Zigbee WSN Round Trip Latency in Function of Channel Occupation and Nodes Configuration

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***Abstract*—Wireless sensor networks (WSN) allow measuring temporal and spatial distribuited variables. WSN nodes measure variables and send them to a base station through a low data rate wireless communication channel. This wireless communication channel is shared by all nodes that comprised the WSN. WSN have been developed to allow high spatial density of data. Therefore, communication protocols for WSN have been developed in order to allow a large number of nodes. However, if a large number of data are transmitted through a low speed communication channel, latencies may increase considerably. This situation could happen in WSN with a large number of nodes sending data periodically, or in WSN that can increase the data rate when a specific event is detected. In this papers, round trip latency measurements in function of the communication channel occupation and sleep and active status time intervals of nodes are presented.**

***Resumen*—Las redes de sensores inalámbricos (WSN) permiten medir variables temporal y espacialmente distribuidas. Los nodos que forman una WSN miden variables y envían sus valores a una estación base a través de un canal de comunicaciones inalámbrico de baja velocidad de datos. Este canal de comunicación inalámbrico es compartido por todos los nodos que componen la WSN. Las WSN han sido desarrolladas para permitir alta densidad espacial de datos. Por lo tanto, los protocolos de comunicación para WSN han sido desarrollados con el fin de permitir un gran número de nodos. Sin embargo, si un gran número de datos son transmitidos a través de un canal de comunicación de baja velocidad, las latencias pueden aumentar considerablemente. Esta situación podría ocurrir en una WSN con un gran número de nodos que envían datos periódicamente, o en una WSN que puede aumentar la velocidad de datos cuando se detecta un evento específico. En este artículo se presentan mediciones de latencia total (ida y vuelta) en función de la ocupación del canal de comunicaciones y los intervalos de tiempo en estado activo y bajo consumo de los nodos.**

I. Introduction

A wireless sensor network (WSN) is a system composed of devices known as nodes with capacity of sensing, data processing, data storing, and wireless communication [1]. The WSNs have a large number of application areas, such as: environmental monitoring, agriculture, health monitoring, factory and process automation, building automation, military applications, etc. It is expected that the number of applications, and the number of WSNs grow enormously [1][2][3][4].

The IEEE 802.15.4 standard [5] defines the physical layer and the media access control sublayer (MAC) for low speed wireless networks. This standard is used by almost all WSN nodes available on the market. ZigBee [6] is a communication protocol widely used for WSN. ZigBee defines the routing layer and data application sublayer over the MAC layer specified by the IEEE 802.15.4 standard.

The IEEE 802.15.4 standard use CSMA/CA (carrier sense multiple access with collision avoidance) mechanism for media access control. This mechanism uses a back-off algorithm to reduce packet collisions. When a node needs to transmit a data packet, first waits for a randomly chosen time interval. Then, the node verifies if the communication channel is empty, and if so, it send the data packet. But if the node detects the communication channel busy (due to other nodes are transmitting), it doubles the randomly chosen time interval, and after verifies if the communication channel is empty again. After five repetitions of this mechanism, the time interval is fixed to its maximum value [7].

Some applications require sensors transmitting data to a data rate that may be very high for WSN. For instance, in fire detection applications, sensors detecting the fire front evolution, have to transmit data approximately every 5 second [8], and a high number of nodes may be needed. In some application like domotic, where sensors may be used as light switch, end to end latencies of 200 milliseconds are desired [9]. Another example are WSN applications with sensors that transmit faster when some events are detected, for instance, frost detection, weather phenomena detection, domotica, etc. The larger number of nodes or higher transmission rate, the higher the probability that a node detects the communication channel busy when needs to transmit data. Then, according to the CSMA/CA mechanism, this node has to wait to transmit data. Therefore, the average latency will increase.

