БЕЗПЕКА КОМП'ЮТЕРНИХ МЕРЕЖ ТА ІНТЕРНЕТ / NETWORK & INTERNET SECURITY

SIMULATION STUDY OF THE RANDOM ACCESS CONTROL IN THE WIRELESS SENSOR NETWORK

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Abstract. *In this paper we present the research results of WSN network work with random access control, using the PASTA system (Poisson Arrivals See Time Averages). We present the results of simulation tests of the efficiency of the network operation, for the two cases: 1) when all network nodes transmit protocols with the same average time between transmissions, 2) when the network nodes were divided into groups that have different average time between transmissions. This approach has many practical advantages which we present.*

Key words: *Wireless Sensor Network (WSN), Poisson Arrivals See Time Averages (PASTA system), probability of collision, random control, simulation.*

1. Introduction

This paper presents the research on the radio link control for wireless single-hop sensor network with random access (WSN) problem. Probabilistic models have been developed using a Poisson processes. At first we examined situation when the nodes transmit packets with information from the sensors randomly, with the same average times between transmissions. We also examined the situation when the average times between transmissions are different. Simulation studies which aim was to verify the previously presented theoretical practical solutions were carried out for both cases. In this model, a one-way communication using a radio transmission from the node to the base station. The network of sensors works using only one radio frequency. Such assumption for the radio transmission model in practice means a considerable simplification of the communication algorithms and significant simplifications in the construction of the nodes as well as energy savings in supply nodes, which is critical in many applications of WSN networks. The nodes contain only radio transmitters and use very narrow bandwidth. Presented model also lacks the sync channel, so the nodes do not need to receive any information, including those related to synchronization. The nodes do not have to be equipped with receivers implementing the access procedures like in deterministic radio systems such as multi-hop networks. Switching on or off the selected node does not require any special procedures (plug and play) and the scale of individual nodes is not critical for the correct operation of the network. The main objective of this work was to perform simulation studies and also to verify the thesis previously raised in our studies concerning the probabilistic models of transmission control in WSN networks [1-3].

2. Evaluation of recent publications in the explored issue

The issue of control of the radio communications defined as access of the wireless measurement node to the base collecting and processing the collected data is the subject of many publications [4, 5, 6, 7, 8]. A radio communication problem „many to one" (sink) is a known difficult issue in the field of access control and access procedures. At any given time on the one radio channel only one node of the network can transmit in the area covered by a sufficient electric field intensity providing a valid range [9, 10]. Thus, the special access control procedure is required in order to the available radio channels (created as channels of frequency division and time division) are used by only one node in any given time period. As presented in the papers [11, 12] deterministic methods guarantee to solve the above problems, but they also have some significant flaws, which in some applications are not acceptable. Among the mentioned flaws of the deterministic methods are: nodes need to communicate with each other, or their access process should be coordinated by the base station. This means that the network must be available not only to the radio channels for the transmission of measurement information, but also to information managing the transmission procedure. In such case the node mas to be also be provided with a radio receiver, which will allow to control the operation of the node external signal. This in turn requires a more complex nodes operating in listening (wake-up) mode. Thus, in situations of limited access to the power supply, the node has to reduce its working time. In many applications working time is one of the most important parameters. Creating a network that assumes only a one-way transmission from the sensor node to the base station nodes, without neither communication between sensor nodes, nor transmissions from the base station node, can significantly improve wireless network (WSN) performance. The conditions that we can find a solution for collision-free transmissions from sensor nodes. Collision-free broadcasting nodes means that if one node transmits the other nodes don't start transmitting. In order to solve this problem the probabilistic methods of access control should be used. The proposed solution [1, 2, 3] use the so-called Poisson stream treatments method for Poisson Arrivals See Time Averages (PASTA) for modeling WSN [13]. In this method, we accept a small loss of information transmitted by the network. The benefit is a significant simplification of procedures and a significant simplification of hardware. Another advantage is the improvement of the energy efficiency. In some specific applications of these network model we got very interesting features of WSN networks. In the papers [1, 2, 3] we have theoretically solved the above problem, especially in terms of transmission correctness. In the subsequent sections we present simulation studies to verify the proposed probabilistic WSN control model. We have performed computer simulations for different operating parameters of the network.

