Acknowledged data transmissions in wireless sensor network with optimized sensor energy consumption

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Abstract – **This paper describes communication method for use in a wireless sensor network, which focus on a bidirectional communication with prevention of data loss and minimization of a power consumption of the wireless sensor. The method described was successfully tested and verified on an existing installation of a wireless sensor network. The power consumption is a key parameter for a disposable, battery powered, wireless sensor with small dimensions. Small dimensions lead to a very limited amount of energy available for the sensor. Together with the requirement for a maximized life time of the sensor, an energy efficient data transmission algorithm is a key component, which significantly affects life time of the sensor. The sensor used for testing of the algorithm was disposable, hermetically sealed, battery powered, human body wireless temperature sensor, which should provide at least one year of operation with measurement period of sixty seconds. The impact of described algorithm on total sensor power consumption increases with lowering communication period. Sensors with extended functionality, which will focus on other different physiological signals are planned for development as part of the system in future. These sensors will produce higher amount of data and require data transfers with shorter periods. Therefore described power saving method is important. Intended area of use of the system is in hospitals, elderly care facilities, rehabilitation units, spas and even households.**

Keywords – sensor, wireless, wireless sensor network, power consumtion, health care

I. INTRODUCTION

The presented communication method was developed as part of research and development of a system for continuous monitoring and visualization of physiological parameters [1].

Fig. 1 shows the topology of a basic system configuration. The system consists of wireless sensors, wireless routers and a central server. Routers and the server are devices, which have their RF frontends always active and are always listening for incoming communication. Routers are intended to route the wireless communication to its final destination. In our case, sensors are devices, which are battery operated and enables it's RF frontend only for time necessary for a transmission and an acknowledgement of delivery of a transmitted data frame. In our concrete case the sensor uses single chip solution ATmega2564RFR2, which is an 8-bit microcontroller with a low power 2.4 GHz transceiver for ZigBee and IEEE 802.15.4 [2].

The typical current consumption of the microcontroller core running from a 16 MHz crystal oscillator is 4.5 mA and the power consumption of the transceiver in a receive state is 12.5 mA. The typical current consumption in transmit mode is 14.5 mA. Listed values are valid for input voltage of 3.0V and transmit power of 3.5 dBm. Current consumption of the sensor in a sleep mode is around 4 uA.

To extend sensor's life time to maximum value, it's necessary to minimize the power consumption by minimizing the time during which the microcontroller and especially its RF transceiver is in active state.

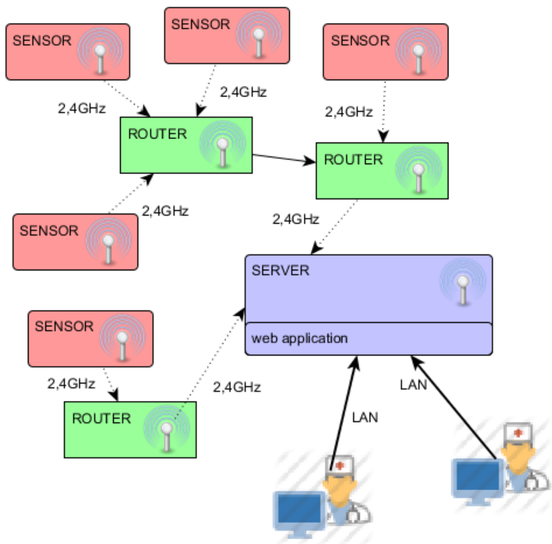

Figure 1 Topology of wireless system

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The sensor performs the measurement in a specified period, which in our case is sixty seconds. Then the sensor transmits measured data to the system server.

The direct transmission of the data from sensor to server is usually not possible and data are routed by wireless routers to its destination, that is the server. To prevent the data loss, the data transfer of each data frame is acknowledged by the server. If the sensor fails to receive the acknowledgement of data delivery, then it stores the data and retries its transmission later. The sensor has an internal memory for several thousands of measurements. The sensor stores undeliverable data to this memory to prevent measurement data loss.

The sensor waits for the data delivery acknowledgement for some time. During that time, the RF transceiver must be enabled and listening for an incoming communication. This causes an increase of sensor's power consumption. If the number of hops of the data frame over routers through the wireless network is higher, then the time between start of transmission and reception of the acknowledgement can be significant and can decrease the sensor's life time significantly.

Another task, which also affects the sensor power consumption is handling of sensor parameters change, which requires the sensor to listen for incoming frames for some time after sending the measurement data. This time is usually longer then the time required to receive the delivery acknowledgement. Therefore we have designed and implemented a data transmission method which focus on an optimization of power consumption during acknowledged data transmission and also on a power effective handling of sensor parameters change.

