Research of Probability-Time Characteristics of the Wireless Sensor Networks for Remote Monitoring Systems

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***Abstract*—A number of scientific researches are being carried out aimed at creating a remote monitoring system through wireless sensor networks to ensure a stable and high-quality power supply for telecommunications equipment in the world. To solve a number of problems in this area, including Smart Grid systems, including a remote monitoring system for wireless sensors, a two-way information system, energy consumption control, an increase in energy demand, reliability and safety models, algorithms, software and technical solutions, special attention is paid to paid. At the same time, research of characteristics of the wireless sensor networks for monitoring systems is considered relevant. This paper researches of probability-time characteristics of the wireless sensor networks for remote monitoring systems of telecommunication objects. In this case, a graph model reflecting the wireless sensor network was created and the characteristics were determined using the theory of the Pubic service system. The wireless sensor network was also simulated using Anylogic software and the results obtained were compared with the analytical results.**

Keywords— wireless sensor network, sensor node, router, coordinator, graph model, public service system, packet, load, intensity, delay.

I. Introduction

Wireless sensor networks are of great importance to solve the problems associated with the creation of remote monitoring tools as one of the modern trends in the development of data transmission networks. Wireless Sensor Network is a distributed, self-organizing sensor network of many sensors and actuators, interconnected by means of radio channels [1]. Advantages of wireless sensor networks: the ability to self-heal and self-organize; power of transmitters (by retransmission); low cost of nodes and their small size; low power consumption and the possibility of electricity supply from autonomous sources; Easy to install, no cabling required (thanks to wireless technology and battery power) the possibility of installing such networks on an existing and operating facility without additional work; low maintenance cost [2], [3]. Wireless sensor networks are used in environmental monitoring, smart home, smart energy, smart transportation systems, smart agriculture, smart medicine and many other fields. Therefore, without based on a general approach in the study of the characteristics of wireless sensor networks, it is expedient to model and study it based on the system parameters and specific features in which it is applied [4], [5], [6], [7].

Telecommunication facilities are a complex structure consisting of both renewable and non-renewable primary and secondary power supply sources [8], [9].

The structure diagram of the wireless sensor network of the remote monitoring system of hybrid power supply sources of telecommunication facilities is shown in Fig. 1.

The router nodes in Fig. 1 are responsible for receiving signals from the sensors located at each source and transmitting them to the coordinator node. The ML-Node-Z device was selected as the router node.

The function of the coordinator node is to transmit data from routers to the monitoring center via the Internet. The ZigBit (ATmega1281) device was selected as the coordinate node.

The main characteristics of the ML-Node-Z and ZigBit (ATmega1281) devices are given in [10].

II. Graph Model of Wireless Sensor Networks

We study the wireless sensor networks of remote monitoring systems of hybrid power supply sources of telecommunication facilities on the basis of Graph model [11], [12]. The graph model corresponding to the network topology shown in Fig. 1 is shown in Fig. 2. In this case, we represent each node of the wireless sensor network as PSS (Public Service System).

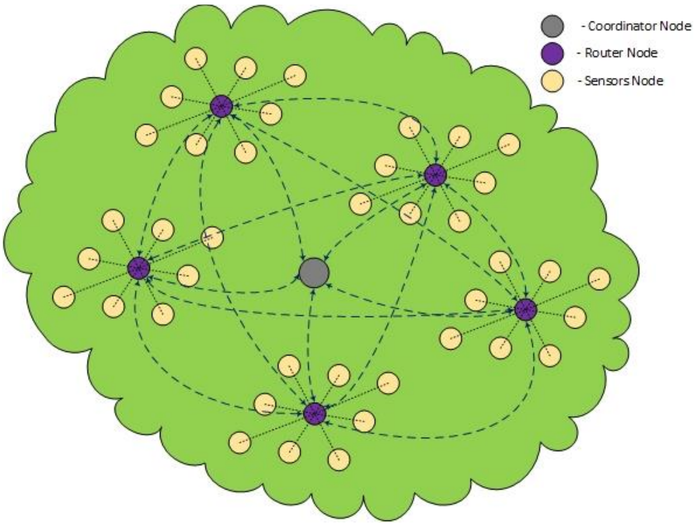

Fig. 1. Wireless sensor network of the remote monitoring system for hybrid power supply sources of telecommunication facilities.

