Intelligent Energy Efficient Wireless Communacation System for Street Lighting

A.K.Saymbetov[1,2]*, M.K.Nurgaliyev[1,2], Ye.D.Nalibayev[1,2], N.B.Kuttybay[1,2], Ye.A.Svanbayev[1,2], G.B.Dosymbetova[1,2], Ye.Tulkibaiuly[1,2], A.K.Meiirkhanov[1], Zh.K.Kopzhan[1], K.A.Gaziz[1]

[1]Al-Farabi Kazakh National University, Faculty of Physics and Technology,
[2]Research Institute of Mathematics and Mechanics (IMM)
Almaty, Kazakhstan
*E-mail: asaymbetov@gmail.com

***Abstract* — The paper considers modern street lighting systems and shows the drawbacks of existing street lighting systems. The concept of an autonomous street lighting system with wireless monitoring is considered. The power of this system is provided by solar panels and accumulators. The organization of a wireless network inevitably raises the question of energy consumption. In this paper, we presented a router duty mode, which reduces the overall power consumption of the wireless network. The router's duty mode is a process of sequentially switching nodes from the role of routers to the role of sensor nodes. The graphs of discharge of accumulators are constructed for the stationary mode of the network operation and for the duty mode.**

Keywords— autonomous street lighting system; wireless sensor network; routers; sensors; duty mode; stationary mode

I. INTRODUCTION

Street lighting is one of the main attributes for ensuring the safety of citizens at night. Today street lighting systems in our country use overwhelmingly gas-discharge lamps of DNAT and DRL models with a power of 250 W. Such systems have a low level of efficiency, since they do not take into account how often passers-by pass at a given place at night. These lamps are equipped with ballasts and that ballast provides lamp operation, can perform simple control functions. There are two types of ballasts: induction and electronic. Electromagnetic ballasts limit the power at the expense of jet inductive reactance. The main element of the electromagnetic ballast is inverters that convert the power frequency currents into currents with a frequency of 20 kHz. Due to this brightness increased and lamp efficiency could be increased [1-3]. The best idea to reach maximum efficiency without changing anything is to change the algorithm of work of lamp during night. It is possible to turn on street lighting only at a certain time. The rest of the time use 60-70% brightness.

However, the use of gas discharge lamps for such purposes will dramatically reduce their lifetime. For discharge lamps are characterized by three types of operating modes: instant start, quick start, programmable start. Instant ignition means start without preheating, which leads to a strong ion emission from cold cathode surface. Quick start - simultaneous ignition of the power supply and the cathode heating. Finally, a programmable start, which is characterized by successive feed of the cathode heating power and then igniting the electric arch [4,5]. No one of these modes are suitable for our purpose. Hence the conclusion: for reaching maximum energy efficiency we need to know, when evening passers require lighting mostly. For this time of the day it makes sense to include the lamps to maximum brightness for the comfort of people. The time, when the density of the passers-by tend to zero, the lighting should be reduced to 60-70% of maximum brightness.

In order to maximize the efficiency of the street lighting system, lamppost are transferred to the autonomous mode powered by solar panels. In [6] is presented application of energy efficient public lighting system with adaptive algorithm to minimize energy consumption providing smart city services. To reduce wasting of energy at night time authors in [7] propose using adaptive algorithm of lighting, which provides detection of vehicles and adjusts brightness of lamps in real time. To increase generated power of solar panels we propose using solar tracking system which is considered in [8]. Calculations of accumulation and discharge of batteries at night time are shown in [9]. Although autonomous lampposts will improve the efficiency level, it will reduce the level of protection from various system failures. In this case, wireless monitoring of the lighting system is required. For this purpose we use wireless sensor networks (WSN).

The WSN is a wireless system that is a distributed, self-organizing and fault-tolerant network of miniature computing devices with an autonomous power supply [10]. The most frequently used monitoring object is temperature, humidity, illumination and gas composition.

The main task in the technology of wireless sensor networks is the development of an transceiver with sensor modules that would have an exclusively autonomous power supply. A more detailed analysis of the problem of energy-independent power supply is presented in [11].

