Applications of Multipath Routing for Energy Balancing in Sensor Networks

I.S. Shostko, Ye. Kulia

***Abstract* — When designing a wireless sensor network (WSN) with autonomous nodes there emerges an issue how to provide the maximum duration of its life. For this purpose the use of multipath routing with support of the regime of energy balancing nodes is proposed in the article. The model for study of algorithms, multipath routing considering redressing the imbalance of power consumption in WSN transit nodes is developed.**

Keywords: **wireless sensor network, routing, power, imbalance.**

I. Introduction

Autonomous wireless sensor networks (WSN) are a special direction of development of telecommunication networks (TCS). The load on the communication lines WSN can fluctuate significantly over time: from the formation of a constant flow of information to rare, short signals or packets. In some cases, transmission of information from the sensor occurs only as a result of occurrence of certain events. Information signals may be analog or digital, and data to transfer, image, speech, etc. Unlike traditional TCS where by routing methods the maximum volume of traffic in the WSN is achieved, this task is usually not necessary. Is not important and the order of the nodes participating in the routing process. What is important is the accuracy of the transmitted commands or messages with a maximum length of the lifetime WSN. To increase duration of time the network operation saving power both of the sensor and other network nodes operating independently is of particular importance. This imposes a restriction on the choice of FSU routing protocols on the topology of the network and the strategy of nodes relationship.

Manuscript received February 8, 2015.

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II. Analysis of published data and problem statement

Improving the energy efficiency of nodes WSN is a hot topic for many researchers. The following is an analysis of the number of publications devoted to reducing energy consumption and optimization modes WSN.

Energy balancing of data transfer route is considered in Y. Chen [1]. The proposed new approach to routing EBMR (Energy-Balancing Multipath Routing), is based on the account of the energy sources of supply constraints for nodes with WSN energy balancing route. The method of dynamic reconfiguration of WSN described in [2], allows to optimize traffic flow on the criterion of maximizing the time of its life. With the help of a set of programs developed by the author the proposed methods and algorithms for dynamic reconfiguration of the existing network are compared, and the dependence of the lifetime of a possible increment of the parameters of operation of the network sensor nodes and mobile runoff is investigated. In the work [3] the author noted that when the energy parameters and the level of signal / noise ratio of the sensor network topology changes for each cycle of the network. Moreover, since the choice of the headend is based on residual energy, each node can be selected mainly in a cluster, and thus the life of the sensor network can be extended in general. The large number of scientific papers on the development of methods to reduce energy consumption WSN suggests that research questions are relevant. Each of the considered methods has its advantages and disadvantages and is well suited for a particular situation.

III. Problem Formulation

The object of study is the process of functioning of the autonomous wireless sensor network. The purpose of work is the increase of lifetime of the autonomous WSN through the use of algorithms for routing support of the regime of nodes energy balancing. To achieve the goal the task is defined: - development of model for the study of algorithms, multipath routing considering redressing the imbalance of power consumption in the transit nodes WSN.

IV. Statement of the Problem of Routing Considering Redressing the Imbalance of Power Consumption in the Transit Nodes of Wireless Sensor Network

Let us consider a network consisting of m routing nodes. As part of the basic model network configuration is described by a graph $G_s = (V_s, E_s)$, where $V_s = \{\alpha_1, \alpha_2, \alpha_3, ..., \alpha_m\}$ – a plurality of network routing nodes, $E_s = \{\beta_1, \beta_2, \beta_3, ..., \beta_n\}$ – a plurality of communication channels (Fig. 1). For each communication channel $(i, j) \in E_S$ given its carrying capacity $c_{i,j}$. Magnitude $x_{i,j}$ describes the proportion of the incoming traffic flowing in the duct $(i, j) \in E_S$.

If the role of nodes is dynamically changed and the network topology is reconstructed, it is possible to bring the lifetime of the network to the terminal device (TD) lifetime. This may increase the lifetime due to the fact that most of the time each of the nodes will be in the role TD. In addition the set of concurrent routing nodes (RN) cyclically follow each other. Decisions on how to rebuild the topology are taken at the level of the network coordinator.