In Fig. 2, the parameter λ represents the total intensity of the data stream coming from the sensors to the routers.

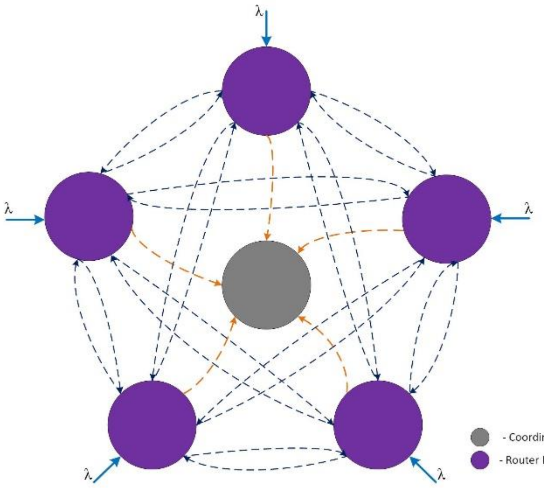

Fig. 2. Graph model of a wireless sensor network.

The components of an PPS that represent a wireless sensor network node are [13], [14]:

- Input stream - a stream of data received from the object by various sensors and transmitted to the monitoring center. The main parameter is the flow rate;
- Queue is the data that is stored temporarily (while processed in the processor) in the wireless sensor network node buffer memory. The main parameter is the queue length. It should be noted that the concept of buffer is often confused with the concept of queue, and buffer capacity is confused with the concept of queue length. The buffer is a device that temporarily stores the queue (data waiting for the service queue), and the buffer capacity is the maximum queue length that can be stored in the buffer. Always in one PSS the buffer capacity is greater than or equal to the queue length;
- Lost transaction is the part of the incoming data flow due to buffer capacity overflow (ie the queue length is equal to the buffer capacity);
- The service device (SD) is the processor of the sensor node. The main parameter is the service life, which depends on the processor discharge and clock frequency;
- Output transaction - a stream of data that is successfully processed in the service device and sent out of the PSS (transmitted to the next node). In turn, the outgoing data stream constitutes the incoming stream for another PSS.

The processes that take place in PSS representing a wireless sensor network node can be classified as follows [13], [15]:

- The node receives information from the sensor;
- Waiting in line in the buffer;
- Data loss;
- Device maintenance;
- Transfer of data to the next node;

To determine the intensity of the packets coming from the sensors and other routers to each router and coordinator, we construct a system of balance equations corresponding to the graph model in Fig. 2. In general, each router can receive packets of different speeds from n sensors, and in particular, we can specify that each router receives packets from 6 sensors with a total speed of 6 packets/sec, as well as the probability of routers transmitting outgoing data to neighboring routers. We have 0.04, the probability of transmission to the nodes far from it is 0.01, and the probability of transmission to the central node - the coordinator is 0.9.

$$\begin{cases} \lambda_1 = 0{,}04\lambda_2 + 0{,}01\lambda_3 + 0{,}01\lambda_4 + 0{,}04\lambda_5 + 6 \\ \lambda_2 = 0{,}04\lambda_1 + 0{,}04\lambda_3 + 0{,}01\lambda_4 + 0{,}01\lambda_5 + 6 \\ \lambda_3 = 0{,}01\lambda_1 + 0{,}04\lambda_2 + 0{,}04\lambda_4 + 0{,}01\lambda_5 + 6 \\ \lambda_4 = 0{,}01\lambda_1 + 0{,}01\lambda_2 + 0{,}04\lambda_3 + 0{,}04\lambda_5 + 6 \\ \lambda_5 = 0{,}04\lambda_1 + 0{,}01\lambda_2 + 0{,}01\lambda_3 + 0{,}04\lambda_4 + 6 \\ \lambda_6 = 0{,}9\lambda_1 + 0{,}9\lambda_2 + 0{,}9\lambda_3 + 0{,}9\lambda_4 + 0{,}9\lambda_5 \end{cases}$$

Solving the system of equations, we obtain the following results:

$$\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \frac{20}{3} \approx 6{,}667; \lambda_6 = 30.$$

Considering that the sensor nodes installed in the power supply receive signals at certain time intervals and transmit the received data to the router, the time interval of arrival of the packet to the routers is the distribution law "Uniform" and the time of service of the packets at the router node is the distribution law "Exponential" [16], [17].

