Asynchronous wake-up scheme for wireless light curtains

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1) Introduction

Light curtains are often used in safety applications. One instance is in the control of automatic doors, when these are being opened or closed. In such a case, it is mandatory to make sure that there are no obstacles (persons, animals or objects) at the wrong place when the door is in movement.

Fig. 1: IR transmitter / receiver pair (CEDES.

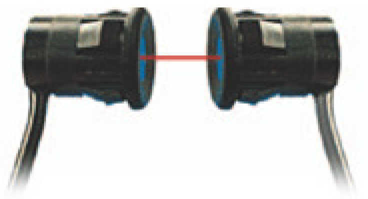


Fig. 2: Example of light curtain application (CEDES)

A motor is used to displace the movable part of the door, and sensors are placed at the right places to watch for obstacles (Fig. 3). This could for instance be the contact sides of the stationary door post and the moving door. If a presence is detected inside the door, the movement of the door is stopped.

Several types of sensors are in use for the detection. One possibility is to install optical elements such as IR emitters and IR detectors. An obstacle between the sender and the receiver of the IR beam will prevent the light from reaching its destination. When interrogated, the detector will show that no light was received. The number of emitter/detector pairs used for a door depends on the application and the degree of safety required. Another type of detector used in such application is a pressure sensitive doormat. Such a mat senses the pressure due to the weight of a person or object that is standing on it. It could be placed inside the door in order to monitor presence and stop the door movement.

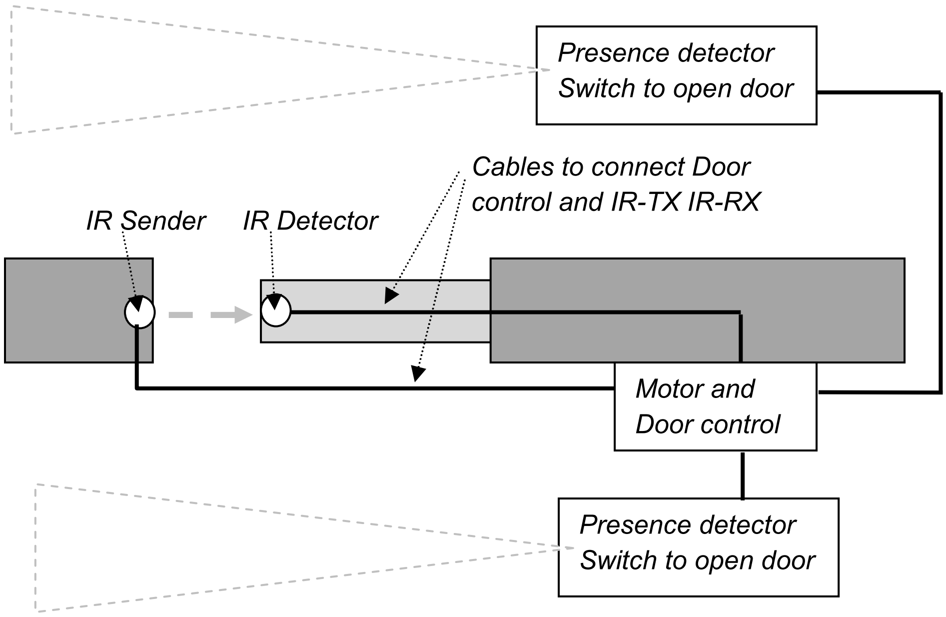


Fig. 3: Sliding door where sensors are linked to main controller using cables.

Such detectors can be found in elevators, in commercial or industrial buildings, garage doors or factory floors where moving equipment could be a safety hazard.

In the case of doors, a cable is mostly used between the door control unit and the sensors, in order to bring power and control signals, or to get the sensor data (Fig. 3).

The presence of cables is not always welcome. They reduce flexibility, have high installation costs, and can have a negative aesthetic impact. Also, servicing is not easy, adding to maintenance costs.
For these reasons, a wireless solution, at least for the emitter/detector is desired. Such a solution is however not obvious, and needs to take several factors into account.

- The IR sender and detector need independent energy sources. This is required to power the IR diode, the receiver and the wireless modules.
- The size of the IR sender and detectors should be small.
- The wireless link should allow a fast and reliable communication, in order not to affect the security of the opening/closing operations.

