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WSN Sensor Node for Protected Area Monitoring

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Abstract—**The article is dedicated to sensor node design focused on minimalization of energy consumption. The mote is proposed for low rate or occasional data transmission so that communication subsystem energy consumption can be minimal. In case of simple applications, the sensor could be energized from two super-capacitors 50F/2.3V during 14 hours. The mote consists of acoustic sensor monitoring specific events and switching microcontroller from stop-status to active-status. All rest mote functions are controlled by microcontroller. Real time clock (RTC) can activate sensor node too. It can be used for time synchronization of communication subsystem as well.**

I. Introduction

NONTRADITIONAL applications of ICT means are presented more than less in present days. Wireless sensor network (WSN) applications are classified like relatively new ones. They were judged rather as interesting solutions than powerful technology couple years ago. WSN world market is expected to grow five times in next decade (from 0.45 billions USD in 2011 to 5 billions USD in 2021). The values do not include non-mesh wireless sensor applications. In present, the most popular WSN implementations are focused on energy and water consumption measurement and registration systems.

WSN consists of large scale distributed sensing elements in monitored area, cooperating with each other, evaluating status of selected objects in consecutive way. Term object could be understood in wider sense, e.g. protected area, production link or living being, etc. In present, most of installed sensors communicate via wire line. It is expected that during next ten years about 10% of them will be part of WSN. WSN solutions decrease expenses related to system installations, maintenance and software update, in comparison with traditional technologies, see literature [4], [5], [13]. In present, average price of sensor node is about 9USD. It is expected that it will drop down to 5USD by 2021. This fact drives development of new WSN applications. According to [4] and [6], the development is growing in the states with good financial situation. Research centers are founded and development of new applications are supported. Referring to mentioned information, the USA is leading country from global point of view. The university workplaces were financed on the level of cca 100 millions USD from 1998 to 2005. The center for development of embedded network measurement systems (CENS) was established at the University of California in Los Angeles (UCLA). 40-million USD financial support was arranged for the center.

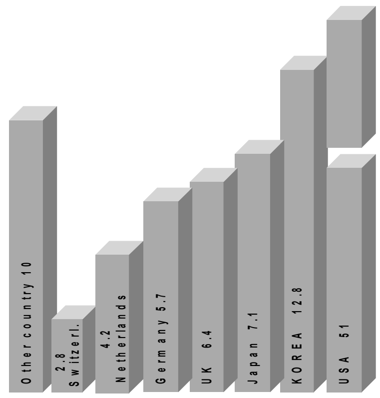

Fig 1. Sharing market of WSN according to countries

European commission decided to support research and development of WSN applications in 7th Framework Programme (7FP) in Information and Communication Technologies section, 7thFP-ICT. 50 millions EUR were reserved for years 2007-2013. This step could be evaluated as positive signal in sense of future EU interest in the field of WSN applications. Interesting ones presented in [1], [2] and [3] confirm the trend.

Meaningful applications have been realized in environmental sector. The authors in [9] describe forest areas monitoring on the basis of WSN. Temperature and humidity of environment were measured. Fire detection, in monitored region, has been possible on the basis of collected data evaluation. The network consists of clusters of sensor nodes and communication cluster head connecting WSN with network coordinator and monitoring center (via router). Technical solution and strategy of network operation is proposed in compliance with minimalization of energy consumption. Detecting fire alarm signal is sent to monitoring center. It allows information verification via the nearest camera to signaled mote. IP cameras are part of the network. Proposed solution improves fire identification. On the other hand, technical solution requires more investments, energy consumption and sophisticated communication system. Referring to the paper [10], detailed review of sensing and data processing methods in environment of WSN is presented. The methods support reliable and fast fire identification in monitored area. The problem of acoustic signal evaluation for monitoring and protection of national park was analyzed in the work [12]. The article is focused on methods and implementation of automatic gain control of acoustic signal. Development and examples of WSN applications powered by solar energy are described in the article [11]. In most cases chargeable batteries are used as energy storage devices.

Referring to above mentioned analysis of existing WSN applications, it is clear that several research centers are interested in problems of environmental monitoring, especially forest one focused on fire detection. Certainly, WSN can be applicable in other applications as well, for example: protection against poachers, illegal trees cutting and constructing in the forest, etc.

II. Sensor Node Design

Energy consumption of every element of WSN has dominant influence on successful implementation of it in environmental monitoring and protection. Referring to discussed applications, every sensor node represents unnatural element in monitored area. Sensor node design had to satisfy requirement of WSN elements energizing on the basis of energy collection from surrounding environment. This solution expects super-capacitor to be energy storage. Referring to current stage of super-capacitors production technology, energetic cubic density of them is about 100 times lower than in case of chargeable batteries. Referring to figure 2, alternative solutions of sensor node energizing are presented for comparison and illustration.