The purpose of the experiments described in this paper is to measure the relation between the round trip latency of a node to a command that asks some information, in function of the communication channel occupation produced by all the nodes that comprise the WSN and time intervals configurations of all nodes

This paper is organized as follows. Section II presents related works. Experimental methodology common at all experiments is described in section III. Section IV presents measurements of round trip latency in function of the communication channel occupation and the active status time interval of interfering nodes. Measurements of round trip latency in function of the communication channel occupation and the sleep status time interval of interfering nodes are displayed in section V. Section VI exhibits measurements of round trip latency in function of number of interfering nodes and data packets rate transmitted by each interfering node. Finally, conclusions are presented in section VII.

II. Related Work

In [10], the authors measure the transmission latency between ZigBee nodes in function of packets length. The results show that there is a very small difference between experimental and theoretical results. This is an expected result since the packet length determines the time interval during which the communication channel will be occupied by each node. In [11] the throughput (amount of data received by a node on a time period) for different network topologies, point-to-point and multi-hop, is measured. This work shows that in a multi-hop transmission the throughput is the half with respect of a point-to-point transmission. This result is due to when the router is re-transmitting data, is occupying the transmission channel, and the end devices nodes can not transmit data until the transmission channel is idle.

In [7] the authors measure, among other parameters, the delay between the generation of a data packet and its correct reception, as a function of the number of nodes, which transmit 2 data packets per second. However, the authors do not describe the accurate procedure to perform this measurement. In addition, the presented graphics show an unexpected behavior, due to delays for 25 nodes, 50 nodes, 100 nodes or more is about 100 millisecond. But the delays for these numbers of nodes should be different and should increase in function of the number of nodes. In the cited paper, the measurements were performed through simulation.

In [12] the author measure the latency and the round trip time delay between 2 ZigBee nodes in a not saturated communication channel. The measured latency is in average 58 millisecond, and the round trip delay time is in average 170 millisecond.

In [9], authors measure the probability that the message latency exceeds a threshold value (200 ms), and analyze different routing techniques to decrease this probability. The experiment uses a real WSN composed by eight nodes deployed in a office environment. Nodes used in [9] are configured to answer as fast as possible, which is desirable in some domotics applications. However, in agricultural, environmental or outdoor applications, where the low energy consumption is critical, nodes may stay large time intervals in sleep status, and answer as fast as possible is not a real behavior.

III. Experimental Methodology

The round trip latency is defined as the time interval since the coordinator node sends a command to a end-device node, until the end-device answer returns to the coordinator node. The communication channel occupation is defined as the average number of data packet per second generated by all nodes that comprise the WSN.

The communication channel occupation can vary by different causes. In this paper, the communication channel ocupation was varied through modifying the active status time interval, sleep status time interval and number of nodes.

The round trip latency of two nodes was measured, an end device node and a router node. In this paper these nodes are called under test end device node and under test router node. The under test end device node was configured as follow:

- Active status time interval: 10 milliseconds
- Sleep status time interval: 1 second

The router node is on active status all the time. In addition, eight nodes were used to produce data traffic in the wireless communication channel and thus to interfere the communication between the under test nodes with the coordinator node. In the rest of the paper these eight nodes are called interfering nodes.

The communication channel occupation was calculated as:

$$\text{Communication channel occupation} = N * r_{end-device}$$

Where N is the number of interfering nodes and $r_{end-device}$ is the measured data packet rate (packets per second) produced by each interfering nodes. It is important to state that this probably is not the real data rate transmitted trhough the communication channel. This is the needed data rate in order to transmit all the data generated by nodes without collisions. We use this variable due to from the point of view of the applications, the needed data is the number of data that is needed to transmit.

The command sent to the under test end device and router nodes was the DB command, that asks the RSSI received by the node in the last communication. In order to perform the experiments, XBee nodes [13] were chosen.

IV. Round Trip Latency in Function of the Communication Channel Occupation and the Active Status Time Interval of Interfering Nodes

A. Experiment Setup

Nodes can stay into one of the following states:

- Active status: The node transceiver is on, and the node can send and receive data.
- Sleep status: The node transceiver is off for saving energy, and the node can not send or receive data (some nodes also can turn off other components).

