Active RFID System with Wireless Sensor Network for Power

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Abstract— **Radio frequency identification (RFID) and wireless sensor networks (WSNs) are complementary technologies that reduce power consumption. Battery-operated WSNs suffer from issues related to power consumption and latency. WSN already in the market use either duty cycling or wake-up radio mechanisms. The research puts forth ZigBee-based RFID that employs active (battery-powered) tags based on a new deep-sleep mechanism. This mechanism reduces the tags' power consumption as a whole. To best show the system's efficacy, different parameters are in place to execute and analyse. All the testing is done in realistic indoor network settings and in turn benchmarked against calculated predictions. A comparison is done between conventional duty-cycle tag methods of protocol with the sleep-mode protocol. The findings indicate that the sleep-mode protocol is more energy efficient with consumption being 98% lower than the IEEE802.15.4 tag.**

Index Terms— **WSN, ZigBee, Active RFID, Power Efficiency**

1. Introduction

Tags, a reader, and the computer network make up a standard RFID system, and each can be tailored to fit the planned use for the technology (Rao et al., 2009) (Callaway et al., 2002). The last decade has witnessed many technologies that have overcome the downsides of RFID, allowing the technology to cater to increased demand (Akyildiz et al. 2002). The WSN are mainly concerned with sensing and communication functions (Xu et al. 2005). A WSN is made of a number of sensor nodes that can be used in vehicles, on the ground, and even inside buildings (Culler et al., 2004). Some of the challenges to WSNs include reliable communication and power consumption of the radio communication performance. These challenges are only increased when RFID tags are used in a real-world monitoring and controlling system, for example a manufacturing or warehouse facility.

However, WSN-based active RFID devices tend to be self-powered, with a battery located in the tag that provides energy to the RF transceiver. The Transceiver transmits stored data constantly. This circuit restricts tag life-time, which is a major drawback of the system. Tag lifespan is affected by the sleep and wake times, and the energy consumed during continuous active and sleep modes. Basically, reducing idle mode can enhance the tag lifespan. As a result, the idle mode consumes energy excessively. Hence, there is a need to design an active RFID tag with motion sensors which do not take up much power use. As mentioned above, the RFID technique is circumscribed by difficulty in execution. Thus, it is obvious that there is a need to surpass issues the tag's energy use (Zanal and Ismail, 2013). The commercial availability of RFID in the 1980s has resulted in its widespread use in tolled highways, animal tracking and personnel access cards. In logistics, RFID tags are also gaining acceptance instead of bar codes, especially since it does away with the need for a line of sight and provides even more information than barcodes (Domdouzis et al., 2007). The ZigBee technology is a combination of "smart identification and asset tracking systems" and it was developed by (Abdulla, 2013).

RFID has many applications, including in merchant shipping (Moeinfar, 2012). The RFID domain is so large that it requires a more in-depth research. An active RFID that can operate at 2.45 GHz is required for example in container shipping. Even though an active tag has a small size and high data range, one negative cited is the exact concurrency between the reader and tags. Therefore, to ensure low power consumption, the sleep mode was activated, and will only be switched to awake if there is a signal from the reader.

This research tackles the problem of prolonging network lifetime for RFID tag based on WSN. WSN-based active RFID devices are self-powered, containing a battery within the tag to power the transceiver. The transceiver then broadcasts the stored data continuously. This circuit is what limits the tags' life-span, which is a key drawback. Sleep time, wake up time, and the energy consumed during the wake-up and sleep states all affect the life-span. Enhancing tag lifetime by choice of protocols and suitable parameters is the main objective of this paper as it provides the metrics used to evaluate and compare performance.

IEEE 802.15.4 protocol is the basis for duty-cycle scheme mechanism implementation. In this mechanism, the result can show a higher cost in terms of energy, which happens because of high energy use while idly listening.

The design of the above mechanism became inclusive of a wake-up mechanism in order to maximize RFID tag lifetime by ensuring there is little idle listening. The current work used IEEE802.15.4 protocol and suggested a different circuit that utilizes an external hardware to trigger and wake up the tag only when necessary to send identifying packets. This is done without continuous listening to reader commands (in other words, not on-demand).

2. Materials and Methods

Considering that RFID tags send the data towards the reader periodically, the following points are noteworthy:

1) Energy for data receiving and processing (E_{Rx}): energy is wasted when the tag needs to process the node-discover command after receiving from the reader.

$$P_{Rx} = I_{TRx} \times V \quad (1)$$

$$E_{Rx} = P \times T_{TRx} \times P_{Rx} \times T_L \quad (2)$$

Where (P) is the number of packets received, (T_{TRx}) is the data receiving and processing time in the active tag, (I_{TRx}) is the current draw of the tag while in received mode, V is the battery voltage, and TL is the traffic load.