In this work, we have replaced the data cables by a wireless link (802.15.4 / ZigBee) that is used for a two way communication between the sensor elements and the door control unit. Although all factors mentioned above are important, we have concentrated on the power aspects. The energy needs of the system are dictated by the power consumption of the IR sender, IR receiver, and wireless link. We did not take the power consumption of the IR LED into consideration. This work looked only at the needs for the wireless link, with the purpose of keeping the consumption low and having a fast reaction time.

The sensors are powered using batteries; therefore, low power requirements are crucial for customer acceptance. Nobody wants to change batteries every month. To achieve low power in the communication link, similar applications typically use a synchronous wake-up to keep the duty cycle of the transceivers low. The transceiver, microcontroller and other elements are kept in a mode where they consume the least amount of energy, until an event takes them in their operating mode.

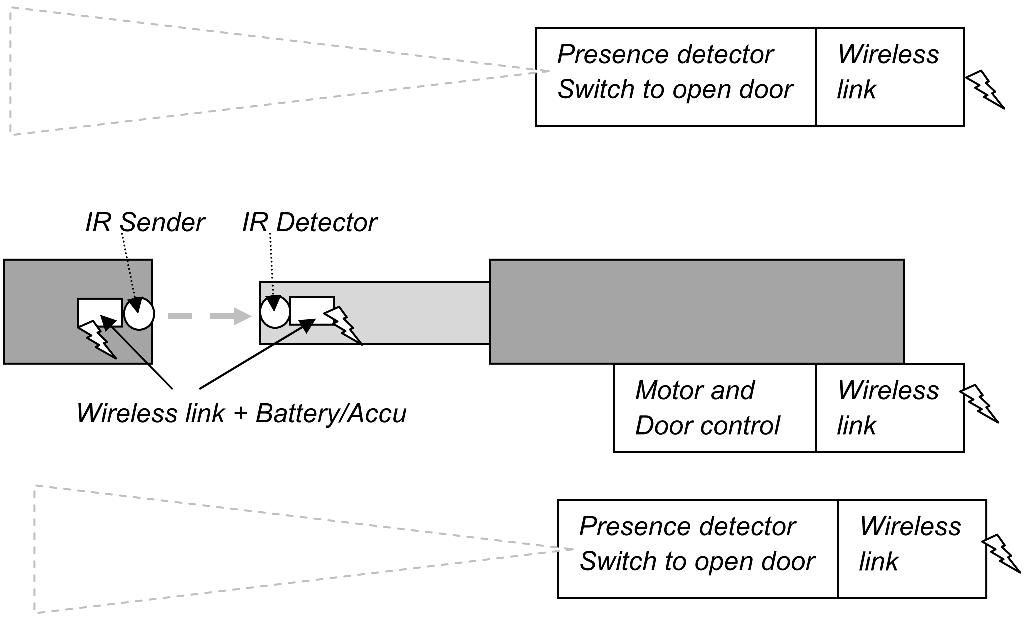


Figure 4: Cable is replaced by wireless units.

Since it is not known in this application when a door activity will start, an obvious solution is to periodically wake up the system and check if action is needed. In case it is not, the system will return in sleep mode. Because of the asynchronous nature of the events that trigger the opening/closing of the door, the system will wake up most of the time to find that there is no action needed. This will result in a waste of battery energy. So, the wake-up period must be chosen such as to allow a fast response time and yet sleep as long as possible. This is a conflicting situation, where a compromise is needed between energy consumption and fast response time.

2) <u>Solution proposal</u>

The optimal situation will be to detect the events that trigger the opening/closing of the door, and only then to start the communication. The detection of these events should itself use less power than the energy consumed when a timer unnecessarily wakes up the system. This calls for an asynchronous wake-up scheme.
Asynchronous wake-up scheme have been used in several applications before. For instance, Malinowski has used parameters such as vibration, light, shock, sound ...etc to trigger measurements and communication [5] [6]. Events are monitored using a very low power comparator or ADC, allowing the other elements of the system to remain in power down mode until a defined threshold of the triggering parameter is reached.