II. WIRELESS SYSTEM

The presented method was designed and implemented to be used in a system for sensing and transmission of physiological parameters. The system consists of wireless server node, wireless router nodes and wireless sensor nodes as shown in Figure 1. The sensor, which uses described methods, is a miniature, battery operated device designed for sensing of human body temperature. Fig. 2 shows the sensor fastened on human body.

The system communicates in 2,4 GHz ISM frequency band and is compliant with IEEE Std 802.15.4TM - 2003, 2006 Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR - WPANs) [3]. The communication rate is 500kBit/s.

The system adopts a Lightweight Mesh, an easy to use proprietary low power wireless mesh network protocol from Atmel Corporation [4].

Figure 2 Wireless temperature sensor fastened on skin

The protocol uses an automatic route discovery algorithm, which discovers the route of a data frame through the network during the data transmission without an additional communication related to the route discovery process. The protocol allows an acknowledged transmission, which is important for use in our system.

We don't want to lose any measured data, even if the sensor is not able to make the data transfer to the server node. The sensor, under all circumstances, performs the measurement in a defined period. If the sensor can't transfer the data, then the data are stored in sensor's internal memory. This ensures, that even if the patient leaves the area covered by the wireless sensor network, or the communication is not possible due to other reason, the data are stored and transferred to the system once the transmission is possible. This method requires the sensor to know, whether the data frame was delivered to the server. This is implemented with the use of an acknowledged transmission, which is provided by the Lightweight Mesh protocol. When the sensor sends some data to the server, then the server receives it and sends an acknowledgement frame telling, that the frame was delivered to its destination.

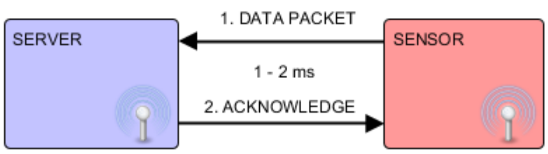

Figure 3 Direct data transmission

The direct data transmission with acknowledgement is shown in Fig. 3. The period of time that the sensor must stay active from 1 to 2 milliseconds in our system. This is the most optimal case. But the system is intended for covering large areas. Let's assume, that we would like to cover 10 rooms in a hospital. To ensure a reliable data transmission from sensors, it's necessary to install at least one router to each room, which will receive data from sensors in the room. Then, we can say, that the data frame from most distant sensor can be routed over 10 routers on its path to the server. The acknowledge can go the opposite direction of the same route. Each hop in the route takes usually from one to two milliseconds. This means, that the time between the sensor sends the data frame and the reception of acknowledgement from the server can be up to 40 milliseconds, which is very long in comparison with up to 2 milliseconds for direct transmission without routing.

TABLE I shows an average current consumption of the sensor for various transmission periods. Listed values are based on 4 uA standby current and 20 mA active current. The calculation is simplified and serves as a basic demonstration of the impact of the transmission active time on the average sensor current consumption. We can see, that the average current consumption of the sensor is 3.7 times higher for 60 seconds transmission period. For 1 second transmission period, the average current is 18.3 times higher. This shows that the optimization on sensor's active time can bring a significant power saving.

TABLE I. Current consumption

Transmission period [s]	Transmission active time [ms]	Average current [uA]	Current ratio
60	2	4.7	
60	40	17.3	3.7
10	2	8.0	
10	40	84.0	10.5
1	2	44.0	
1	40	804.0	18.3

We plan to extend the wireless system for more battery powered sensors, which will communicate in shorter periods. Therefore, the saving in the sensor's power consumption is important.

III. USED COMMUNICATION METHOD

The communication method designed and implemented in our wireless system is based on a combination of the Lightweight Mesh communication protocol and our own proprietary communication methods. It brings a shortest possible active time during the sensor data transmission and allows a two-way communication with the sensor on each sensor's transmission. The method doesn't increase sensor's active time if no communication with the sensor is required.

The Lightweight Mesh network header and application payload are encapsulated inside the standard IEEE 805.15.4 data frame payload. The Lightweight Mesh protocol uses two layers for routing purposes. First is MAC layer, second is network layer. MAC layer defines source and destination address for previous and next node in the routing path and is changed as the data frame is routed through the network. Addresses in the network header of the frame defines source and destination addresses. The protocol allows an acknowledged transmission of frame, which is required for our wireless system. Both the data frame and the acknowledge frame have to be routed through the network. The time required for transmission and acknowledge increases with the number of hops in the route.

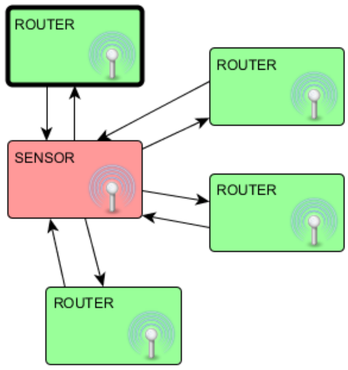

Figure 4 Delivering router discovery process

To minimize sensor's active time, we have proposed and implemented the described method. The principle is following. Each sensor choose one of routers in its communication range as its delivering router. This is done during delivering router discovery process shown in Fig. 4. The sensor sends broadcast delivering router request data frame. All routers, which are in the communication range replies with a response to this message. The sensor chooses one of available routers and stores it as its delivering router. This procedure is repeated only when the delivering router is not accessible, which can be caused, for example, by moving sensor to a different location.