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In terms of power consumption, the most difficult case is the WSN for gas monitoring. At the same time, when organizing gas monitoring of toxic gases, catalytic, optical, semiconductor and electrochemical sensors can be used. Of all the variety of gas sensors, electrochemical sensors are distinguished by the fact that they practically do not consume electric energy. This opens the possibility of their wide application in wireless sensor networks for ecological monitoring of air composition. In this case, wireless sensor networks can be deployed in places where there is no access to electrical networks and, therefore, it is necessary to ensure continuous operation of wireless gas sensors due to autonomous power.

To date, majority of street lighting systems with wireless monitoring are based on ZigBee [12-14]. The article [15] describes the development of a sensor network based on the integrated system of ZigBee and WiMAX technologies for the purpose of Internet access. Although, the power consumption of the transmitting and receiving devices, is small, discharge of the battery will lead to the failure of the node. Thus, we are faced with the task of reducing the level of consumption of a wireless sensor network.

II. The Concept Of Streetlighting System With Wirelees Monitoring And Controle

Today, there are quite a lot of intelligent street lighting systems which are fundamentally different from the traditional ways of organizing street lighting. On the eve of the energetic crisis efficient systems in any field have an obvious advantage over conventional systems. The main role in that kind of systems takes automation and elimination of the human factor, the construction of the entire premeditated workflow algorithm providing all the nuances of the system. This is a big step towards the development of instrumentation, computer technology and software. Development of semiconductor electronics and digital information processing reveals vast horizons to ensure the complete comfort of living. Machines that perform the most complicated, laborious, boring and routine work associated with the endless repetition of the same action is the future, where human life will be held not in the constant race of survival, but in the conscious harmonious coexistence with nature and the social environment. Eco-friendly power generation technologies, the subsequent efficient use - the key to sustainable human development. Therefore, the modernization of street lighting systems is of paramount importance in an attempt to use energy resources of the planet more efficiently.

The main criteria for evaluating the effectiveness of street lighting systems are firstly a minimum downtime of the entire lighting system. The second important aspect is the level of energy savings when using this or that street lighting control system. And lastly, the cost of repairs and maintenance of the system should be minimal, i.e. the life of the equipment should be maximized in these conditions.

There are three ways to construct efficient algorithm. First, the development of switching schedule of the system's operation, based on the geographical location of the area in which the system is installed, as well as the density level of passers by in the area depending on the time of day. Second, the use of ambient light sensors, motion and presence. And the third: Switching between modes of system manually. The first method is simple conceptually, however, statistics on traffic areas, depending on the time of day is associated with certain difficulties. Automation systems implies the maximum exclusion of human factor. Therefore, it is advisable to consider a second embodiment.

Motion and light sensors give a signal to the master microcontroller, which in turn, according to the working algorithm, goes into one operating mode of the system. Simple, but highly reliable light sensors based on the principle of work of photoresistors and photodiodes. In order to develop the most effective modes of operation of the street lighting system in addition to the light sensors are used motion sensors (Fig.1).

The next step for the implementation of modern outdoor lighting system is to replace the discharge lamps by high-brightness LEDs. LED lamps, due to their high cost, are not widely used in this field. The obvious advantages of LED lamps to gas discharge lamps, such as long life, low power consumption and high brightness make LEDs essential lighting devices. Moreover, LEDs do not require preheating, and in some cases, on the contrary, require refrigeration. This is the best solution for modern lighting systems, outdoor lighting, which require instantaneous switching on and off of the lighting.