The data packet rate transmitted by each node can be modified by variation of the active status time interval or the sleep status time interval. Figure 1 shows these time intervals. In addition, the active status is divided in two:

- Data transmission status: the node is sending or receiving data from a coordinator or station base node.

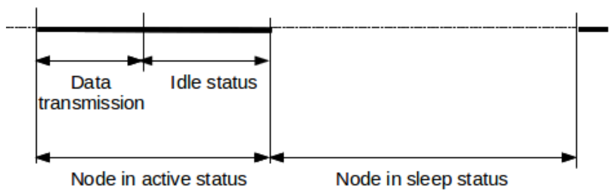

Figure 1. Duty cycle of a WSN node

- Idle status: after communicating with the coordinator node, the end device node stays in idle status a specified time interval before going to sleep status.

In order to perform this experiment, interfering nodes were configured to transmit periodically data packets all at the same rate. A two bytes value (corresponding to a digitalized analogical variable) per data packet was transmitted. The sleep status time interval was maintained constant, and the active status time interval was varied. As a result, the data packet rate of interfering nodes is modified.

Three values of the sleep status time interval were chosen. For every value of the sleep status time interval, eight values of the active status time interval were chosen. For every combination of these values, thirty round trip latency measurements of under test nodes were taken. Average and standar deviation were calculated.

B. Result

To show the total number of obtained average and standard deviation values would be needed three tables like table I. Therefore, to save space and to greater clarity, results are shown graphically. As an example, table I shows the round trip latency, when the interfering nodes send data packets periodically with a sleep status time interval of 290 milliseconds. Table I shows that the standard deviation values are large, similar to the average values. This is a feature of the WSM behavior.

Figure 2 shows the relationship between the round trip latency of under test end device node and under test router node, in function of the channel occupation, when the WSN data traffic is modified through varing the active status time interval of interfering nodes. Figure 2 show that, for each sleep status time interval, there is a threshold value of the channel occupation around which the average round trip latency varies quickly. Below this threshold value, the round trip latency is around 1 second. Above this threshold value, the round trip latency is greater than 30 seconds, and the behavior is irregular. It can be noted that all curves are similar, and the router node round trip latency is slightly less than the end device node round trip latency.

Figure 3 shows the relation between the round trip latency in function of the active status time interval of interfering nodes. It can be noted that there is not a proportional relation, but there is a quickly variation of the round trip latency around a specific value of the active status time interval of interfering nodes. This threshold value of the active status time interval of interfering nodes is around 125 millisecond. Table I shows that into this region the chosen values of the active status time interval of interfering nodes were closer together for major

Table I
ROUND TRIP LATENCY IN FUNCTION OF ACTIVE STATUS TIME INTERVAL FOR INTERFERING NODES TRANSMITTING DATA PACKETS PERIODICALLY WITH A SLEEP STATUS TIME INTERVAL OF 290 MILLISECONDS

Active status time interval	Channel occupation (packet per second)	Under test end device node		Under test router node	
		Average	Standar deviation	Average	Standar deviation
10 ms	26.7	32502	23079	34138	12112
50 ms	23.5	34410	24778	33578	17286
100 ms	20.5	32117	21381	26587	8686
112 ms	19.9	27136	25449	18235	21647
120 ms	19.5	820	273	176	32
125 ms	19.3	635	421	431	598
150 ms	18.2	556	225	317	308
400 ms	11.6	470	228	163	53

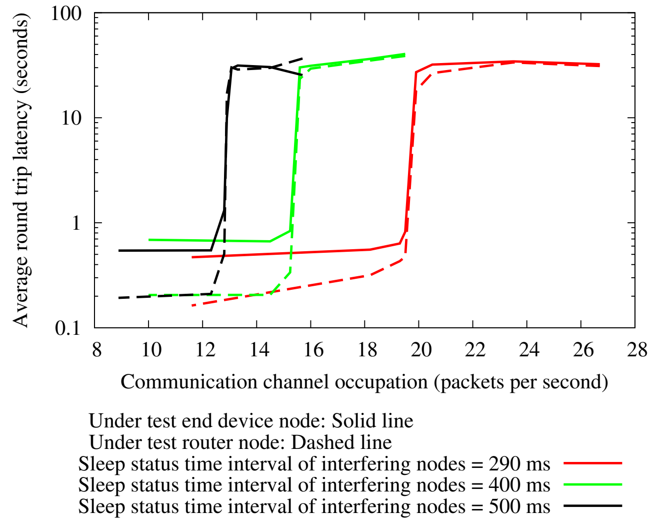

Figure 2. Under test nodes round trip latency in function of communication channel occupation