TABLE I. THE CHARACTERISTICS OF THE WIRELESS SENSOR NETWORK

Characteristics	Analytical model	Simulation for the node	Simulation for the network
Characteristics of node 1			
ρ_i	0.247	0.225	0.226
w_i	0.012	0.01	0.01
l_i	0.081	0.065	0.066
U_i	0,0492	0,047	-
Characteristics of node 2			
ρ_i	0.247	0.225	0.222
w_i	0.012	0.01	0.009
l_i	0.081	0.065	0.063
U_i	0,0492	0,047	-
Characteristics of node 3			
ρ_i	0.247	0.225	0.223
w_i	0.012	0.01	0.01
l_i	0.081	0.065	0.065
U_i	0,0492	0,047	-
Characteristics of node 4			
ρ_i	0.247	0.225	0.216
w_i	0.012	0.01	0.009
l_i	0.081	0.065	0.059
U_i	0,0492	0,047	-
Characteristics of node 5			
ρ_i	0.247	0.225	0.229
w_i	0.012	0.01	0.01
l_i	0.081	0.065	0.068
U_i	0,0492	0,047	-
Characteristics of node 6			
ρ_i	0.0375	0.037	0.037
w_i	0.00004875	0.000049	0.0000486
l_i	0.0015	0.001	0.001
U_i	0,001299	0,001249	-
Characteristics of network			
U	-	-	0.049

III. THE MAIN CHARACTERISTICS OF THE PSS

Now, we present the mathematical expressions for calculating the basic characteristics of each PSS (routers and coordinators) (load, average queue time, average queue length, average time in the system). Each node load can be calculated using the following formula [13]:

$$\rho_i = \frac{\lambda_i}{\mu_i} = \lambda_i b_i. \quad (1)$$

The average waiting time for k-type orders (where k represents the priority of packets coming down from the sensors) is determined by the following formula [13]:

$$W_k = \frac{\sum_{i=1}^{H} \lambda_i b_i^2 \left(1 + v_{b_i}^2\right)}{2(1 - R_{k-1})(1 - R_k)} \; (k = 1, \dots, H), \quad (2)$$

where R_{k-1} and R_k are the total loads generated by packets with priority k-1 and k, respectively [13]:

$$R_{k-1} = \sum_{i=1}^{k-1} \rho_i; \; R_k = \sum_{i=1}^{k} \rho_i. \quad (3)$$

The average length of a queue at each node can be calculated using the following formula [13]:

$$l_i = \lambda_i w_i. \quad (4)$$

The time that packets are in the system can be calculated using the following formula [13], [18]:

$$U_i = w_i + b_i. \quad (5)$$

The characteristics of each node were calculated using these analytical expressions by the computer program on the above parameters.

IV. RESULTS AND DISCUSSION

Also, the PPS corresponding to each node and the topology-compatible public service network shown in Fig. 2

were simulated and characterized in the Anylogic modeling environment [19], [20], [21], [22].

The results obtained by the mathematical model derived from the representation of the wireless sensor network nodes as a public service system and the results obtained from the simulation models of these network nodes and the integrated network built in the Anylogic modeling environment are compared in Table 1.

The following are the characteristics of a wireless sensor network derived from a mathematical model, simulation for network nodes, and simulation for a whole network.

The following is a comparative analysis in the form of graphs of the λ intensity characteristics of a wireless sensor network derived from a mathematical model, an imitation model for network nodes, and an imitation model for an integrated network (Figures 3-8). Fig. 3 shows graphs of the load ρ dependence λ on the wireless sensor network routers.

