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METHOD OF NODES RADIOCONNECTIVITY CONTROL IN THE MOBILE RADIO NETWORKS (MANET)

У статті запропоновано метод управління радіозв'язністю вузлів мобільних радіомереж на основі комплексного застосування нечіткої логіки та технології інтелектуальних агентів. Суть методу полягає в інтеграції функцій прикладного, мережевого та фізичного рівнів моделі OSI для підтримання радіозв'язності між мобільними вузлами в процесі передачі інформації. В умовах високої динаміки зміни топології, які характерні радіомережам класу MANET, це дозволить не лише підвищити ймовірність успішного прийому пакетів, але й скоротити енергетичні та часові витрати на їх передачу.

Романюк В.А., Сова О.Я., Симоненко А.А., Сальник С.В. Метод управления радиосвязностью узлов м обильных радиосетей класса MANET. *В статье предложен метод управления радиосвяностью узлов мобильных радиосетей на основе комплексного применения нечеткой логики и технологии интеллектуальных агентов. Суть метода заключается в интеграции функций прикладного, сетевого и физического уровней модели OSI для поддержания радиосвяности между мобильными узлами в процессе передачи информации. В условиях высокой динамики изменения топологии, которые характерны радиосетям класса MANET, это позволит не только повысить вероятность успешного приема пакетов, но и сократить энергетические и временные затраты на их передачу.*

V. Romanyuk, O. Sova, O. Symonenko., S. Salnyk Method of nodes radioconnectivity control in the mobile radio networks (MANET). *The method of nodes radioconnectivity control in the mobile radio networks based on integrated using of fuzzy logic and intelligent agent technologies is proposed in the article. The method consists in functions integration of application, network and physical OSI levels to support radioconnectivity between mobile nodes in the time of information transmission. In highly dynamic topology changes conditions, which is characterific for the MANET, it will allow not only to increase the probability of successful packets reception, but also to reduce energy and time for their transfer.*

Key words: *radioconnectivity, intelligent management system, mobile radio network, intelligent agents.*

Relevance of the research. Combat units management in modern military operations requires a full informativenes of officials regards to the situation on the battlefield at any given time. Collection, processing and responsiveness of such an information in the tactical command and control link are possible only through the use of the modern radio communication networks that can provide "anywhere anytime" principle of communication. Examples of such networks are the mobile radio networks (MRN) of MANET class (Mobile Ad-Hoc Network) [1], the main feature operation of which – the all nodes mobility and the ability to organize themselves in the radio network without advance expanded network infrastructure under uncertainty (the reliable information about the situation on the battlefield is absent). Another feature operation of MRN is that almost every node running on battery power, limited capacity of which affects directly on a "lifetime" of mobile node and therefore on its ability to take part in the reception and data transmission [2].

In MRN the data transmission between transmitter and addressee (addressees) can be carried out both directly and by intermediate nodes retransmission. The main condition for successful reception and data transmission between any two nodes is a radio connectivity presence between them. Due to the full mobility of MRN elements (both nodes and base stations) the radio connectivity between mobile nodes is possible both by controlling the transmitter power and by choosing the optimal routes of transmission between transmitter and addressee nodes. Thus, both of the cases adduct a current task, which is to choose such a control solutions that can provide data transmission in MRN with a given quality of service and also can minimize energy source of mobile nodes. Given the conditions of uncertainty which characterize the functioning of MRN and unpredictable tactical situation (nodes physical destruction, impact of the radio electric suppression, variations of nodes speed and directions of transfer in each moment). This task can be solved by comprehensive using of fuzzy logic and technologies of intelligent agents.

Accordingly, *the purpose* of the article is to develop a method of nodes radioconnectivity control in the mobile radio networks of MANET class. *The object* of the research is the data transmission in MRN. *The subject* of the research is a method of mobile nodes radioconnectivity providing.

The analysis of the subject area. As noted above, according to the MRN topology, that is defined of organizational structure of combat forces in a tactical link of command and control (Fig. 1), the data transmission between transmitter and addressee (addressees) can be carried out both directly and by intermediate nodes retransmission using predefined routes (or route) of transmission [3]. However, in any case, the MRN successful transmission between two nodes can occur only if radioconnectivity presences between them. Lack or loss of radioconnectivity during a data transmission lead to inability of communication between nodes or break the existing transmission route. In the first case it can directly affects the quality of combat forces management due to inability to deliver management commands to individual combat units. In the second case – it will negative affects the quality of data transmission because of the delays, that associated with a necessary to find out new routes between transmitter and addressee.

