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PROBABILISTIC METHODS OF CONTROLLING EMISSIONS IN THE RADIO NETWORK

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This paper presents a method of probabilistic radio transmission control in wireless sensor networks (WSN). Specified probability of collision-free conditions in the network transmission of the single-hop type. We propose the concept of WSN with random moments of time-signal emissions with a one-way transmission using one radio frequency. We use Poisson Arrivals See Time Average (PASTA) for modeling probability of a collision during the transmission of the radio network to control the correct network operation. The proposed model WSN network access allows the improvement of the reliability and security of information.
Key words: Wireless Sensor Network, Poisson Arrivals See Time Averages (PASTA system), probability of collision, random control

Problem formulation

In the paper we present problems of radio communications for wireless measurement networks. We analyze the random access control for wireless measurement nodes by examining the conditions of communication, depending on their number, average working time of transmission based on the previously proposed algorithm which uses a Poisson stream. In particular, we estimate probabilities of the determined number of times messages by nodes that are in a collision during communication based on the number of nodes and other network communication parameters. We estimate both unconditional and conditional probability on the assumption of a given number of sensor transmissions. It also provides an estimation of the expected number of nodes that are in collision and the variance. Proposed probabilistic model can increase the reliability of the network and increase the security of the information.

Evaluation of the recent publications in explored issue

Wireless sensor networks create a new quality in modern systems, acquisition and transfer of information (Wireless Sensor Network – WSN). Implementation of WSN puts an entirely new requirements for the radio communication and control processes, which manage to meet the increasingly sophisticated technologies [1]. The use of radio communications in the network-type convergecast is much more difficult than in a well operated radio broadcasting systems (broadcasting, television, satellite GPS, etc.) and conciliation point-to-point (cellular telephone). The main difficulty lies in the organization of radio traffic which is represented by the controlled access to the transmission medium which in other terms represents the surrounding space. In the surrounding area, an active space in the radio communication is defined by the value of the electric field which produces a transmitting device at a given point of space. There can be only one sender at a particular frequency. As we know from Maxwell's equations [2]. In vacuum by physical constants permittivity of vacuum $\varepsilon_0 = 8.854 \cdot 10^{-12}$ F/m and the magnetic permeability of vacuum $\mu_0 = 4\pi \cdot 10^{-7}$ H/m) defines the vacuum as a transmission medium impedance $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega$. In the terrestrial conditions of the troposphere, the situation is quite similar, but each object field and the Earth itself has a very different electrical and magnetic parameters. This results in significantly different impedances of these centers and their contact with the air comes to the many reflections of radio waves. Reflections considering additionally the principle of Huygens created another problem in the radio transmission – the multipath transmission and thus it created a problem of the multi-way loss. In the air we observe a large heterogeneity due to the different temperatures of the different air, water vapor content, rain, snow, pollination layers, the state of the air ionization which constitutes the source of refraction and transmission path of the increased attenuation [1]. Designing radio communication types, these phenomena must always be taken into account. In case of wireless network design aggregation of all these phenomena effectively impedes proper communication and discussion in case of a success or a failure of the radio transmission. The fundamental problem in WSN network concerns the controlling of the network access to the information mouth (sink), so that the transmission medium is occupied at a certain frequency and at a given point of time by only one sender [3]. In an environment covered by a wireless network must be developed ways to control access of each node – network components that information seamlessly redirected to the mouth (sink) [4–7]. It should be noted that the correct reception depends not only on the resolution of the network itself, but also on external influence of other radio communication types. The subject of this paper concerns the issue of controlling the node access to the base station in the single-hop type wireless networks [8] applying random methods.

