Impact of in-band interference on a wake-up radio system in wireless sensor networks

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Abstract. The energy efficiency of Wireless Sensor Networks (WSNs) is considerably improved with Wake-up Radio (WuR) systems. However, their resilience to interference is often neglected in the literature. This might be an issue due to the proliferation of wireless devices and the growing field of internet of things. In this paper, we evaluate the impact of in-band interference from wireless devices on a WuR system. The approach proves that WuR systems are still performing well when coexisting with external wireless networks, even if the energy-efficiency is slightly reduced.

1. Introduction

Wireless Sensor Networks (WSNs) are exploited in numerous applications such as telemedicine, robotic, intrusion detection or environmental monitoring. WSNs are comprised of sensor nodes which can collect, process and transmit the data related to its application. Sensor nodes are operated through limited batteries and their replacement after depletion is usually not possible. An essential challenge is then to reduce the nodes energy consumption for extending the WSN lifetime.

Medium Access Control (MAC) protocols are designed to manage the wireless communication with the first goal being to avoid packets collision in the network. Various MAC protocols have been proposed in the literature to reduce energy wastage during data communication such as idle listening or overhearing [1]. Wake-up Radio (WuR) protocols have been recently proposed to replace traditional MAC protocols with the benefit of avoiding the aforementioned energy wastage. A WuR protocol essentially relies on the inclusion of a second radio into the node, the latter must be low-power or completely passive, and it is used to wake up the main radio when communication is required. The energy reduction through WuR protocols compared to conventional MAC protocols is well presented in the literature [2, 3].

However, WuR systems might be partially triggered by wireless devices communicating at the same frequency since their RF front end is typically an RF energy harvesting circuit. The harvested energy is only used by the WuR circuit here, but it is generally used for recharging the batteries and thus extending the WSN lifetime. The only work evaluating interference effects on WuR systems was performed in [3], but it was limited to the interference in a homogeneous network.

In this paper, we evaluate the interference from an external wireless network such as WiFi devices on the WuR systems. This approach aims to show the robustness of the WuR system while being interfered by existing wireless networks.

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2. System model

WuR systems are defined by a specific hardware and protocol. The design of WuR receiver (WuRx) was presented in [4] and it should be added to the sensor nodes for enabling the WuR functionality. The WuRx is mainly composed of a compact rectenna array working at 2.45 GHz [5], an extremely low-power microcontroller (PIC24F16KA102) for validating the address included in the Wake-up Call (WuC) message, and a nano-power comparator which is used for increasing the WuRx sensitivity.

Our WuR protocol was first implemented in OMNeT++ with the MiXiM framework and its implementation details are given in [6]. This work has been further ported into the INET framework for more advanced simulations. The simulation framework gives reproducible and consistent results with the input parameters related to energy consumption and latency obtained by experimental measurements.

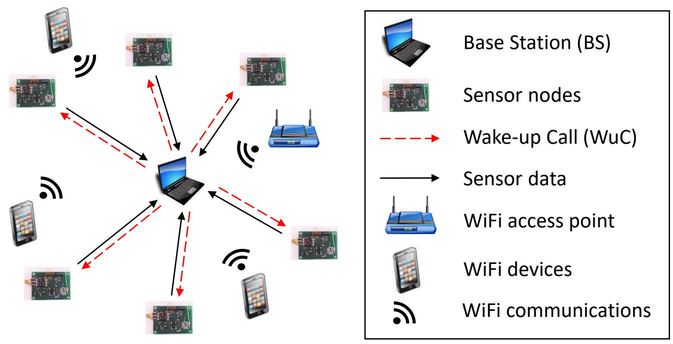

Figure 1. Network topology considered for the simulation.

The scenario considered in the simulations is illustrated in figure 1. The WuR network is composed of a Base Station (BS) and N sensor nodes equipped with a WuRx. Data are requested by the BS through the WuC message, which triggers the WuRx for waking up the addressed node. An interferer network is added through WiFi devices, all of them sending data to the WiFi access point. Both networks are operating at 2.45 GHz with a different modulation type, which is On-Off Keying (OOK) for the WuR system and Quadrature Amplitude Modulation (16-QAM) for the WiFi devices. The main simulation parameters are given in table 1.