3. Network model 1

We analyze a network consisting of n nodes 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 the communication protocol is t_p, the nodes send the information to the receiving point in randomly selected moments, every T s. at an average.

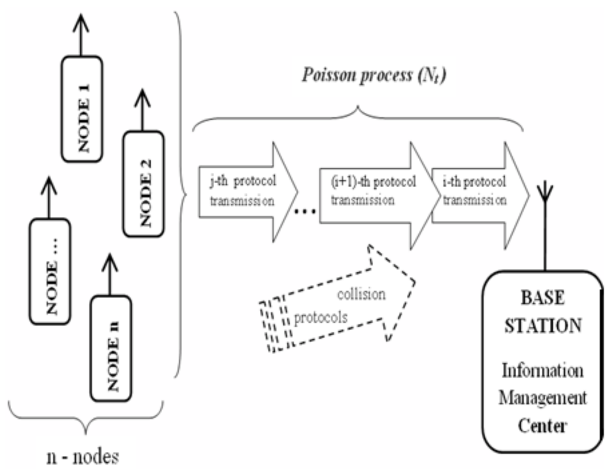

Fig. 1. Poisson modeling of network transmission protocols in WSN (model 1)

Beginning and cessation of transmission of a particular node takes place in random moments of time but these moments are relatively rare. It is a one-way transmission, i.e. from nodes to the receiving base. The nodes are completely independent of one another and their on or off state is of no influence on the operation of the network. All the nodes 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 nodes start sending while protocol transmission of t_p time is going on from another nodes, 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.

As mentioned in the Introduction, we used to modeling our wireless network a Poisson process. Mathematically the process N is described by the so called counter process N_t or $N(t)$ (see [14]) 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 (mean $\lambda(t-s)$), for $t \geq s \geq 0, j = 0, 1, 2, \ldots,$

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

Let us state our main assumptions. There are n identical nodes 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 star topology. We also assume every node always has packet ready for transmission. We assume that nodes 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 t_p (the awake interval). Assume that the wake-up- times corresponding to nodes are independent each of other. Let N be the Poisson process representing the time counter of sending nodes (see [15, 16, 1, 2]). We say that a collision occurs in time interval s , if there exist at least two nodes 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)

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

In [2, 16] we give the following theorem on the probability of collisions in the interval of s length in the case $s > t_p$.

Theorem 1. Let n be the number of nodes and let T be the average time between transmission of a node. Then the probability of collisions in the interval of s length $(s > t_p)$ is given by the following formula

$$P(A_s) = \sum_{j=2}^{\infty} e^{-\lambda s} \frac{(\lambda s)^j}{j!} [1 - (1 - j\frac{t_p}{s})^j], \quad (3)$$

where $\lambda = \dfrac{n}{T}$ and t_p is the duration time of a protocol.

The below three graphs with the simulation results present behavior of the random

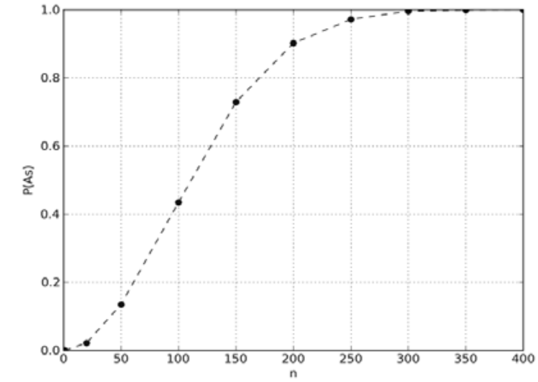

Fig. 2. Influence of the number of nodes on the probability of collision of the average time between transmissions T = 10s. The simulation result

Wireless network access control based on the number of active nodes. This allows to estimate the range of possible applications of this solution. It can be assumed that the tolerable level of quality is when the collision level range from 5% up to 10%. At the presented figures that point lies before the first inflection point on the characteristics, and it determines the number of nodes *n* (in presented experiments *n* is in the range from 40 to 100 nodes). Further increase of packet traffic in the network (number of nodes *n* and their incidence rate for fixed t_p) results in increasing the probability of collision. Then saturation effect occurs, and it causes frequent collisions. This effect is visible before the second inflection point on the characteristics.