We have implemented a wake-up scheme that uses low frequency RFID signals to wake up the wireless transceivers exactly when communication is required. The opening or closing of the door is initiated by pressing a button, or by detecting a moving object in the field before the door. The door controller will then send the needed RFID wake-up signal, and the RF communication will start. Since 802.15.4 allow a registered note to quickly send or retrieve data (order of milliseconds), this scheme leads to energy savings without compromising the response time. Although here implemented for 802.15.4 networks, the scheme can be used for other wireless technologies which allow a fast reaction.

At the heart of the wake-up scheme is a 3D RFID receiver, which, according to the data sheet, consumes only a few microamperes in its operating mode. It will recognise a pattern sent by an RFID reader placed as far as 6 m, and give an interrupt to the microcontroller (Fig. 5).

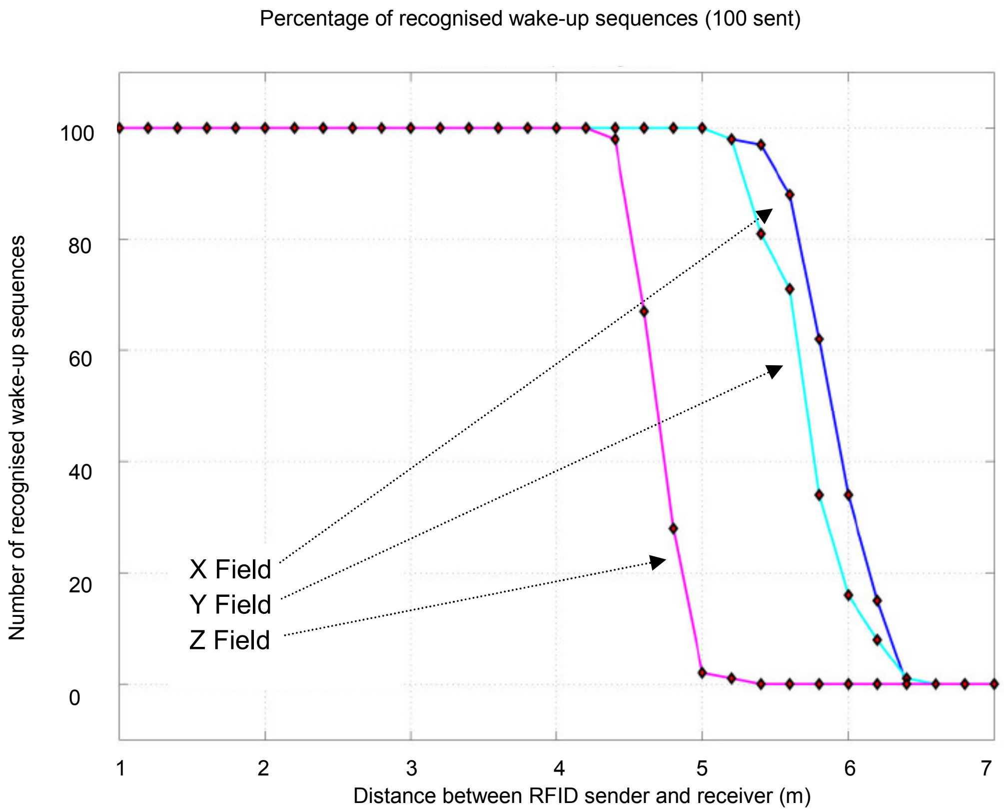


Figure 5 : Response of 3D receiver in function of distance

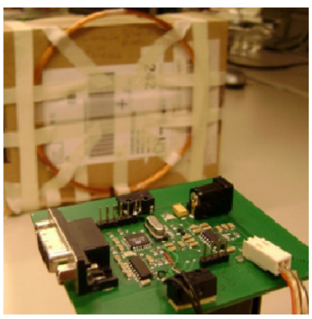
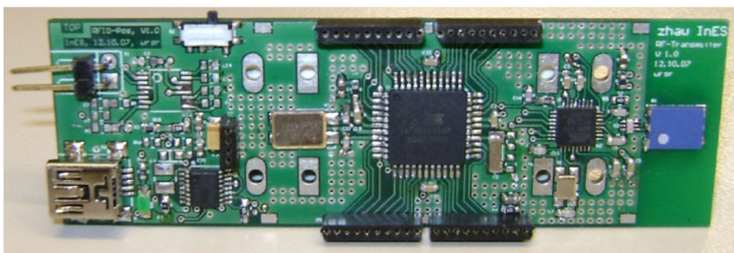