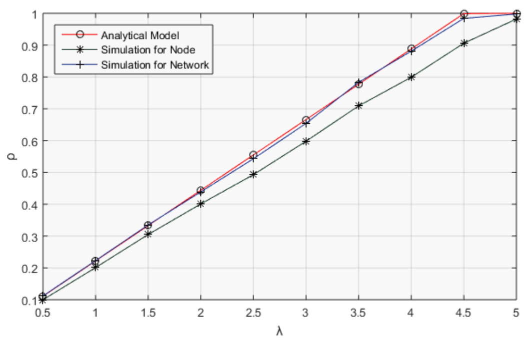

Fig. 3. The load to intensity dependence of the wireless sensor network routers.

Fig. 4 shows graphs of the load ρ dependence λ on the wireless sensor network coordinator. As can be seen from the graph, the load value obtained from the imitation model for the integrated network is higher than the values obtained from the imitation model for the analytical and node.

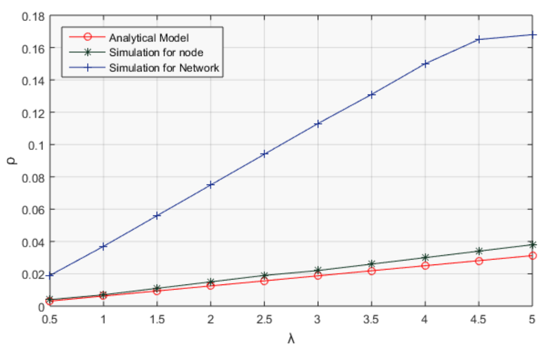

Fig. 4. The load to intensity dependence of the wireless sensor network coordinator.

The main reason for this is that in simulation models for analytics and nodes, it is not possible to account for packets that rotate between nodes of the wireless sensor network. From this it can be concluded that the simulation models for the analyst and the node make significant errors in expressing the coordinate node load.

Fig. 5 shows graphs of the dependence of the average queue waiting time w dependence λ on packets on wireless sensor network routers. As can be seen from the graph, a sharp increase in the waiting time w can be observed when the intensity exceeds λ=4.

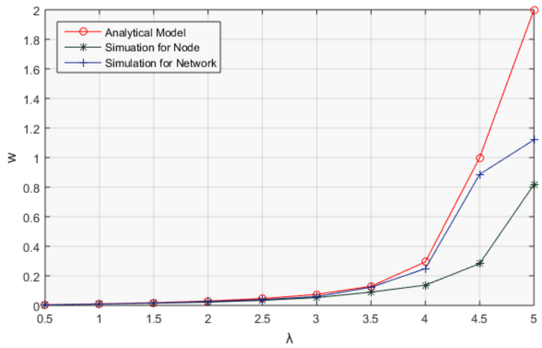

Fig. 5. The packet delay time to intensity dependence of the wireless sensor network routers.

Fig. 6 shows graphs of the average queue time w to intensity λ dependence of packets in a wireless sensor network coordinator. As can be seen from the graph, the load value obtained from the imitation model for the node differs significantly from the values obtained from the imitation model for the analytical and integrated network. From this it can be concluded that the imitation model for the node allows significant errors in the expression of the coordinator node load.

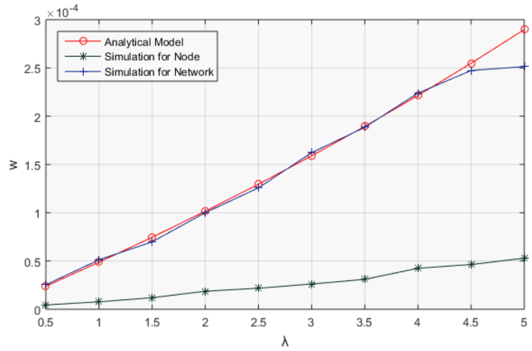

Fig. 6. The packet delay time to intensity dependence of the wireless sensor network coordinator.

Fig. 7 shows graphs of the dependence of the average length of the packet queue L to intensity λ on wireless sensor network routers. As can be seen from the graph, a sharp increase in the length L of the sequence can be observed when the intensity exceeds λ=4.

