Why is Important the Knowledge of Inaccessibility for Supporting Real-Time Communication over IEEE 802.15.4 ? ⋆

Jeferson L. R. Souza and José Rufino

University of Lisboa
Large-Scale Informatics System Lab. (LaSIGE)

Abstract The main advantage of wireless networks is the flexibility provided by non-existence of cables. However, the presence of perturbations in the medium may create temporary partitions (called inaccessibility periods) in the network, an undesirable phenomenon for time-critical communications. In this way, this paper presents the importance of knowledge of inaccessibility for supplying an effective and complete real-time communication support. The IEEE 802.15.4 specification was used in our analysis for showing the main problems caused by the occurrence of inaccessibility scenarios when their existence are unknown, presenting the impact of this scenarios in the network temporal behaviour.

Resumo A principal vantagem oferecida pelas redes sem fios é a flexibilidade derivada da não existência de cabos. Entretanto, a presença de perturbações no meio físico de transmissão podem criar partições temporárias (chamadas de periodos de inaccessibilidade) na rede, um fenómeno indesejável para transmissões com restrições temporais críticas. Nesse sentido, este artigo apresenta a importância do conhecimento da inacessibilidade para fornecer um suporte efetivo às comunicações de tempo-real. A especificação 802.15.4 foi utilizada na nossa análise para mostrar os principais problemas causados pelo ocorrência de cenários de inacessibilidade, apresentando o impacto desses cenários no comportamento temporal da rede.

1 Introduction

The flexibility provided by Wireless technologies has been used in the design and implementation of network infrastructures. These infrastructures help data transmission in environments where the utilization of cables is very difficult. Some of these infrastructures are projected to be used within environments with a set of restrictions such as Industrial and aerospatial.

⋆ Faculdade de Ciências da Universidade de Lisboa, Bloco C6, Piso III, Campo Grande, 1749–016 Lisboa, Portugal. This work was partially motivated by our work within the scope of the ESA (European Space Agency) Innovation Triangular Initiative program, through ESTEC Project AIR-II (ARINC 653 in Space — Industrial Initiative), URL: http://air.di.fc.ul.pt). This work was partially supported by FCT through the Multiannual Funding and the CMU-Portugal Programs and the Individual Doctoral Grant SFRH/BD/45270/2008.

As a common characteristic, applications executed over those environments need guarantees about transmission time bounds. In the low-level domain, the external interferences, more susceptible on wireless networks, may generate perturbations in the medium access, and therefore may create temporary partitions in the network. Moreover, the occurrence of these partitions contributes to decrease the predictability and is jeopardous for guaranteeing the timeliness of the environment.

For that reason, this paper discusses the importance of the knowledge of this temporary partitions in 802.15.4 wireless networks. These partitions are called inaccessibility periods [1,2], and their study is important to known the network behaviour and to define means to control them. Moreover, an example of this phenomenon within IEEE 802.15.4 standard are used for showing that the support of real-time communication in wireless networks has to be improved by the knowledge and control of inaccessibility.

This paper is organized as follows: Section 2 presents some related works, describing some temporal aspects of the 802.15.4 standard. Section 3 presents the main concept of inaccessibility periods, describing the characterization of inaccessibility in 802.15.4 networks, and showing its impact in the network temporal behaviour. Finally, section 4 draws some conclusions.

2 Related Work

There are some related works that study the temporal aspects of the IEEE 802.15.4 standard. Ramachandran et. al. [3] focus their analysis in the throughput and energy consumption of the IEEE 802.15.4, considering the superframe only with Contention Access Period (CAP), no presence of MAC-level acknowledgements, and communications only from nodes to Personal Area Network (PAN) coordinator, to simplify their model. Further, the authors make a modification in CSMA/CA parameters to better the performance and energy consumption of applications that do not need reliable data transfer, i. e., the use of acknowledgement to transmit their data.

The Markov model described for [4] allows analysis of the impact of the CSMA/CA parameters, the number of contending devices, and the data frame size on the network aspects such as throughput and energy efficiency. The authors utilize two two-dimensional Markov chains to make their analyzes and verifying that CSMA/CA parameters have a large impact on the network performance, being necessary to adjust these parameters for the network traffic conditions.

