Simulation Study of the IEEE 802.15.4 Standard Low Rate Wireless Personal Area Networks

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***Abstract*—This article presents a description of the simulation study of the low rate wireless personal area networks, defined by the IEEE 802.15.4 standard. The obtained results make it available to evaluate the effective transmission rate of a transmission channel, the resistance to the phenomenon of hidden station as well as the sensibility to the problem of exposed node.**

***Index Terms*—Exposed station, hidden station, low rate wireless area network**

I. INTRODUCTION

THE IEEE 802.15.4 standard was created in 2003, and its current form results from the modifications introduced three years later. The specification defines the physical layer (PHY), the medium access control sublayer (MAC), as well as the principle of their interaction with the higher layers.

The LR-WPAN are characterized by very low energy consumption, simplicity of their structure making it possible to implement the transmission protocol on 8-bit microcontrollers, as well as low costs of receiving and transmitting equipment. LR-WPAN are designed to be used in different industrial, agricultural and alarm systems, building automatics, monitoring, interactive toys and in particular in wireless sensor networks (WSN).

The bit rate of the IEEE 802.15.4 network can be equal to: 20 kb/s, 40 kb/s, 100 kb/s or 250 kb/s. The nodes realize the transmission in a discontinuous way, trying to remain for the longest possible time in inactive mode – this make it possible to achieve low energy consumption. The radiated power is less than 1 mW, and the transmission range, characteristic for the personal operating space class solutions (POS), equals 10 m.

The IEEE 802.15.4 standard offers a high capacity of the system and a very fast identification of equipment appearing in its range. The number of operating nodes can equal 2^{16} or 2^{64}, dependent on the length of addresses, whereas in general the time of registration of a new node does not exceed 30 ms. Moreover, a precious advantage is the automatic modification of connections with moving equipment.

The IEEE 802.15.4 standard offers two ways of transmission: in non-synchronized (non-beacon) and in synchronized (bacon enabled) mode. The first one defines only a contention access, using a simple mechanism permitting to identify the channel state and avoid collisions – unslotted-CSMA/CA (carrier sense, multiple access with collision avoidance). In the second method a less developed, slotted contention protocol has been implemented – slotted-CSMA/CA, as well as a no-collision access mechanism.

II. SIMULATION TESTS OF THE CONTENTION PROTOCOL

The main objective of the tests of the contention protocol implemented in the IEEE 802.15.4 network was to define its efficiency and resistance to the appearance of hidden stations or exposed stations in the system, named also blocked nodes. The simulation was realized using a NetSim package created in the Department of Electronics, AGH University of Science and Technology. The NetSim software has been written in C++ language. The package uses an event-planning technology (event queue). Its mechanisms permit to correctly render the reciprocal time interrelations existing between several simultaneous processes. The importance of simulated time as well as the number of stages of the tested processes can be dynamically adapted to the following factors: the character of the observed events, the momentary importance of the offered traffic, the size of the tested system as well as the required precision of obtained results.

In the further part of this work we have presented the results of tests relating to the evaluation of the efficiency of CSMA/CA protocol implemented in non-synchronized and synchronized LR-WPAN network. In all the studied cases the assumptions are as follows: transmission rate of 250 kb/s, the DATA frames transmit data fields with maximal permitted size, the node emitters are equipped with buffers with a capacity of 50 packets and every successful transaction ends with an ACK frame. Moreover, we have admitted a two-ray ground propagation model, meaning that the nodes located within the emitter range correctly receive its transmission with a probability equal to 1. The other stations do not hear the transmission – their probability of packet reception equals 0. In the simulation model, we did not take into consideration the possible impact of any external interference that might decrease the efficiency of the transmission. Therefore, the only possible cause of unsuccessful transfer can be a collision.

A. *Effective transmission rate of the transmission channel*

The effective transmission rate of the transmission channel indicates a maximum number of user's data transmitted within a time unit [1]. Usually, the value of this parameter is largely different from the used transmission rate, because of the overhead introduced by the second and first layers as well as because of the inactivity periods related to the duration of transmission delay times and the testing of channel occupation during the contention.