Fig.6: RFID antenna and RFID wake-up sequence generator



Interface to R ID reader ***Microcontroller*** ***Transceiver***

Fig.7: Main controller board

3) Implementation of the solution

a. Elements of the solution

The hardware used in the solution is shown on Fig.7, Fig.8, Fig.9 .
For simplification reasons, we will just consider 3 boards:

- 1 Main board. It controls the opening and closing of the door, and communicates with the IR-TX and IR-RX boards to establish the presence of an object at the door. The main board will get requests to close or open the doors, and start the process. This is also the coordinator for 802.15.4
- The IR-TX and the IR-RX boards. They communicate with the main board to pass information about the safety of the opening or closing operations. Both boards have the same elements, and differ only in that one is equipped with an IR emitter, and the other with an IR receiver.

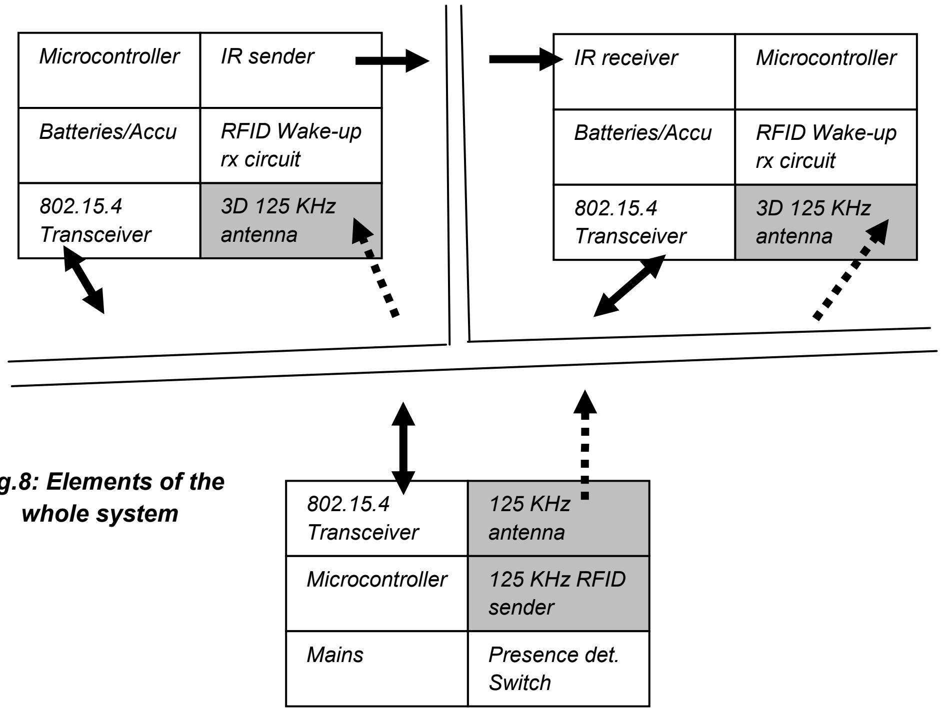


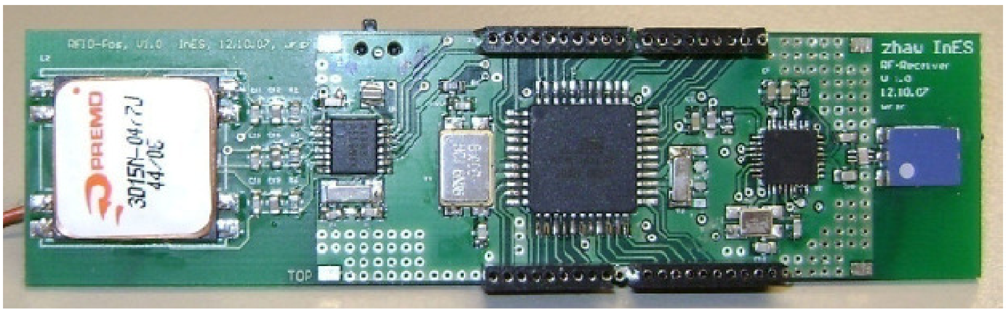
Fig.8: Elements of the whole system

All 3 boards use the same microcontroller and transceiver type.
The microcontroller is an 8-bit device (ATMega324) from Atmel [1].
The RF 802.15.4 transceivers are 2.4 GHz AT86RF230 from Atmel [2].
Optionally, the IR-TX and IR-RX boards also include a 3D RFID wake-up circuit, the AS3931 from Austriamicrosystems [3]. A 3D LF coil from the firm Premo (in Spain) is used to pick up the LF signal in all 3 dimensions, and pass it on to the wake-up device. An option on the main controller board is the EM4095 circuit from EM Marin, which is used to generate a 125 KHz magnetic field, radiated by a coil antenna [4].

b. Solution with synchronous wake-up

In this case, the RFID parts are not used. A timer is used to periodically start the communication between the main station and the IR-TX/IR-RX pair. Every time the timer expires, the radio of the IR sender/detector will be started. If there is a message pending and indicating that an open/close door activity should begin, the communication will be kept, and the wake-up timer disabled. The parties will then communicate by 2.4 GHz radio in a continuous way, in order to control the opening/closing door activity. At the end of that activity, the main controller will indicate to the IR sender and IR detector that they can go back into power down mode. After restarting their wake-up timers, they will go into power down mode. The timer wake-up interval is chosen to be an acceptable compromise between saving power and reacting quickly enough.

Event	Main controller	IR sender	IR Receiver	comments
	802.15.4 radio rx on	IR diode off 802.15.4 radio off	IR photodiode off 802.15.4 radio off	
