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Towards an Energy Efficient Protocol for Active RFID

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Abstract

The use of Radio Frequency Identification systems (RFID) is growing rapidly. Today, mostly “passive” RFID systems are used because no onboard energy source is needed on the transponders. However, “active” RFID with onboard power source gives a new range of opportunities not possible with passive systems. To obtain energy efficiency in an Active RFID system a protocol should be designed that is optimized with energy in mind. This paper describes the on-going work of defining and evaluating such a protocol. The protocol’s performance in terms of energy efficiency, aggregated throughput, delay, and number of air collisions is evaluated and compared to that of the medium-access layer in 802.15.4 Zigbee, and also to a commercially available protocol from Free2move.

1. Introduction

Automation in logistics has driven Radio Frequency Identification (RFID) in the past few years. Mostly “passive” (i.e. the tag has no own power source) RFID has been in focus but recently also “active” (where the tag has an onboard battery) RFID has gained more interest [1]. By using an onboard power source for the transponder¹ unit (tag) a wide range of new applications can be found. There are several advantages in using an onboard power source. An active tag is able to gather sensor information and store it for later delivery to a reader. Also, reader-range and -directivity is improved compared to Passive RFID [6, 7], because higher output power from the transmitter and a more sensitive receiver can be achieved by adding onboard tag power. The drawback is that it limits the life time of the active tag compared to the passive tag due to dependency of the power source. For active tags the wireless link is what uses most of the power. To achieve power efficiency in the wireless RF-link an energy efficient protocol for Active RFID should be used. This paper presents the on-going work of defining and evaluating such a protocol.

The evaluation is done against the MAC-layer in the standard 802.15.4, a commercially available protocol and an “optimal protocol”.

2. The energy efficient protocol

In order to measure how well different protocols, described further in this paper, work regarding energy efficiency, it is practical to define a protocol that would be optimal in terms of energy efficiency (if all the necessary information were available). In the following this is called the “optimal protocol”.

2.1. Defining an “optimal” Active RFID protocol

In the optimal protocol there would be no energy loss for the tag to detect an RFID-reader and wake up from sleep-mode. The only energy that this optimized tag uses is when transmitting information to the RFID-reader and receiving a confirmation that the RFID-reader has successfully retrieved the tag information. After the received acknowledge message the tag enters deep-sleep-mode. The tag stays in this mode for a pre-determined time, specified in the acknowledge message from the RFID-reader. The flow chart in Figure 1 shows the typical state operation for a tag executing the optimal protocol. The power consumption in deep-sleep- and sleep-mode for all described protocols is much less than in the wake-modes where the tag is receiving and transmitting. Of great importance is then, of course, the duty cycle between wake- and sleep-mode.

Figure 1. State diagram of a tag executing the optimal protocol.

¹ The Transponder is the unit carrying information, i.e. the identity in an RFID system. The transponder is often referred to as a “tag”.

3. Evaluation

The criterion for efficiency in an Active RFID protocol is that it minimizes draining the onboard power sources and still fulfills the demands for fast wake up when approaching an RFID-reader and delivery of information on time.

3.1. Evaluation methods

For evaluation, simulations of the optimal protocol are compared with simulations of protocols described further down in this text. All simulation is done using MATLAB 7.1 and the Monte Carlo method.

The simulations generate tags that wake up randomly in a uniform distribution over one wake-up cycle. The wake-up cycle (or, for short, “cycle”) is described as when a tag wakes up and tries to communicate with a RFID-reader and then sleeps until next awakening. The cycle does not vary; it stays the same during the entire simulation. The *throughput* value used in the evaluation is the number of tags being successfully read by the RFID-reader during one cycle when a well known amount of tags wake up under the same cycle. *Delay* is the number of cycles it takes until all tags have delivered at least one packet of information each to the RFID-reader. Evaluating energy efficiency is done by calculating the energy cost per successfully transmitted data bit, as a function of the number of tags.

4. Existing protocols and standards

In this section an existing commercially available protocol for Active RFID is described, as well as an IEEE standard for wireless short range communication

4.1. Free2move’s current protocol

This existing protocol from Free2move, described in Figure 2, works either in synchronized or non-synchronized system mode. In the synchronized mode (also called RTF, Reader Talk First-mode) the RFID-reader sends beacon signals on which tags react, while in the non-synchronized mode (also called TTF, Tag Talks First-mode) tags react independently of the reader. None of the modes represents conflict free schemes [3], rather they are both examples of contention based schemes [3].

The RFID-tag device always works in a periodic way, waking up and releasing information to the RFID-reader and then entering sleep mode. In the RTF-mode the RFID-reader continuously sends beacon signals to create a slotted scheme, between the beacon signals the reader listens for answers from the tags. The RFID-reader is able to listen to two frequency channels at the same time and receive information from two tags that are synchronized with the RFID-reader beacon signal. When answering, the tag randomly chooses one of the two frequencies. Also the RFID-reader switches between and

transmits on two different channels. The methods used are much like a limited frequency hopping spread spectrum scheme (FHSS).

In the TTF mode a tag wakes up randomly and delivers information on one out of four possible frequencies to the reader without being synchronous with it. These four frequencies are divided into two channels where information from two simultaneously transmitting tags can be received at the same time in each channel. Due to the absence of synchronization between tags, the first recognized tag (on one of the channels) is read by the RFID-reader, while the second first (on this channel) is excluded from a read. This can be said to be a ‘first come first served’ (and also only to be served) technique.