Jung et. al. [5] analyze the performance of CSMA/CA protocol under unsaturated traffic conditions. Although the initial assumptions about the topology and the transmission range of the nodes, the authors consider that there are no transmission errors and no channel sense errors.

Huang et. al. [6] propose an adaptive GTS allocation scheme that use two phases: a classification phase utilized for assigning priorities to nodes; and a scheduling phase where the GTS resources are allocated considering the priority

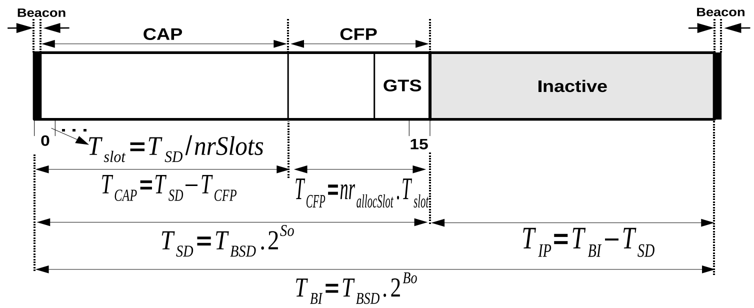

Figure 1. Superframe Structure

numbers, the superframe length, and the GTS capacity of superframe. This changes are inserted without any modification of the IEEE 802.15.4 standard.

Hameed et. al. [7] propose a GTS allocation scheme called "Earliest Due Date GTS allocation". This modification considers the deadline of each GTS request, assigning the GTS slots for nodes with smaller normalize deadlines within each superframe. This algorithm assumes that no collisions and no packet lost occurs during transmissions.

Moreover, [8] uses network calculus to model the IEEE 802.15.4 behaviour and propose an implicit GTS allocation called i-GAME. The i-GAME allows the use of one slot by multiple nodes, considering available bandwidth resources, traffic specification and deadline requirements for accept or reject a GTS request.

Cena et. al. [9] propose the combination of wired and wireless worlds to provide real-time communication in industrial environments. This work presents some means to build an hybrid network that incorporates the best of these worlds. Further, this work shows different forms to implement this combination.

The next sections present the main concepts of the inaccessibility and make some considerations for improving the support of real-time communication provided by the IEEE 802.15.4 standard.

3 The Concepts and Characterization of Inaccessibility in 802.15.4 Networks

All applications need the support of some communication infrastructure when require to communicate with other devices along the network. Real-time applications, with temporal constrains, need guarantees in the successful delivery of the data within a deadline. For that reason, delays and other problems in the transmission, caused by the presence of perturbations in the medium access, are jeopardous and must be controlled.

These perturbations, caused by external interferences (e. g. electromagnetic waves, obstacles) or modifications in the execution flow of some services present within MAC protocol, are undesirable and increase the unpredictability on the

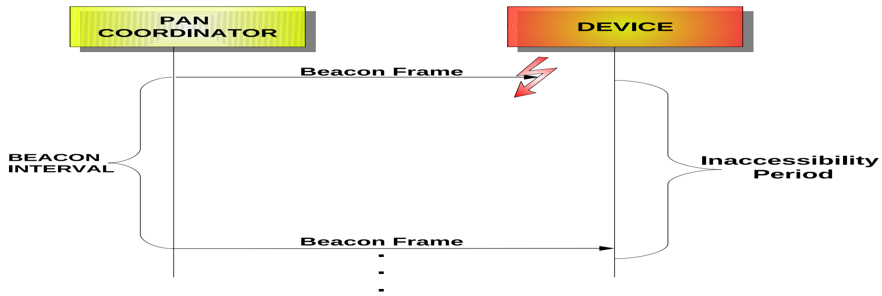

Figure 2. Example of Beacon Lost Inaccessibility scenario

network environment, creating temporary partitions. These partitions, from a node view, induce the network to enter in a state that it does not represent a failure but where the network does not provide service, i.e., the network is inaccessible to that node. This undesirable phenomenon is called inaccessibility period [1,2].