This applies in particular to the organization and process control of the radio emission with an aim to obtain data on the deliberate quality level under all relevant physical conditions of the wireless network work [9].The paper [10] presents a random access algorithm for a class of wireless network measurement and the analysis of working conditions. The concept of the convergecast networks (sink) (e.g., wireless sensor network (WSN)) involves the fact that the information sources distributed in space (fixed and mobile), which are considerably numerous, communicate with the information directly to the base station (the mouth of the information) [11]. These are networks of single-hop. Networks of the single-hop is a traditional star topology in which each link can be implemented duplex or Simple, depending on the needs and dispose the number of required frequency channels (frequency dispose). If the network is organized in a way that it is capable to provide information through other nodes, somewhat indirectly, than the networks are multi-hop. Network of the multi-hop architecture is the most common type mesh [12, 13]. Network architecture of the multi-hop is more complex. It is also a sophisticated hardware and requires complex control algorithms. However, it has many advantages over a solution of the single-hop. For example, the possibility of reconfiguration in case of a failure or unavailability of certain nodes, allows the range enlargement within the same low-power transmitting nodes [14]. It is assumed that the various communication nodes (associated with the sensors) can move in a field study of the physical effects and are controlled by sensors (they are mobile). This means that it will require a dynamic reorganization of the network architecture.

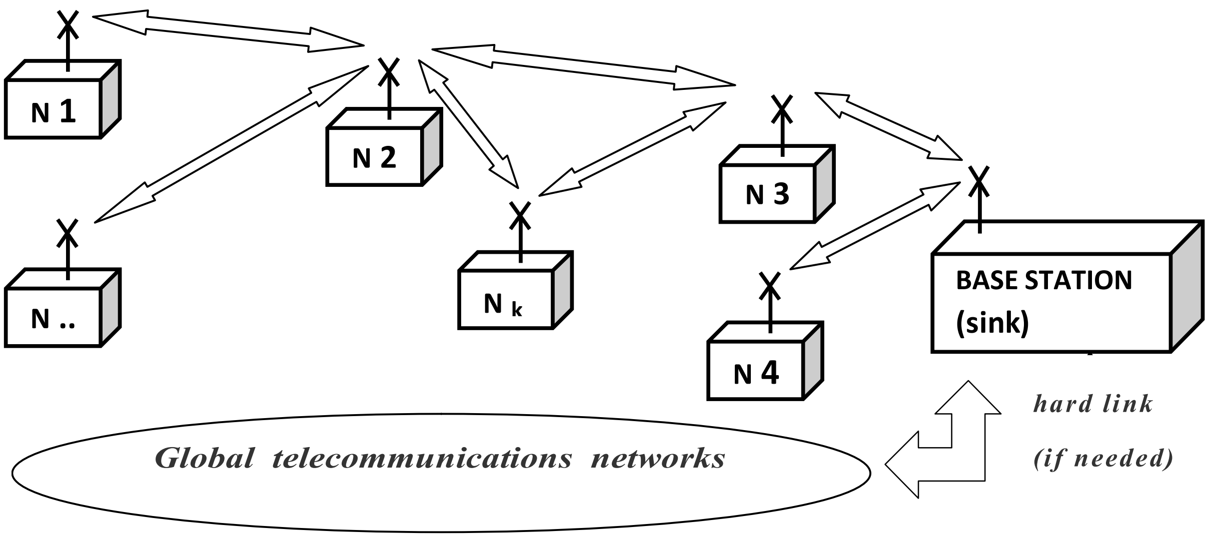

Fig. 1. Wireless network multi-hop

The WSN network conditions limiting the power supply and energy supply sources capacity constitute the primary problem of determining the solutions further consequences [15]. For this reason, frequent solution is the multi-hop topology (retransmission from node to node until the sink), than the single-hop requires more energy for the radio transmission. The multi-hop network requires more complex communication algorithms. Low level of radiated power, can be an advantage on the one hand, but on the other hand it also creates communication problems. Limitations of the power supply require incorporation mechanisms for "savings" that allow the user the possibility of a longer «life» at the expense of reducing the network bandwidth, or increasing the transmission delay [16, 17]. WSN design in terms of access control nodes to the mouth of the data (sink) requires the following conditions [6–8, 15]:

- Bands and frequency communication;
- Hardware limits;
- Restrictions on the external (environmental);
- The demand for power supply (e.g. for communication and data processing);
- Scalability;
- Range of fault tolerance.

