METHODS FOR ENERGY CONSUMPTION MANAGEMENT IN WIRELESS SENSOR NETWORKS

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ABSTRACT:
Principles, methods and possibilities for energy consumption management and optimization in wireless sensor networks are considered and described in the paper. The increasing development and deployment of wireless sensor networks in various outdoor applications results in intention to design and implement low energy consumption wireless sensor networks. Critical aspects and challenges of energy consumption minimization in wireless sensor network are considered at first. Possibilities for reduction of energy consumption in several sensor node components are considered and described. Practical sensor nodes and radio modules configuration and control optimized for lower energy consumption in practically implemented network are presented. Some theoretical and measurement results of energy consumed in different energy consumption management modes of sensor nodes and the network are given.

1. INTRODUCTION
Wireless sensor network (WSN) development is facing different challenges which of the most critical represent the energy consumption in whole sensor node (SN). In most applications sensor nodes (SNs) are considered to have non-permanent power supply and use batteries. As WSN consists of large number of SNs, energy consumption management is very important and crucial. In outdoor applications the energy consumption directly influences the SN lifetime and processing power regardless different possibilities to recharge the battery on SN or organize the WSN in an application sufficient manner.
Since the battery powered SNs have limited energy resource different energy saving methods and management need to be considered and applied on SNs as well as on whole WSN [1-3]. Different possibilities for decreasing energy consumption at WSN and SN various components are considered and described in this paper. Configuration and practical software optimization of a SN to minimize energy consumption is described and presented.
2. ENERGY SAVING AND MANAGEMENT IN WIRELESS SENSOR NETWORK

To realize energy efficient SN with non-permanent power supply different energy management consumption methods can be considered and realized. Therefore, energy saving methods at various levels are considered to minimize the energy consumption evenly on SNs. Whether these levels are based on software optimization, communication or data sampling rate configuration, the energy consumption can be decreased significantly. Another possibility represents usage of framework for energy management. Such framework is considered to monitor and manage SN energy usage to control the SN lifetime [3]. In outdoor applications periodically data measurements and processing can be applied to reduce the energy consumption. Such approach can be considered as duty cycle in which SN wake-up for specific time period to realize data sampling, processing and transmission, and putting to sleep thereafter [1]. Another method is based on event data sampling which is considered to sample sensor data only on specific events. Different data sensing approaches can be adapted which implies areal coverage based sensing, energy available related data sensing, prediction based sensing using previously constructed model of measured phenomena [1,2].

In complex WSN with high number of nodes, implementing and using WSN scalability can reduce the overall sensor network energy consumption. A specific routing algorithm can be implemented to reduce the data transmission distance and therefore to obtain energy efficient routing. Such routing algorithms are characterized on forming cluster hierarchy in specific part of WSN or find the shortest and most efficient data transmission path to establish multihop routing [2,4,5]. Depending on the specific application, this type of technics can evenly load the network forming different paths or cluster nodes on each data transmission cycle. Such approach results in avoiding constantly energy load on the identical part of WSN during different data transmissions and energy management capabilities.

2.1. Energy saving in sensor node components

During periodical data sampling, microcontroller and radio module in SN enter active mode for specific time period to process the acquired sensor data. In this mode significant energy consumption occurs during data processing. In order to lower the energy consumption, SN components such as microcontroller and radio module can operate in different states. The SN can be configured to sleep in periods in which no data measurement and processing are expected. The microcontroller as well as the radio module can be programmed by software to enter energy saving states such as sleep or deep power save states [2]. In those states several dozen mA can be saved which can significantly extend battery lifetime. The radio module can be controlled (e.g. changing operation modes) generating interrupt by microcontroller only in data transmission requirements.