It is clear that if 2 serially connected super-capacitors are used for energy storage then value of utilizable energy is about 200J. Utilizable voltage range 4.6-2.2V is expected. In case of utilizable voltage supply from the range 4.6-2.7V, only 173J of energy will be available for sensor node. Voltage range 4.6-2.2V, respectively 4.6-2.7V, is defined by parameters of used electronic elements (type OA, transceivers). Referring to relatively big leakage current of present super-capacitors, it is logical to expect self-discharging of them.

Referring to testing of electric double-layer super-capacitor (EDL) 50F/2.3V, average voltage drop was 95mV during 14hours. In case of capacity 50F and average voltage value 2.22V, mentioned voltage drop matches 10J of energy. Average value of leakage current 80µA was defined on the basis of measurements. It corresponds with electrical characteristics of current super-capacitors. It is necessary to mention that self-discharging characteristics EDLC are dependent on charging time period as well. In discussed case, super-capacitors were charged to value 2.26V during 3 minutes. Self-discharging process could be significantly improved by longer charging time period.

Charging super-capacitors by solar cells then energy 200/173J will have to assure operating of sensor node during all night. It represents time period cca 14hours in central European winter time environment. It is clear that sensor node energizing is one of core WSN design problem.

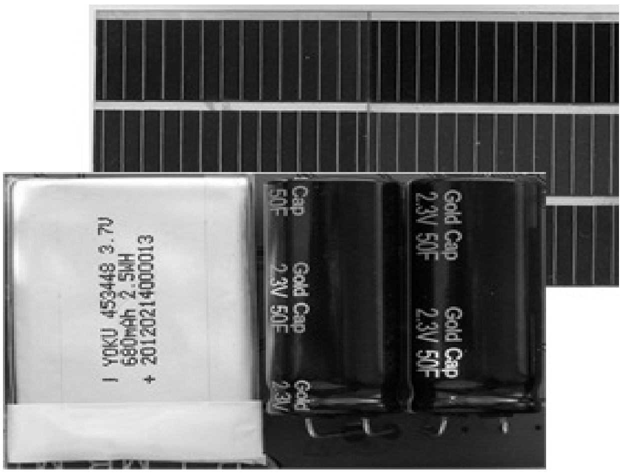

Fig 2. Solar cells (6 pcs. 29.4x12.3mm-40mW@1000W/m^2), rechargeable battery (Li-Pol: E=9057J) and super-capacitors (2x50 F/2.3V: E=264J)

Being able to guarantee mote operation during 14 hours, strategy of node activity must be chosen in compliance with minimization of energy consumption, especially during time period when energy consumption is going to be assure by means of super-capacitors energy.

For purpose of sensor node design it is going to be expected that typical distance between two sensor nodes will be 50m, maximal accepted message delay (time from event appearance to message delivery to monitoring center) will be 10 minute. Operation of the network will be depended on proposed network topology. Technical sensor node design must respect limitations related to energy supplying. In operation mode must be all energy demanding subsystems switched off, respectively in power down mode. Activity measuring subsystem will be non-stop energized. In case of designed mote, acoustic sensor is waking-up master microcontroller. Referring to above mentioned expectations, architecture of mote consists of following basic units: data processing unit (master microcontroller), communication unit (transceiver), activity sensor, sensing unit, power supply unit. Block diagram of basic units of sensor node is presented in figure 3. Energy consumption in operation mode and low power mode is described as well. Activity sensor is energized continuously. Other units of mote are in low-power mode in most of time, potentially are switched off from energy supply.

III. Energy Budget of Sensor Node

Let us analyze energy consumption of particular units of the mote during time period when the elements are energized by super-capacitor. Referring to expectation that continuous energy consumption of activity detector is 100µA under average voltage 3V, energy required for 14-hour operation is given by relation:

