Wake-Up Radio Systems: A New Perspective

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***Abstract*- IEEE Wake-Up Radio is a technology developed by the IEEE 802.11ba standards task group that will significantly extend the battery life of devices and sensors on wireless networks, particularly those that are part of the Internet of Things (IoT). The info graphic below gives a high-level overview of this cutting-edge technology that will greatly improve battery life. Today, the vast majority of personal communication devices, such as laptops, smartphones, and logically wireless fidelity (Wi-Fi) access points feature IEEE 802.11 chipsets. The Wake-Up Radio (WuR) systems are used to reduce the significant energy waste that wireless devices cause during their idle communication mode. The paper presents the prespective of Wake Up Radio.**

***Keywords*— IEEE Standards, Wake Up Radio, Wireless Sensors, Energy, Wi-Fi.**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are one of the most promising technologies and they are used in many applications such as environmental, industrial or medical monitoring. They are also a main component in the growing field of the internet of things [1]. Energy efficiency is crucial in WSNs since sensors nodes are usually powered by limited batteries, while their replacement is not conceivable after depletion. Several approaches have been considered in the literature to reduce the energy consumption of WSNs [2] [3], the problem being tackled in different aspects.

Power management is an important technique to prolong the lifespan of sensor networks. Many power management protocols employ wake-up/sleep schedules, which are often complicated and inefficient. In many sensor network systems, the power supply for the network nodes is usually a depletable power source, such as batteries. To increase the lifespan of sensor networks, researchers have designed a number of power management schemes. Power management schemes need to control when a network node should enter a high-power running mode and when to enter a low-power sleep mode. The high-power to low-power transition can usually be done with a set of instructions that shuts down hardware components, and the power management scheme may perform this action when certain conditions hold, e.g., there are no events in the system for a long time. The low-power to high-power transition is, however, a tricky problem because the network node has its CPU halted and is unaware of the external events. In many applications, it is desirable to have the network awakened when some events of interest happen. But the network node cannot easily know exactly when events happen. To solve this problem, many power management schemes require that each network node wake up periodically to listen to the radio channel. When an event of interest happens, some nodes (possibly some sentry nodes) detect the event and send power management messages to the network. All the nodes that were in their listening mode and hear the power management messages stay awake – they do not enter sleep mode. By choosing a good wake-up/sleep schedule, the network may save much energy without compromising the system functionality. The implementation of the wakeup/ sleep scheduling often involves a timer that wakes up the CPU via an interrupt.

II. LITERATURE REVIEW

The amount of energy consumed due to radio communication is often substantial compared to other components such as Microcontroller Unit (MCU) or sensor unit. The main causes of energy waste for wireless communication are idle listening and overhearing. Idle listening refers to the fact of listening to the channel while there is no ongoing wireless transmission, and overhearing refers to a node listening to wireless transmissions addressed to another node. Various Medium Access Control (MAC) protocols were proposed to improve the energy efficiency of the wireless communication [4]. A survey with most common MAC protocols is presented in [2] with the following classification: TDMA-based, contention-based, and hybrid protocols. Contention-based protocols are the most adopted approaches with B-MAC [5] and S-MAC [6] being the most popular MAC protocols. These MAC protocols essentially rely on a low duty-cycle to reduce the nodes energy consumption. In duty cycling mechanisms, the radio is switched into sleep mode when there is no communication in order to avoid idle listening. Nevertheless, idle listening cannot be completely suppressed with duty-cycling mechanisms since nodes have to check for possible communication while waking up.

Wake-up radio (WuR) systems have been proposed during the last decade to solve the problem of idle listening, by enabling the nodes to wake up on demand by a particular radio message, namely a Wake-up Call (WuC). Concerning the hardware set-up, a second radio module is generally plugged into the nodes for the wake-up communications and the main radio module is used for data transmission. The second radio, also known as wake-up radio, must be a low-power device or completely passive. The first WuR design was proposed in [7] with a basic radio-triggered circuit. Several Wake-up Receivers (WuRx) have been proposed in the literature to reduce the current consumption of the WuR circuit, and they are classified in different types such as RFID, heterodyne, MCU or correlator [8]. However, other MAC protocols need to be defined for implementing the WuR features since they imply a communication with two radios. Few MAC protocols have been proposed during the last years to incorporate the WuR features, such as RTM [9], On Demand MAC [10] and SCM-MAC [8]. These protocols significantly reduce the energy consumption of the nodes, even though a more energy-efficient wake-up scheme can be achieved. The only work comparing WuR protocols performance among themselves was performed by [11], but it was applied for implantable body sensor networks and simulations were carried out in MATLAB with few details about the implementation. While comparing these protocols is particularly interesting, it is not completely effective since each WuR protocol is designed for a specific hardware. The authors in [12] recently compared the performance of their WuR platform to the most widely used MAC protocols for WSNs simulations under three real-world network deployments. While idle listening and overhearing are referred in their paper, they did not give any details about their impact on energy consumption.