Another possibility to lower the energy consumption implies dynamic voltage management at several SN components [2]. At microcontroller or whole SN level, different components (such as A/D controllers, I/O ports, interfaces, etc.) can be powered off if not required in specific situation. Other SN components can also be disabled in sleep periods to save energy, but during active period specific additional time is required (several ms) to turn back in full operational state [2]. This possibility depends on the ratio energy saving against the additional time required in active state which can be exploited by practical measurements compared with manufacturer’s device data sheet.

An energy consumption model of a SN component can be considered as following. If the energy consumed in period between sleep and active mode of component is lower than the average energy consumption, than the specific SN component (if possible) can be translated into one of sleep modes. Such model considers how efficient energy saving is realized and depends on energy wasted during time period of translating into sleep mode and turning back into active mode. Therefore, it depends on time period being in active and sleep mode, also. This model can be represented by following equation [2]:
Energy consumed in a specific time while turning back in active mode is represented as [2]:

\[ E_{\text{overhead}} = \tau_{\text{up}} \left( P_{\text{active}} + P_{\text{sleep}} \right) / 2. \]

The values \( \tau_{\text{down}} \) and \( \tau_{\text{up}} \) represent additional specific time required for translating into sleep mode and from sleep mode back into active mode when processing is required, respectively. Parameters \( t_{\text{event}} \) and \( t_{\text{event}} \) represent times in which translations from active mode to sleep mode occur and from sleep mode to active mode, respectively. Therefore, energy saving is only efficient if \( E_{\text{overhead}} < E_{\text{saved}} \). Such representation can also be interpreted on time basis as [2]:

\[ \left( t_{\text{event}} - t_{\text{event}} \right) > \frac{1}{2} \left( \tau_{\text{down}} + \frac{P_{\text{active}} + P_{\text{sleep}}}{P_{\text{active}} - P_{\text{sleep}}} \tau_{\text{up}} \right). \]

A clock prescaler on microcontroller can be configured which results in lower operating frequency and energy saving also. The Dynamic Voltage Scaling (DVS) technic represents the possibility to decrease the supply voltage at lower clock rates which results in lower microcontroller speed [2,6]. Depending on the required SN processing power and speed, this method can be established to successfully realize energy management and savings during the active period of microcontroller. Software based optimization in which decreasing number of data write into memory and data read from memory can result in energy saving [2]. This can be realized for example in active period by minimizing the number of temporary data variables in which temporary values are stored. Software optimization is also vital key of overall SN design. It can in most cases be adapted on every SN to establish energy saving as the microcontroller unit (MCU) operating frequency can be lowered by a distinct value and thereby fulfill the processing requirements in active period.

3. PRACTICAL ENERGY SAVING RESULTS OF A SENSOR NODE

Possibilities and energy saving methods and results have been tested and analyzed on one practically implemented WSN intended for monitoring of environmental parameters. A performance exploitable sensor node in the network was configured to establish different energy consumption and saving methods and to measure consumption results. The sensor node is based on Arduino Uno 3 board along with XBee radio communication module as well as simple sensors for environment temperature and humidity measurements [7-9]. Block scheme of the wireless sensor node is shown in Fig. 1. All the mentioned SN components use 3.6V battery as power supply. The board shown in Fig. 1 is interfaced with sensor in order to obtain data from sensor during active period of the board and the radio module.

The board uses Atmel 8-bit microcontroller of AVR type which has possibilities to operate in different energy saving modes during inactive period [10,11]. The radio module itself is configured to enter sleep mode and turn back in active mode only during data transmission.

A section of software code on the SN for data processing and energy saving testing purpose is presented in Fig. 2. The software code is written in Arduino Integrated Development Environment (IDE) which has rich set of supporting library functions [7]. The software portion represents a call to a function which switches the microcontroller in one of different energy saving modes.
Results of SN energy consumption in different operation modes including power saving modes were practically tested and measured. Practical measurement results of board current consumption in different operation modes are presented in Fig. 3.

