is unacceptable, and the inactive portion interval is not zero?

Chapter four introduces a methodology for energy efficient scheduling in WSNs. Energy consumption is a very important aspect of the WSNs due to the fact that end devices and even network coordinators may be battery-powered. The author's solution is a Time Division Cluster Schedule (TDCS) mechanism, which is based on the previously published Time Division Beacon Schedule mechanism. This chapter is also well referenced and significant previously published works are mentioned. The schedule example in Fig. 4.3b is slightly confusing. Proposed scheduling for data flow 2 does not cover the entire data flow in the cluster tree topology in Fig. 4.1 – waves f_2^k from cluster 5 to cluster 2 and from cluster 2 to cluster 6 are missing and thus, the example seems to be incomplete. Proposed methodology and simulation results represent a significant contribution of the author into the area of minimizing the energy consumption in cluster-tree WSNs; however, utilization of this methodology into the real WSN application is challenging due to the following reasons. Firstly, the most difficult aspect of identifying the collision domains remains open. In real installations (either in the open space or indoors), it is very difficult to identify and to ensure isolated collision domains; thus, the author's proposed solution should not only take into the account the reliability of the communication channel itself (retransmitting the frames due to time-varying communication error), but also the errors based on inter-cluster interference. Secondly, the proposed methodology naturally leads to the beacon intervals as long as possible because a longer inactive portion together with low duty cycle (1%) means low power consumption. Nevertheless, a real device is in sleep mode controlled by the internal oscillator. Such an oscillator is usually made by an RC circuit or similar approach with poor frequency stability (app ±30%) with high temperature dependence. It would be a problem for a WSN with tens of clusters and hundreds of nodes to achieve adequately precise timing that is required by a TDCS mechanism, especially for long beacon frames.

Chapter five deals with a comprehensive methodology for acquiring the worst-case dimensioning of the network resources and minimizing the duty-cycle of the clusters. The selected approach that is based on Network Calculus is another significant contribution of the author into this scientific area. It is necessary to underline that the author has provided a comparison of theoretical and experimental results (especially for buffer requirements and data traffic) – such a comparison is presented at the end of the chapter. These results make it possible to help designers of the WPNs with dimensioning of network elements.

Conclusion

The thesis is very well written and the presented research is of an excellent standard; however, its practical utilization seems to be challenging. It certainly meets the academic requirements of technical universities for a Ph.D. degree. The minor problems, questions, or suggestions, which are mentioned above, can be discussed during the oral presentation. The thesis is acceptable in the present form and I, therefore, recommend awarding Mr. Petr Jurčík with the Ph.D. degree.

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22.4.2010