One realization of low-power wireless sensor node

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Abstract **–** In this paper a practical realization of sensor node is described. Performance analisis for new implemented protocol is also described. In proposed model a sensor network is organized into local clusters. Within the cluster a nodes are battery powered and fixed cluster-head or gateway node have large power supply. In this paper a data exchange between sensor node and cluster head only bee analyzed. Data exchange and number of nodes in cluster is effect statistical analysis based upon in Poisson distribution. Minimum number of trials needed to be sure that the packet reaches the receiver with prescribed probability for varying bit error rate is discussed, too. Lastly, for our hardware solution and example application for temperature measurement energy consumption analysis is given. Comparative results display a power consumption reduction of one order of magnitude regard to previous solution.

Keywords **– Sensor node, Poisson process, Hamming code.**

I. INTRODUCTION

In recent years, advances in wireless communications, micro-electro-mechanical systems (*MEMS*) technology, and digital electronics have contributed to the development of small and inexpensive low-power sensor nodes. A sensor node (*SN*) consists of some type of sensor, with data processing and communications capabilities. [1]

A wireless sensor network (*WSN*) is a collection of *SN*'s that communicate what is sensed continuously, or to detect specific events.

Sensors come in many types (e.g., thermal, infrared, acoustic) and can monitor a wide variety of conditions (e.g., temperature, humidity, and pressure). The variety in types of sensors and in their usage has precipitated applications for sensor networks that span a range of personal, corporate, and national interests. As a result, research on sensor networks has grown rapidly in order to support the implementation of these emerging applications like environmental monitoring, smart spaces, medical systems and etc.

Another characteristic of these networks is that sensors have limited resources, such as limited computing capability, memory and energy supplies, and they must balance these restricted resources to increase the lifetime of the network.

In addition, sensors will be battery powered and it is often very difficult to change or recharge batteries for these nodes.

Therefore, in sensor networks, we are interested in prolonging the lifetime of the network and thus the energy conservation is one of the most important aspects to be considered in the design of these networks

While some applications demand a high transmission data rate, most sensing applications will require very low data rates compared to conventional multimedia traffic and they operate in burst mode.

As a result, there are several new challenges faced at the circuit level. For example, the design of a very low duty cycle radio is essential for transmitting small packets (e.g., a temperature sensor may transmit *100* 's of bits every few minutes). Existing radio architectures are not suitable for these very low data rates since they have significant energy overhead in powering on and off.

In order to design application specific network that have extremely long lifetime, we propose a sensor network structure that relay on clusters. A cluster is of a battery powered wireless sensors with transmitting capabilities only and one cluster head with large power supply. We first present a hardware structure of sensor node and communication scenario is described. MAC layer and error correction technique is also described. Based on *16* sensor nodes network model, energy consumption is analyzed.

II. SENSOR NODE HARDWARE OVERVIEW

In this section, hardware architecture of proposed sensor node will be shortly described and pointed out main charecteristics. Block structure of the sensor node is shown on Fig. 1

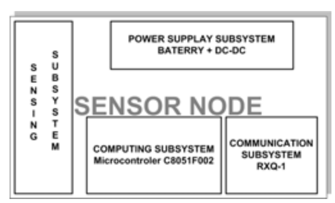

Fig 1. Block structure sensor node

A sensor node usually consists of four sub-systems :

Computing subsystem: It consists of a microcontroller unit, which is responsible for the control of the sensors and execution of communication protocols. Our computing subsystem is realized with 8-bit MCU type C8051F002 [2]. Its basic characteristics what it recommend for this application sort are: Pipelined instruction architecture, 21 vectored interrupt sources offer capability event-driven power management, 12-bit SAR ADC, built-in temperature sensor, clock source can be switch on-the-fly.

Communication subsystem: It consists of a short range radio which is used to communicate with cluster-head. For communication subsystem we select commercially available FM narrow band transceivers RXQ1 [3]. Main characteristics are: host data rate up to 19.2 kBaud, data rate to 20 kBaud, 2 selectable RF channels and optimal range 200m. Radios can operate under the Transmit, Receive and Power Down modes.

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Sensing subsystem: It consists of a group of sensors and actuators and link the node to the outside world. Energy consumption can be reduced by using low power components. In our *SN* example take advantage built-in temperature sensor.

Power supply subsystem: It consists of a battery which supplies power to the node. The lifetime of a battery can be increased by reducing the current drastically or even turning it off often.