For the identification of effective transmission rate of the system, we have used a model containing two nodes, one of them working as coordinator. The transmission is realized only in one direction – towards the coordinator. Therefore, the network is free of collisions and the intensity of the operated traffic is the maximal possible.

The results obtained for both network operation modes (non-synchronized and synchronized) are summarized in Fig. 1. The effective transmission rate in the non-synchronized mode equals to 116 kb/s, corresponding to the utilization of 46 % of the channel operation time. The remaining transmission rate of the system is absorbed by the transmission overhead and by the dead periods, related to the random delay of the moment starting transmission. The effective transmission rate of the synchronized network is even worse and equals about 98 kb/s, corresponding to 39 % of the assumed transmission rate. The supplementary band losses result from the necessity of the periodical transmission of BEACON frame, the increasing of the channel occupation test, the increasing of the contention window size and the non-utilization of the last fragment of the superframe, which remains empty because the transmitting node cannot manage to fit the entire transaction in it. The average length of this section corresponds to the half of the transaction time.

The Fig. 1.b presents the relation between the coefficient of delivered packets and the intensity of the offered traffic. The losses of frames appear only during the overloading of the system. The superiority of the traffic offered over the traffic operated leads to the overfilling of the emitter's queue and the resulting refusal of a certain part of the requests.

The same model of the system, loaded with a traffic directed in a symmetrical way to both nodes, makes it possible to define the influence of the bidirectional transmission for the available transmission rate of the network. The obtained results are summarized in Fig. 2. Their values are not significantly worse, even if it could seem that the nodes should initiate a contention concerning the access to the common channel, leading to collisions. In the LR-WPAN, the transactions realized in both directions are initiated by a single slave station, so any contention is excluded. The decrease in the transmission rate of the transmission channel results from a worse efficiency of transmission directed towards the slave node. Any such transaction must start with the transmission of REQUEST and ACK frames [1], increasing its duration.

The coefficient of delivered packets, defined for the discussed configuration, has slightly changed because of the decrease in the transmission rate of the network (Fig. 2.b). The form of both curves remains identical, confirming a total operation of the requests directed toward a system free of overloading.

B. *Influence of a hidden station on the transmission rate of the system*

The collisions caused by hidden stations are much more troublesome for the system than those resulting from the contention for the access to the radio channel. A long time of emission of a single frame significantly increases the probability of generating a new request directed to the hidden station in this period [2]. Its immediate realization will disturb the transaction being already in progress with the distant node.

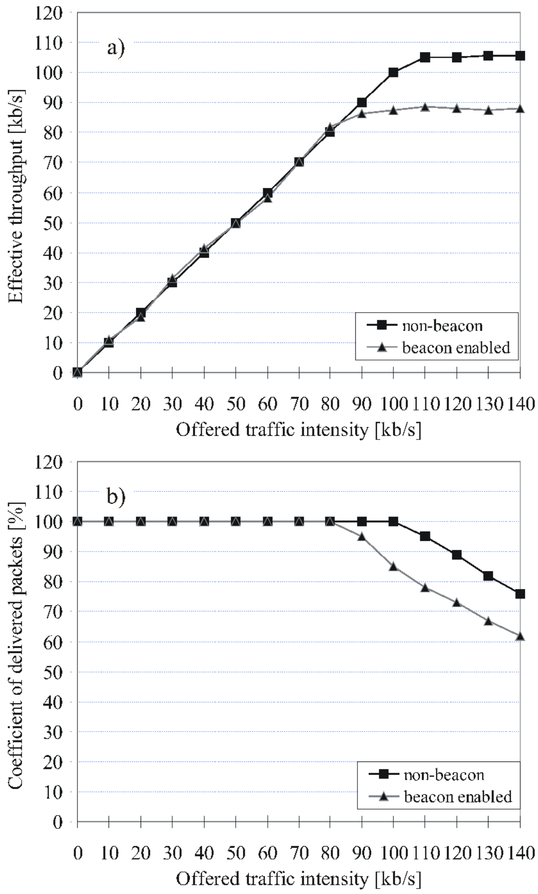

Fig. 1. Unidirectional transmission in a system consisting of two nodes: a) intensity of the operated traffic, b) coefficient of delivered packets

