The MANET`s Hierarchical Control System Using Fuzzy Logic

Valeriy Romanyuk, Oleg Sova, Anton Romanyuk, Sergey Salnyk

Abstract – **The hierarchical model of interaction between mobile nodes in the MANET using fuzzy logic is proposed in the paper. Proposed model is based in the conceptual representation of the mobile radio network control systems as a hierarchical structure with vertical connections that define management tasks subordination using the hierarchical control system and fuzzy logic.**

Keywords – **MANET, control systems, fuzzy logic.**

I. Introduction

Mobile radio network class MANET using fuzzy logic distributed and fault-tolerant radio network consisted of miniature electronic devices (sensor nodes, which can be both stationary and mobile) that capable to collect data about the environment and to transmit them to the information center [1, 2]. In general, radio network using fuzzy logic based on a large number of wireless sensors which may be located in a great geographical area, making simultaneous monitoring of numerous environmental parameters, and also transmission of monitoring information to the special gateways using relaying through intermediate sensors. Because of the large dimension of geographic areas, where measurements can be conducted, it was proposed using of network the MANET`s hierarchical control using fuzzy logic [3, 4].

Mobile radio network using fuzzy logic will be functioning in automatic or semi-automatic modes, so sensors should be able to make decisions on nodal and network resources control without human intervention. Consequently each sensor must be composed of a control system (CS) able to make decisions according to decentralized principle to ensure necessary information transmission quality of service. Moreover, because of the sensor nodes heterogeneity, every node's CS must consider not only its own objective function, but the objective functions of all neighboring nodes [5 – 7]. To collect information about the nodal objective functions, their analysis and generalization, it was proposed using of hierarchical control using fuzzy logic control system.
Thus, the hierarchical control system using fuzzy logic control can be represented as a multilevel hierarchical structure: the highest level will be represented hierarchical control control system, and lower levels will be represented fuzzy logic control systems. In addition, because of the large amount of node and network resources management tasks, it is offered to decompose nodal control systems into subsystems, according to control functions on different OSI levels (routing subsystem, radio resources management subsystem, data flow subsystem, safety subsystem, etc.)..

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II. Problem Statement

Taking into account the features of MANET functioning, it`s proposed to use intelligent agents' (IA) and multi-agent systems (MAS) technology to fuzzy logic control system elements [8, 9]. Main feature of this technology is that an agent is considered as a hardware and software system that can make decisions in uncertain conditions. That is, IA and MAS can adapt to the changes in surrounding environment they interact with, even in the case when said changes are not defined in their behavior schemes.

IA functions depend on the tasks that they must solve at every OSI level and on the purpose and characteristics of nodes. Therefore, the goal of this article is to develop the of hierarchical control system using fuzzy logic, on the basis of the intelligent agents interaction.

III. Hierarchical Model of IA Interaction

Formal description of the fuzzy logic control system functional structure (with decentralized management) can be represented as a hierarchical IA structure with vertical relations between them. Given relations define the subordination of tasks that are resolved by IA at each layer [5]:

Zero (executive) layer – resolves management tasks according to the OSI model (routing, resource management, data streams management, security, etc.) by selecting the required values of sensor node CS subsystem parameters;

First (node) layer – consists of sensor node CS meta-agents that coordinate the zero layer IA by selecting optimal set of management actions and their implementation sequence on all sensor node CS subsystems;

Second (network) layer – consists of the master node that corrects the goal functions of first layer meta-agents in view of network status, as whole, or its part.

Using graph theory we can picture the given functional structure as shown on Fig. 1. Located at root tree is a master node subsystem (I_2, U_2), at the vertices that are one edge away from root are subsystems $(I_{11}, U_{11}),...,(I_{1q}, U_{1q}),...,(I_{1Q}, U_{1Q})$ that represent Q meta-agents node CSs. Every mentioned subsystem of network CS contains a control (identification) block I and management block U .

In turn, every first layer subsystem $\left(I_{1q}, U_{1q}\right), q = \overline{1,Q}$ is connected to multiple functional subsystems of zero layer $P_{qr}, q = \overline{1, Q}, r = \overline{1, R}$, that are located on two edges distance from the root. These subsystems represent IA interaction processes of every functional subsystem of nodal CS [9, 10]. This interaction consists of service information exchange and management decisions of each IA.