Characteristic features of the networks topology WSN in the access control

It is assumed that the various communication nodes (associated with the sensors) that can move in a field study of the physical effects are controlled by the sensors. Thus, the mobility of nodes is assumed, which often entails changes in the network configuration, and in particular, changes in the conditions required for the propagation of electromagnetic waves. These requirements impose very significant and needed characteristics of the wireless network nodes [3] as follows: algorithms and protocols must possess the ability to self-organization. This means that the node must be equipped with the hardware in the processor, which will implement very complex algorithms, often operating under changing environmental conditions of measurement [18–21]. The following is a random solution to control access to the network architecture of the single-hop assumption implementing the structural simplicity of nodes and limiting the solution to use only one frequency channel [11]. The solution for many applications, WSN has many desirable advantages. Theoretical principles of the random access control model.

Probabilistic network model

We consider a network consisting of n sensors which are able to send information about the measured physical magnitude on one selected radio frequency to the receiving base, quite independently of each other. Duration of communication protocol is t_p, the sensors send the information to the receiving point in randomly selected moments, every T s. at a average.

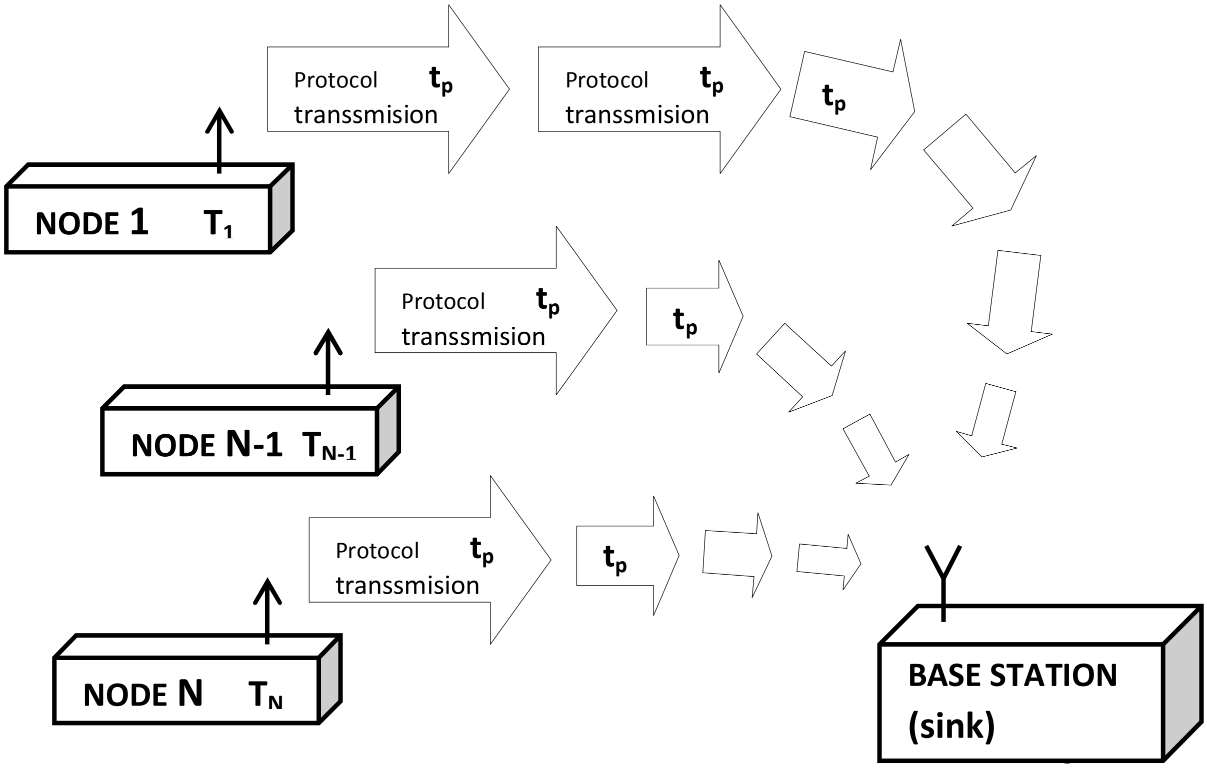

Fig. 2. Model analyzed single-hop network with one-way transmission

Beginning and cessation of transmission of a particular sensor takes place in random moments of time but these moments are relatively rare. It is a one-way transmission, i.e. from sensors to the receiving base. The sensors are completely independent from each other and their on or off state is of no influence on the operation of the network. All the sensor- senders or a part of them may be mobile provided that their senders have been left within the radio range of the receiving base. If one or more senders start sending while protocol transmission of t_p time is going on from another sensor, then such a situation is called collision. Collision excludes the possibility of the correct receiving of information by the receiving base. Such a disturbed signal is ignored. The receiving base rejects the erroneous message and waits for a retransmission to be made after the average time T. We must accept a certain loss of information in exchange for simplicity in respect of both system and equipment.