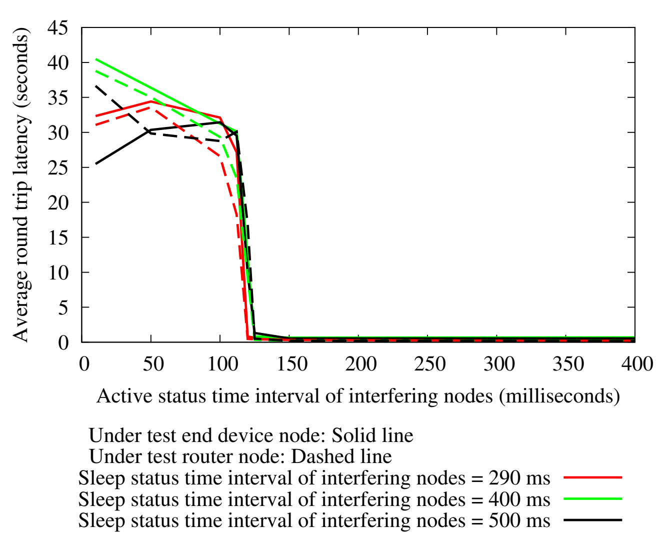

Figure 3. Under test end device node round trip latency in function of active status time interval of interfering nodes

clarity in the region with faster variation. Figure 3 shows that this threshold value of the active status interval for the interfering nodes does not depend of the sleep status time interval.

This behavior is difficult to explain, since the XBee nodes allow to modify the idle status time interval after coordinator node and end device node have been able to communicate. These nodes do not interrupt a communication if the active status time interval has been exceeded. Therefore, to argue that the active status time interval is too short for allowing communication is not a valid explanation.

Figures 2 and 3 show that, for aboiding too long response latencies, the active status time interval of all nodes in the WSN must be longer than a minimum threshold. However, too long active status time intervals produce high power consumption. Therefore, this parameter have to be configured carefully.

V. Round Trip Latency in Function of the Communication Channel Occupation and the Sleep Status Time Interval of Interfering Nodes

This experiment have the purpose of analize if the modification of the sleep status time interval of interfering nodes has influence on the round trip latency.

A. Experiment Setup

In order to perform this experiment, interfering nodes were configured to transmit periodically data packets all at the same rate. One analogical variable per data packet was transmitted. The active status time interval was maintained constant, and the sleep status time interval was varied. As a result, the data packet rate of interfering nodes is modified, like is shown in figure 1.

Three values of the active status time interval were chosen. For every value of the active status time interval, eight values of the sleep status time interval were chosen. For every combination of these parameters, thirty round trip latency measurements of the under test nodes were taken. Average and standard deviation were calculated.

B. Result

Figures 4 and 5 show the obtained results. Figure 5 shows that the longer the sleep status time interval, the shorter the round trip latency. However, this behavior can be attributed to, when the sleep status time interval increases, the communication channel occupation decreases.

It can be noted that the curve corresponding to active status time interval of 125 ms shows significantly lower values of round trip latency than curve corresponding to active status time interval of 10 and 50 ms. This is consistent with the result obtained in section IV, that show that above a threshold value for the active status time interval of interfering nodes, the round trip latency is shorter.

It can be noted that there are not any unexpected or strange behavior on the round trip latency, like a threshold value, when the sleep status time interval of interfering nodes varies.