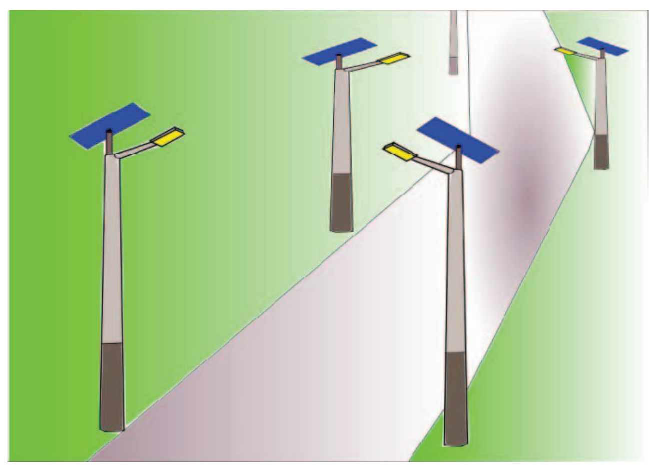

Figure 1. The concept of autonomous street lighting system with wireless monitoring

Thus, each lamp post is equipped with a light sensor, motion sensor and controller, which checks the level of illumination, and the presence of passers-by. The level of brightness of the lamps depends on presence of passers-by. Also, to provide wireless data transmission, the lamppost is equipped with a transceiver device. Data transmission is carried out at regular intervals and contains information about the state of the charge of the batteries and shows the transition of the lamp post from the active mode to the standby mode.

The topology of the street lighting system is based on the topologies "tree" and "star". Fig. 2 shows the topology of a wireless communication system. Information is transferred from nodes to the router. Routers are connected by a tree topology. Then information is transferred to the controller, which processes the information and displays the dispatcher.

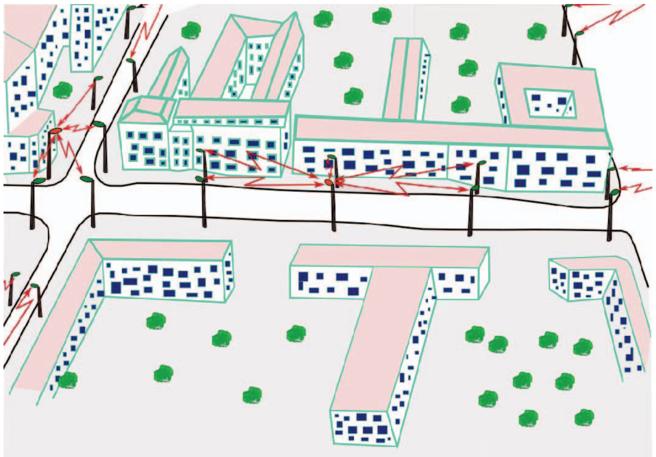

Figure 2. Topology of street lighting system

The organization of such a wireless communication system raises the issue of the power consumption of wireless modules. The communication nodes that act as routers consume more power than the sensor nodes. Consequently, the discharge of the batteries of these nodes is faster. In the case of a rapid discharge of the node from the routers, all the sensor nodes connected with it will fail. To solve this problem, we propose using router duty mode. This mode allows us to distribute the load between the nodes evenly.

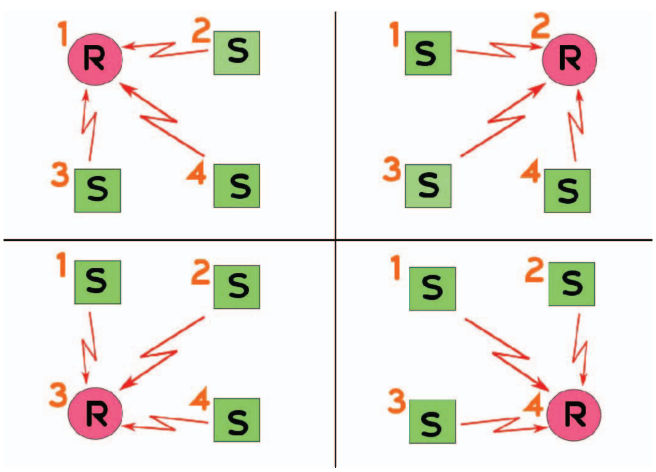

Figure 3. Duty cycles of four nodes

Fig. 3 shows the duty cycles for the "star" topology. Each cycle passes an equal period of time, which allows us to distribute evenly the power consumption of the system. In the upper-left quadrant, the role of the router is performed by node 1, all other nodes act as sensors and send data to node 1. In the second cycle, we move to the quadrant in the upper-right corner. In this case, the role of the router is performed by the node numbered 2. In the next cycle, by the number 3, and further - under the number 4.