Both the TTF- and the RTF-mode allow tags to be reconfigured in functionality by being directed to a scheduled FIFO queue on a special configuration channel by the RFID-reader.

Figure 2. Free2move's current protocol. A tag executing in RTF-mode (top) and in TTF-mode (bottom).

4.2. IEEE 802.15.4

An existing radio technology that is a supposed nominee for Active RFID is the IEEE 802.15.4 standard [2]. The specification supports short range, low rate and low power radio interconnection of electronic devices.

The physical layer is based on direct sequence spread spectrum (DSSS) and is available in two flavors; the first version operates in the 868/915 MHz ISM band and the

second version in the 2.45 GHz ISM band. The 868/915 MHz version (Europe/U.S.) supports a raw bit-rate of 20/40kbit/s and the 2.45 GHz version (worldwide) supports a raw bit-rate of 250kbit/s over the radio link.

Two different network topologies are supported by the IEEE 802.15.4 standard: a peer-to-peer topology and a star topology. The second topology is a possible candidate for an Active RFID application. The star topology is built out of two types of devices; the full functioning device (FFD) and the reduced functioning device (RFD). A star topology must contain at least one FFD, the so called coordinator. In the Active RFID application the reader is an FFD device (coordinator) and the RFID tags are RFDs.

Contention based and contention free channel access is supported by the IEEE 802.15.4 standard. For the Active RFID application the contention based channel access mechanism is preferable since the number and identity of tags in range of the reader (coordinator) change over time, i.e. resource allocation is of no use if the target is to deliver the device ID (or some other small amount of data to the reader) once.

The contention based channel access mechanism is based on a distributed slotted/non-slotted carrier sense medium access with collision avoidance (CSMA-CA) back off algorithm. If slotted CSMA-CA is used the coordinator sends a beacon every 16th slot to synchronize all units. When a tag wakes up it first listens for the beacon, and when the tag finds the beacon it waits for a random back off time (aligned with the slot boundaries). After the random back off time has passed the tag acquiring the channel performs carrier sense, and if the channel is free it starts the transmission.

If non slotted CSMA-CD is used the tag wakes up, waits for a random back off time, and performs carrier sense. If the channel is sensed free, the tag starts the transmission. All transmissions can optionally be acknowledged, if requested by the application.

4.3. Performance and comparison of protocols

Simulations were done for both the RTF- and the TTF-mode. Figure 3 compares throughput for the two modes (the two lower curves). The non-synchronized TTF-mode shows higher throughput. This is because the TTF mode's usage of the radio channel is about half of that of the RTF-mode. The probability of collision for the two modes is shown in Figure 4 (the two upper curves). Collisions occur when several tags try to deliver information to the RFID-reader at the same time and on the same channel. The simulations of delay, illustrated in Figure 5, show how many cycles are needed before all tags have delivered at least one packet of information each to the RFID-reader. When simulating the optimal protocol described earlier, the same physical constraints as for RTF and TTF were used, that is, using 2.45 GHz ISM band, 4 channels, each with 1MHz bandwidth and a bit rate of 250kbit/s. The optimal protocol also uses

Figure 3. Simulated throughput. First simulation starts with 50 tags.

Figure 4. Probability of collision when a tag tries to deliver information to the RFID-reader.

Figure 5. Packet delay as a function of the number of tags reachable from the RFID-reader.

deep-sleep as described above and sleeps for an application-dependent number of cycles (set to 10 in the simulations) after a successfully delivered packet to the RFID-reader. Preliminary simulations of 802.15.4 have also been done and the good results compared to the others could be explained with the short acknowledge sent from the RFID-reader and that carrier sense is used for collision avoidance. The RTF-mode and the Optimal protocol also include some extra information in the acknowledge packet increasing the usage of the radio channel.

4.4. Comparison of energy efficiency

The different protocols described will be further simulated in the on-going work and described in terms of energy efficiency in this Section. Figure 6 shows the tag executing different protocols. Some general conclusions (to be verified by further simulations) can be drawn already. The most efficient is of course executing the

Figure 6. Tag executing different protocols and reacting on the presence of an RFID-reader.

Figure 7. Energy cost per successfully delivered pay-load data bit.

optimal protocol. Sleep mode and deep-sleep mode are modes where hardly any energy is consumed. In receive mode (RX) the tag consumes about 33% more energy than in the transmit mode (TX). These values about energy consumptions are obtained from measurements on the Free2move tag. When the delay obtained by simulations is combined with the energy consumption for RX and TX, the energy efficiency can be calculated. The energy cost per successfully transmitted pay-load data bit is shown in Figure 7 as a function of the number of tags. Energy consumption for a tag based on 802.15.4 is obtained from data sheets for circuits delivered by Texas Instrument.

5. Summary

Simulation of Free2move's commercial Active RFID protocol and its different modes has been compared to an optimal protocol. The contention based channel access supported by the IEEE 802.15.4 standard has been studied to see how well it is suited to be used for Active RFID. Calculations and comparison of energy consumption for all the described protocols are shown.

A new protocol may evolve from conclusions drawn after further simulations are completed.

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