III. Protocol funadmentals -MAC Layer

The fundamental task of any *Medium Access Control* (*MAC*) protocol is to regulate the access of a number of nodes to a shared medium in such a way that certain application-dependent performance requirements are satisfied. This section presents the fundamentals of *MAC* protocols and explains the specific requirements and problems these protocols have to face in wireless sensor networks. The single most important requirement is energy efficiency and there are different *MAC*-specific sources of energy waste to consider:

A. Overhearing Since the radio channel is a shared medium, a node may receive packets that are not destined for it.

B. Collision If two nodes transmit at the same time and interferer with each others' transmission packets is corrupted. Hence, the energy used during transmission and reception is wasted.

C. Overhead The MAC headers and control packets used for signalling (*ACK/RTS/CTS*) do not contain application data and are therefore considered as overhead.

D. Idle listening If a node does not know when it will be the receiver of a message from one of its neighbours, it must keep its radio in receive mode at all the times.

IV. Error Control Technique

Error-control techniques are designed with the goal to achieve a certain level of reliability in the transmission of packets despite errors on the transmission channel.

In wireless sensor networks, we have the additional requirement to achieve this reliability level with a minimum amount of energy.

The most important error-control techniques are *Forward Error Correction* (*FEC*) and *Automatic Repeat Request* (*ARQ*).

In all *FEC* mechanisms, the transmitter accepts a stream or a block of user data bits or source bits, adds suitable redundancy, and transmits the result toward the receiver. Depending on the amount and structure of the redundancy, the receiver might be able to correct some bit errors. *FEC* can be used as an open loop technique, which means that there is no feedback from the receiver. Accordingly, the transmitter uses the same coding method all the time.

In this project *Hamming* code (12, 8) is used [4]. *Hamming* code is linear error-correcting code. Using *Hamming* code a single bit errors can be corrected and double bit error can be detected.

V. Model

In this work we used protocol model based on ALOHA protocol with certain modification [5].

Let analyze a cluster with N nodes and one central cluster head. For given coverage range of node, all of the nodes will have a random number (N) of neighboring nodes. Assume that all nodes have unlimited number of packets for transmission. Performance of the model is subjected to stochastic *Poisson* distribution defined as: [6]

Def: *Poisson* distribution is a discrete probability distribution that expresses the probability of a number of events occurring in a fixed period of time if these events occur with a known average rate, and are independent of the time since the last event.

$$f(k,\lambda) = \frac{e^{-\lambda}\lambda^k}{k!} \tag{1}$$

Quantitative measurement of analyzed protocol is achieved by next assumptions:

1. Packets' lengths are fixed.
2. Time consumed for packet transmission is declared as one time unit.

According to *Poisson* model, probability that k packets will attempt to accomplish the transmission in t time units amounts:

$$P[k\ tran\ in\ t\ time\ units] = (G*t)^k * \frac{e^{(-G*t)}}{k!} \tag{2}$$

Where are:

G - Offered load: number packet transmission attempted per unit time or it is the expected number of occurrences in the specified interval t .

k - Packet transmission attempts in t time units

For proposal model cluster with N nodes arrival rate i.e. average number of attempts to access the channel, in our case is G . If there are N nodes each of which produces an individual arrival rate G , the overall rate is $N \cdot G$.

For successfully transmitted packet needs at least two frames. In other words there have to be 0 arrivals of other packets during two periods.

The probability that frames are transmitted successfully, in unit time, is:

$$P_S(0) = \frac{(2GN)^0}{0!} e^{-2NG} \tag{3}$$

If we have frame of length T_F per unit time, probability is:

$$P_S = e^{-2NGT_F} \tag{4}$$

Achievable data throughput, L (having N participants with a transmission rate of G packets per frame length and participant) is:

$$L = GNT_F * P_S \tag{5}$$

For the throughput per node, S , we get:

$$S = \frac{L}{N} = G \cdot T_F \cdot P_S \tag{6}$$

The probability to transmit the message successfully at the K^{th} attempt will be given by geometric distribution

$$P(K = k) = (1 - P_S)^{k-1} P_S \tag{7}$$

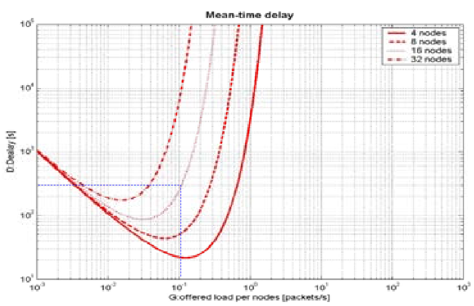

Fig 2. Mean-time delay

From theory about *Poisson* process we have that the mean time between two attempts is $1/G$ and described by an exponential random variable with parameter λ .