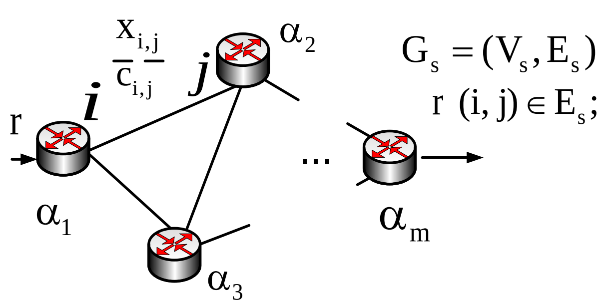

Fig. 1. An example of a graph for describing the network model

We solve the problem of maximizing the lifetime of the network. We construct all related subgraphs T_k, $k \in \overline{1,K}$ graph G_s, it is a tree with a root element containing all vertices G_s. R_k - set of all RNs of the graph T_k. Consider an arbitrary subset $\{R_{k_s}\}_{s=1}^{S}$ of a plurality $\{R_k\}_{k=1}^{K}$. We have S independent sets of plurality $\{R_{k_s}\}_{s=1}^{S}$ each comprising S_u RNs and $S - S_u$ TDs. Then the average current in the node α_j is expressed by the formula

$$I_j = I_R\left(\frac{S_u}{S}\right) + I_E\left(\frac{S - S_u}{S}\right) = I_E + (I_R - I_E)\frac{S_u}{S}, \quad (1)$$

where I_R — an average current strength in BI time (Beacon Interval — interval between beacons) at a node located as RN; I_E — an average current strength in BI for a node which currently plays the role of TD. The lifetime of the device is determined by WSN with the shortest lifetime

$$T_{WSN} = \min_j \frac{Q_{bat\ j}}{I_j} \to \max, \quad (2)$$

where $Q_{bat\ j}$ — battery charge of the node α_j. For simplicity, we assume that at the initial time all devices have the same battery charge $Q_{bat\ j} = Q_{bat}$. Then the condition (2) becomes

$$\max_j I_j = I_E + (I_R - I_E)\frac{\max_u S_u}{S} \to \min. \quad (3)$$

If sets $\{R_{k_s}\}_{s=1}^{S}$ are independent, $\forall s \in \overline{1,S} \to S_u \in \{0;1\}$, therefore $\max S_u = 1$ and there remained only one condition

$$S \to \max. \quad (4)$$

This is the required condition. Thus, in order to achieve a maximization of network life time it is necessary to find the maximum number of independent sets of routers.

Statement of the problem of routing in view of redressing the imbalance of power consumption in the transit nodes WSN:

Given:

- number of communication channels in the network (n);
- number of nodes in the network (m);
- the sending node packages α_j;
- the recipient node packages α_j;
- network bandwidth ($c_{i,j}$);
- metric of communication channels ($f_{i,j}$);
- traffic intensity incoming in the network (r).

It is necessary to define:

- the way (ways) from the sending node to the recipient node, that passes along the channels of the simulated network and are "optimal" in the framework of the selected metrics;
- the dependence of the number of ways which are used during routing, as a function of the intensity of the traffic entering the network;
- the dependence of energy consumption on the number of engaged nodes.

V. Model of Multipath Routing Using Traffic Engineering Technology in the Form of the Quadratic Programming Problem

Let the network structure and the capacities of its of communication channels are shown in Fig. 2. Then the total number of nodes in the network is equal to five (m = 5), and the total number of links is ten (n = 10). Let the sending node packages be the unit 1 and unit-recipient – the unit 5.

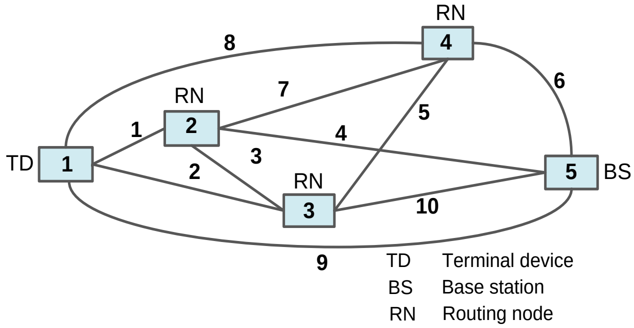

Fig. 2. The structure of the simulated network

The number of communication channels in the network (n) defines the dimension of the vector x, variables $x_{i,j}$ of which characterizes the share of traffic in the channel of communication between the i-th and j-th nodes. The dimension of the vector metrics f corresponds to the number of communication channels in the network (n), variables $f_{i,j}$ which characterize metric communication channel between i-th and j-th nodes. To implement multipath routing coordinates of the vector x the following restrictions are imposed