Studying the influence of the presence of a hidden station on the operation of the LR-WPAN network, we have used the model presented in Fig. 3. A centrally placed coordinator works with two slave nodes, located out of their reciprocal range. The entire offered traffic is evenly divided between slave stations, which direct their transfers exclusively to the coordinator.

The results of simulation tests, summarized in Fig. 4, indicate a radical decrease in the transmission rate of the system – for both transmission modes it equals only 23 % of the effective channel transmission rate. Moreover, the network works with the efficiency close to maximal only in certain, relatively narrow interval of the intensity of the offered traffic. A further increase in the number of requests results in an important worsening of the quality of their servicing and in system overloading. The shape of obtained characteristics corresponds to the panic curve, defining the operation of many systems with collision access.

The reason of the decrease in the network transmission rate – when the intensity of the offered traffic exceeds of a given threshold value – is the increase in the channel occupation time, favorable to the appearance of collisions with the hidden stations. The retransmissions activated by both nodes increase in an artificial way the intensity of requests directed towards the system, leading to its overloading. It is worth mentioning

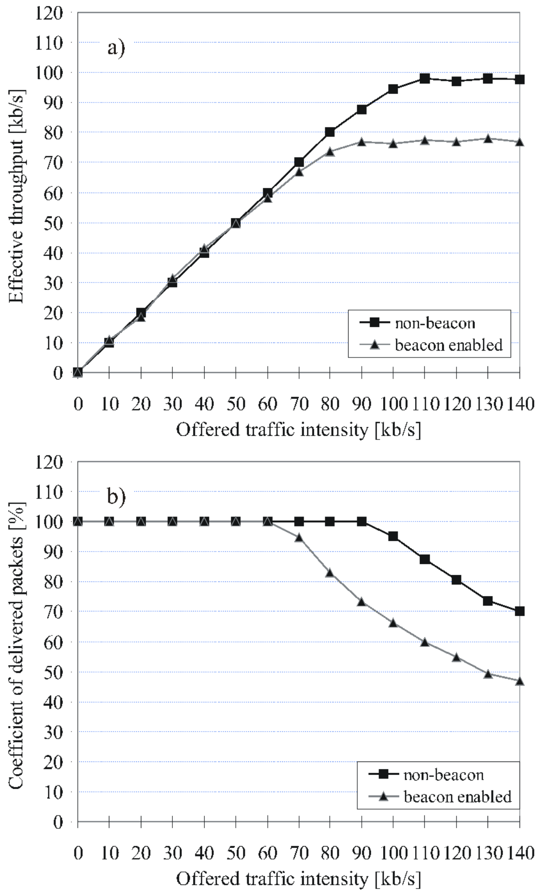

Fig. 2. Bidirectional transmission in a system consisting of two nodes: a) intensity of the operated traffic, b) coefficient of delivered packets