Table 1. Simulation parameters.

Network	Parameter	Value
Common	Surface area	400 m^2
	Carrier frequency	2.45 GHz
	Simulation duration	30 min
WSN	Number of nodes	10
	Transmission power (BS)	100 mW
	Data size	100 bytes
WiFi 802.11g	Number of access point	1
	Data size	1 kbytes
	Inter packet arrival time	1 s
	Bit rate	2 Mbits/s
	Transmission power	100 mW

3. Results and Analysis

In order to evaluate the interference effects, four performance metrics are analysed here. First, the energy per bit is used to evaluate the energy-efficiency, and it is defined as the ratio of the total energy consumed by a node and the total number of correct bits received at the BS. Secondly, the average packet delivery ratio is used to evaluate the network reliability, which is calculated as the average number of packets received at the BS by the total number of requests (WuC messages) sent by the BS. Thirdly, the false alarm probability $P(FA)$ directly quantifies the interference impact on the WuRx. It is defined as the probability of detecting a wake-up signal when there is no wake-up signal in the channel. Fourthly, the Bit Error Rate (BER) gives an indication of the data link at the BS. It is calculated as the number of bit errors divided by the total number of bits received at the BS.

Several simulations are executed while incrementing the inter packet arrival time, which is the time between two consecutive packets reception at the BS. We varied this parameter from 200 ms to 20 s for considering a wide range of potential applications. Simulations are also performed for different numbers of interferers, varying from 0 to 6 in order to increase the interference traffic. Results are averaged for a consequent number of simulations and the 99% confidence interval is given.

Results regarding the energy per bit are depicted in figure 2. While the traffic rate in the WSN is relatively high, interferer nodes do not influence the WSN energy efficiency. However, when considering a low traffic rate in the WSN, the energy efficiency decreases with the number of interferers. This is mainly due to the small amount of energy consumed by the sensor nodes in this scenario, and the WuRx would be triggered numerous more times by interferers than it is fully activated by the BS. In the worst case, the energy per bit is multiplied by 2 when there are 6 interferers compared to the case without interferers.

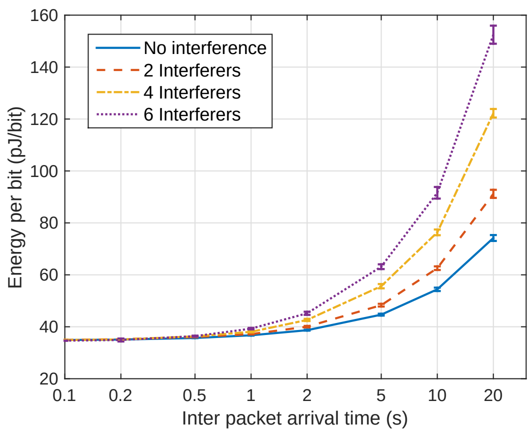

Figure 2. Energy per bit consumed by the nodes vs. the WSN inter packet arrival time and for different numbers of interferers.

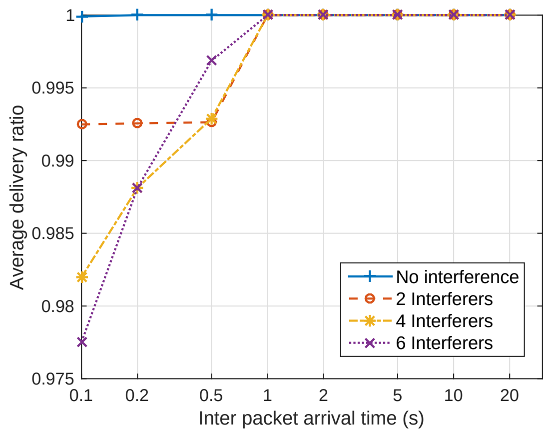

Figure 3. Average packet delivery ratio at the BS vs. the WSN inter packet arrival time and for different numbers of interferers.

