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Evaluating the Energy Overhead Generated by Interferences within the 2.4 GHz Band for a Hybrid RFID Network

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Abstract

Energy efficiency is one of the key elements in the design of pervasive wireless communications systems. This metric can be influenced by several factors, one of which is the presence of interference in the already overcrowded 2.4 GHz ISM Band. A quantitative evaluation of the energy overhead generated by interference in the above mentioned frequency band is a first step in the optimization process meant to reduce this overhead. Through this paper the authors have designed and implemented a test bed for measuring and analyzing the impact that wireless sources of interference (i.e. Wi-Fi) have on the energy efficiency of a pervasive communications system.

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Keywords: interference; energy efficiency; pervasive; RFID

1. Introduction

With the rise of wireless technologies operating in the 2.4 GHz band (e.g. Bluetooth, ZigBee, Wi-Fi, etc), the problem of mitigating the interferences within this frequency band has become a major concern for all those involved in this sector. One of the main applications of these wireless communication technologies is the development of pervasive networks of smart objects that will integrate into the Internet of Things. Such networks need to operate in an autonomous, energy efficient manner, therefore it is important to evaluate and minimize the energy impact of interferences within the 2.4 GHz band.

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There have been numerous studies that have focused on the topic of interferences between wireless technologies in the 2.4 GHz band. These studies have focused on the functional impact that interferences have on the performance of wireless technologies, in terms of reliability (measured using the Packet Error Rate – PER), QoS, real-time operation [1,2,3], but few studies have focused on the energy overhead generated by interferences.

Papers such as [4,5,6], have proven that Wi-Fi has a major influence on the performance of networks operating based on the IEEE 802.15.4 standard. Researchers have studied the possibility of these technologies coexisting [7,8], but it is preferred to implement cognitive interference avoidance strategies [9].

The idea behind this paper was generated by the lack of real-time experiments analyzing the impact that interferences have on the energy efficiency of active RFID networks that use the 2.4 GHz band. As a result, the main purpose of the present paper is to focus on the impact that Wi-Fi has on the energy performance of such active RFID networks. As a test bed for their study the authors have used one of their previous projects in which they have implemented a framework for integrating active RFID systems with wireless sensor networks based on the IEEE 802.15.4 protocol [10].

2. Architecture of the experimental test bed

In order to support their experimental findings the authors have developed a hybrid network of wireless sensor nodes that also embed the active RFID functionality. The network consists in the following types of nodes:

- Tag nodes – wireless sensor nodes capable of self-describing their capabilities and role within the network through the use of RFID codes. The tag communicates with the reader node using a “tag talks first” strategy built on top of the IEEE 802.15.4 protocol; these are extremely low power nodes which spend most of their duty cycle in hibernation mode; they wake from hibernation in order to acquire data from the sensors that are attached to them and to send this data to the reader, along with the RFID code.
- Reader nodes – they act as the interface between the tag nodes and the coordinator nodes, routing data through the network.
- Coordinator node – is the central gateway between the hybrid network and the Internet of Things allowing users to gain access to the data acquired by the hybrid network of sensor nodes.

The prototype hybrid network used as part of the test bed was implemented using the Memsic MICAz platform [11]. The energy consumption was measured using an automated test systems developed by the authors in LabVIEW (see Fig. 1), using the PXI platform.

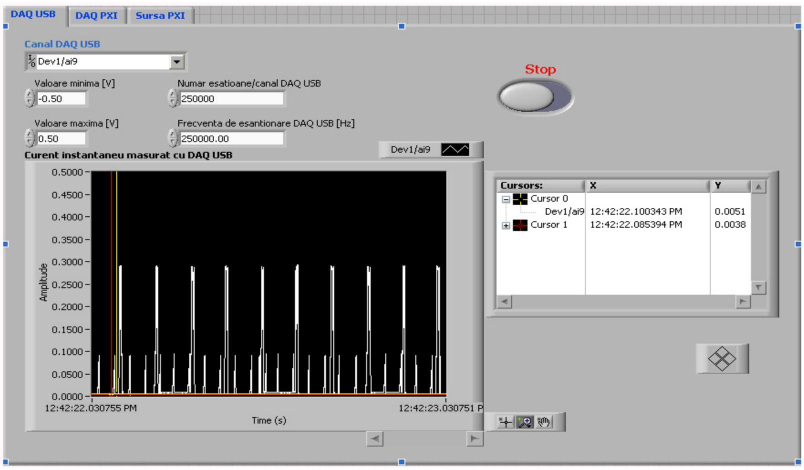

Fig. 1. The GUI of the LabVIEW automated measurement application.