Wake up timer		Wake-up. Start 802.15.4 link Get message from main controller about door opening/closing activity. Go back to sleep (no activity)	Wake-up. Start 802.15.4 link Get message from main controller about door opening/closing activity. Go back to sleep (no activity)	
	802.15.4 radio rx on	IR diode off 802.15.4 radio off	IR photodiode off 802.15.4 radio off	
Wake up timer		Wake-up. Start 802.15.4 link Get message from main controller about door opening/closing activity. Go back to sleep (no activity)	Wake-up. Start 802.15.4 link Get message from main controller about door opening/closing activity. Go back to sleep (no activity)	
Request to close door	Prepare messages for door opening activity			
Wake up timer		Wake-up. Start 802.15.4 link Get message from main controller about door opening/closing activity. Stop wake-up timer.	Wake-up. Start 802.15.4 link Get message from main controller about door opening/closing activity. Stop wake-up timer.	
	Orders via 802.15.4 link for the activation and verification of the IR beam. Activate motor to open door and control it according to the status of the IR detector.	Communicate with main station to control Activation of IR LED	Communicate status to main controller via 802.15.4 link Turn on IR detector.	Opening door.
		Restart wake-up timer. Go in sleep mode.	Restart wake-up timer. Go in sleep mode.	Door is open.
	802.15.4 radio rx on RFID sender off	IR diode off 802.15.4 radio off RFID wake-up on	IR receiver off 802.15.4 radio off RFID wake-up on	
Wake up timer		Wake-up. Start 802.15.4 link Get message from main controller about door opening/closing activity. Go back to sleep (no activity)	Wake-up. Start 802.15.4 link Get message from main controller about door opening/closing activity. Go back to sleep (no activity)	



3D antenna ***Wake-up receiver*** ***Microcontroller*** ***802.15.4 transceiver***

Fig.9: Sensor controller board

c. Solution with asynchronous wake-up

In this scenario, the IR sender and IR detector will mostly be in sleep mode. The RFID wake-up chip will be enabled

If a door open/close activity is requested, the main controller will use its RFID sender to generate a wake-up sequence. That sequence will be detected by the wake-up detectors of the IR-TX/IR-RX. The respective microcontrollers of these boards will then be woken up. They will start their 802.15.4 radio link, and communicate with the main controller to supervise the safety during the opening or closing of the door. At the end of this activity, the IR-TX and IR-RX microcontroller will be instructed by the main board to go back into power down mode.