$$E= I \cdot U_S \cdot t = 15.12\ J. \qquad (1)$$

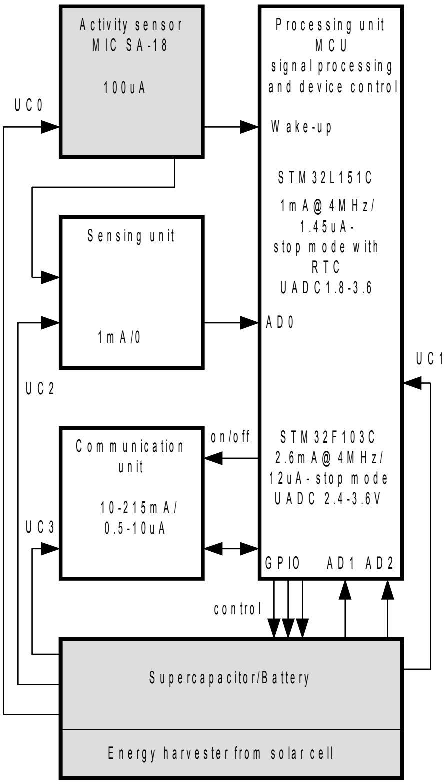

Fig 3. Block diagram of sensor node basic units

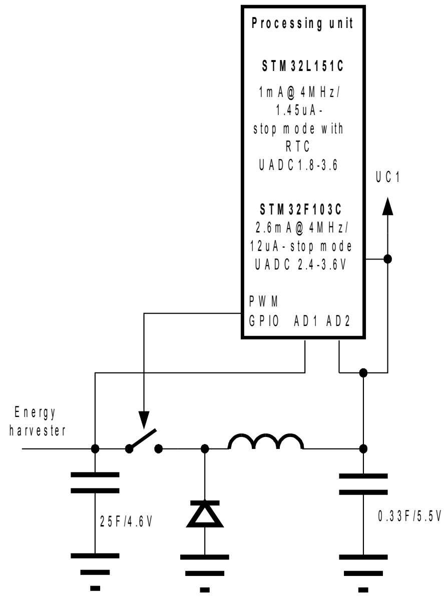

Fig 4. Solution of sensor node energizing

Basic energy consumption of sensor node during 14 hours (without communication and appearing of monitored event) is then given especially by energy consumption of activity sensor, i.e. 15.1J. If total available energy for energizing of the mote is 180J (after subtracting of losses related to self-discharging) then it is necessary to choose such strategy of WSN operation so that rest 164.9J would be enough energy to guarantee correct node operation during time period when solar cells are not going to generate energy. Let us remember that consumption of communication module is depended on selection of transceiver. It is clear that module consumption will be depended on required communication distance, frequency band, data rate and other parameters. Communication system must meet requirements of valid norms and standards. Selected parameters of various transceivers are presented in table 1. Energy consumption of activity sensor is treated by primary super-capacitor 25F/4.6V (2x50F/2.3V). The consumption of communication unit, microcontroller and sensing unit is treated by secondary super-capacitor 0.33F/5.5V, figure 4. In case of estimated value of consumption for low-power modes 20μA, the voltage on secondary super-capacitor will drop down by 0.5V during 139 minutes. From mentioned idea implies that if no event appeared in monitored area (which could wake-up sensor node) it is enough to activate microcontroller to check voltage on primary and secondary super-capacitor every second hour. In case when it is not necessary to charge secondary super-capacitor, sensor node will be switched to low power mode again. In case when the super-capacitor must be charged (the voltage will drop bellow defined value 2.5V) MCU will start its charging using PWM signal.

Processing unit can be activated in two ways:

- By alarm generated by RTC (real-time clock) unit (real-time unit is part of the MCU and is also active in stop mode),
- Using activity detector, which is able to generate an interrupt signal when the sound pressure rises above a defined level.

Presented sensor node activations allow WSN to be event-driven, time-driven as well as time/event-driven.

Control system of WSN is depended on basic requirements that imply from defined application. In case of simple monitoring systems (long-time measurement of air quality, meteorological networks, etc.) message delay is not so much important. In case of other applications, e.g. monitoring and protection against illegal access into areas, messages delays could make all security system nonfunctional. It is clear that in these cases messages must be delivered to monitoring center in time, i.e. in case of multi-hop communication motes activity sensors must be continuously active. Receiver is relatively high energy consumptive element of communication unit, see table 1.

This is reason why it makes sense communication subsystems to synchronize. It will allow communication modules to activate periodically in the same time. Messages transmissions will be realized during these time periods. Ones transmissions will finish, communication subsystem of the network will be switched to low-power mode. Presented communication strategy will be energetically successful only in case when amount of transmitted data for time unit is going to be significantly lower than throughput of communication channels and accepted message delay will be big one in relation to start-up time of transceivers. This strategy keeps communication modules in nonactive mode during most of time.