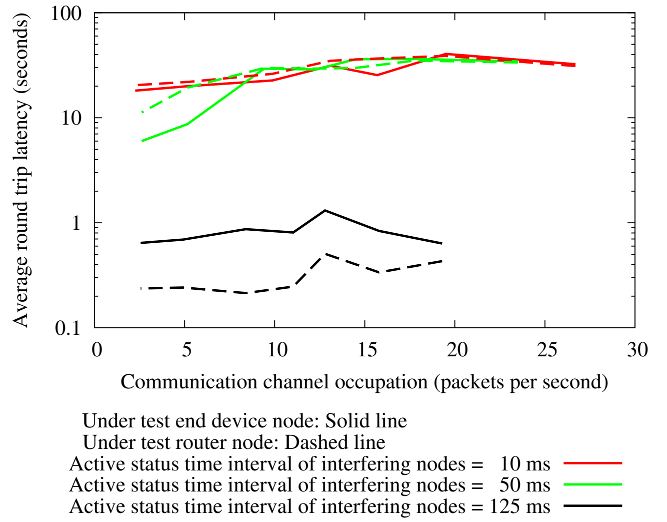

Figure 4. Round trip latency in function of the communication channel occupation and the sleep status time interval of interfering nodes

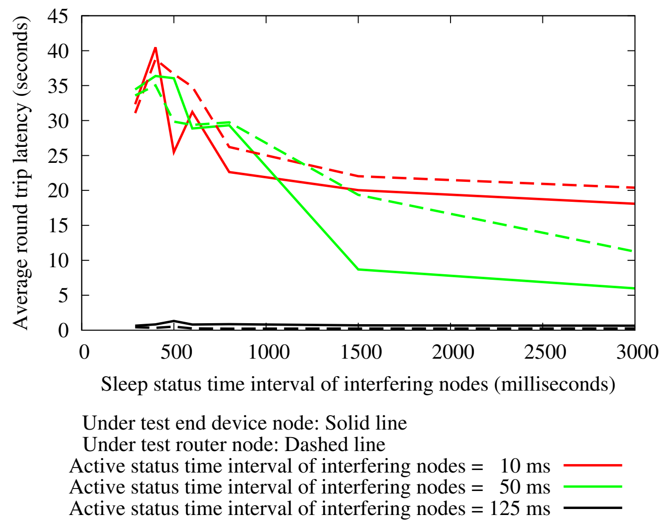

Figure 5. Round trip latency in function of the sleep status time interval of interfering nodes

VI. Round Trip Latency in Function of the Data Packets Rate and the Number of Interfering Nodes

A. Experiment Setup

Sections IV and V show that if active status time intervals of interfering nodes is below a threshold value, the round trip latency increases quickly. But for active status time intervals above this threshold, the round trip latency is around some seconds. In this section the round trip latency for active status time intervals of interfering nodes above this threshold value is measured, for different channels occupation values and number of interfering nodes.

In order to perform this experiment, interfering nodes were configured to transmit periodically data packets all at the same rate. One analogical variable per data packet was transmitted. The active status time interval and the sleep status time interval of interfering nodes were maintained constant in all measurements. The chosen values are:

- Active status time interval of interfering nodes = 240 ms
- Sleep status time interval of interfering nodes = 290 ms

The active status time interval was set in the region above the threshold value found in section IV. The sleep status time interval was set at its minimun value.

Four values of the data packet generation rate per interfering node were chosen: 2, 4, 6, and 8 data packets per second per node. Through measurements it was determined that the packets generation rate values per second per interfering nodes were: 2.0 packets per second, 4.1 packets per second, 6.13 packets per second and 8.18 packets per second. For every value of the packet generation rate per second, measurements of the rond trip latency for different number of interfering nodes were performed. For every measurement point, thirty values of round trip latency were taken. Average and standar deviation values of the round trip latency were calculated.