2) Energy for data processing and transmitting (ETX): energy is wasted because the tag needs to process the identification data report packet before sending it to the reader.

$$P_{Tx} = I_{TTx} \times V \quad (3)$$

$$E_{Tx} = P \times T_{TTx} \times P_{Tx} \times T_L \quad (4)$$

Where P is the number of packets sent, (T_{TTx}) is the data processing and transmitting time in the active tag, and (I_{TTx}) is the current draw of the tag while in transmit mode.

3) Energy for Idle listening (E_{IDLE}): energy is wasted as the tag is turned on and off periodically according to the duty-cycle mechanism. Hence, the RF module is active but not receiving or sending any data.

$$P_{IDLE} = I_{IDLE} \times V \quad (5)$$

$$E_{IDLE} = T_{IDLE} \times P_{IDLE} \times T_L \quad (6)$$

Where, (T_{IDLE}) is the time during every cycle that the tag remains awake, and (I_{IDLE}) is the current draw of the tag while in idle mode.

4) Energy for sleeping (E_{SLEEP}): energy is wasted when the tag is asleep for a short time according to the duty-cycle mechanism.

$$P_{SLEEP} = I_{SLEEP} \times V \quad (7)$$

$$E_{SLEEP} = T_{SLEEP} \times P_{SLEEP} \times T_L \quad (8)$$

Where (I_{SLEEP}) is the current draw of the tag while in sleep mode

Let (E_{IEEE}) is the overall energy of the tag, given by

$$E_{IEEE} = E_{Rx} + E_{Tx} + E_{IDLE} + E_{SLEEP} \quad (9)$$

$$E_{IEEE} = (P \times T_{TRx} \times P_{Rx} \times T_L) + (P \times T_{TTx} \times P_{Tx} \times T_L) + (T_{IDLE} \times P_{IDLE} \times T_L) + (T_{SLEEP} \times P_{SLEEP} \times T_L) \quad (10)$$

2.1. Development of Proposed RFID System with Wake-up Mechanism

This section describes the modifications implemented to overcome the issues of insufficient tag sleep and idle listening, namely the incorporation of a wake-up mechanism that enables tags to sleep until they are required to send packets. A block diagram of the proposed structure is shown in Figure 1, illustrating an active RFID tag able to achieve energy efficiency.

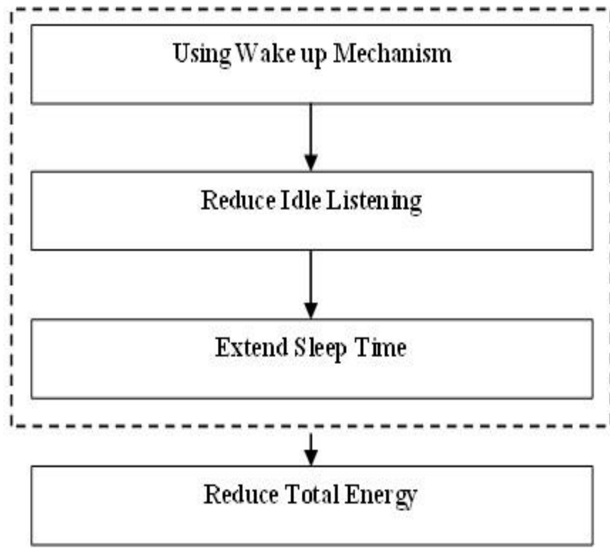

Figure 1: Block diagram contributions segment of modified active RFID tag

From now on, this system will be referred to as the IEEE802.15.4 system which represent the conventional duty-cycle mechanism while the new proposed system will be referred to as the RFID system. In the RFID system, the tags are battery-powered devices capable of sleeping for extended periods of time.

2.2. Design of the RFID Tag Software Layer Based on Wake-Up Mechanism

This design focuses on an energy-saving mechanism, for the purpose of maintaining the longevity of the tags as long as possible. Hence, all tag modules are set to the low-power mode, so the tag modules are put into deep sleep mode, so the RFID tags sleeps most of the time and just wakes up if excited by an interrupt produced from the real-time clock alarm (RTC). RTC alarm periodically wakes RFID tag up from deep sleep mode in a way that it can send its identification packet to the reader without waiting for the RFID reader collection command. The tag transmits data to the reader and then waits for an acknowledgment (ACK) signal from the reader.

2.3. Energy Efficiency Optimization

According to the wake-up method of the proposed RFID system, a tag is awakened only when it must send a packet to the reader; this results in reduced idle listening energy consumption. Figure 2 gives an energy efficiency comparison between the IEEE802.15.4 and the modified RFID system.