The knowledge of inaccessibility is very important to provide more information about the status of the network, and for allowing more predictability within communication infrastructure.

In 802.15.4 networks, two operation modes are allowed: Beacon-enabled PAN and NonBeacon-enabled PAN. The nodes, within a beacon-enabled PAN, access the medium based on the reception of special frames called beacons. The beacon frames are sent by (PAN) coordinator[1] and bounds a special structure called superframe. The superframe is used to synchronize and control the medium access of all nodes within the network. Figure 1 presents the organization of a superframe structure.

The unpredictability is the main problem presented in a network environment susceptible to inaccessibility periods. If the upper-bounds duration of these periods are unknown, no guarantees about the support of real-time communication can be provided. As consequence, deadlines may be missed and catastrophic problems may occur (hard real-time).

Let us to show a concrete example. In 802.15.4 standard, using a beacon-enabled PAN, the beacon is a control frame that provides network synchronization for its associated nodes. Further, if a node does not receive the beacon successfully, the network will stay inaccessible to it until the PAN coordinator send the next beacon and the affected nodes receive it successfully. Figure 2 shows a sequence diagram between the PAN coordinator and a device node that represents an inaccessibility scenario based on this situation.

Note in Fig. 2 when the device does not receive the beacon frame its transceiver is maintained in listen mode searching for the beacon. As the beacon frame was lost, the node stays inaccessible during the period between two beacons received

[1] The first node that join the network is a special coordinator called PAN coordinator

Table 1. The best and worst cases for $2.4GHz$ frequency band

PHY (2400-2483.5 MHz)		
Scenario	**Modulation Technique (*O-QPSK*)**	
	best case (ms)	**worst case** (ms)
$t_{ina \leftarrow sbfl}$	3859	3859
$t_{ina \leftarrow mbfl}$	12336	15435
$t_{ina \leftarrow nosync}$	15435	15435
$t_{ina \leftarrow GTS}$	1	2

successfully ($t_{ina \leftarrow sbfl}$). Moreover, without the knowledge of the inaccessibility periods the timeliness of network can not be guaranteed.

The solution to minimize the problems caused by the occurrence of inaccessibility periods is to define means to control the inaccessibility. This control is based on the knowledge of all inaccessibility scenarios present in the network. The identification of these scenarios is totally dependent of the network type and its parameters.

Table 1 presents the inaccessibility times for $2.4GHz$ frequency, considering default values of constants and parameters defined in the 802.15.4 standard. The inaccessibility times of the four scenarios are presented: three scenarios based on the beacon loss ($t_{ina \leftarrow sbfl}$, $t_{ina \leftarrow mbfl}$, and $t_{ina \leftarrow nosync}$), and one scenario based on GTS scheme ($t_{ina \leftarrow GTS}$). A data transfer, under normal network conditions, with frame size equal to **64 Bytes**, has a duration $t_{Data} \cong$ **2 ms**. The occurrence of some inaccessibility scenarios, presented in table 1, increases significantly this time, demonstrating the importance of our study. As the beacon synchronizes the network and contains information about allocated slots and other features important to well-operation of the network, its loss affects the nodes catastrophically. If a node has a GTS allocated and loose the beacon, it does not known which moment was reserved for it, generating a great negative impact in real-time applications that use GTS to time-critical transmissions.

4 Conclusions and Future Directions

This paper presented a characterization of inaccessibility in IEEE 802.15.4 based on the beacon-enabled mode. Perturbations in the medium are the main originator of this temporary partitions. The knowledge of this periods helps to known the network behaviour, allowing a more detailed analysis about it.

Applications timeouts, or other type of solutions used for controlling temporal execution of real time protocols, can use the knowledge of the inaccessibility times to make a fine adjust on its parameters, and provide a better support for execution of real-time applications.

Future work directions will focus on providing means to reduce the periods of inaccessibility; extending the study to make a complete coverage of inaccessibility scenarios in IEEE 802.15.4; to provide support to signal the periods of inaccessibility for higher layers. Additionally, the results of these future works can be used to improve the support of real-time communications, providing the means of analyzing network delays and message schedulability under a performability perspective.

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