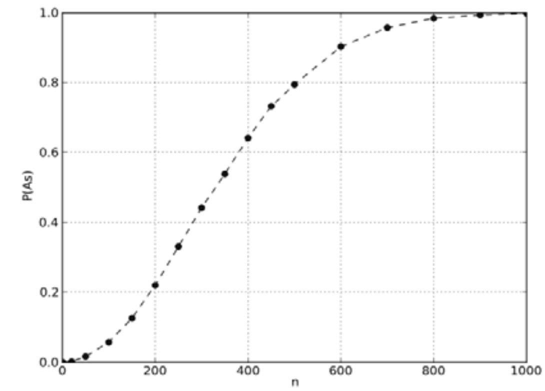

Fig. 3. Influence of the number of nodes on the probability of collision of the average time between transmissions T = 30s. The simulation result

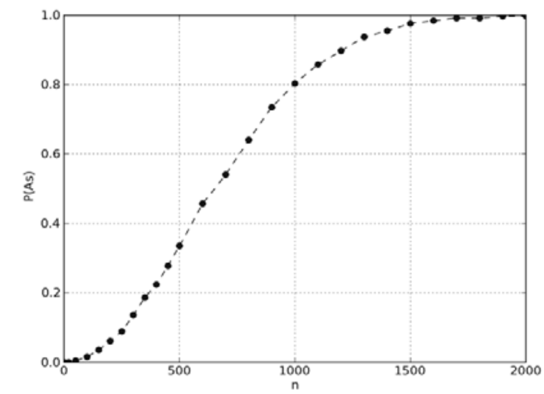

Fig. 4. Influence of the number of nodes on the probability of collision of the average time between transmissions T = 60s. The simulation result

It can be assumed that this point determines the final network capacity (the number of nodes the network) for the specified parameters (the duration of the communication protocol t_p and the average time between transmissions of T).

4. Network model 2

In several uses of the proposed network solution with a random network access control, it is possible to divide the total number of nodes into groups with different average time between transmissions. This division has its own technical reasons, in particular if the wireless network acquires measurement data for various physical quantities at different speeds, change their parameters. For example: monitoring of environmental parameters, in particular the measurement of diurnal changes in soil temperature and wind speed measurement. This example suggests the possibility of varying the measurement frequency. The question is interesting, because the opportunity to reduce packet congestion always has a positive effect on transmission quality.

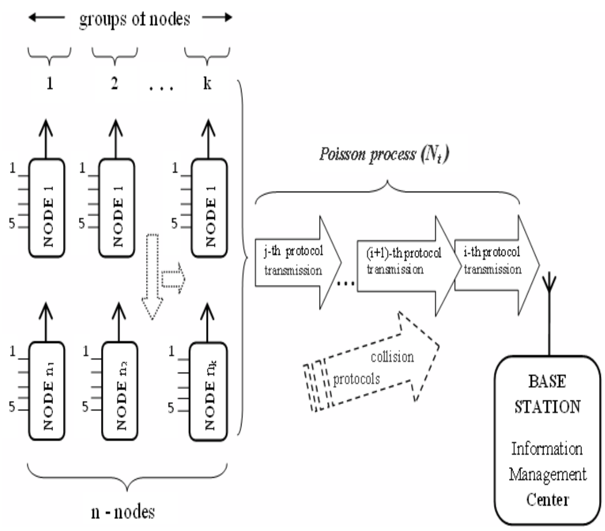

Fig. 5. Poisson modeling of network transmission protocols in WSN (model 2)

Let $N(t)$ be the Poisson process representing the time counter of n nodes, divided into k groups $(1 \le k \le n)$, such that $n = \sum_{i=1}^{k} n_i$, where n_i is the number of nodes in the i-th group and T_i is the average time between transmissions of a node $(i = 1,...,k)$. Let $X_{(i)}(t)$ $(i = 1,...,k)$ be the Poisson process representing the time counter of sending nodes for which T_i is the average time between transmissions of a node. Then $X_{(i)}(t)$ has the rate $\frac{n_i}{T_i}$ $(i = 1,...,k)$. Note, that $N(t) = \sum_{i=1}^{k} X_{(i)}(t)$. This implies that the Poisson process $N(t)$ has the rate $\lambda = \sum_{i=1}^{k} \frac{n_i}{T_i}$. Then, by Theorem 1 with $\lambda = \sum_{i=1}^{k} \frac{n_i}{T_i}$ in place of $\lambda = \frac{n}{T}$, we obtain the following theorem on the probability of collisions in the case, when the average times between transmissions of nodes are not necessarily the same (see [16]).