Event	**Main controller**	**IR sender**	**IR receiver**	**comments**
	802.15.4 radio rx on RFID sender off	IR diode off 802.15.4 radio off RFID wake-up on	IR photodiode off 802.15.4 radio off RFID wake-up on	
Request to open door				
	Send RFID wake-up sequence	Interrupt from RFID wake-up. Start 802.15.4 link	Interrupt from RFID wake-up. Start 802.15.4 link	
	Orders via 802.15.4 link for the activation and verification of the IR beam. Activate motor to open door and control it according to the status of the IR detector.	Communicate with main station to control Activation of IR LED	Communicate status to main controller via 802.15.4 link Turn on IR detector.	Opening door
				Door is open
	802.15.4 radio rx on RFID sender off	IR diode off 802.15.4 radio off RFID wake-up on	IR receiver off 802.15.4 radio off RFID wake-up on	
Request to close door				
	Send RFID wake-up sequence	Interrupt from RFID wake-up. Start 802.15.4 link	Interrupt from RFID wake-up. Start 802.15.4 link	
	Orders via 802.15.4 link for the activation and verification of the IR beam. Activate motor to close door and control it according to the status of the IR detector.	Communicate with main station to control Activation of IR LED	Communicate status to main controller via 802.15.4 link Turn on IR detector.	Closing door
				Door is closed
	802.15.4 radio rx on RFID sender off	IR diode off 802.15.4 radio off RFID wake-up on	IR receiver off 802.15.4 radio off RFID wake-up on	

4) Tests

a. Simulations

Before the hardware was built and the software written simulations were made using Matlab, in order to compare the two solutions. Parameters such as the operating and sleep mode currents of the microcontroller, the operating current of the wake-up device, were first taken from data sheet.

The battery life was then simulated in function of the number of door open/close activities per hour and the number of hours per day that the door will be in use. The simulation program was also later used to predict battery life time, by using real measurements values (under the condition dictated by the written software) and calculating the energy consumption over a long time.

The figures below (Fig. 10) show the simulation results.
As expected, it can be seen that the more often the door is in use, the smaller the difference between the synchronous and the asynchronous variations.
If the door is not often in use, the energy savings of the asynchronous variation is substantial.

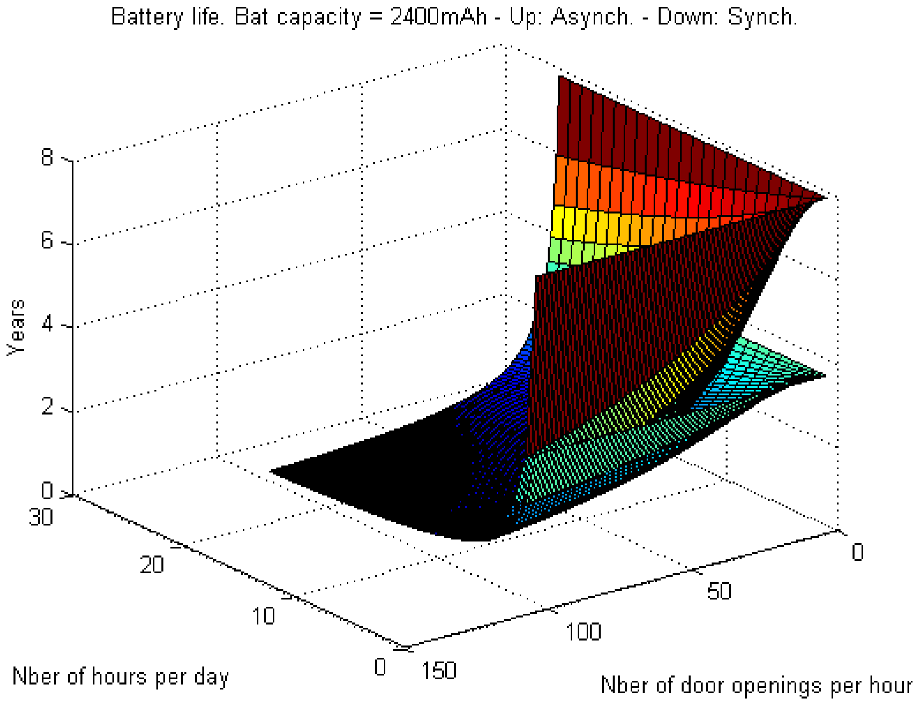
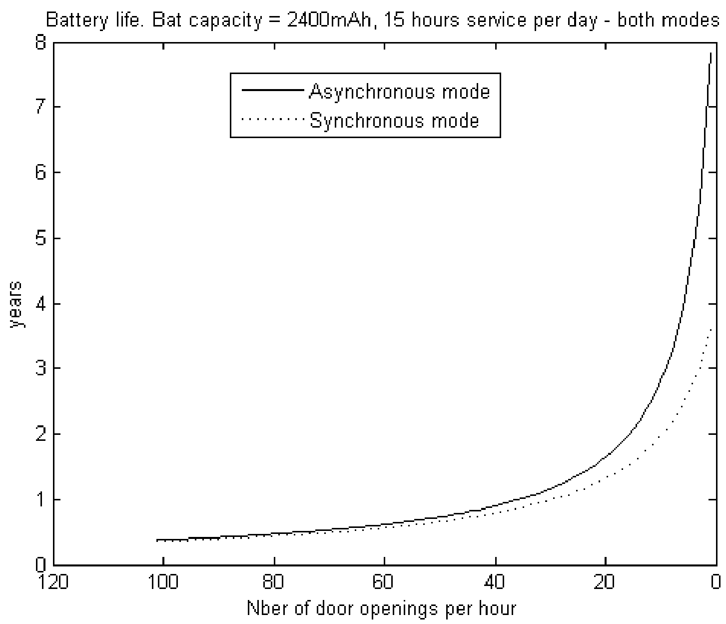