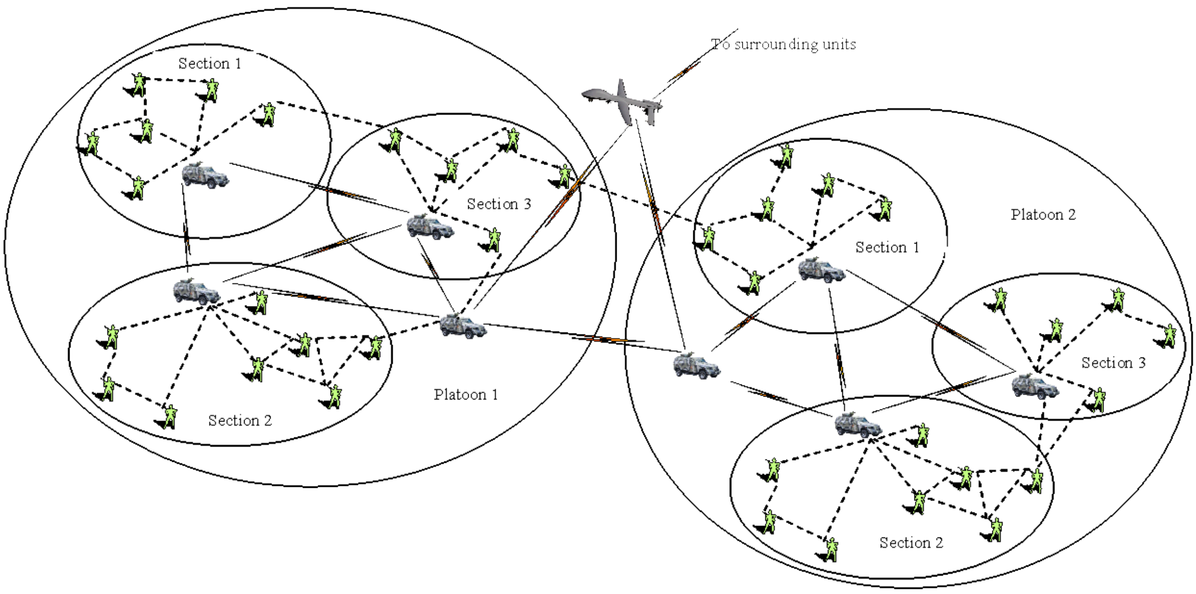

Fig. 1. Radioconnectivity mobile nodes of the mobile radio networks (section–platoon)

Radioconnectivity Z_{ij} – the mutual location of transmitter node i and addressee node j in each other radiovisibility zone (Fig. 2), that ensures the specified service quality (QoS) of ξ– traffic type. In general, the physical layer of the OSI model the service quality of each traffic type $\xi = \overline{1,3}$ (data, speech, video) determined by acceptable value probability of erroneous reception of information bits $BER_{\xi_{ij}}$ (*Bit Error Rate*) [4], that is assessed on the statistical data. However, due to the dynamic nature of the MRN functioning and a high MRN rate of radio settings change assume – the decisions about quality of traffic service will be taken by node SU based on the current values of the signal / noise ($SINR$) at the receiver input (error rate [5]):

$$BER_{\xi_{ij}} = f\left(SINR_{ij}\right), \tag{1}$$

that is determined by

$$SINR_{ij} = \frac{p_{ij}G_{ij}}{\sum\limits_{k \neq j} p_{kj}G_{kj} + \text{З}_j}, \tag{2}$$

$$G_{ij} = k_a F d_{ij}^{-\alpha}, \tag{3}$$

$i, j, k \in N$ – MRN area nodes; p_i – i-node transmission power; G_{ij} – attenuation value between nodes $i-j$; k_a – antennas characteristics coefficient; F – attenuation factor; d_{ij} – distance between nodes $i-j$; $\alpha = 2...4$ – degree of power loss, depending on radio wave propagation conditions; $з_j$ – noise power spectral density in the receiver passband.

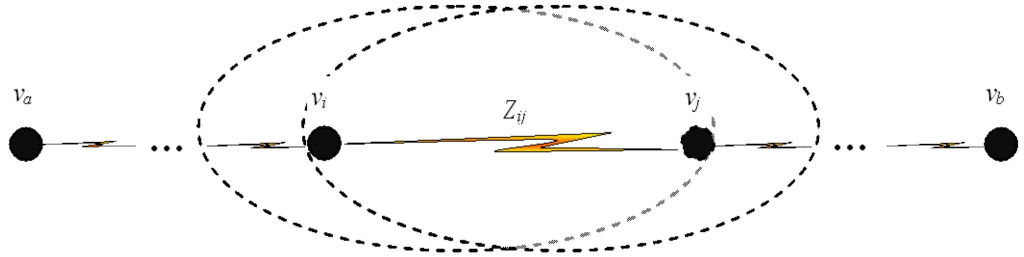

Fig. 2. Radioconnectivity between two nodes in MRN

Herewith, to avoid transmission interruptions associated with a sharp decrease of *SINR* when receiving (through the increasing noise in a radio channel or through the fading signal, etc.), it is necessary that the following conditions are fulfilled:

$$SINR_{ij} \geq SINR_{\text{allowable}}, \tag{4}$$

$$p_{\text{s}} - p_{\text{rs}} \geq p_{\text{es}}, \tag{5}$$

where $SINR_{\text{allowable}}$ – defined by specific model and mobile node transceiver parameters; p_{rs} – real receiver sensitivity; p_{es} – energy supply. Requires coefficient p_{es} shows that node needs time for transmitter power decision in a case of sharp changes of signal reception p_s, which depends on mobile nodes speed and radio wave propagation conditions.

The main reasons for radioconnectivity loss between MRN nodes may be: mobile node destruction, node battery discharging and node output out of mutual radiovisibility zone. However, as noted above, two last reasons are directly dependent on a mobile node data transmission power , but they have different physical nature: increasing of nodes transmit power leads to increase the probability of successful packets reception, but requires more energy of batteries and creates a high mutual interferences that causes a sharp decrease of radio network bandwidth capabilities.

In fixed wireless telecommunication networks (GSM, CDMA, 802.11 standards), where the mobile are only subscribers and transmission routes between them are built through a fixed telecommunication network, the node radioconnectivity control with a base station is carried out by changing the transmission power p_{ij} (t). RSSI index (Eng. Received Signal Strength Indication) determines a reception signal level [6]: if RSSI is low – the transmitter signal has to be powerup and vice versa. For example, in cellular networks with a code division the power control is performed by the following iterative rule [7]:

$$p_{ij}(t) = \min_{p_{ij} \leq p_{ij\max}} \left(\frac{SINR_{\text{доп}}}{SINR_{ij}(t-1)} p_{ij}(t-1) \right). \tag{6}$$

From the rule (6) we can see, that fixed wireless network nodes select the minimum power only through the formula $SINR_{\text{allowable}} / SINR_{ij}(t-1)$. In other words, if the signal level exceeds the threshold, the transmission power decreases and vice versa. At that – transmitter node work at a minimum level let to minimizes a battery capacity (although this figure is not taken into a transmission power control) and to reduce mutual interference in a wireless network.

However, the main difference MRN from cellular networks is a lack of base stations and, as a result, fixed transmission routes between transmitter and addressee nodes, that makes the routing problem one of the main in MRN engineering. Also, as noted above, the full node battery capacity flow, that is used in a tactical wireless network, can lead not only to the inability to receive and transmit an information by the given node, but also to the inability to use this node as a retransmitter. This, in its turn, can lead to MRN essential topological modifications, that can affect negatively to the quality of data transmission in MRN and management of combat units in general.