B. Result

Figure 6 show the round trip latency of under test end device and router node in function of the number of interfering nodes, for different values of the data packet generation rate per interfering node. It can be noted that, when there are not interfering nodes (number of interfering nodes = 0), the round trip latency of the under test end device node is around 800 ms (solid lines), and for the under test router node the round trip latency is around 200 ms (dashed lines). This result agrees with the results presented in [12], that presents measures the round trip latency in a no saturated communication channel. For 1, 2 and 3 interfering nodes, the round trip latency of under test nodes does not depend on the number of interfering nodes. In addition, the end device node round trip latency stays greater than the router node round trip latency (all solid lines above all dashed lines in figure 6). This is due to the under test end device node is into sleep status 99% of the time, while the under test router node is in active status all the time. When the number of interfering nodes increases above of 4 nodes, the round trip latency increases, no longer depends on the configuration of under test nodes, and becomes dependent of the number of interfering nodes and the data rate produced by each interfering node (solid and dashed lines with the same tone tend to get closer in figure 6), except for a data rate per interfering node of 2.0 packets per second, since to this data rate per node the communication channel is not saturated with eight interfering nodes.

Figure 7 shows the under test nodes round trip latency in function of the communication channel occupation. Similar to figure 6, it can be noted that, when the communication channel occupation is small, the round trip latency depends on the configuration of the under test nodes. But when the communication channel occupation increases, the round trip latency becomes dependent on the communication channel occupation, and does not depend on the configuration of the under test nodes. In addition, it can be noted that for values of communication channel occupation above 30 packets per second, the round trip latency depends only on the communication channel occupation (all curves tend to get closer).

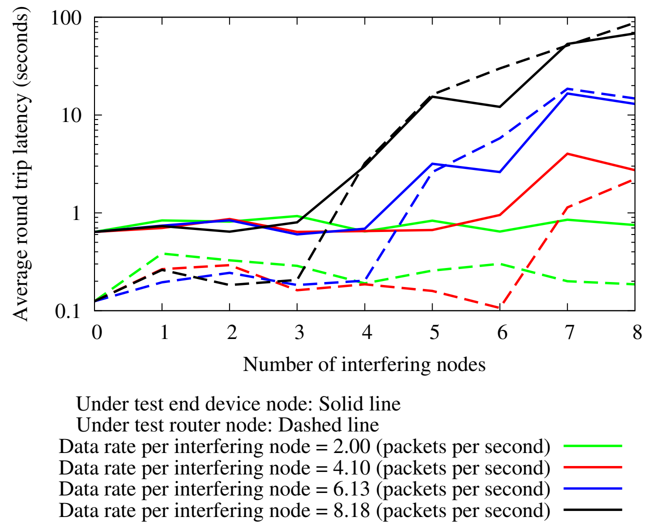

Figure 6. Round trip latency in function of the number of interfering nodes

Figures 2, 4 and 7 show that when the active status time interval of interfering nodes is above a threshold value, the round trip latency is shorter for the same values of communication channel occupation (figure 7 has been obtained for active status time interval of interfering nodes above the threshold value, whereas figures 2 and 4 have been obtained for values above and below the threshold value). From these results, it can be concluded that the WSN nodes can transmit a greater number of data, without increase significantly the round trip latency, if the active status time interval of all its nodes is above the threshold value.

Figure 8 shows the round trip latency obtained in 15 different samples used to construct figures 6 and 7. The 3 curves correspond to different number of interfering nodes.