III. Modeling Work of Nodes in Duty Mode

To identify the energy efficiency of the above-mentioned duty mode, we simulate the situation in which we have 4 nodes, each can be either a node-sensor or a node-router. As a hardware platform, we took the microcontroller AtMega328, transceiver NRF24L01, light sensor and motion sensor HC-SR501. Power is supplied by 18650 lithium-ion batteries. Table 1 shows the current consumption of each node in sensor mode and in router mode.

Table 1. Consumption of nodes in sensor and router modes

Node 1			
Load	***I, mA***	***t, ms***	***C, μAh***
ATMega 328	20	200	1,11111
NRF24L01 sleep mode	0,14	199,99	0,00778
NRF24L01 TX mode	11,3	0,01	0,00003
NRF24L01 RX mode	13,5	0	0
Light sensor	0,5	200	0,02778
HC-SR501 active mode	65	1	0,018
HC-SR501 sleep mode	0,05	199	0,00278
	Total, mAh:		0,00117
Node 2			
Load	***I, mA***	***t, ms***	***C, μAh***
ATMega 328	20	200	1,11111
NRF24L01 sleep mode	0,14	199,99	0,00778
NRF24L01 TX mode	11,3	0,01	0,00003
NRF24L01 RX mode	13,5	0	0
Light sensor	0,5	200	0,02778
HC-SR501 active mode	65	1	0,018
HC-SR501 sleep mode	0,05	199	0,00278
	Total, mAh:		0,00117
Node 3			
Load	***I, mA***	***t, ms***	***C, μAh***
ATMega 328	20	200	1,11111
NRF24L01 sleep mode	0,14	199,99	0,00778
NRF24L01 TX mode	11,3	0,01	0,00003
NRF24L01 RX mode	13,5	0	0
Light sensor	0,5	200	0,02778
HC-SR501 active mode	65	1	0,018
HC-SR501 sleep mode	0,05	199	0,00278
	Total, mAh:		0,00117

Node 4			
Load	***I, mA***	***t, ms***	***C, µAh***
ATMega 328	20	200	1,11111
NRF24L01 sleep mode	0,14	199,99	0,00778
NRF24L01 TX mode	11,3	0,01	0,00003
NRF24L01 RX mode	13,5	0	0
Light sensor	0,5	200	0,02778
HC-SR501 active mode	65	1	0,018
HC-SR501 sleep mode	0,05	199	0,00278
	Total, mAh:		0,00117
Router mode			
Load	***I, mA***	***t, ms***	***C, µAh***
ATMega 328	20	200	1,11111
NRF24L01 sleep mode	0,14	0	0,00778
NRF24L01 TX mode	11,3	0,01	0,00003
NRF24L01 RX mode	13,5	199.9	0
Light sensor	0,5	200	0,02778
HC-SR501 active mode	65	1	0,018
HC-SR501 sleep mode	0,05	199	0,00278
	Total, mAh:		0,00117

Using the data in table 1, we plot the discharge graphs of the batteries in the stationary mode, where roles of nodes do not change, and in the duty mode and compare the results. Fig. 4 shows the graph of the discharge of batteries under stationary mode. One cycle of work is 30 minutes. After 90 cycles, the battery discharges to 30% of the charge. Fig. 5 shows the graph of the battery discharge when routers are in duty mode. In this case, the system runs 127 cycles before the batteries are discharged to 30%. Figures 6 and 7 show graphs of discharge of batteries after 6 and 13 work cycles respectively.