Therefore, a mean time for successful transmission can be computed as:

$$D = \sum_{k=1}^{\infty} k \frac{1}{G} (1 - P_S)^{k-1} P_S = \frac{1}{G \cdot P_s} \quad (8)$$

Let us consider other approach. The packet success probability P_s for fixed bit error probability p (*BER*), a packet of l bits length, and an infinite number of trials, is given by

$$P_s(l) = (1-p)^l \quad (9)$$

Then the packet error probability is

$$P_e(l) = 1 - P_s(l) \quad (10)$$

The number of trials $i \in N$ needed to successfully transmition of the packet is a geometric random variable X with probability function give in Eq 7. and cumulative distribution function

$$F(k) = P_r[X \le k] = \sum_{i=1}^{k} P_r[X = i] = 1 - P_e(l)^k \quad (11)$$

The number k^* of trial needed to deliver the packet with at probability δ is given by Eq 12.:

$$k' = F^{-1}(\delta) = min\{ k \in N : F(k) \ge \delta \} = F^{-1}(1 - P_e(l)^{\delta})$$

$$k' = \frac{log(1-\delta)}{log P_e(l)} \quad (12)$$

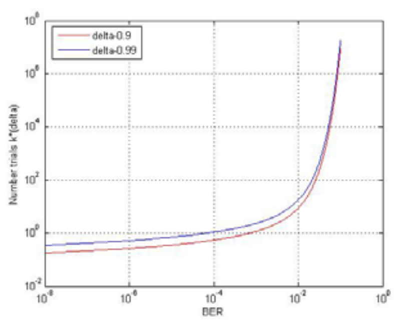

Fig 3. Number trials $k' = f(delta, BER)$

The number k' is graphed in Fig 3. for packet length of $l = 144$ bits and two different reliability values $\delta_1 = 0.9$ and $\delta_2 = 0.99$.

Based on Fig. 3 we conclude that the channel will successfully transmit the packet in the first try for BER with approximate value of 10^{-5} having in mind additionally improvement achieved by Hamming's coding which is shown in Fig. 4

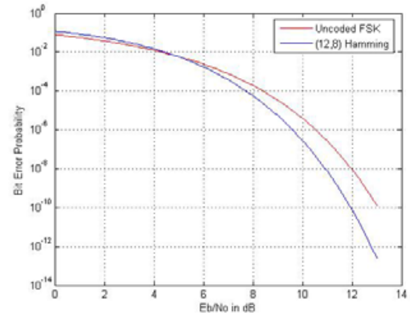

Fig 4. Bit error probability

VI. ANALYZE SENSOR NODE ENERGY CONSUMPTION

Power consumption analyze of experimental sensor node model will be observed trough next three situations:

A. Mathematical model of the proposed protocol.
B. Power consumption analyze for temperature measurement application.
C. Sensor node power consumption analyze due to working mode

A. In proposed protocol model every node only sends message so that the total power consumption is equal to the sending energy. Let us observe a node which has G number of tries to channel access and assigned with p_{RX} probability.

If the node does not send any messages then:

$$p_{TX} = 1 - p_{RX} = 1 - \frac{(1G)^0}{0!} e^{-1G} = 1 - e^{-G} \quad (13)$$

From here it is obvious that statistical consumption energy per node in dependence to G number attempt to access channel is:

$$Power_{node} = p_{TX} * Power_{TX} = (1 - e^{-G}) * Power_{TX} \quad (14)$$

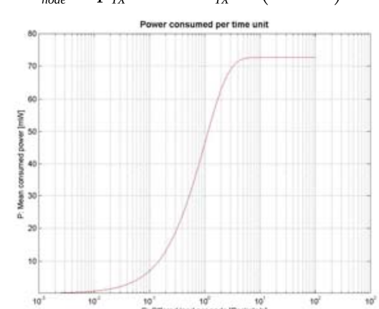

Fig 5. Power consumption per time unit

B. As can be concluded from above, this type of protocol will bee optimal for low level data traffic. This can be achieved through the use of appropriate number of nodes and implementation in low speed measurement applications.