Theorem 2. Let n be the number of node, $n = \sum_{i=1}^{k} n_i$ and n_i be the number of nodes such that T_i is the average time between transmissions of a node, $1 \le k \le n$ is the number of groups. Then the probability of collisions in the interval of s length $(s > t_p)$ is given by the formula:

$$P(A_s) = \sum_{j=2}^{\infty} e^{-\lambda s} \frac{(\lambda s)^j}{j!} [1 - (1 - j\frac{t_p}{s})^j], \quad (4)$$

where $\lambda = \sum_{i=1}^{k} \frac{n_i}{T_i}$ and t_p is the duration time of a protocol.

The charts below [numbers: 6, 7, 8, 9, 10] present the simulation results of the behavior of the wireless network for different percentage shares of the specified nodes (with different average time between transmissions). The study was performed for the following percentages:: 10% of the nodes with average intervals between transmissions at 10 s and 90% of nodes with average intervals between transmissions every 30 seconds (write in brief 10% / 10 s, 90% / 30s.). Then, 10% / 10 s, 90% / 60 s. Another study 33% / 10s, 67% / 30s. And final two tests: 50% / 10 s + 50% / 30 s and finally: 50% / 10 s + 50% / 60 s. The duration protocol was still $t_p = 3{,}2 \cdot 10^{-5}\, s$. The results are consistent with our previous theoretical results described in [1-3, 16]. The longer the average time between transmissions of

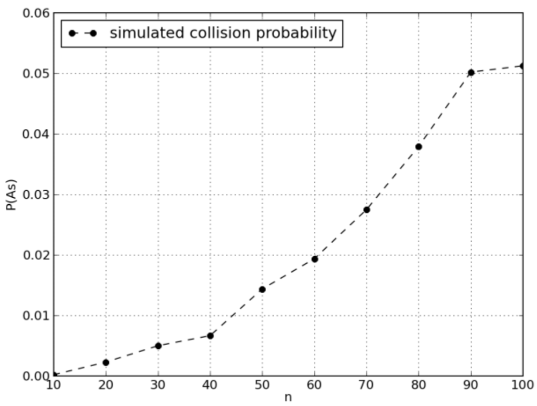

Fig. 6. Effect of the number of nodes with different average time between transmissions on the probability of collisions

The number of nodes the average time between transmissions is T = 10 seconds 10% of the total number of nodes, and 90% of nodes running with a mean time between transmissions T = 30.

The number of nodes the average time between transmissions is T = 10 seconds 10% of the total number of nodes, and 90% of nodes running with a mean time between transmissions T = 60s.

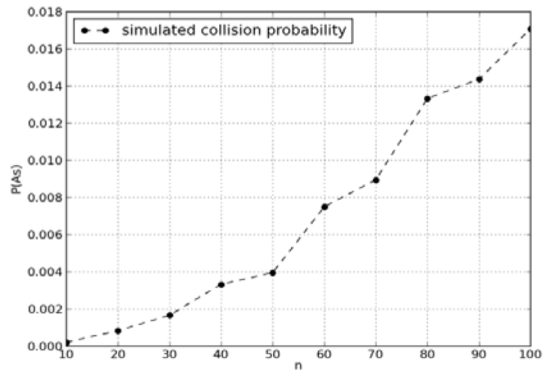

Fig. 7. Effect of the number of nodes with different average time between transmissions on the probability of collisions

Nodes T, the network works better (with fewer collisions). An important condition is that the duration of the transmission (t_p) is smaller than the average time between transmissions of the sensor nodes (T). Thus, if a significant portion of the radio packet can be transmitted as sparsely as possible, the better the overall result of the radio transmission is. So the grouping percentage of nodes with different average time between transmissions is fully justified. A further consequence of this fact, visible in the presented figures, is that in comparison with the situation when there is only one group of the nodes (with the same average time between transmissions) the number of the nodes in the network can be

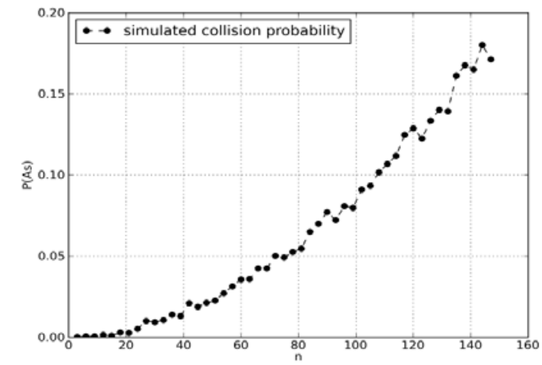

Fig. 8. Effect of the number of nodes with different average time between transmissions on the probability of collisions

The number of nodes the average time between transmissions T = 10s is 1/3 of the total number of nodes, and two thirds of nodes running the average time between transmissions T = 30s.