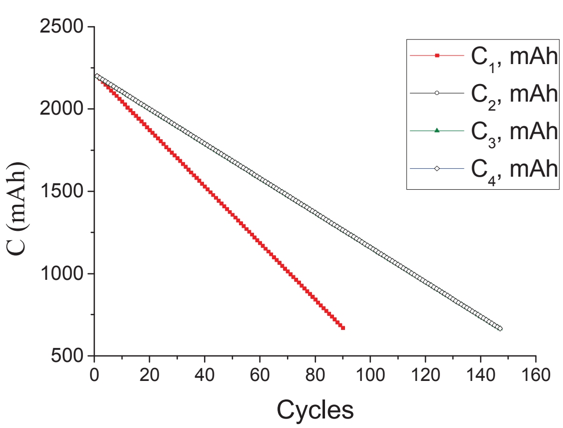

Figure 4. Discharge of batteries in stationary mode.

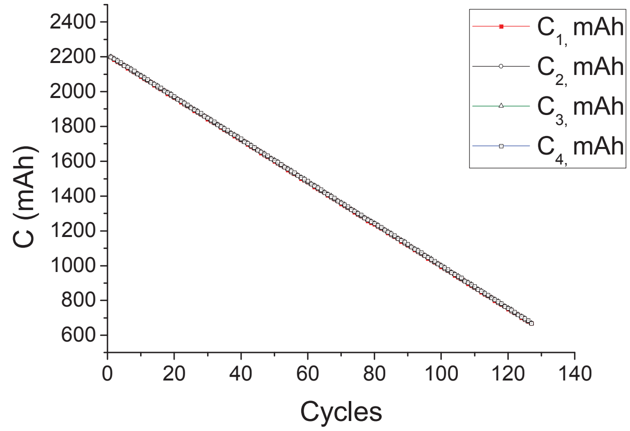

Figure 5. Discharge of the batteries in duty mode.

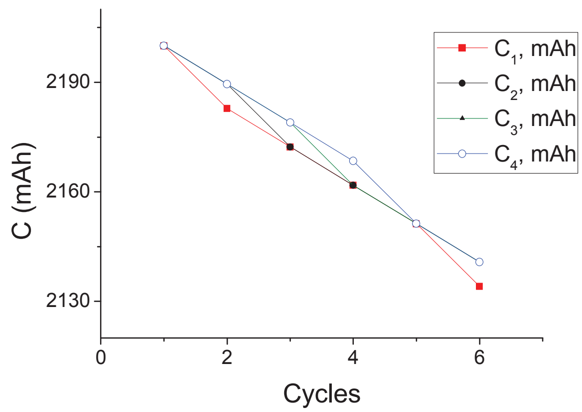

Figure 6. Discharge of the batteries in duty mode (during 6 cycles)

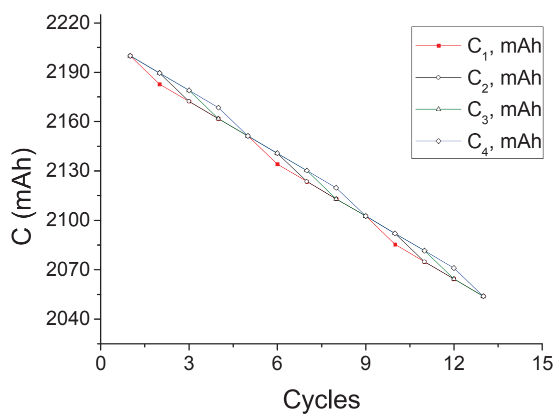

Figure 7. Discharge of the batteries in duty mode (during 13 cycles)

If we reduce the scale of the graph in Figure 5, we will be able to observe the periodicity of the router's duty mode, as shown in Figure 7. The graphs of the battery discharge shown in Figures 6 and 7 clearly show how the batteries discharge when using the duty mode. Comparing the discharge graph for stationary mode and the discharge graph for the duty mode, we can conclude that the router duty mode allows us to distribute the load evenly, and it is more energy-efficient.

IV. CONCLUSION

The wireless street lighting monitoring system allows us to respond quickly to various errors and system failures. In conditions of a shortage of electrical energy during operation, the energy efficiency of the wireless network plays a decisive role. The router duty mode offered by us allows us to reduce the energy consumption of the wireless network by up to 1.5 times. In addition, in the event of a failure of one of the routers, an automatic switchover from one router to another allows us to restore the system wireless connection.

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