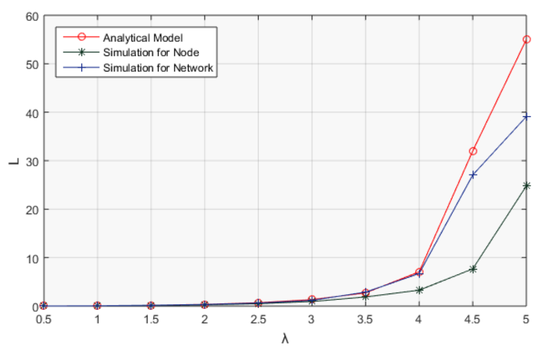

Fig. 7. The average queue length in the buffer to intensity dependence of the wireless sensor network routers.

Fig. 8 shows graphs of the dependence of the average length of a packet queue L to intensity λ on a wireless sensor network coordinator.

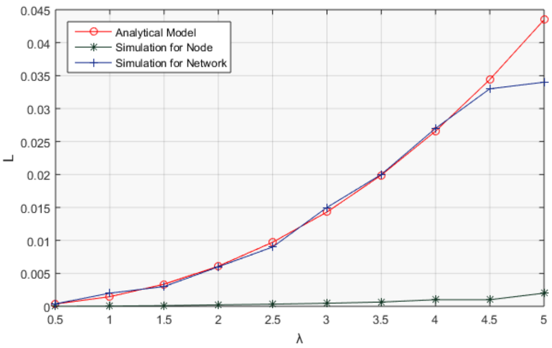

Fig. 8. The average queue length in the buffer to intensity dependence of the wireless sensor network coordinator.

The following are graphs of the average latency time of packets in the network (Fig. 9) and the intensity λ dependence of the probability of packet loss in the network (Fig. 10) obtained from the simulation model of a wireless sensor network for an integrated network.

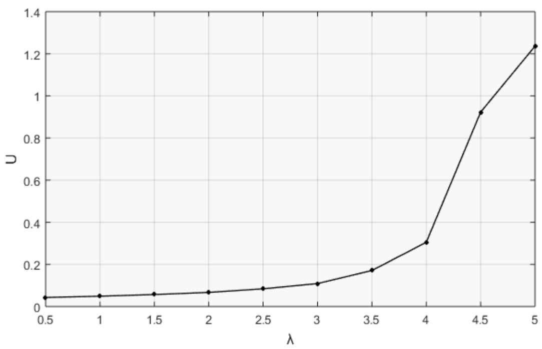

Fig. 9. The packet delay time to intensity dependence of the wireless sensor network.

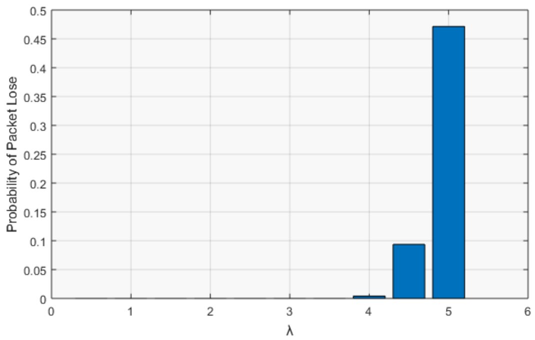

Fig. 10. The packet lose to intensity dependence of the wireless sensor network.

As can be seen from the obtained characteristics, the imitation model for the network implemented in the Anylogic software environment of the three studied models has a higher accuracy than the others in representing the wireless sensor network.

V. Conclusion

In conclusion, we can say the following. We have presented a block diagram of the wireless sensor network of the remote monitoring system of hybrid power supply sources of telecommunication facilities. We selected the ML-Node-Z device as the wireless sensor network router node, the ZigBit device as the coordinate node, and studied their characteristics. We created a graph model of a wireless sensor network and represented each node as a PSS. By constructing and solving a system of balance system of equations to the graph model, and by analyzing it, we determined the characteristics of the wireless sensor network analytically using the PSS theory. We also obtained the characteristics by simulating the network in the Anylogic environment. We made a comparative analysis of the obtained characteristics in tabular form. We also present the following characteristics in graphical form: The load to intensity dependence of the wireless sensor network routers (and coordinator); the packet delay time to intensity dependence of the wireless sensor network routers (and coordinator); the average queue length in the buffer to intensity dependence of the wireless sensor network routers (and coordinator); the packet delay time to intensity dependence of the wireless sensor network; the packet lose to intensity dependence of the wireless sensor network.

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