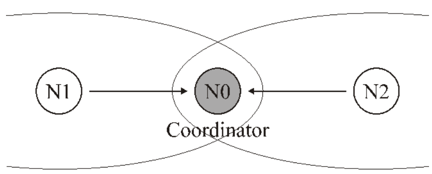

Fig. 3. Model of a system containing hidden stations

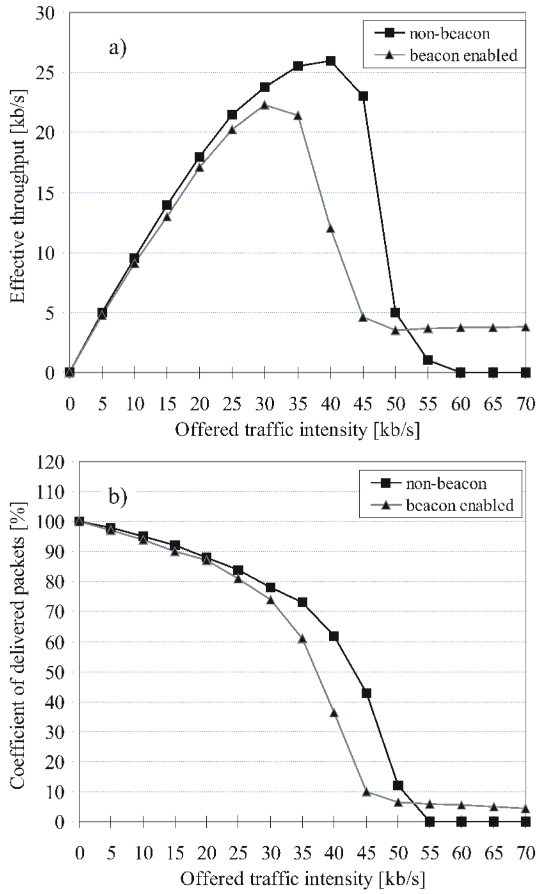

Fig. 4. Unidirectional transmission in a system containing hidden stations: a) intensity of the operated traffic, b) coefficient of delivered pa

that in congestion conditions the transmission rate of a non-synchronized network decreases to zero, whereas a synchronized system always guarantees a certain minimal level of servicing the transmission requests. Such an advantage is a side effect of the algorithm realized by the node of the LR-WPAN network, verifying before the start of each transaction if its duration does not exceed the limits of the finishing superframe. Thanks to that, the hidden station rarely disturbs the last transmission that can fit into the superframe.

The defined characteristics of the coefficient of delivered packets (Fig. 4.b) indicate that the loss of frames appears even with a very little intensity of the offered traffic. The reason is the cancellation of further retransmissions of these packets, not delivered with a pre-defined admissible number of attempts. As the intensity of the requests increases, this phenomenon appears more and more often. In an overloaded system, the queues of single emitters become overfilled and a more significant part of the offered traffic is refused.

The objective of successive series of tests consisted in verifying the influence of the hidden station on the node located in the range of its signal. In the system presented in Fig. 3 this function is assumed by the coordinator. We should remind that the transactions of the coordinator are initialized by other nodes of the cluster, strongly influenced by the presence of the hidden station. Based on this, we can presume that the hidden station will also disturb the servicing of requests directed towards the coordinator.

The diagrams presented in Fig. 5 have been obtained using the model given in Fig. 3, in which the offered traffic has been evenly divided between all the nodes. Contrary to the assumptions, the presence of the hidden station has only a limited influence for on transactions realized by the coordinator. Moreover, the intensity of traffic realized by this station is not suddenly decreased when the threshold value is exceeded, as it was the case for the other nodes.

The differences existing in the way of servicing the transactions realized in each direction are connected with the length of initiating frames. A transaction directed to the coordinator starts with a long DATA packet, whereas the transfer in another direction is initiated with a much shorter REQUEST frame [3]. Therefore, in the second case the probability of a collision caused by the hidden station is much lower. Moreover, if a