Above said aspects, MRN need new approaches to providing nodes radioconnectivity. One of them – is finding and using the optimized route of transmission between transmitter and addressee, that, together with the control of transmission power, will not only increase the probability of successful packets reception (by increasing SINR), but also reduce their energy and time costs for transfer [8]. This is because of the dependence of the necessary transmission power from a distance is not linear, so a several „short” intervals route, consumes less power than a „long” intervals route – $p_{ij} > p_{ik} + p_{kj}$, but transmission packet delay will be greater along such a route $t_{ij} < t_{ik} + t_{kj}$ (fig. 3).

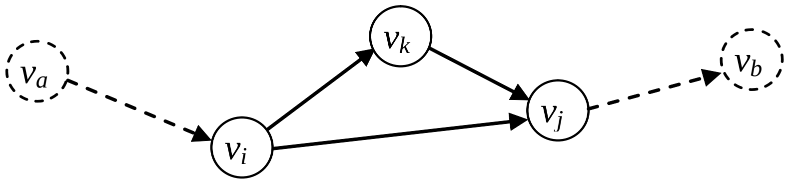

Fig. 3. Example of network construction

For this in MRN usage routing protocols [2] as a cost metric of the route, except of packets time difference, a minimum power transmission level is proposed for usage between i and j nodes and for providing a given value of bit error probability of (1), also an index, that displays the status of a node battery at present sampling time $e_i^{б}(t)$, and also a priority (importance) of the information $\Pi_{\xi_{ij}}$, transmitted in the radio channel.

Task description of scientific research. Due to the inability to collect a real–time information about whole MRN status we will consider a dataflow routing process in the information line *a – b*, that consists of tail–end *a* and *b* nodes (transmitter and addressee), and also a good number of nodes that form transmitting channels between *a* and *b*.

MRN preset parameters: network is a flow graph $G = (V,\ E)$, where $V = \{v_i\},\ i = \overline{1,\ N}$ – a number of nodes in random allocation, each of which has an ID number, and $E = \{e_l\},\ l = \overline{1, L}$ – a number of radio channels between mobile nodes (symmetrical, half–duplex). N – MRN nodes total number. Each node is equipped with a battery and its capacity at any specific time *t* can not be higher than some maximum value $e_i^{б}(t) \le e_{i\max}^{б}$. MRN nodes can change a transmitter power according to the situation $p_i(t) \le p_{i\max}$. Also, each mobile node receiver is characterized by a usable sensitivity $p_{рч_i}$, which determines the minimum signal strength $p_{с}$, that node can receive. Each mobile node has an intelligent control system (ICS), that consists of a variety of subsystems, that have functions of node and network resources control according to the OSI model levels [9]. In [10] for node ICS subsystems construction we are proposed to use a knowledge processing technology and intelligent agents (IA) technology that can allow ICS to take control decisions under uncompleteness and ambiguity of informationand about MRN. Addressees number in each session – is one (single–user transmission); m_{ab} – route between node–transmitter v_a and node–addressee v_b, that consists of *h* intervals of retransmitting ($h = \overline{1,\ N-1}$); route between transmitter and addressee is according to the OLSR [11] protocol, that gives information to the node-transmitter about neighbor nodes v_k, that are on the one or two intervals of retranslations .

Admission: According to the organizational structure of units in command tactical level, the smallest MRN area, that needs a fixed coupler between nodes, is a variety of section or platoon nodes (Fig. 1), that is $N \le 10$. From Fig. 1, in area (section) the connection between mobile nodes is direct or with a routes construction by using a minimum amount of retranslations (up to three).

Given that each node has information about neighbor units, decentralized principle MRN management and dynamic nature of their service (frequent MRN topology changes are caused all nodes mobility), and we can conclude that the radioconnectivity is better to be considered separately between each pair of nodes that forms h interval, but not on the whole transmission route m_{ab}.

Simplifying a good number of parameters, that determine the state of node and MRN, we mark as $X = \{x_b(t)\},\ b = \overline{1,\ B}$.

The variety of requirements to radioconnectivity control methods $\{Bq\} = \{B_1,\ B_2,\ B_3\}$: operation in a decentralized management; minimum loading of network with service information; interoperability with different layers of OSI model.

Necessary: to synthes the method of nodes radioconnectivity control in the MRN, that will consider the situation $X(t) = \{x_b(t)\},\ b = \overline{1,\ B}$, in MRN (or its area), will allow for such administrative decisions on the physical $U_{ф}(t)$ and network $U_{м}(t)$ OSI model layers and will satisfy a system objective function

$$U^*(t) = \arg \underset{U_{ф}(t),U_{м}(t)\in\Omega}{opt} Y(t)(X(t),U_{ф}(t),U_{м}(t)),\ \forall\ Z_{ij} = 1,\ i,j \in N,\ i \neq j, \tag{7}$$

where

$$Y(t) = P(t) \cup M(t); \tag{8}$$

$$X(t) = \left\{p_{ij}(t),\ p_{c}(t),\ p_{рч_i},\ BER_{\xi_{ij}}(t), m_{ab},\ e_i^{б}(t),\ \xi(t), \Pi_{\xi_{ij}}\right\}, \tag{9}$$

and allow to minimize the energy resource costs of mobile nodes and provide a given quality of ξ–type traffic service on transmission route m_{ab} with resource limit

$$\Omega = \{p_{ij} \le p_{i\max},\ p_{c_i}(t) \ge p_{рч_i},\ BER_{\xi_{ij}}(t) \le BER_{доп\,\xi},\ e^{б}_{ij\min} < e^{б}_{i} \le e^{б}_{i\max}\}, \tag{10}$$

where $U_{ф}(t)$ – variety of control decisions of SU node at the physical layer of OSI model for choosing the optimal values of transmitted power $P(t) = \{p_{ij}(t)\},\ i,j = \overline{1,\ N}$ in radio channel ij; $U_{м}(t)$ – variety of control decisions at the network service layer of OSI model for choosing the optimal transmission routes $M(t) = \{m_{ab}(t)\},\ a,b = \overline{1,\ N}$ between transmitter node v_a and addressee node v_b or interconnection node v_i and v_j in route m_{ab}; $e^{б}_{ij\min}$ – the minimum battery capacity, reguired for volume of traffic flow transmission, that is defined in the current connection (for pulsing/random traffic, such as speech or video in real time, is defined by minimum allowed battery capacity $e^{б}_{ij\min}$, that required for the node operation); $\Pi_{\xi_{ij}}$ – priority of ξ traffic type in channel ij.