We used in modeling our wireless network a Poisson process. Poisson process is the stochastic process in which events occur continuously and independently of one another. Mathematically the process N is described by the so called counter process N_t or $N(t)$(see [22], and [10, 11]) of rate $\lambda > 0$. The counter tells the number of events that have occurred in the interval $[0, t]$ $(t \geq 0)$. N has independent increments (the number of occurrences counted in disjoint intervals are independent from each other), such that $N(t) - N(s)$ has the Poisson ($\lambda(t-s)$) distribution, for $t \geq s \geq 0,\ j = 0,1,2,\ldots,$

$$P\{N(t)-N(s)=j\}=e^{-\lambda(t-s)}\frac{[\lambda(t-s)]^j}{j!}. \tag{1}$$

A counting process has two corresponding random sequences, the sequence of count times (T_j) and the sequence of inter count times (U_j), such that $U_1 = T_1$ and $U_j = T_j - T_{j-1}$, for $j \geq 2$. It is well known (see [22]) that N is a Poisson process with the rate $\lambda > 0$ if and only if the inter count times $U_1, U_2, \ldots$ are mutually independent and each is exponentially distributed with parameter λ (mean $1/\lambda$).

Let us state our main assumptions. There are n identical sensors observing a dynamical system and reporting to a central location over the wireless sensor network with one radio channel. For simplicity, we assume our sensor network to be a single hop network with the star topology. We also assume that every node (sender-sensor, shortly sensor) has always packet ready for transmission. We assume that sensors send probe packets at Poissonian times. The average time between sending (the wake-up- times) of a sensor is T (the epoch period), and the duration of the on-time is t_p (the awake interval). Assume that the wake-up-times corresponding to sensors are independent from each other. Let N be the Poisson process representing the time counter of sending sensors. Let $T_1, T_2, \ldots$ be the sending times (the wake-up- times) of sensors, $U_1, U_2, \ldots$ the inter sending times. Then the average time between sending of sensors is T/n, the average number of sending sensors in the time interval of T length equals to n. We say that a collision occurs in the time interval of t_p length, if at least two sensors start sending within this interval. We say that a collision occurs in time interval s, if there exist at least two sensors which start sending within this interval with the difference between the beginning of their sending time not exceeding the value of t_p. Then the Poisson process N has the rate $\lambda = n/T$. By (1)

$$P(N_t = j) = e^{-\lambda t}\frac{[\lambda t]^j}{j!}(j = 0,1,\ldots). \tag{2}$$

In [11, 23] we give the theorem on the probability of collisions in the interval of s length in the case $s > t_p$. In the following theorem we give the lower and upper estimations of the conditional probability of the number sensor transmissions in collision in the interval of s length, assuming that the number of sensor transmissions that have occurred in the interval of s length $(s > t_p)$ equals j. Let Y_s be the number sensor transmissions in collision, in the interval of s length.

Theorem 1. Let $s > t_p$. Then we have

$$\left(j\frac{t_p}{s}\right)^{\kappa-1}\left(1-j\frac{t_p}{s}\right)^{j-\kappa} \leq P(Y_s = \kappa / N(s) = j) \leq \left(j\frac{t_p}{s}\right)^{\left[\frac{\kappa+1}{2}\right]}\left(1-\frac{t_p}{s}\right)^{j-\left[\frac{\kappa+1}{2}\right]}. \tag{3}$$