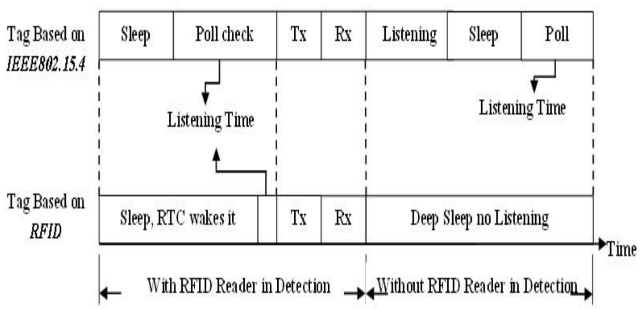

Figure 2: Comparison of energy efficiency between IEEE802.15.4 and proposed RFID system

To achieve the design goal of energy efficiency in the Proposed RFID system, the overall RFID tag energy is formulated and analyzed.

1. Energy for sleeping (E_{SLEEP}); energy is wasted when the tag sleeps for a long time, according to the wake-up mechanism.

$$P_{SLEEP} = I_{SLEEP} \times V \quad (11)$$

$$E_{SLEEP} = T_{SLEEP} \times P_{SLEEP} \times T_L \quad (12)$$

Where (I_{SLEEP}) is the current draw of the tag while in sleep mode, (T_{SLEEP}) = Sleep time, V = Battery voltage, and TL is the traffic load.

2. Energy for data processing and transmitting (E_{Tx1}); energy is wasted because the tag needs to process the tag identifier string packet before sending it to the reader.

$$P_{Tx1} = I_{Tx1} \times V \quad (13)$$

$$E_{Tx1} = P \times T_{Tx1} \times P_{Tx1} \times T_L \quad (14)$$

Where P is the number of packets sent, (I_{Tx1}) is the current draw of the tag while in transmission mode for the tag identifier string packet; (T_{Tx1}) is the identification of data processing and transmitting time.

3. Energy for Idle listening (E_{IDLE}); energy is wasted because the tag needs to wait to receive the ACK packet from the reader.

$$P_{IDLE} = I_{IDLE} \times V \quad (15)$$

$$E_{IDLE} = T_{IDLE} \times P_{IDLE} \times T_L \quad (16)$$

Where (I_{IDLE}) is the current draw of the tag while in idle mode, (T_{IDLE}) is the time during every cycle that the tag remains awake.

4. Energy for receiving ACK (E_{Rx}); energy is wasted when the tag needs to process the ACK packet after receiving it from the reader.

$$P_{Rx} = I_{Rx} \times V \quad (17)$$

$$E_{Rx} = P \times T_{Rx} \times P_{Rx} \times T_L \quad (18)$$

Where (P) is the number of packets received, (I_{Rx}) is the current draw of the tag while in receiving mode, while (T_{Rx}) corresponds to the tag when it needs to process the ACK data packet after receiving it from the reader, at which time it goes back to sleep. Let (E_{RFID}) be the overall energy of tag,

$$E_{RFID} = E_{SLEEP} + E_{TX1} + E_{IDLE} + E_{RX} \quad (19)$$

$$E_{RFID} = (T_{SLEEP} \times P_{SLEEP} \times T_L) + (P \times T_{Tx1} \times P_{Tx1} \times T_L) + (T_{IDLE} \times P_{IDLE} \times T_L) + (P \times T_{RX} \times P_{RX} \times T_L) \quad (20)$$

3. Results and Discussion

3.1. IEEE802.15.4 Tag Current Consumption Analysis

The tags enabled by the IEEE802.15.4 system could not go into power-down mode; instead, they can go to sleep for a specific time and wake up for a short time. In the IEEE802.15.4 system, the time period utilized for each mode, based on the next waveforms, are called T_{TRX}, T_{TTX}, T_{IDLE} and T_{SLEEP}, respectively.

Idle mode does not affect the transmission or receiving process. The total time period utilized for idle mode is based on the sampling frequency selected, such that the tag consumed 24.8 mA. Furthermore, the XBee Series2 must stay awake for 17.28 ms during every poll request message interval to check if it has any buffered data for the tag. Poll interval takes an average time of 100 ms.

When the tag in receiving mode, it listens for reader discover commands, and processes the command data packet after receiving it from the last hop. Data receiving and processing in an active tag takes an average time of 130 ms to complete the receiving cycle and it consumes 70.6 mA. The receiving period does not depend only on the length of bytes received, but also on the written algorithm. For example, there is a delay used to check the incoming sync word.

When the tag in sleep mode, the RF goes to sleep in accordance with the duty-cycle operations, while the MCU stays idle and does not go into power-down mode. The total time period utilized for sleep mode is based on the sampling frequency selected, while the tag consumes only 6.8 mA.

When the tag obtains the identification data packet, processes the identification data, and then broadcasts it to the next hop. Identification data processing and transmitting time in active tags takes an average of 185 ms to complete the transmission cycle and consumes 72.2 mA. However, (I_{TTX}) is significantly higher than (I_{TRX}) and depends upon the XBee Series2 output power level, which was set to maximum (3 dBm) during these tests.