The use of a wake-up radio in the home wireless network, like personnel digital assistant (PDAs), has been firstly presented in [13]. In [14] a low power sleep mode and an out of band wake-up mechanism has been adopted, a low power radio module to carry out of band control information is used to switch theWiFi AP into the sleep mode when no users exist. The use of secondary low power wireless module, which has the same frequency and shares the same antenna with the co-locatedWiFi radio interface, was proposed in [15]. Based on modulation of the frame length of IEEE 802.11g, the wake-up signal recognition need an analogue to digital converter and a signal detection module that introduce more power consumption to the wake-up receiver.

III. Wake Up Radio Design Consideration

The use of the radio front ends highlights the need of a sleep state. This state corresponds to the smallest level of power consumption. To switch to an active state, a wake-up mechanism must exist. There are two kinds of wake-up strategies. First, synchronous protocols are needed to periodically activate the radio front ends. At regular time instants, the nodes probe the radiofrequency channel to determine whether another node wants to establish a communication, and the activation decision is taken at the node level. Such method supposes that global synchronization across all nodes in the wireless network is guaranteed. Second, remote nodes request a node to activate its main radio-frequency interface. In this case, the use of an auxiliary radio is needed. The ideal case is to have zero DC power consumption in standby mode. This is why passive wake-up receivers have been proposed [16-17]. The key feature is that energy is received from a remote system. The majority of wakeup receivers are active. In this case, the autonomy of the entire network will be given by the power consumption in standby mode. Radio-frequency wake-up systems can also be divided in two categories. The first group is represented by rectenna systems first presented in [17]. This kind of wake-up systems detects only a certain power level on a radio channel. Despite its very low power consumption, the main drawback is that it cannot make the difference between a noisy channel and a real wake-up signal, and consequently, its robustness in terms of false wake-ups is much degraded. The wake-up signal is transformed into a DC level by using charge pumps or voltage multipliers. In [17], a diode-based architecture is presented, and in [18], MOS transistors replace the diodes. The wake-up receivers are gathered into a second group of wake-up systems, which are able to receive, demodulate, and decode a wake-up signal. In this category, the energy consumption is correlated to the type of modulation and there are two types of radio architectures. The first one is the classical homodyne architecture that transposes the received signal in the baseband signal [19]. The second type is the on-off keying (OOK) modulation dedicated architecture, which is an envelope detector that recovers the digital signal as the amplitude of the radio-frequency signal. This last architecture is proposed in most of wake-up scenarios because of the low complexity and low energy consumption.

IV. Wake Up Radio

Figure 1 presents a possible usage scenario of the proposed wake-up receiver. Suppose that all the sensors are in standby mode and the sink wants to communicate with the i^{th} node. In this case, the sink sends a frequency pattern which is the address associated to the node i. The wake-up radio of the i^{th} node switches on the power supply of the main data front end, and the communication begins while the rest of the sensors remain asleep. Once the communication is ended, the node deactivates the main radio interface and goes back into a standby mode where only the wake-up receiver is on.

Under the assumption that the sink has an OFDM compliant transceiver, the wake-up signal is emitted by its classical data emitter, using a particular and predetermined sub-carrier pattern as identifier. The total number of sub-carriers is divided into a number n of subgroups of adjacent sub-carriers, and in this way, N sub-bands are formed. If there is spectral occupancy on a sub-band, this is associated to a logical 1 and the absence of signal on a sub-band to a logical 0. In this way, 2N possible identifiers can be formed.

The problem of idle listening for events can be solved using the separate hardware that is continuously listening for a certain wake up signal. Typical application will be in a WBAN network with ranges less than 2m. There will be a dedicated device acting as a Master Node that will act as a network coordinator. This device would send wake up signals, and receive data packets from sensors.