The new method of nodes radioconnectivity control in the MRN. Given above analysis of possible ways of improving the control effectiveness of radioconnectivity of MRN nodes, a new method of nodes radioconnectivity control in the MRN can be proposed. The principle of a new method is in the decision for finding new routes, that based on a predictive lifetime of the current route, that is calculated by the parameter of residual capacitance of nodal batteries, maximum power of transmitter signal of addressee–node, valued $BER_{\xi_{ij}}$.

The choice of these parameters as criterias of providing radioconnectivity, is determines that each MRN node is powered by batteries, that is why its capacity defines a node „lifetime" in a transmission direction and each node has a maximum capacity of signal transmission $p_{i\max}$. After that, cost estimates of capacity of nodal battery will allow to account a node energy needs, that coupled with the reception and data transmission and service processing by nodal processor and also predict a node "lifetime" in transmission direction, that will allow to build new routes forehand, except nodes, that have a low residual capacitance of batteries.

The proposed nodes provides three main phases of operation (Fig. 4). *The first phase* is the input data processing by information node v_b about a network status in the direction *a–b* (Fig. 5).

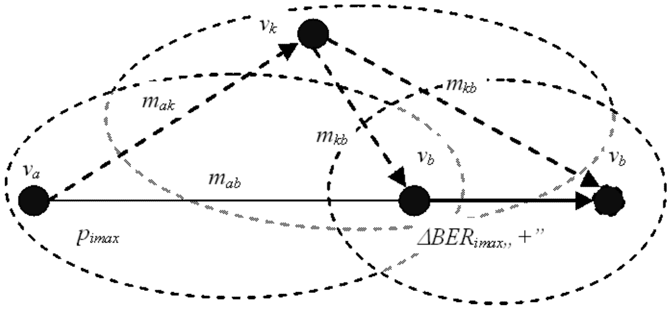

Fig. 4. Example of method of nodes radioconnectivity control at maximum transmitter power and high values of the error index at the reception

For this, node v_b calculates the values of the error index $BER_{\xi ab}$.

With the ascending of $BER_{\xi ab}$ node v_b sends a maintenance and control message to addressee node v_a.

In *the second phase,* on the basis of a receiving service information from addressee node v_b to transmitter node v_a about increasing $BER_{\xi ab}$, the decision to increase transmitter power is concluded (in the case of nodal resources). At the approach to the maximum transmitter signal $p_{a\max}$ or fast (maximum transmitter power $p_{a\max}$) nodal battery discharge (in other words – near value $e^{б}_{ij\,\min}$), node v_a starts to search for alternative routes of transmission.

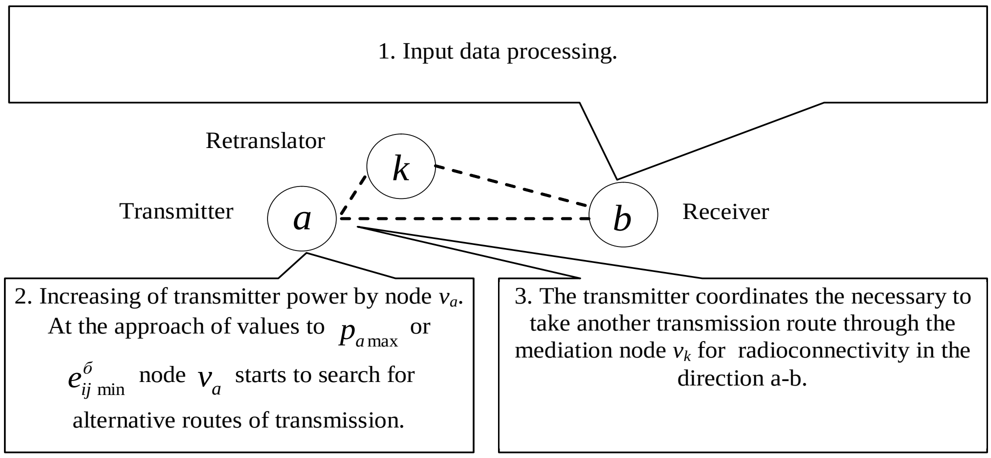

Fig. 5. Phases of the proposed method

In the third phase node v_a connects to an alternative neighbor node, which is the optimized among a variety of other nodes in the transmission direction *a–b* v_k (a mediation node in the direction of transmission).

Radioconnectivity, that is provided with it, has a high quality of service and minimum transmission power $p_{a\min}$, that gives an energy conservation and increasing of lifetime $T_m(t)$ of the route m_{ab} – it's a route between transmitter node v_a and addressee node v_b. After that radioconnectivity in the direction is through a mediation node v_k.

In a case of several mediation nodes for a route building, node v_i can serve for and a minimum nodal recources can be used for radioconnectivity with it.

According to the expressions (1) – (5) at the physical layer of OSI model a condition for a successful data transmission between each node pair $i - j$ in transmission route m_{ab} (or two nodes *a* and *b*) can be written in such a form:

$$Z_{ij} = \begin{cases} 1, \text{ if } BER_{\text{доп}\,\xi} - BER_{\xi_{ij}}(t) > 0; \\ 0, \text{ y } than, \end{cases} \quad (11)$$

where Z_{ij} – radioconnectivity between nodes i and j $(i, j \in N,\ i \neq j)$; N – total number MRN nodes or its area; $BER_{\xi_{ij}}(t)$ – particular error value for ξ type of traffic at given time t; $BER_{\text{доп}\,\xi}$ – permitted errror value for ξ type of traffic.