TABLE I.
PARAMETERS OF DIFFERENT TRANSMITTERS/RECEIVERS

Type	Range (outdoor)	Data rate	Frequency	Power supply	RX	TX	Power down
XBee (802.15.4)	90 m	250 kbps	2.4 GHz	2.8-3.4 V	50 mA	45 mA	10 µA
XBeePro (802.15.4)	750 m 1500 m	250 kbps	2.4 GHz	2.8-3.4 V	55 mA	137 mA - 215 mA	10 µA
XBeePro 868 (802.15.4)	40 km	24 kbps	868 MHz	2.8-3.4 V	55 mA	137 mA - 215 mA	10 µA
MRF24J40MA (802.15.4)	120 m	250 kbps	2.4 GHz	2.4-3.6 V	19 mA	23 mA	2 µA
MRF24J40MB (802.15.4)	1200 m	250 kbps	2.4 GHz	2.4-3.6 V	25 mA	130 mA	5 µA
ProFlex01 (802.15.4)	1200 m	250 kbps	2.4 GHz	2.2-3.3 V	30 mA	145 mA	3 µA
LT2510	2.4 km	280/500 kbps	2.4 GHz	3.3V	10 mA	90 mA	50 µA
RFM12B	200 m	115/256 kbps	315/433/868 MHz	2.2-3.8 V	11-13 mA	22-24 mA	0.5 µA
RFM22/23B	800 m	256 kbps	433/868 MHz	1.8-3.6 V	18.5 mA	30-85 mA	0.45 µA
RFM70	10 m	1-2 Mbps	2.4 GHz	1.9-3.6 V	17 mA	11-23 mA	3 µA

Let us expect maximal message delay equal to 10 minutes. Evaluation and registration of event (acoustic information) is realized in sensor node and for transmission is prepared only very short message (maximally 10B, event description, source and receiver address, energy status). Then information transmission and network synchronization lasts 2 seconds. Consumed energy for defined transmission in case of transceiver MRF24J40MA is 140mJ. During 14 hours of operation is necessary 14·6=84 communication windows with total energy consumption 11.8J. Let us assume microcontroller to be active during communication windows, i.e. it is active during time period 84·2 seconds. About 7·100s is dedicated to monitoring and control of source of energy supply. Total energy consumption of master microcontroller for securing of functionality of sensor node is 6.8J for STM32F103Cxx. In case of utilizing of low-power MCU STM32L151Cxx is total energy consumption only 2.6J. Then energy consumption of particular units of the mote during 14 hours is presented in table 2.

Referring to information about consumption of particular node units, total energy required to guarantee basic functionality of sensor node during 14 hours is 37.6J (31.82J). Energy 180 –37.6= 142.4J is available for energizing of microcontroller and sensing unit in cases when activity detector detected monitored event.

TABLE II.
ENERGY CONSUMPTION PER 14 HOURS

Subsystem	Energy consumption Active mode [J]	Energy consumption Low-power mode [J]
Activity sensor	15.1	0
Micro-controller	6.8 (2.6)	1.8 (0.22)
Transceiver MRF24J40MA	11.8	0.1
Other	2	2

For better understanding, energy 142J can energize micro-controller STM32F103Cxx@4MHz during time period equal to 5 hours and 46 minutes, low-power MCU STM32L151Cxxx@4MHz even 15 hours, transceiver MRF24J40MA in active mode 47 minutes or allow transmission during 39 minutes.

It is clear that in cases of large scale multi-hop networks 2 second width of time period available for communications will not to be satisfactory. In this cases, communication time period is necessary to extend to satisfy requirements of all sensor nodes. Certainly, if maximal message delay is going to be constant it will bring increasing of energy consumption.

Another solution supporting keeping energetic limits is based on adaptation of WSN topology. WSN is split into proper number of autonomous areas called clusters. Every cluster consists of cluster head which can communicate with every mote of cluster as well as sink node (base station). It means cluster head can transmit aggregated data. This topology simplifies communication system which is usually single-hop one as well as routing strategies. Energetic effectiveness of WSN communication system is increased. Disadvantage of clustering is related to limitation of communication distance because of defined transmit power limit and sensitivity level of transceivers.

IV. CONCLUSION

Presented wireless sensor network is in stage of realization. Only expected experimental works will give clear answer if theoretical calculations are going to meet practical measurements. WSN is primary designed for monitoring of illegal visitors in protected areas. In each case it would be possible to use it for fire detection in forest, monitoring of traffic flows and vehicles on the basis of sound emission, objects and border protection and so on. Proposed sensor node can be energized from chargeable Li-pol battery or super-capacitors in cooperation with solar system with active area of $12cm^2$. Since it is expected that super-capacitor can be used as energy storage, design of mote took into account minimalization of energy consumption. Communication subsystem is part of sensor node which plays crucial role from energy consumption standpoint, in case of large data amounts transmission. This is reason why suitable operation strategy and network topology can have significant influence on total energy consumption of sensor node. Problems associated with suitable network topology and communication subsystem operation will be analyzed in depth during experimental activities with realized WSN.

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