$$0 \le x_{i,j} \le 1, \; i, j = \overline{n, m}; \; i \ne j, \tag{5}$$

where the variables $x_{i,j}$ can take values in the interval from zero to one. The physical meaning of the variables (5) determines the possibility of branching into several flow paths in the network, i.e. traffic may be transmitted as one or a plurality of ways. In this case, each communication channel will be assigned to the metric,

$$f_{i,j} = \frac{10^7}{c_{i,j}},$$

where $c_{i,j}$ - bandwidth connections between i - th and j - th nodes (1/s).

In the course of solving the problem of routing is important to prevent packet loss at the network nodes in the network as a whole, it is necessary to ensure that the conditions of conservation of flux:

$$\begin{cases} \sum\limits_{j:(i,j)} x_{i,j} - \sum\limits_{j:(j,i)} x_{j,i} = 1, & \text{for sender node} \\ \sum\limits_{j:(i,j)} x_{i,j} - \sum\limits_{j:(j,i)} x_{j,i} = 0, & \text{for transit nodes} \\ \sum\limits_{j:(i,j)} x_{i,j} - \sum\limits_{j:(j,i)} x_{j,i} = -1, & \text{for recipient node} \end{cases} \tag{6}$$

In addition, it is necessary to ensure fulfillment of the conditions in the channels to prevent overloading the network:

$$r \cdot x_{i,j} \le c_{i,j}, \quad \left(i, j = \overline{n, m}; \quad i \ne j\right). \tag{7}$$

To solve the problem we use the model of multipath routing using the technology of Traffic Engineering where as the objective function to be minimized the quadratic form is used:

$$\min_x \left[x^t H x + f^t x\right],$$

where H - additionally defined diagonal matrix of $n \times n$ size, coordinates of which (like the vector f) characterize metric of communication channels.

Thus, the solution to the problem of multipath routing using the technology of Traffic Engineering is reduced to solving the optimization problem of quadratic programming using the tool «Optimization Toolbox» of MatLab package v.14.b, which is represented by subroutine «quadprog»:

$$[x,fval]=quadprog(H,[],A,b,Aeq,beq,lb,ub) – decision,$$
$$fval = \min_x \left[x^t H x + f^t x\right] \text{ при } Aeq \cdot x = beq, \; A \cdot x \le b \text{ и}$$
$$lb \le x \le ub,$$

where $H = diag(f)$, that is, the main diagonal matrix H are located metrics of communication channels;

f, x, b, beq - vectors, A and Aeq - matrix, lb и ub – column vectors of size n, and in accordance with the expression (5), all coordinates of the vector lb zero, and all the coordinates of the vector ub equate units. To describe the routing problem in the formalism of the conditions of preservation of the environment MatLab flow (6) should be submitted in vector-matrix form: $Aeq \cdot x = beq$. Thus, the matrix Aeq has dimension $m \times n$, the coordinates of which take numerical values {-1,0,1} at $\left(j = \overline{1, m}, i = \overline{1, n}\right)$:

$a_{j,i} = 1$, if i-th communication channel exits from j-th node;

$a_{j,i} = -1$, if i-th communication channel enters in j-th node;

$a_{j,i} = 0$, if i-th communication channel is not incident j-th node.

The dimension of the vector beq It corresponds to the number of nodes in the network (m), and its coordinates are formed as follows $\left(j = \overline{1, m}\right)$:

$beq_j = 1$, if i-th is the node-sender;

$beq_j = -1$, if i-th node is receiving packets;

$beq_j = 0$, if i-th is transit node.

Condition (7) must also be to submitted in vector-matrix form of inequality $A \cdot x \le b$.