As noted before, in a case of absence of line–of–sight coverage between transmitter and addressee, radioconnectivity can be achieved by building transmission routes between them [3]. Taking into account the fact that while information transmission route, that consists of h, $h = \overline{1,\ N-1}$, intervals (retranslations), number of unfixed errors at each interval will be added [5, 4], and we can rewrite the expression (11) as:

$$Z_{ij} = \begin{cases} 1, \ ifBER_{\xi} - \sum_{h=1}^{H} BER_{\xi}^{h}(t) > 0; \\ 0, \text{ y than,} \end{cases} \quad (12)$$

where $BER_{\xi}^{h}(t)$, $h = \overline{1,\ H}$ – particular error value for ξ type of traffic at given time *t* between two nodes on the transmission route, that are appropriated h interval of retranslation.

In general, at the physical layer, a dual node interconnection in data transmission can be written with a following equation systems:

$$\begin{cases} BER_{\xi_{ij}}(t) = f\left(p_{ij}(t), BER_{\xi_{ij}}(t-1)\right), \\ p_{ij}(t) = g\left(u_i(t), p_{ij}(t-1)\right), \end{cases} \quad (13)$$

where $p_{ij}(t), p_{ij}(t-1) \in P(t)$ – transmitter node powers at a current and precedent time $(t-1)$; $BER_{\xi_{ij}}(t)$ and $BER_{\xi_{ij}}(t-1)$ – particular error value for ξ type of traffic at given time (t) and $(t-1)$; $u_i(t) \in U_{\text{ф}}(t)$ – node i managerial solution to select a target value of transmitter power.

However, expressions (11) – (13) do not include the impact of node battery capacity and the transmission path to ensure the possibility of radioconnectivity between nodes. Since these settings $X(t) = \{x_b(t)\},\ b = \overline{1,\ B}$ relate to different levels of model OSI (physical and network), then, according to the proposed in [12, 13] Cross – tiered model of network architecture, interaction levels to ensure radioconnectivity units in MRI can be represented by the following scheme (Fig. 6).

As seen from the figure, the information on the set of parameters comes to cross–level, which acts as a database service information. Further processing of the information carried nodal ICS for decision–making on the selection of transmitter power required value, which corresponds to the current situation in MR, or change the existing route of transmission.

As with any ICS, ICS central node takes knowledge base (KB), which contains information on the status of nodes and MR as a whole, as well as rules on the use of this information on the implementation of control nodes and network resources.

Due to the inaccuracy and incompleteness of official information on the situation of knowledge in MR, MR caused by the complexity of the system as a dynamic nature and functioning of its elements, [10] the comprehensive application of fuzzy sets [14] and neural networks [15] to build rules BRs.

The use of neuro-fuzzy systems provide nodal ICS such as learning, adaptation, accumulation and systematization of knowledge about the situation in the marketing year.

In view of the objective function (7) decision making fuzzy system software for radioconnectivity nodes can be represented as follows:

$$y^{*} = f_{y}\left(x_1^{*},\ x_2^{*}, \ldots,\ x_b^{*}\right),\ b = \overline{1,\ B} \quad (14)$$

where $X^* = \langle x_1^*, x_2^*, ..., x_b^* \rangle$ – the vector of fixed variables which act on the input node ICS; y^* – the value of output variable that displays the selected power level of the transmitter or the decision to transition to new routes of transmission.

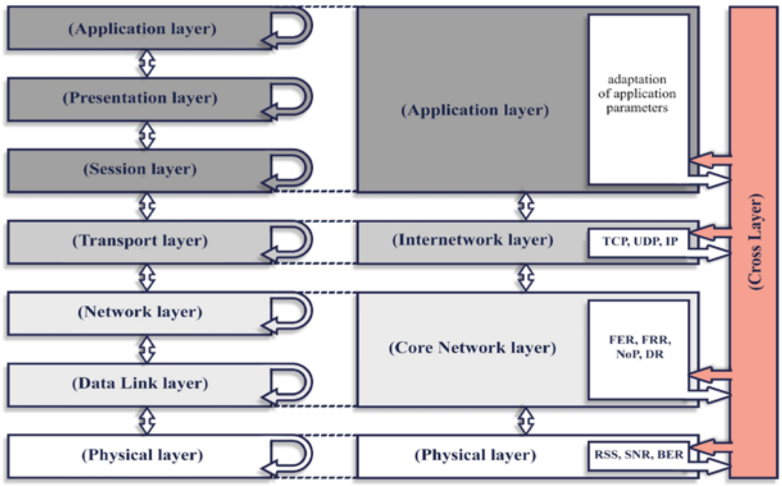

Fig. 6. Example interlevel interaction

Under the system of equations (13) and the objective function (7) as input variables neuro–fuzzy system of radioconnectivity proposed to use the following options assessment unit and MR:

$x_1^* = p_{ij}(t-1)$ – meaning power transmitter node sender at the time;

$x_2^* = BER_{\xi_{ij}}(t) - BER_{\xi_{ij}}(t-1)$ – the difference between the probability of error for ξ–type traffic identified node receiver (t) and $(t-1)$ at times;

$x_3^* = e_j^б$, $e_{ij\ \min}^б < e_j^б \le e_{j\ \max}^б$ – battery capacity unit–destination (or smart host to route m_{ab});

$x_4^* = \{v_k\}$, $k \in N$ – information about neighboring nodes, which in time (t) in the zone radioconnectivity th node ($Z_{ik} = 1$);

$x_5^* = \Pi_{\xi_{ij}}$ – priority traffic transmitted in the channel ij (high priority assigned to teams battle management and real–time traffic, lower degree of priority – in traffic, which does not operate in real time and requires guarantees of quality of service [12]).