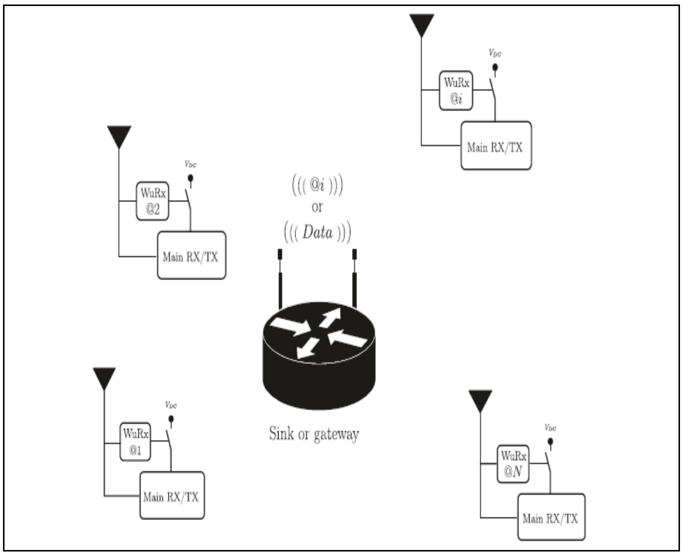

Figure 1 Wake-up mechanism.

The wake up receiver intended for WBAN is expected to operate in the dense network environment. At any given moment some nodes will be communicating within a WBAN, while some may stay in a sleep mode, monitoring the channel for communication requests. Also, we can expect numerous high power transceivers and noise in the vicinity of a network. The optimal WUR must be immune to this ambient traffic and should avoid waking up the sensor on signals intended for the neighbouring nodes, as well as on the ambient noise.

From a functional perspective, WUR is not as restricted regarding bit error rate and data rate as the standard receiver. The metric of interest is probability of detection of wake up signals and probability of false alarms. Retransmissions increase power consumption for the transmitter as well as the latency. False alarms are costly from a power perspective because of the needless sensor activations.

There are two functional groups of WUR: wake up circuits and wake up receivers. Wake up circuits can have very low power consumption (even zero power), but these only detect the activity on a channel, and cannot distinguish a wake up signal from other RF activity of sufficient power. They are mostly realised using a charge pump. This concept was first presented and simulated in [20]. The circuit is zero power, and it is realised using the Schottky diodes. A similar solution using MOSFET is presented in [18]. Also, battery assisted (semi passive) RFID tags demand similar solutions for their power-on sensing circuitry as explained in [21]. In 1998 an RF field detector was presented as a low power wake up method that could be used in semi passive RFID tags [22]. Another design, with a power on circuit based on multi stage charge pump is presented in [23]. A complete micro-power sensor node with RF quasi-passive wake-up circuit is presented in [24]. Wake up receivers (WUR) have the ability to demodulate and decode some packet of information following the signal, which can be used for addressing to reduce the number of activations. A low power WUR that has addressing capabilities is presented by [25]. A solution with a Schottky voltage doubler followed by a programmable amplifier and integrator is developed in [26].

V. Power efficiency with WUR

The main issue in low power wireless networking is to keep the network functionality, but to lower the power consumption. This is achieved by deliberately increasing the communication latency, to reduce the communication duty cycle.

Most of the protocols are based around a centralised network structure and beacon communication. This means that either the network coordinator sends beacons at regular time intervals, or the sensor scans the channel at regular time intervals, in order to keep the network alive, and to synchronise for data transfer. Since data transfer cannot happen in those protocols before the initial polling (reception of the beacon and request for data send/receive), the maximum latency is the time interval between two beacons.

When the communication is frequent, this is proper way to organise a network, since a timeslot can be given and data can be sent during regular time intervals, but when communication is scarce, or irregular, this regular awakening becomes the main communication power consumer, especially when desired latency is low. It is not mentioned in the literature, but in practice, this kind of operation requires an active timing and control circuit, which if not implemented within the transceiver, is usually a microcontroller that consumes current by staying in active mode or running the timers.

The WUR can be used on top of the existing protocols, as a method to control the power consumption, and solve the latency problem, by allowing the rest of the circuit to be in the low power "sleep" mode, while continuously listening to a wireless channel. The next sections discuss the usage of the proposed WUR, and its benefits in the standardised and frequently used WBAN protocols. Introducing the wake up receiver as a component that can listen to a channel reduces the duty cycle (time spent on idle listening), but introduces new component with quiescent power consumption. Good power model must be derived to justify the introduction of this component and maximum power consumption it can have in order to be practical in applications.

VI. Conclusion

Today, the vast majority of personal communication devices, such as laptops, smartphones, and logically wireless fidelity (Wi-Fi) access points feature IEEE 802.11 chipsets. In turn, wake-up radio (WuR) systems are used to reduce the significant energy waste that wireless devices cause during their idle communication mode. A novel WuR system is introduced that enables any IEEE 802.11-enabled device to be used as a WuR transmitter without requiring any hardware modification. The paper presents about the concept of wake up radio, its architecture and its power efficiency.

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