Fig.10: simulation results



Parameters used for the simulations above.

Time needed to close the door	2 sec
Energy available in battery	2400 mAh
Polling interval for synchronous variation	3 sec
Radio transmit time	0.005 sec
CPU running time	0.010 sec
Radio transmit current	20 mA
CPU alone active	5 mA
Only wake-up circuit is active	0.035 mA

b. <u>Tests with hardware and software</u>

For the real tests, hardware was built and software written.

The current consumption in different states (operating, sleep) for both variations was measured, and the battery life estimated. The values could then be fed back into the simulator for accurate results.

The measured values are:

TX power set for maximal power.

Micro in power down; Wake-up device on; radio off	28 uA
Micro running; Wake-up device on; radio in RX mode	20.57 mA
Micro running; wake-up device on; radio sending every 15 ms	20.39 mA
Micro running; wake-up device on; radio off	5.38 mA

The results confirmed the fact that savings in energy will be achieved by the asynchronous variation, especially in case of a small number of opening/closing activities. For both variations, the battery life time was found to be smaller than expected, due to a larger value of the current consumption of the wake-up circuit. The difference between the datasheet specification and the measured value could not yet be explained.

5) Conclusions and outlook

This work has shown that in applications where asynchronous events are used to start a wireless communication, important energy gains are possible if the asynchronous event is used to trigger the communication. However, it is important to consider the following parameters:

- A wake-up source that consumes on average less energy that an active wake-up timer must be found.
- It must be able to use the wake up source in the environment of the application.
- The increase in cost and space associated with the wake-up channel should be taken into account.

It is also important to note that the whole RFID asynchronous scheme described here only makes sense if the devices are within about 5 m of each other, which is the case in the example considered. For such a distance, the transmitting power of the 802.15.4 radio could be reduced, leading to more energy savings.

In the last months, new transceivers and microcontrollers have appeared on the market, which consume 2 to 3 times less energy than the elements used in this work. Such devices will also help to increase the battery life [7].
In future works we will look at the use of the RUBEE devices [8]. They have a lower data rate than 802.15.4, but this is not a problem for this kind of application. The devices will be considered not only because of the energy savings, but also because of their potential in difficult physical environment.

Our thanks go to CEDES A.G. in Landquart, CH, for their help in this work, and for ANATEC in Zug, CH, for providing the devices.

References

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