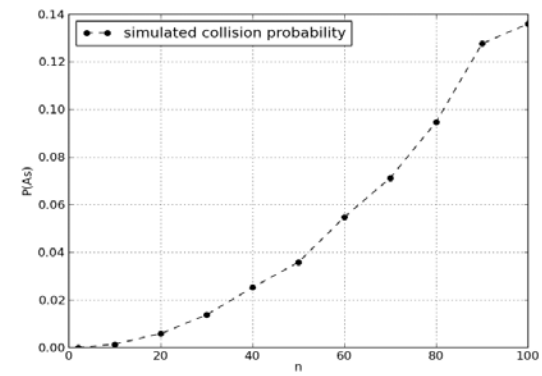

Fig. 9. Effect of the number of nodes with different average time between transmissions on the probability of collisions

Number of nodes with a mean time between transmissions T = 10s is 50% of the total number of nodes remaining 50% of the nodes is working with a mean time between transmissions T = 30s.

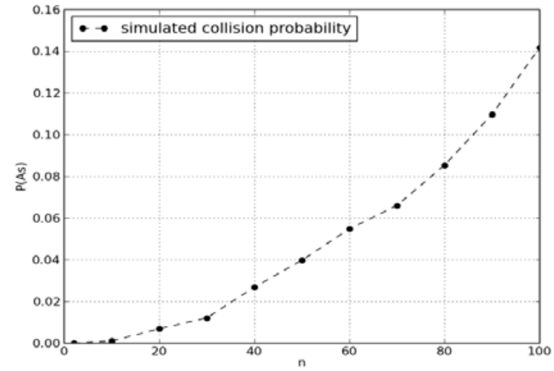

Fig. 10. Effect of the number of nodes with different average time between transmissions on the probability of collisions

Number of nodes with a mean time between transmissions T = 10s is 50% of the total number of nodes remaining 50% of the nodes is working with a mean time between transmissions T = 60s.

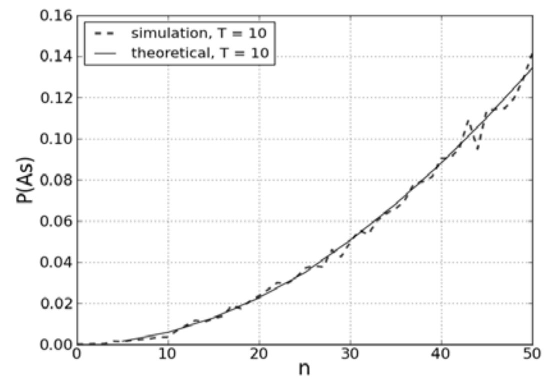

Fig. 11. The collision probability (theoretical and simulation) depending on the number of nodes for $t_p = 3{,}2x10^{-5}$ s., T = 10 s

Increased. In addition to the theoretical calculations of the probability of collisions, we carried out a computer simulations of the network based on the assumptions outlined above. In the following figures we show the probability of collisions calculated from the theoretical dependence (solid line) and as a result of the simulation (dotted line) depending on the number of nodes in the network with fixed average transmission times.