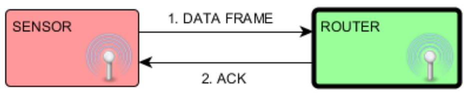

Figure 5 Sensor communication

The sensor always uses its delivering router for sending the data to the server. The principle of shortening the active time of the sensor is based on passing sensor's data to delivering router, receiving an acknowledge from delivering router and going to sleep mode without waiting for physical delivery of the data frame to the server as shown in Fig. 5.

The delivering router rejects any further data from sensor, until the previous data are delivered to the server. This ensures, that the sensor keeps the data in buffer if it can't be delivered to the server. As soon as the delivering router starts receiving the data frame and receives the frame header, it check status of data delivery for particular sensor and decides about allowing of denying the acknowledge. An acknowledge frame sending is hardware assisted, which saves computing time and speeds up the response. This method results in an active time about 1 ms for data transmission form the sensor.

The delivering router starts the sensor's data transmission to server immediately after its reception and uses the Lightweight Mesh protocol. Fig. 6 shows the delivery of sensor's data from the delivering router to the server. If the data are delivered to the server and the delivery is acknowledged by the server, then the delivering router is ready to receive further data from the sensor. This part of delivery process requires longer time, dependent on number of hops in the data route. But this task is handled by routers, which aren't battery operated and thus without high demands on power saving.

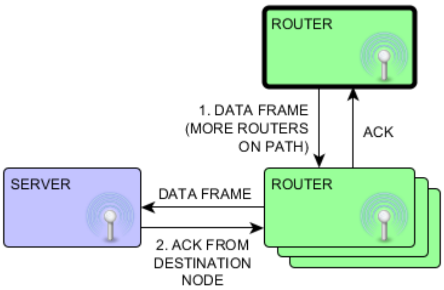

Figure 6 Delivering router to server communication

Another important functionality of the system is an ability to communicate with the sensor to modify its parameters or initiate some special modes like software update or RF performance test. When an application, running on the server, requires to communicate with the sensor, it sends a request for communication to the sensor's delivering router as it's shown in Fig. 7.

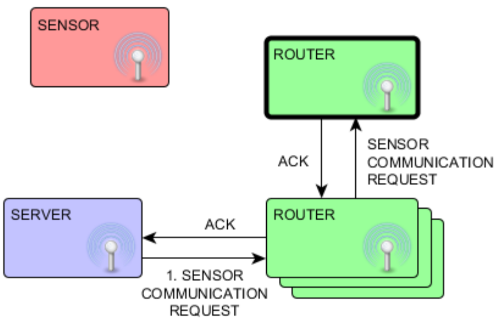

Figure 7 Request for communication with sensor

The application knows sensor's delivering router from previously received data frame originating from the sensor. The delivering router stores the request for communication and when the data from the sensor are received, the delivering router sets the data pending flag in acknowledge frame sent to the sensor. The sensor then checks the flag and sends communication request frame to the server and stays active for a predefined amount of time, waiting for response from the server. All communications following reception of the acknowledge with data pending flag set uses the Lightweight Mesh protocol to profit from well verified protocol and its implementation. This method provides all required functionality of the sensor while keeping sensor's energy consumption very low.

IV. Measurement Results

Described solution was implemented to temperature sensor shown in Fig. 2. A test setup of wireless sensor network was prepared and configured to always route the data from the sensor over 5 routers to the server. The transmission period was set to one second. 24 hour measurements of power consumption with and without described method were performed. The average active time and average current consumption of the sensor were measured. With the use of the described method, the average active time was 1.15 ms and average current consumption was 27 uA. With the use of Lightweight Mesh communication without described method, the average active time was 12.3 ms and average current consumption was 230 uA. This result shows a significant battery life prolongation for sensor with the described method implemented.

V. Conclusion

The described method was implemented as an extension to Atmel Lightweight mesh stack to provide suitable solution for battery powered sensors of physiological parameters. The solution can be used with any kind of battery powered device, which has to communicate in Lightweight Mesh network and take advantage of extended battery life. The solution is used in a Wireless system for monitoring body temperature which is tested at orthopedic department of University Hospital Olomouc, Czech Republic, where the research focused on postoperative states of patients after hip and knee replacement surgical procedure takes place.

The system will be extended for more sensors for sensing various physiological parameters in future. The use of the system is not limited only to physiological parameters, but it can be also used in different areas like monitoring of environmental parameters, industry, or other areas, where battery operated sensors with long life are suitable.

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