Proof: Let $2 \leq i_2, i_3, \ldots, i_j \leq j$, be such that $U_{i_2} \leq U_{i_3} \leq \ldots \leq U_{i_j}$. Since $Y_s = \kappa$, there exists $\left[\frac{\kappa+1}{2}\right] \leq k \leq \kappa - 1$, such that $U_{i_{k+1}} < t_p \leq U_{i_{k+2}}$. Consequently, we obtain that

$$P(U_2 < t_p, U_3 < t_p, \ldots, U_\kappa < t_p, U_{\kappa+1} \geq t_p, \ldots, U_j \geq t_p) \leq P(Y_s = \kappa / N(s) = j) \leq$$

$$\le P\left(U_2 < t_p, \ldots, U_{\left[\frac{\kappa+1}{2}\right]+1} < t_p, U_{\left[\frac{\kappa+1}{2}\right]+2} \ge t_p, \ldots, U_j \ge t_p \right).$$

This implies (3).

In the next theorem we estimate the unconditional probability of the number sensor transmissions in collision in the interval of s length $(s > t_p)$.

Theorem 2. Let $s > t_p$. Then we have

$$\sum_{j=2}^{\infty} e^{-n\frac{s}{T}} \frac{\left(n\frac{s}{T}\right)^j}{j!} \left(j\frac{t_p}{s}\right)^{\kappa-1} \left(1 - j\frac{t_p}{s}\right)^{j-\kappa} \le P(Y_s = \kappa) \le \sum_{j=2}^{\infty} e^{-n\frac{s}{T}} \frac{\left(n\frac{s}{T}\right)^j}{j!} \left(j\frac{t_p}{s}\right)^{\left[\frac{\kappa+1}{2}\right]} \left(1 - \frac{t_p}{s}\right)^{j-\left[\frac{\kappa+1}{2}\right]}.$$

In the next theorem we give estimations of the expected value and the variance, respectively.

Theorem 3. Let $s > t_p$. Then we have

$$\sum_{\kappa=2}^{\infty} \kappa \sum_{j=2}^{\infty} e^{-n\frac{s}{T}} \frac{\left(n\frac{s}{T}\right)^j}{j!} \left(j\frac{t_p}{s}\right)^{\kappa-1} \left(1 - j\frac{t_p}{s}\right)^{j-\kappa} \le EY_s \le \sum_{\kappa=2}^{\infty} \kappa \sum_{j=2}^{\infty} e^{-n\frac{s}{T}} \frac{\left(n\frac{s}{T}\right)^j}{j!} \left(j\frac{t_p}{s}\right)^{\left[\frac{\kappa+1}{2}\right]} \left(1 - \frac{t_p}{s}\right)^{j-\left[\frac{\kappa+1}{2}\right]},$$

$$\sum_{\kappa=2}^{\infty} \kappa^2 \sum_{j=2}^{\infty} e^{-n\frac{s}{T}} \frac{\left(n\frac{s}{T}\right)^j}{j!} \left(j\frac{t_p}{s}\right)^{\kappa-1} \left(1 - j\frac{t_p}{s}\right)^{j-\kappa} - \left[\sum_{\kappa=2}^{\infty} \kappa \sum_{j=2}^{\infty} e^{-n\frac{s}{T}} \frac{\left(n\frac{s}{T}\right)^j}{j!} \left(j\frac{t_p}{s}\right)^{\left[\frac{\kappa+1}{2}\right]} \left(1 - \frac{t_p}{s}\right)^{j-\left[\frac{\kappa+1}{2}\right]} \right]^2 \le$$

$$\le D^2(Y_s) \le \sum_{\kappa=2}^{\infty} \kappa^2 \sum_{j=2}^{\infty} e^{-n\frac{s}{T}} \frac{\left(n\frac{s}{T}\right)^j}{j!} \left(j\frac{t_p}{s}\right)^{\left[\frac{\kappa+1}{2}\right]} \left(1 - \frac{t_p}{s}\right)^{j-\left[\frac{\kappa+1}{2}\right]} - \left[\sum_{\kappa=2}^{\infty} \kappa \sum_{j=2}^{\infty} e^{-n\frac{s}{T}} \frac{\left(n\frac{s}{T}\right)^j}{j!} \left(j\frac{t_p}{s}\right)^{\kappa-1} \left(1 - j\frac{t_p}{s}\right)^{j-\kappa} \right]^2.$$

Below we give an example of calculating estimates of the expected value (the lower and upper) for a wireless network with random access, where the average transmission time is $T = 10$ s, the number of nodes is $n = 5$ and the observation time is $s = 180$ s.