The task of deciding on maintenance radioconnectivity units is that on the basis of information on vector inputs X^* to determine the output $y^* \in Y$. To solve this problem, a system of fuzzy rules (SDA) type

R if $x_1 \in a_{1m}$ TA $x_2 \in a_{2m}$ TA ... TA $x_b \in a_{bm}$, $y \in d_h$, $(b = \overline{1, B})$, $(h = \overline{1, H})$, $(m = \overline{1, M})$, (15)

where a_{bm} – m linguistic score (term) input variable x_b, which is selected from the respective term –sets; A_b; d_h rating linguistic output variable y that is defined with the term – set of possible solutions D:

$$A_b = \{a_{b1}, a_{b2}, ..., a_{bm}\}$$
$$D = \{d_1, d_2, ..., d_h\}$$

Table 1 shows the basic fuzzy terms mentioned above term – set input and output linguistic variables.

Fig. 7 shows the membership functions for input and output. As seen from the figure, in order to maximize performance neuro–fuzzy system of radioconnectivity proposed to use parametric, normal unimodal, triangular membership function [16].

Table 1

Knowledge base of radioconnectivity neuro–fuzzy system

Loose	The value of linguistic terms	Note
x_1^* – power transmitter	a_1^1 – low (L); a_1^2 – below average (BA); a_1^3 – average (A) a_1^4 – above average (AV) a_1^5 – maximum (M)	Clear the values obtained from the physical layer
x_2^* – difference of error probability	a_2^1 – negative; a_1^2 – zero; a_1^3 – positive	
x_3^* – the residual capacity of the battery	a_3^1 – high a_3^2 – medium a_3^3 – low	
x_4^* – neighboring nodes	a_4^1 – no; a_4^2 – one; a_4^3 – more than one	Clear the values obtained from the network layer
x_5^* – priority traffic	a_5^1 – high; a_5^2 – average; a_5^3 – low	Clear previously set the values obtained from the application layer
y^* – the decision to provide radioconnectivity	d^1 – to reduce transmitter power; d^2 – to keep the transmitter power at the same level; d^3 – to increase transmitter power; d^4 – move to a new route to the destination nodes; d^5 – to initiate the search for new routes to the destination node, the criterion $\min p_{ij}$ *; d^6 – continue the existing transmission route taking into account the priority of traffic $\Pi_{\xi_{ij}}$; d^7 – go to standby radioconnectivity with neighboring nodes	Clear mentioned transmitter power (the physical layer) or decision on the choice of alternative routes of transmission (at the network level)

* *Note*: Depending on the selected routing method can be used by other criteria (metric) of the route search, for example, the minimum transmission delay time, the maximum capacity batteries and more.

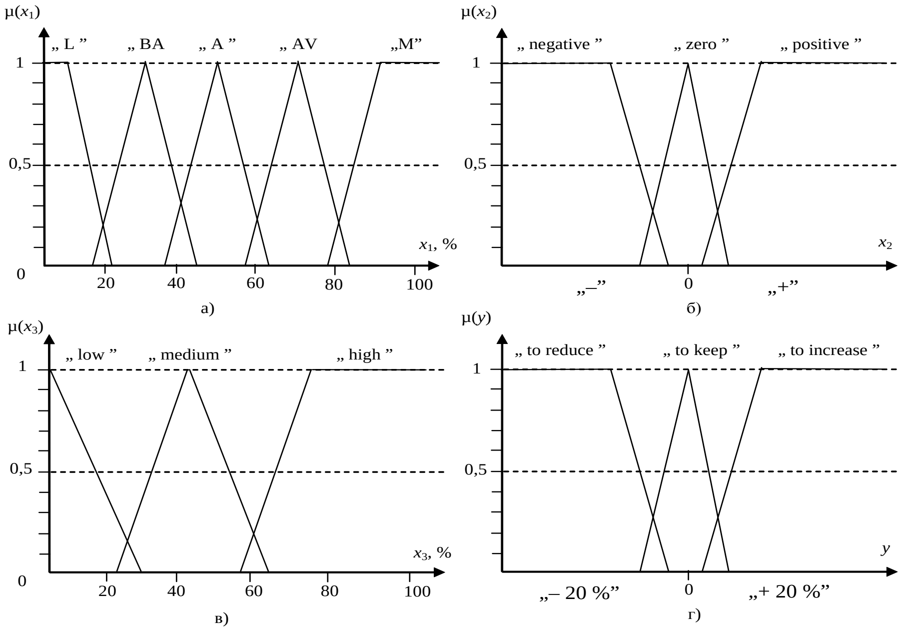

Fig. 7. Functions

In accordance with the values of linguistic terms that reflect the fuzzy decision system of radioconnectivity between nodes MRI (Table. 1), in two groups proposed SDA rules governing the transmission power node sender and the rules for choosing alternative routes to the host–transfer recipient.

Thus, each group of rules should provide two cases of routing transmission: when sending node and the destination node connected directly (route of transmission consists of one interval, $i = a$ and $j = b$, $i, j, a, b \in N$) and when the transmission route consists of h, $h = \overline{1, N-1}$, intervals (Fig. 3). Here are some examples of rules for each case.

1. Direct connection nodes of the sender and recipient.

1.1. Group management rules power transmission unit sender will be as follows:

Rule 1.1.1: IF transmitter power of "low" values AND the difference in error probability of receiving "positive" AND the remaining battery capacity node–recipient "high" maintenance " THAN increase transmitter power."

Rule 1.1.2: IF transmitter power "average" values AND the difference in error probability of receiving "negative" AND the remaining battery capacity node–recipient "average" THAN "reduce transmitter power."

Rule 1.1.3: IF transmitter power "high" AND the difference values at a reception error probability "zero" AND the remaining battery capacity node–recipient "low" THAN "save transmitter power at the same level."

1.2. Terms choosing alternative routes of transmission are used fuzzy system when providing a given service quality traffic cannot be achieved by increasing the transmitter power ($p_{ab}(t) = p_{a\max}$):

Rule 1.2.1: IF transmitter power "maximum" values AND the difference in error probability of receiving "positive" AND junctions neighbors "one" THAN "move to a new route to the destination node," (Fig. 6).