According to previously stochastic analyze, Fig. 2, a 16 nodes in network and temperature measurement as application is adopted. The application provide two levels of temperature tracking: i) temperature measurement in regular time intervals of 20 seconds, and ii) recording of temperature excursions from declared temperature window, *T_window*.

The application algorithm is given in the folowing section as high level language description.

Begin
Init; *//Initialize sensor node*

WHILE (1)
Go to sleep; *//Node goes to sleep mode*
IF Timer_Interrupts(400ms@1.8432MHz)==20s
THEN
Temperature_Measurement;
IF Temp_Value > ADC_Programmable_Window
THEN
Generate_Frame_And_Send;
ELSE
IF Timer_Interrupts(400ms@1.8432MHz)==300 s
THEN
Compute_Taverage_Tmax_Tmin
Generate_Frame;
Hamming_Code (12, 8);
Send_After_Rand+Fixed_Number_Different_For_Nodes;
ELSE
ENDWHILE

In our model data transmition is acomplished by using the next packet, shown on Fig. 6, which is the consequence of analyzed trafic and application requirements.

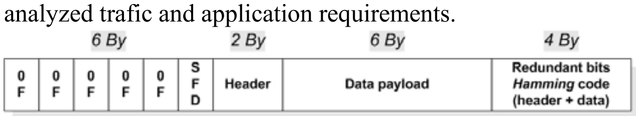

Fig 6. A typical data packet

As it was mentioned in section V, convenient technique channel coding is *Hamming* code. For transfering of 8 By data by *Hamming* (12,8) code techique, there are redudancy for extra 4 By. Analisys point that time neded for transfer a *18 By @ 19.2 kbps* mesage amounts *7.5 ms.* From this result we obtain that energy per bite is $3.78\ \mu J$.

There is also one more side of energy consumption. It is software execution which is given on Fig. 5.

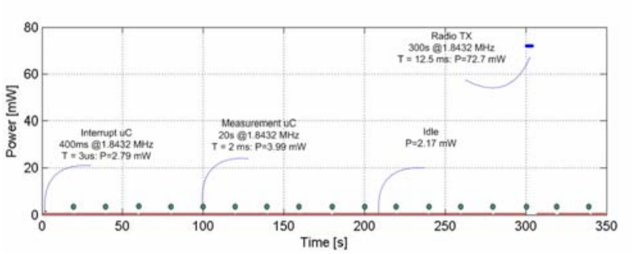

Fig 7. Power consumption for our system during a period data-sampling and communication time

C. The result of examination of the selected application is a fact that the average current for proposal protocol in interval of 3600s is

$$I_{SR}\Big|_{T=3600\ s} = \sum_{i=1}^{3} \frac{T_{RUN_i} * I_{RUN_i}}{T} + \frac{T_{IDLE} * I_{IDLE}}{T} = 805{,}15\,\mu A \quad (15)$$

Where:
$i=1$, timer interrupt $400\ ms$; $i=2$, timer interrupt $20\ s$, and $i=3$, timer interrupt $300\ s$.

Average energy consumption is given by:

$$P_{SR} = I_{SR} * U\Big|_{2.7\,V} = 2.174\ mW \quad (16)$$

On the other hand, the power consumption in data processing $\left(P_p\right)$ can be formulated as follows:

$$P_p = CV_{dd}^2 f + V_{dd} I_0 e^{V_{dd}/nV_T} \quad (17)$$

where:
C is the total switching capacitance; Vdd , the voltage supply and, f the switching frequency. Second term indicates the power loss due to leakage current. For low duty-cycle systems, the overall energy consumption becomes increasingly dominated by leakage effects.

VII. CONCLUSION

In this paper we have presented an stochastic performance analysis of the protocol for low data traffic. Attained results are practical confirmed with temperature measurement application. Measurements are executed in regular time intervals of 20 seconds and transmission of data in regular time interval of 300 s which is meteorological standard.

Data packet is formed from minimal, maximal and average values of temperature so that message length is minimized. In the worst case for the time interval of 300 s + random number + fixed number for different nodes there are 16 messages which give *0.0533* offered load packets per node per second. In this way receiving mode of *SN* is eliminated. Mostly sources of energy waste at *SN* as overhead, overhearing, and idle listening, is eliminated, too.

By using *Hamming* code channel coding technique we have achieved significant improvements of reliability transfer. Lastly, proposed protocol represents effective solution for low duty-cycle systems, the overall energy consumption becomes increasingly dominated by leakage effects and significant reduce battery lifetime.

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