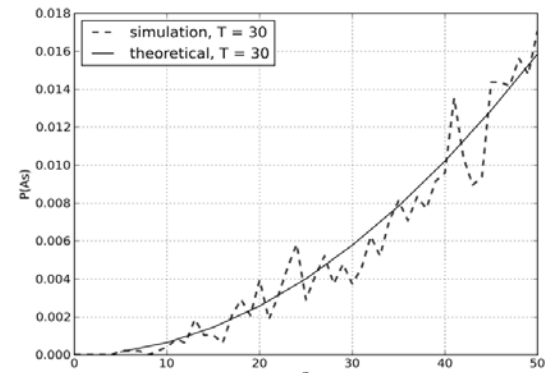

Fig. 12. The collision probability (theoretical and simulation) depending on the number of nodes for $t_p = 3{,}2x10^{-5}$ s., T = 30 s

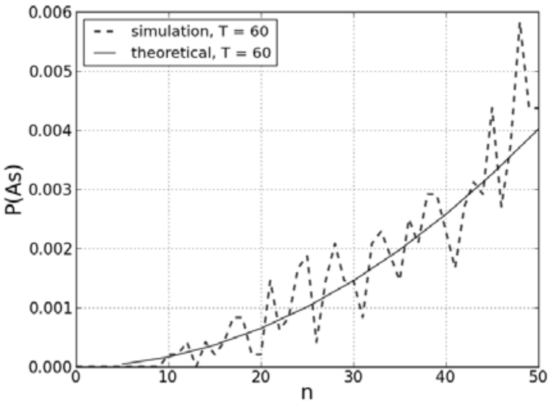

Fig. 13. The collision probability (theoretical and simulation) depending on the number of nodes for $t_p = 3{,}2\text{x}10^{-5}$ s., T = 60 s.

5. Conclusions

The effect on the probability of collisions radio nodes participating in the broadcast random and average transmission time of the nodes. Figures 11, 12 and 13 show the dependence of the probability of collision $P(A_s)$ on the number of nodes n in the network, and for the average fixed transmission times T (10s., 30s., 60s.). The solid lines represent the theoretical calculation results in accordance with the proposed model, and the dashed lines are the results of the computer simulation. It can be seen that, in the situation when collisions are relatively frequent, the curve derived from the simulation approximates very well the theoretical curve and the fluctuations are relatively small. When the average times between the single node transmissions are larger there are less collisions in the network (Fig. 12, Fig. 13). The curve derived from the simulation still well approximates the theoretical curve and the average value is consistent with the theoretical computations but fluctuations deviations from the theoretical curve is increasing. The observed phenomenon does not affect the compliance of the results of theoretical computations, it is probably the result of the limited accuracy of the simulation methods and tools. When the probabilities are smaller, in order obtain the smoothed curve (smaller deviations from the theoretical curve) requires a increased simulation time. The results obtained indicate that the number of collisions in the network is decreasing together with increasing time T as well as with decreasing of the transmission duration (t_p). The conclusion is obvious, proposed model of such a network solution is very beneficial. This network solution has a number of other advantages, which are listed at the beginning of this paper. In summary, we can tell that the proposed model of the WSN network with random access, has been confirmed.

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Райба С.В., Райба Т.Я, Райф П.Б. Моделювальні дослідження випадкового керування доступом в безпровідній сенсорній мережі

Анотація. *У статті представлено результати дослідження роботи мережі БСМ з випадковим керуванням доступом, використовуючи систему PASTA (середнє значення за час спостереження надходження пуассонівського потоку). Наведено результати моделювальних тестувань ефективності функціонування мережі для двох випадків: 1) коли всі вузли мережі передають протоколи з тим самим середнім часом між передачами, 2) якщо вузли мережі поділено на групи, які мають різні середні часи між передачами. Цей підхід має багато практичних переваг, які висвітлено у статті..*

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

Райба С.В., Райба Т.Я, Райф П.Б. Моделирующие исследования случайного управления доступом в беспроводной сенсорной сети

Аннотация. *В статье представлено результаты исследования работы сети БСС со случайным управлением доступом, используя систему PASTA (среднее значение за время наблюдения поступления пуассоновского потока). Приведено результаты моделирующих тестирований эффективности функционирования сети для двух случаев: 1) если все узлы сети передают протоколы с тем же средним временем между передачами, 2) если узлы сети разделены на группы, которые имеют разные средние времена между передачами. Этот подход имеет много практических преимуществ, которые отражено в статье.*

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

Отримано *15 січня 2013 року*, затверджено редколегією *19 лютого 2013 року*

МОДЕЛІ ЕТАЛОНІВ ЛІНГВІСТИЧНИХ ЗМІННИХ ДЛЯ СИСТЕМ ВИЯВЛЕННЯ ТА ІДЕНТИФІКАЦІЇ ПОРУШНИКА ІНФОРМАЦІЙНОЇ БЕЗПЕКИ

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