3. Design of experiments and results

In the experiments designed by the authors the following input parameters were considered:

- T_{TX} – the interval between two consecutive data transmissions by the tag node (also called the transfer period)
- The data transfer rate within the Wi-Fi network
- The number of retransmissions / packet – the network designed by the authors uses an acknowledgement mechanism in order to ensure reliable data transmissions; in case an acknowledgment is not received from the reader node, the tag tries to resend that particular packet for up to 7 times. The value of this input parameter was measured using XSniffer, a traffic monitoring tool designed especially for Wireless Sensor Networks [12].

The following output parameters were evaluated:

- I_{tag} – the average current consumption for a measurement tag connected to the automated test system
- The convergence interval – the time required by a tag node to join the network; so as to join the network, the tag node needs to remain active in order to receive the routing update control packet from the reader node. This packet is sent periodically (every TRU seconds). Once it receives this packet the tag node enters its low power duty-cycle.

The configuration of the testing scenario designed by the authors is presented in Fig. 2. The source of interference is represented by a dual band Netgear DGND3300B Wi-Fi router, which is placed 1 m away from the measurement tag. The distance between the measurement tag and the reader node is also 1 m. The average power consumption of the tag node was measured for a 30 minutes period. In this interval the Wi-Fi router was permanently active, generating constant network traffic. Afterwards the same parameter was evaluated with the Wi-Fi router turned off. The traffic through the WLAN network was controlled through a traffic generator, which allows the tuning and monitoring of the transfer rate. Thus the influence of different transfer rates on the hybrid node's power consumption was evaluated.

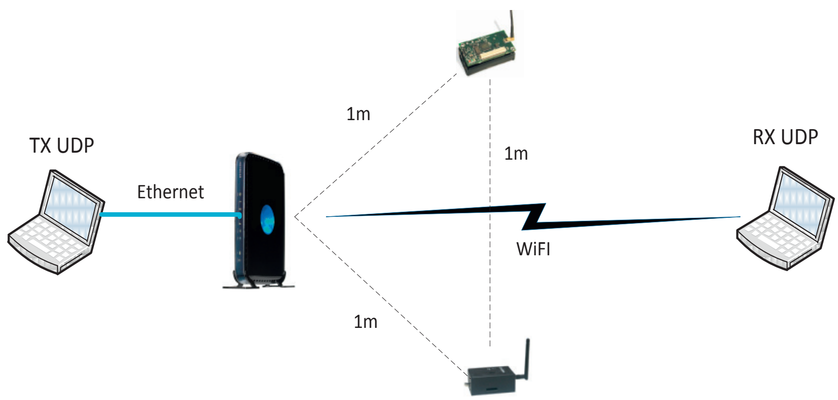

Fig. 2. Evaluation of the energy overhead of Wi-Fi induced interferences – testing scenario.

In the first phase the most favorable scenario was evaluated, in which the frequency bands of the two networks do not overlap. Thus, the Wi-Fi router was set on channel 1 (2412 MHz), while the hybrid network was set on channel 24 (2470 MHz). Fig. 3a illustrates the influence that different Wi-Fi transfer rates have on the average power consumption of the hybrid node, in this particular scenario.

One can notice that for constant T_{TX} values, the presence of the source of interference does not generate major fluctuations in the average power consumption of the tag node (because it does not have a major impact on the number of retransmissions and on the PER parameter). As a result, based on this first experiment we can conclude that a Wi-Fi source of interference that operates on a channel that doesn't overlap with the channel on which the hybrid active RFID network operates, generates no significant energy overhead.

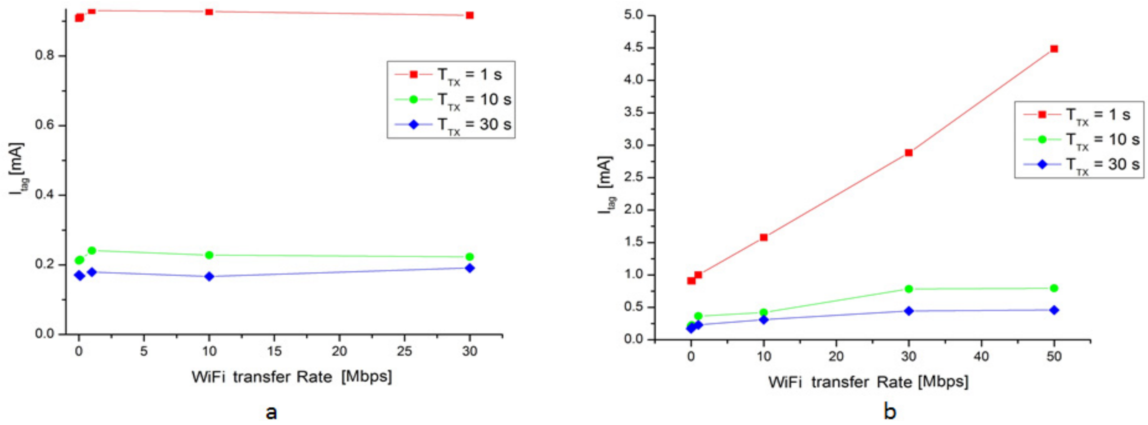

Fig. 3. (a) The energy impact of Wi-Fi interferences in the best case scenario (frequency bands not overlapping); (b) The energy impact of Wi-Fi interferences in the worst case scenario (frequency bands overlapping).