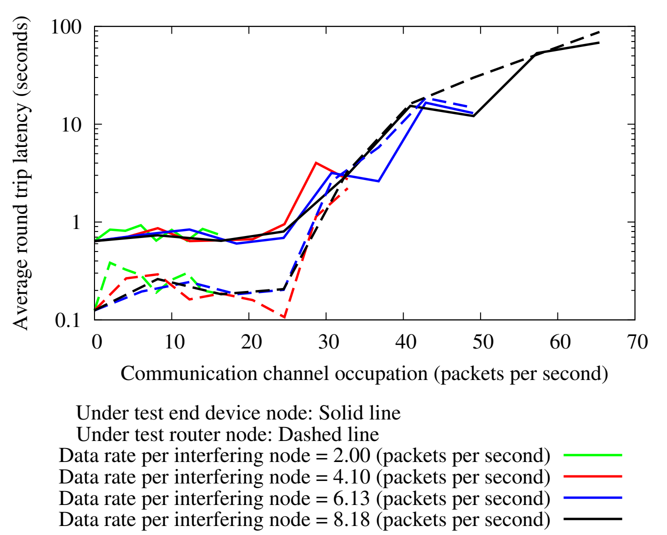

Figure 7. Round trip latency in function of communication channel occupation

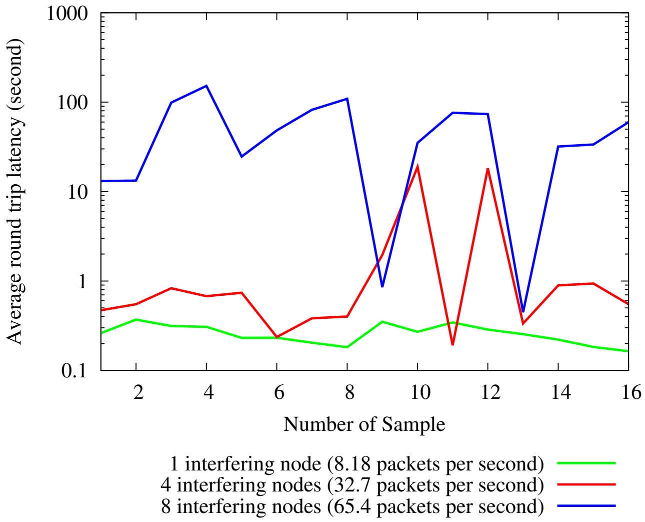

Figure 8. Temporal sequence of round trip latency samples for different numbers of interfering nodes

Each interfering node produces 8.18 data packets per second. The samples are not simultaneous. Each curve represents the temporal sequence of samples taken for obtaining previous figures.

Figure 8 shows that the saturation of the communication channel affect the round trip latency in different ways according the communication channel occupation. If the communication channel occupation is low (1 interfering node), the round trip latency is little affected by the WSN data traffic and is below 1 second in all samples. When the communication channel occupation is around 30 packets per second (4 interfering nodes) most round trip latency samples are around 1 second, but some round trip latency samples are above 20 seconds. A possible explanation is that, to this communication channel occupation value, the communication channel saturation takes place for short time periods. However, to higher communication channel occupation values (8 interfering nodes), most round trip latency samples are above 20 seconds, with some samples above 100 seconds, and few samples around 1 second. This behavior is due to, to these communication channel occupation values, the communication channel is saturated most of the time, and all nodes have problems to transmit data.

VII. Conclusions

Measurements presented in this paper show that the WSN round trip latency depends directly of the active status time interval of all nodes in the WSN and the communication channel occupation. Other parameters that affect the communication channel occupation can affect indirectly the round trip latency, like sleep status time interval and number of nodes. But they not have a direct effect, like a critical value or an strange behavior.

In addition, figures 6 and 7 show that the duty cycle configuration of under test nodes affects the round trip latency only for low communication channel occupation values. For high communication channel occupation values, the round trip latency does not depend on the under test node configuration, but depends on the configuration of all nodes in the WSN.

Figures 2 and 3 show that the active status time interval of all nodes in the WSN affect significantly the round trip latency for communication channel occupation values above specific values. For active status time intervals of all WSN nodes below a threshold value, the round trip latency in the communication between two nodes increases quickly. More experiments of data traffic in this region are needed in order to understand better this behavior.

Average round trip latency increases if the communication channel occupation increases above certain values. Figure 8 shows that this is caused by the communication channel saturation, due to several nodes try to transmit messages in a short time interval, and collisions occur. Round trip latency of individual samples are not proportional to the communication channel occupation. But, the round trip latency of some individual samples may increase ten or more times than others. The number of samples that suffer this increase, and the increment of the round trip latency of affected samples is proportional to the communication channel occupation. As a result, the proportional increase of the average round trip latency in function of the communication channel occupation is a statistical result.

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