Complete parameters of approximate values for the current measurement data and the duration of each of these intervals based on the waveforms of the experimental results are shown in Table 1. Table 2 shows tag measured current consumption for a period 60 s.

Table 1: Measured current consumption and time of *IEEE 802.15.4* tag

Time Mode	Average time Interval (s)	Current Mode	Average current consumption (mA)
T_{TRX}	0.130	I_{TRX}	70.60
T_{TTX}	0.185	I_{TTX}	72.20
T_{IDLE}	Depend on sampling period	I_{IDLE}	24.80
T_{SLEEP}	Depend on sampling period	I_{SLEEP}	6.80

Table 2: IEEE 802.15.4 tag measured current consumption for a period 60 s

Mode	% of Time	mA	Current Consumption (mA)
T_{TRX}	0.2166	70.6	I_{RX} = 0.1529
T_{TTX}	0.3083	72.2	I_{TX} = 0.2225
T_{IDLE}	49.7375	24.8	I_{IDLE} = 12.3349
T_{SLEEP}	49.7375	6.8	I_{SLEEP} = 3.3821
Total	100	I_{Total} = 16.0924	

3.2 Current Consumption Analysis for *Proposed RFID* Tag

The proposed *RFID system* tags could go into power-down mode for long periods of time. Meanwhile, the measurement and calculation procedures are the same as that used for the *IEEE802.15.4 system*. In the proposed *RFID system,* the time period utilized for each mode, based on the next waveforms, are called: T_{RX}, T_{TX1}, T_{IDLE} and T_{SLEEP}, respectively.

XBee Series2 sleep is controlled solely by the state of the (SLEEP_RQ/ pin 9). The wake-up time is 9.5 ms. While a few milliseconds is needed to allow the oscillator time to start up after power-on reset. Before sending the packet through the tag, wake-up time must be accounted and the wake-up process follows a sequence of operations.

(a) Initially, the *RFID* tag is in sleep mode, and then wakes up MCU from sleep state on an interrupt, as the MCU wake-up process takes a certain period of time, about 15 ms.

(b) Then waits for the crystal oscillator to stabilize, this operation takes a certain period of time, about 10 ms. Upon stabilization and before XBee enters transmission mode, the MCU triggers and wakes up the XBee Series2 from sleep state.

(c) Upon initialization, after waking up from sleep mode, the tag initializes configuration of the XBee and the XBee Series2 enters sending mode, as the wake-up process takes a certain period of time, about 9.5 ms for the XBee Series2.

(d) After the XBee Series2 transmit mode switch time, sampling of the transmitted identification data packet at the next hop may begin.

The total wake-up and transmission process takes an average of 0.0772 s to complete the transmission cycle and consumes 69.2 mA. Complete parameters for measured current of the proposed *RFID* tag, based on the waveforms captured in the experiment, are shown in Table 3, while Table 4 shows the measured RFID tag current consumption.

Table 3: RFID tag current consumption and time measurements

Time Mode	Average time Interval (s)	Current Mode	Average current consumption (mA)
T_{RX}	0.0700	I_{TRX}	67.30
T_{TX1}	0.0772	I_{TX1}	69.20
T_{IDLE}	0.0500	I_{IDLE}	24.80
T_{SLEEP}	Depend on sampling Period	I_{SLEEP}	0.14

Table 4: Measured current consumption of proposed RFID tag for a period of 60 s

Time Mode	% of Time	mA	Current Consumption (mA)
T_{TRX}	0.1166	67.3 0	I_{RX} = 0.0784
T_{TX1}	0.1286	69.2 0	I_{TX1} = 0.0889
T_{IDLE}	0.0833	24.8 0	I_{IDLE} = 0.0206
T_{SLEEP}	99.6713	0.14	I_{SLEEP} = 0.1395
Total	100	I_{Total} = 0.3274	

The total measured current consumption of proposed RFID tag as in Table 4 is about 98 % lower than the measured current consumption of IEEE802.15.4 tag as in Table 2.

4. Conclusion

Active RFID systems using the standard (duty-cycle mechanism) and the modified IEEE802.15.4 protocols (with wake-up mechanism) are employed on the ZigBee platforms. The theoretical approaches have been explained to provide a conceptual framework for the paper. The choice and implementation of the protocols, and the analysis used to compare them, are significant contributions of the present work. The current consumption and duration of receive, transmit, idle and sleep mode determine the expected power consumption of an active RFID tag under the given conditions. The main factors that mainly influence the current consumption are the channel assessment and the tag poll rate. The proposed RFID system implemented in this research requires low current consumption during sleep mode as the tag sleeps up to 99.6713 % of time usage in a minute.

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