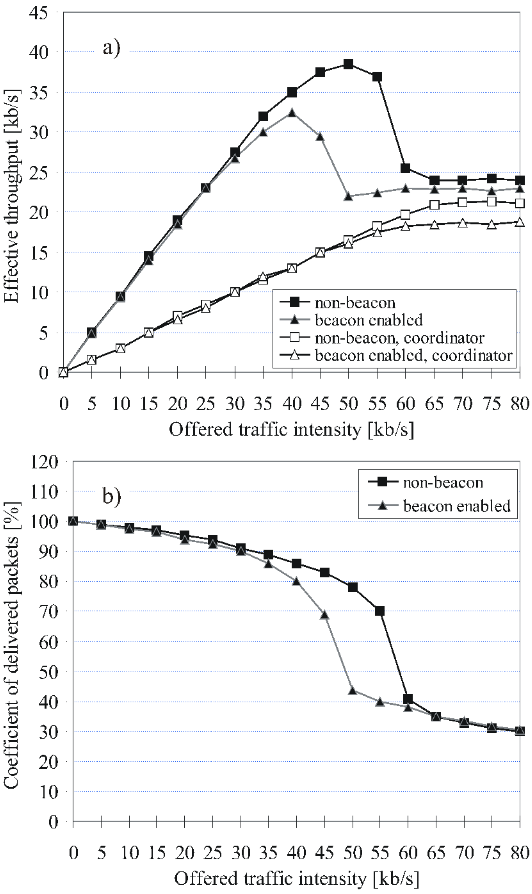

Fig. 5. Bidirectional transmission in a system containing hidden stations: a) intensity of the operated traffic, b) coefficient of delivered packets

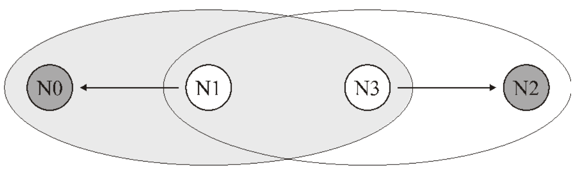

Fig. 6. System with exposed stations

collision appears, its duration will also be shorter, reducing its influence on the channel transmission rate. The frames ACK and DATA initiated by the coordinator are received by all the nodes of the cluster, so the hidden stations have not any influence on further part of the transaction. The transmission directed to the slave node is similar to a transaction concerning the reservation of channels with RTS and CTS frames, used in IEEE 802.11 standard, and protecting WLAN network against problems created by the hidden stations.

Irrespective of the status of the system, when the threshold value of the intensity of offered traffic is exceeded, due to the transmission realized by the coordinator, the coefficient of delivered packets does not decrease to zero, as it was in the previous case (Fig. 5.b). Its value gradually decreases because the overfilling of the buffer in the coordinator's emitter results in the refusal of an increasing number of requests.

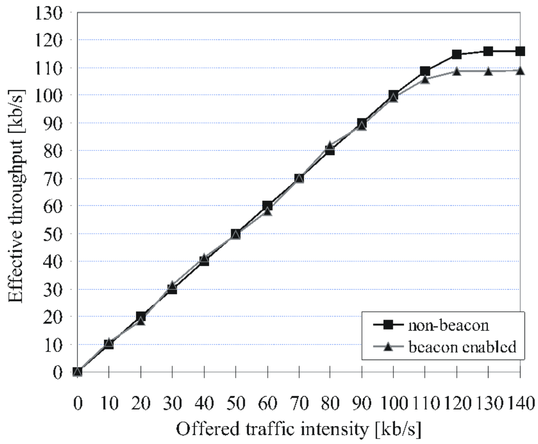

Fig. 7. Unidirectional transmission in a system containing exposed stations

C. *Effect of the exposed station*

Studying the effects of the exposed station, we have used the model presented in Fig. 6. The intensity of the offered traffic is evenly divided between nodes N1 and N3. The characteristics obtained in these conditions are summarized in Fig. 7.

The obtained characteristics, as it concerns their shape and values, are very similar to those observed for the system consisting of two nodes and realizing the transmission towards the coordinator (see Fig. 1). The total transmission rate of both clusters is slightly higher than the effective transmission rate of a single channel. The coefficients of delivered packets are also slightly higher, thanks to a double capacity of the buffers of both nodes. Therefore, the presence of exposed stations permits only a half of transmission resources of each cluster to be used.

III. CONCLUSION

The main objective of the authors of the IEEE 802.15.4 standard was to create a system that could contain an enormous number of nodes (even 2^{64}) and at the same time using a transmission protocol very simple to implement, guaranteeing minimal energy consumption. The fulfilling of all the above-mentioned assumptions proves to be very difficult and – as the realized studies have shown – leads to an important decrease in the available transmission rate of the transmission channel. Important problems result also from the presence of a hidden station and exposed station.

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