Namely: $3.1985376 \cdot 10^{-5} \le EY_S \le 3.1986410 \cdot 10^{-5}$.

The calculation shows that there is approximately 3.1986 collisions at 10^5 intervals of length s in which the phenomenon has been studied. As seen in these conditions, the network will work very well. For the same sample network parameters were calculated upper and lower estimation of the variance: $6.39705 \cdot 10^{-5} \le D^2(Y_S) \le 6.39746 \cdot 10^{-5}$.

It is easy to see from both the estimation of the expected value and variance, the difference between the lower and upper estimate is low, they differ only in fifth place significant digits. So I can tell from the error estimates in the examples is small, the order of 10^{-9}. Calculating the standard deviation (dispersion) $D(Y_S)$ as $D(Y_S) = \sqrt{D^2(Y_S)}$ and then by calculating the coefficient of variation (i.e. dispersion-to-mean ratio) as $DMR(Y_S) = \frac{D(Y_S)}{EY_S}$, we obtain:

$$\frac{D_L}{E_U} \le \frac{D(Y_S)}{EY_S} \le \frac{D_U}{E_L},$$

where

D_L — lower estimate of the standard deviation,

D_U — upper estimate of the standard deviation,

E_L — lower estimate of the expected value,

E_U — upper estimate of the expected value.

All the above estimates upper and lower expected value and variance are given in Theorem 4. For the given example, we obtain the following estimates of value $DMR(Y_S)$: $1.99993 \le DMR(Y_S) \le 2.00012$. Coefficient of variation is around 2, the standard deviation of radio collisions occurring is very small, about two times higher than the expected value, which is very small (approximately $3.198 \cdot 10^{-5}$). This result fully confirms the assumption of random network control algorithm.

Conclusions

In summary it can be said that a significant simplification of the nodes structure (simplex transmission on one frequency), the simplification algorithm simplifies handling radio traffic. Moreover, communication protocols and reduced energy consumption of nodes (node extends the lifespan of the network) have a significant impact on the improving of the network reliability, as well as significantly increase the security of the information transmitted on the network. Further research concerning the number of nodes that are in collision in WSN with the random access networks will be conducted in the networks with the nodes division into groups comprising different average time between transmissions.

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ІМОВІРНІСНІ МЕТОДИ КЕРУВАННЯ ПЕРЕДАВАННЯМ В РАДІОМЕРЕЖІ

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У статті представлено імовірнісне керування радіопередачею в безпровідних сенсорних мережах (БСМ). Визначено імовірність стану без колізій в мережевій передачі одновузлового типу. Нами запропоновано концепцію БСМ з випадковими моментами передавання сигналів часу з односторонньою передачею, застосовуючи одну радіочастоту. Нами використовується середнє значення за час спостереження надходження пуассонівського потоку (PASTA) для моделювання імовірності появи колізії під час передавання в радіомережі з метою контролю правильності роботи мережі. Запропонована модель мережевого доступу дозволяє підвищити надійність і безпеку інформації.

Ключові слова: безпровідна сенсорна мережа, середнє значення за час спостереження надходження пуассонівського потоку (система PASTA), імовірність появи колізії, випадкове керування

ВЕРОЯТНОСТНЫЕ МЕТОДЫ УПРАВЛЕНИЯ ПЕРЕДАЧЕЙ В РАДИОСЕТИ

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В статье представлено вероятностное управление радиопередачей в беспроводных сенсорных сетях (БСС). Определена вероятность состояния без коллизий в сетевой передаче одноузлового типа. Предложена концепция БСС со случайными моментами передачи сигналов времени с односторонней передачей, используя одну радиочастоту. В работе используется среднее значение за время наблюдения поступления пуассоновского потока (PASTA) для моделирования вероятности появления коллизии во время передачи в радиосети с целью контроля корректной работы сети. Предложенная модель сетевого доступа позволяет повысить надежность и защиту информации.

Ключевые слова: беспроводная сенсорная сеть, среднее значение за время наблюдения поступления пуассоновского потока (система PASTA), вероятность появления коллизии, случайное управление