Rule 1.2.2: IF transmitter power "maximum" values AND the difference in error probability of receiving "positive" AND junctions neighbors "more than" THAN "to initiate the search for new routes to the destination node, the criterion $\min p_{ij}$ ".

Rule 1.2.3: IF transmitter power "maximum" values AND the difference in error probability of receiving "positive" AND junction's neighbors "no" THAN "go to standby radioconnectivity with neighboring nodes."

2. Plug the sender and recipient nodes using route.

2.1. Group control rules power transmission unit to the sender when nodes v_a and v_b are intermediate (relay) transmission route (Fig. 8) will have the same form as in the case of direct connection nodes (rule 1.1.1 – 1.1.3).

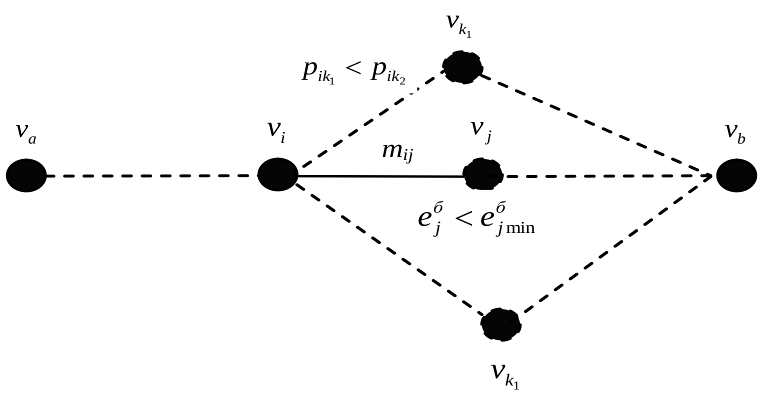

Fig. 8. Implementation example that select an alternate node on the route of transmission at low battery capacity intermediate node on the route of transmission

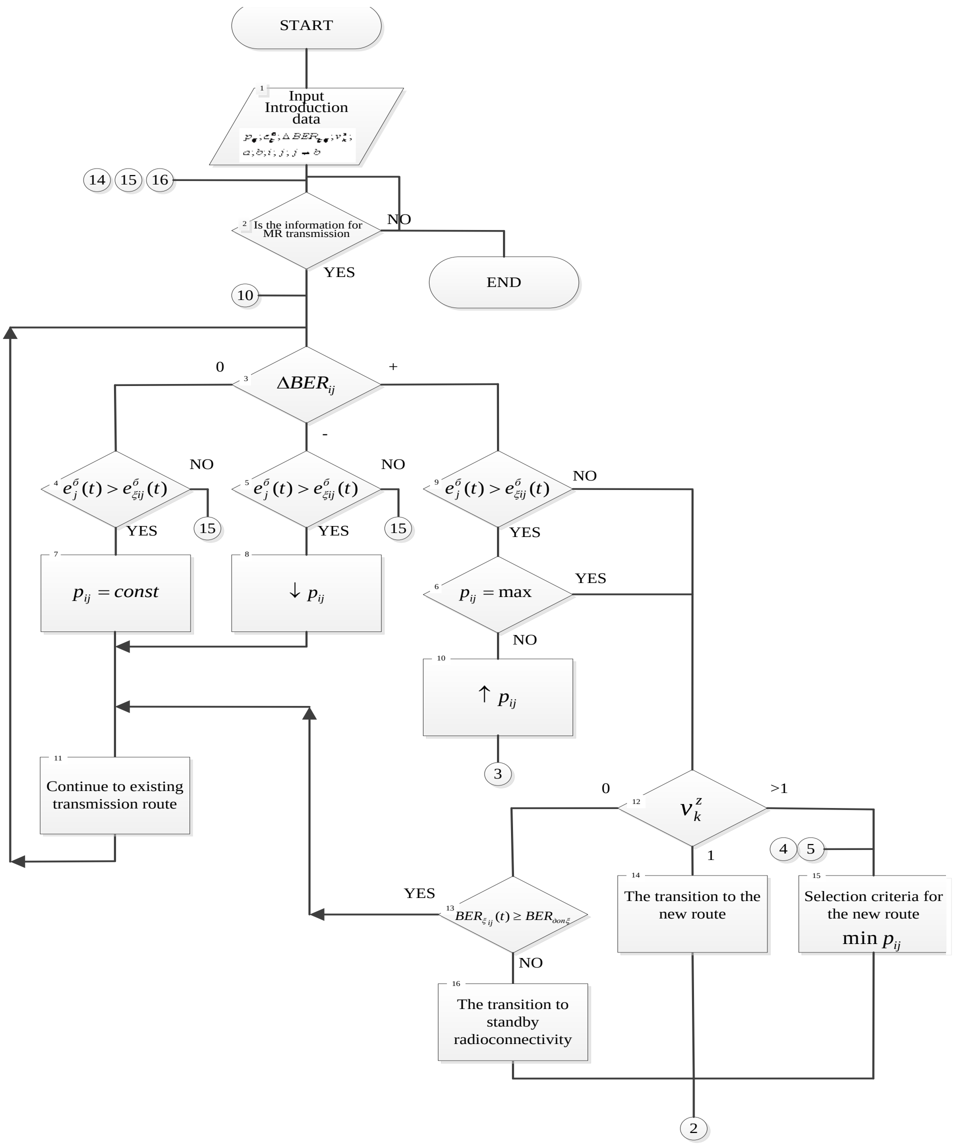

Fig. 6. Algorithm of operation control method of radioconnectivity transmission route for $j \neq b$

2.2. Terms of choosing alternative routes. As noted above, the loss of radioconnectivity between intermediate nodes on the route of transmission (through mobility nodes or exhaustion capacity batteries) may lead to rupture of the existing route and, consequently, lead to delay sending packets of data related to the need to find new routes between sender and recipient. To avoid this situation, in addition to the above rules 1.2.1 – 1.2.3, there are rules for choosing alternative routes of transmission, taking into account the capacity of the battery option th node and priority traffic is passed:

Rule 2.2.1: IF transmitter power "above average" values AND the difference in error probability of receiving "negative" AND the remaining battery capacity j –th node "low" and components neighbors "one" THAN "move to a new route to the destination node,".