In order to analyze the worst case scenario (in which the frequency bands of the two networks overlap entirely) the Wi-Fi router was set on channel 13 (2472 MHz), while the hybrid network on channel 24 (2470 MHz). Fig. 3b presents the experimental results for this scenario.

In this case one can notice a major increase in the average power consumption caused by the source of interference. The dependency between the power consumption and the Wi-Fi transfer rate is almost linear. One can also notice that the slope increases with the decrease of the T_{TX} transfer period.

The interferences can lead to an increase in average power consumption of up to 5 times. This increase is caused by the following main factors:

- The ascent of the number of collisions, which causes an increase in the number of retransmissions/packet. As one can notice in Fig. 4 the number of retransmission/packet surges for medium-high Wi-Fi traffic (with a transfer rate greater than 1 Mbps)

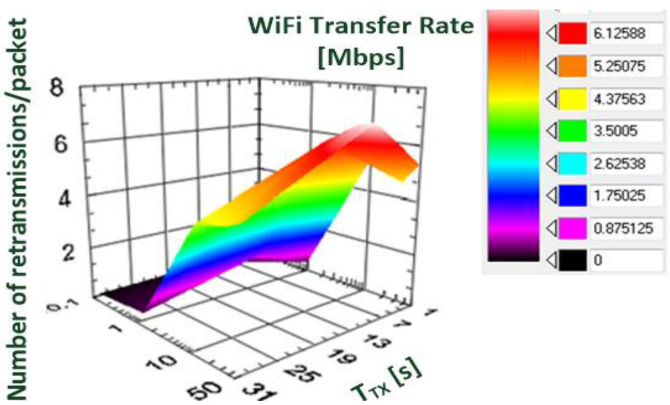

Fig. 4. The impact of Wi-Fi interferences on the number of retransmissions/packet.

- The increase of the network convergence time (whose variation is presented in Fig. 5). For a Wi-Fi transfer rate greater than 10 Mbps the convergence time exceeds the nominal value of 1 T_{RU} (which for the tested scenario was 36 seconds).
- The total loss of tag-reader network connectivity. The duration of this phenomenon is variable, forcing the tag to stay active in order to try to rejoin the network, thus leading to increased power consumption.

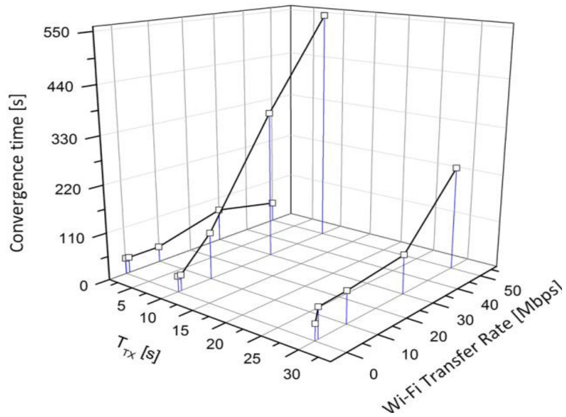

Fig. 5. The impact of Wi-Fi interferences on the hybrid network's convergence time.

4. Conclusion

Through the experimental results presented in this paper, the authors have proven that interferences in the 2.4 GHz band have a major impact on the energy efficiency of pervasive networks operating in this frequency domain. As compared to other studies analyzed in this paper, which focus on the functional impact of interferences, the authors have used an energy-oriented approach, thus analyzing interferences from a different perspective.

The main conclusion of the experiments performed by the authors is that the presence of a Wi-Fi source of interference, which operates on a channel that totally overlaps with the IEEE 802.15.4 channel used by the hybrid RFID network, has a major impact on the network's energy efficiency. The more intense the Wi-Fi network traffic is, the higher the nodes' power consumption gets, with a maximum increase of 5 times.

Another conclusion that can be drawn from these experiments is that the above mentioned energy overhead generated by Wi-Fi interferences is almost zero in case of non-overlapping frequency channels. As a result, a careful design and allocation of radio resources in the ISM band can significantly reduce interferences and their impact.

As a future development the authors intend to implement an energy efficient interference avoidance scheme, based on automatic frequency channel hoping. The tag and reader nodes will automatically switch to a different frequency channel once the PER and the number of retransmissions caused by interferences increases. In this way the interferences' energy overhead will be mitigated.

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