The average packet delivery ratio is depicted in figure 3 for each scenario. First, every sensor node is successfully requested when there is no interference since all packets are received at the BS. Then, the packet delivery ratio globally decreases as the number of interferers increases, while considering WSN inter packet arrival time lower than 1 s. This packet loss is fairly acceptable because the average delivery ratio remains higher than 97.5 %.

Then, the results for the false alarm probability $P(FA)$ of the WuRx are represented in figure 4. $P(FA)$ is always lower than 5 % when there is no interference. However, $P(FA)$ varies from

8 % to 98 % while increasing the number of interferers and decreasing the WSN traffic. Those results clearly show the interference effects and they explain the decrease of energy efficiency. In fact, the rejection of WiFi interference is the reason behind the decrease of energy efficiency.

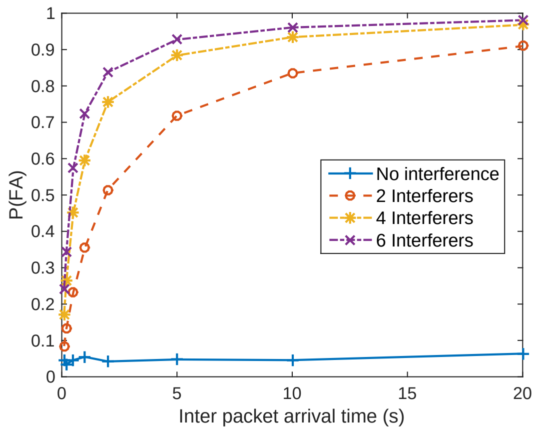

Figure 4. False alarm probability of the WuRx vs. the WSN inter packet arrival time and for different numbers of interferers.

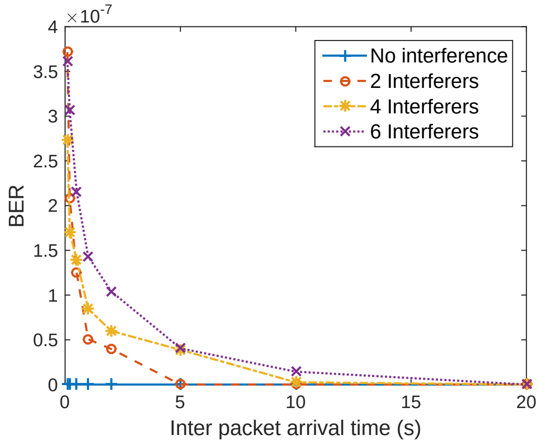

Figure 5. Bit Error Rate at the BS vs. the WSN inter packet arrival time and for different numbers of interferers.

Finally, the BER results are depicted in figure 5. As we can see, the BER increases with the number of interferers. Also, the BER is equal to 0 when there is no interference because the channel is modelled without noise. We did not model the noise for these simulations in order to only evaluate the effect of interference on the BER performance. In these scenarios, the BER varies between 0 and 4.10^{-7}, which is acceptable in most WSN applications.

4. Conclusion and Perspectives

This paper shows the effect of in-band interference on the performance of a WSN equipped with our WuR system. In the worst case where the data traffic is much heavier in the WiFi network than in the WSN, the energy efficiency can be halved. The main reason is the energy spent by the WuRx to reject the interference. However, the energy per bit in such circumstances remains much lower than the order of magnitude of typical WSNs without WuR systems. The network is still working correctly since the average packet delivery ratio remains higher than 97,5 %.

In future works, a more advanced WuR protocol or WuR system can be considered for avoiding or rejecting interference with less energy cost. The interference sources could also be exploited by the energy harvesting circuit for partially powering up the WuR system, or even totally if the harvested energy is sufficient. Finally, a practical implementation is going to be conducted for a comparison with the presented simulation results.

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