Rule 2.2.2: IF transmitter power "above average" values AND the difference in error probability of receiving "zero" AND the remaining battery capacity j –th node "low" and components neighbors "more than" THAN "to initiate the search for new routes to the destination node, the criterion $\min p_{ij}$ " (Fig. 7).

Rule 2.2.3: IF transmitter power "average" values AND the difference in error probability of receiving "zero" AND the remaining battery capacity j –th node "low" and components neighbors "no" and the priority of traffic "high" THAN "continue existing transmission route."

Operation of the control method of radioconnectivity units of mobile radio networks in an integrated use of fuzzy logic technology and intelligent agents can be represented using the algorithm (Fig. 9):

If the node is the final route of transmission, we cannot manage radioconnectivity by changing parameters nodal batteries, that for this case algorithm of the control method of radioconnectivity units have simplified form (Fig. 10).

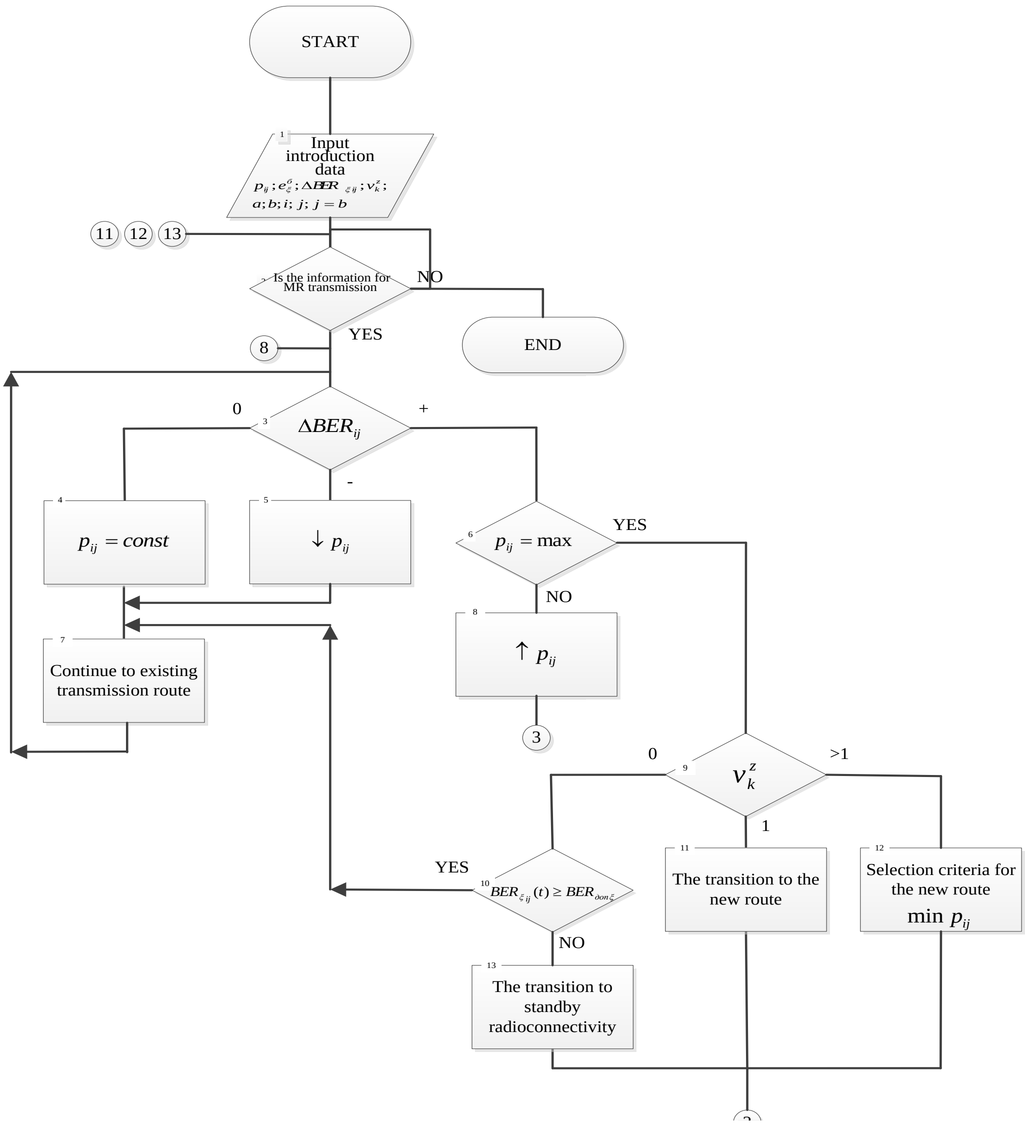

Fig. 10. Algorithm of operation control method radioconnectivity transmission route for $j = b$

Conclusions. Thus, the nodes radioconnectivity control method in the mobile radio networks (MANET) was firstly proposed in the article. The method is to integrate functions of application, network and physical levels of the OSI model to support radioconnectivity between mobile nodes during data transmission.

Unlike the proposed methods for fixed radio networks that provide radioconnectivity between the base station and transmission power control means, in the presented method additionally proposed to solve the problem of providing radioconnectivity between mobile nodes by finding and using optimal routes of transmission between the sender and the recipient, taking into account the capacity of the battery units participating in the formation of the route.

To do this, based on the integrated use of fuzzy logic and machine neural networks, the proposed method of two groups of fuzzy rules, depending on the parameters of nodes allow to select the required value of the power transmission unit sender or decide on the need for alternative routes of transmission to node-recipient. In conditions of high dynamics changes of topology that are characteristic of the mobile radio networks of MANET class, it will not only increase the probability of successful reception of packets, but also reduce energy and time costs for their transfer.

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