Example of routing and address problems in Matlab. Form the unknown vector x and the vector of metrics f:

$$x = \begin{bmatrix} x_{1,2} \\ x_{1,3} \\ x_{1,4} \\ x_{1,5} \\ x_{2,5} \\ x_{3,2} \\ x_{3,4} \\ x_{3,5} \\ x_{4,2} \\ x_{4,5} \end{bmatrix}, \quad f = \begin{bmatrix} f_{1,2} \\ f_{1,3} \\ f_{1,4} \\ f_{1,5} \\ f_{2,5} \\ f_{3,2} \\ f_{3,4} \\ f_{3,5} \\ f_{4,2} \\ f_{4,5} \end{bmatrix} = \begin{bmatrix} 10^7/250/4 \\ 10^7/250/4 \\ 10^7/250/4 \\ 10^7/0 \\ 10^7/250/4 \\ 10^7/250/4 \\ 10^7/250/4 \\ 10^7/250/4 \\ 10^7/250/4 \\ 10^7/250/4 \end{bmatrix}. \quad (8)$$

Formalize the preservation of flow in the network nodes (6):

$$\begin{cases} x_{1,2} + x_{1,3} + x_{1,4} + x_{1,5} = 1 \\ -x_{1,2} - x_{3,2} - x_{4,2} + x_{2,5} = 0 \\ -x_{1,3} + x_{3,2} + x_{3,4} + x_{3,5} = 0 \\ -x_{3,4} - x_{1,4} + x_{4,2} + x_{4,5} = 0 \\ -x_{1,5} - x_{2,3} - x_{3,5} - x_{4,5} = -1 \end{cases}.$$

We form a matrix Aeq and vector beq:

$$Aeq = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ -1 & 0 & -1 & 1 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & -1 & 1 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & -1 & 0 & 0 & -1 & -1 \end{bmatrix}, \quad beq = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ -1 \end{bmatrix},$$

formalize conditions to prevent overloading of communication channels (7):

$$\begin{cases} r \cdot x_{1,2} \le c_{1,2} \\ r \cdot x_{1,3} \le c_{1,3} \\ r \cdot x_{1,4} \le c_{1,4} \\ r \cdot x_{1,5} \le c_{1,5} \\ r \cdot x_{2,5} \le c_{2,5} \\ r \cdot x_{3,2} \le c_{3,2} \\ r \cdot x_{3,4} \le c_{3,4} \\ r \cdot x_{3,5} \le c_{3,5} \\ r \cdot x_{4,2} \le c_{4,2} \\ r \cdot x_{4,5} \le c_{4,5} \end{cases}.$$

Form the matrix A and the vector b:

$$A = \begin{bmatrix} L & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & L & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & L & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & L & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & L & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & L & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & L & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & L & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & L & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & L \end{bmatrix}; \quad b = \begin{bmatrix} c_{1,2} \\ c_{1,3} \\ c_{1,4} \\ c_{1,5} \\ c_{2,5} \\ c_{3,2} \\ c_{3,4} \\ c_{3,5} \\ c_{4,2} \\ c_{4,5} \end{bmatrix},$$

where $L = lamda$.

For the structure of the network with bandwidth of its communications channels, presented in Fig. 2, a diagonal matrix of metrics channels has the form:

$$H = \begin{bmatrix} h_{1,1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & h_{1,1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & h_{1,1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & h_{1,1} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & h_{1,1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & h_{1,1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & h_{1,1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & h_{1,1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & h_{1,1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & h_{1,1} \end{bmatrix},$$

where $h_{1,1} = 10^7/250/4$.

$H = diag(f)$, that is, there are metrics of communication channels on the main diagonal matrix H (8).

In accordance with the original data intensity of incoming traffic at r = 250 all the ways except for 3, 5 and 7 will be used. Thus through 2, 3 and 4 node passes on 33,3(3)% transmitted traffic - with an intensity 83,3 (3). Thus, for 2, 3 and 4 node energy consumption is distributed evenly. This ratio will not change with a decrease in intensity incoming traffic. By increasing the number of nodes involved repeaters for multipath routing incoming traffic will be equally shared between all RNs. Thus, for the example of considered life expectancy has increased in proportion to the number of WSN nodes involved repeaters, between which the load is redistributed.

V. CONCLUSION

The studies have shown that if the role of nodes is dynamically changed and rebuilt the topology of the network, we can bring the network to lifetime of TD. This may increase the lifetime due to the fact that most of the time, each of the nodes will be in the role of TD. In addition the set of concurrent RNs cyclically follow each other. Decisions on how to rebuild the topology of the network are taken by a coordinator.

Also the author solved the problem of multipath routing in view of redressing the imbalance of power consumption. To achieve maximizing network lifetime it is necessary to find the maximum number of independent sets of routers. In solving the optimization problem of quadratic programming a uniform load between the transit nodes is obtained and hence their energy consumption will be the same.

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