The written software code is tested for different microcontroller operation and sleep modes along with wireless radio module. The sensor itself consumes about one mA. In every sleep mode practical current consumption measurements were taken as well as in active mode, in which the radio module is also active. The average current consumption in the active mode was approximately 63.3 mA. The 26.4 mA current consumption value presented in Fig. 3 represents average current consumption for active period of board with inactive wireless radio module. It can be seen from the Fig. 3 that there was very significant energy saving if the wireless module is inactive and sleeping. The energy saving in that state is more than 55%. It means that it is very important to optimize usage of wireless module and to make it inactive in every situation when it is not needed to transfer data. Next two results shown in Fig. 3 are for different power saving modes (the power save mode and power down mode) of
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Microcontroller and inactive wireless module. The last result and mode presented in Fig. 3 is when the MCU clock frequency was scaled. In that situation the MCU operates at frequency of 1MHz, and the speed fulfills the sensor data processing requirements. It can be also seen from results in Fig. 3 that different microcontroller power saving modes can also contribute to further decreasing and reduction of power consumption. Using power save mode can decrease average power consumption for almost 30% compared with consumption of active board. Power down method can also reduce average consumption. That power consumption reduction can be more than 30% compared with active board consumption and almost 5% compared with operation in power save mode. Further energy consumption decreasing can be achieved by using MCU clock scaling. It is shown in the last result given in Fig. 3. The last result shows that using MCU power down mode and MCU clock scaling the average energy consumption can be decreased for more than 33% compared with consumption of active board, for approximately 3% compared with consumption of power save mode without MCU clock scaling, and for approximately 4% compared with consumption in power down mode without MCU clock scaling.

Practically obtained measurement results presented in Fig. 3 show that using different and appropriate methods for energy consumption saving and appropriate methods for energy consumption management can be significantly reduced average consumption of wireless sensor nodes and of complete WSN implemented in such a way using given hardware components. By writing appropriate software for hardware components management it can be minimized and optimized average and total power consumption of wireless sensor nodes and complete WSN. Practically obtained results show that for such implemented wireless sensors and wireless network using appropriate consumption management in some situations can be achieved power consumption reduction for more than 70%, and in some situations power reduction of almost 75%.

Real power consumption reduction in concrete implementation depends on concrete application and possibility to apply different power saving modes with need to satisfy all application requirements. So, it is very important for the designer to optimize and minimize software for application together with part for energy consumption management. In the design should be taken in consideration and implemented optimal methods for energy reduction management having in the mind needs and requirements of concrete application.

In outdoor applications such reduction of energy consumption can directly extend batteries lifetime and SN’s and complete WSN lifetime. Since the battery powered SN’s have limited energy appropriate energy saving methods and energy consumption management have to be considered and applied in SN’s and complete WSN.
4. CONCLUSION

Inexpensive and relatively simple widely used wireless sensor networks, especially in outdoor applications for monitoring and control environment, are mainly battery powered and require minimal energy consumption. It requires usage of one or several energy saving methods in the wireless sensor nodes and complete network depending on concrete network application and environment conditions. There are more possible energy consumption reduction methods for wireless sensor nodes and wireless sensor network. Considered and proposed energy saving and management methods represent the most used solutions to lower energy consumption at various levels on sensor nodes and whole wireless sensor network.

Designing sensor nodes and networks using energy efficient policies result in extended sensor node and battery lifetime. Such approach has many advantages and is more efficient in overall wireless sensor network usage because it does not need frequently battery replacement.

Presented practical tests and measurements show possibilities to realize energy saving and give some comparative results for different methods for energy consumption reduction. The results show that can be achieved significant savings in energy consumption using appropriate consumption reduction methods and appropriate consumption management. Obtained results show that the average and total energy consumption can be significantly reduced and minimized by optimizing power consumption management with satisfying all processing, transmission and speed requirements of concrete application. It is needed from the designer to optimize and minimize software for application and for energy consumption management implementing optimal methods for energy reduction management and fulfilling all needs and requirements of concrete wireless sensor network application.

5. REFERENCES