For q-th management subsystem of the first layer $\left(I_{1q}, U_{1q}\right), q = \overline{1,Q}$ let us denote the following:

$X_{1qr}(k)$ – multiple state vectors of the qr-th IA, where the size of $X_{1qr}(k) = \left\{x_{1qr}^{a}(k)\right\}, a = \overline{1, a_{1qr}}$ is $a_{1q} \times 1$;

$\tilde{X}_{1q}(k)$ – multiple generalized estimated state vectors of q-th subsystem of the first layer (e.i. sensor node), where the size of $\tilde{X}_{1q}(k) = \left\{\tilde{x}_{1q}^{a}(k)\right\}, a = \overline{1, a_{1q}}$ is $a_{1q} \times 1$;

$U_{1qr}(k)$ – multiple management vectors of q-th subsystem of the first layer, that are directed to r-th IA of zero layer, where size of $U_{1qr}(k) = \left\{u_{1qr}^{b}(k)\right\}, b = \overline{1, b_{1qr}}$ is $b_{1qr} \times 1$;

$Y_{1q}(k)$ – multiple management vectors of q-th subsystem of the first layer, that are directed to upper layer management subsystem, where the size of $Y_{1q}(k) = \left\{y_{1q}^{d}(k)\right\}, d = \overline{1, d_{1q}}$ is $d_{1q} \times 1$;

$Z_{1q}(k)$ – multiple estimated state vectors of q-th subsystem of the first layer, that are directed to upper layer management subsystem, where the size of $Z_{1q}(k) = \left\{z_{1q}^{d}(k)\right\}, d = \overline{1, d_{1q}}$ is $d_{1q} \times 1$.

For the second layer control subsystem $\left(I_2, U_2\right)$, let us denote:

$\tilde{X}_2(k)$ – multiple generalized estimated state vectors of the first layer subsystems (metaagents of the node CS), where the size of $\tilde{X}_2(k) = \left\{\tilde{x}_2^{l}(k)\right\}, l = \overline{1, l_r}$ is $l_r \times 1 = \left(\sum_{q=1}^{Q} a_{1q}\right) \times 1$;

– multiple management vectors of control variables, that are sent to lower layer control subsystems (metaagents of the nodal CS), where the size of $Y_{2q}(k) = \left\{y_{2q}^{d}(k)\right\}, d = \overline{1, d_{2q}}$ is $d_{2q} \times 1$;

$Z_{2q}(k)$ – multiple management vectors of variable estimated states, that are sent to the lower layer control subsystem (metaagents of the node CS), where the size of $Z_{2q}(k) = \left\{z_{2q}^{d}(k)\right\}, d = \overline{1, d_{2q}}$ is $d_{2q} \times 1$;

Finally, for qr-th subsystem of the zero layer $P_{qr}, q = \overline{1, Q}, r = \overline{1, R}$ let us denote:

Fuzzy logic hierarchical model of interaction presented intermediate layer consisting of FL units [11]. Block fuzziness is a fuzzy logical conclusion that receives a plurality of input parameters, which can be characterized by unclear, incomplete, inaccurate. As a result which each fuzzy input parameter data will be given to a clear appearance.

The unit fuzziness operates at the stage of obtaining the input data, when input in the subsystem FL_{qr}, and at the stage of obtaining objective data – agents. This stage is represented by block fuzzy objective function FL_{UI}.

In turn fuzzy logical conclusion is a fuzzy process obtaining necessary conclusions regarding management of facility based on fuzzy conditions or assumptions, which are about current state object. This process combines basic concepts of fuzzy sets, membership functions, linguistic variables, fuzzy methods of implementation and more.

The use fuzzy logic includes aforementioned stages, which form basis for hierarchical model of mutual relations components class MANET.

– phasing – is establish consistency between specific values of particular input variable fuzzy inference system and values S_n^{mk}, which reflects degree truth in terms rules based on the value membership function corresponding input linguistic variable term:

$$S_n^{mk} = \mu_n^{m}(\overline{x_n}),$$

where $\overline{x_n}$ – the vector values of input variables fuzzy inference system; $\mu_n^{m}(\overline{x_n})$ – membership function m-th term.

– the degree aggregation is definition truth conditions $S^{hk}, h = \overline{1, H}$ every rules of fuzzy inference system based on the known values of truth preconditions S_n^{mk}, included in it. If the condition rules given in form of fuzzy linguistic expressions $x_1 = a_1^{m}, m = \overline{1, M}$, stage of aggregation degree of truth leaves unchanged. If the rule is a condition consisting of several pi $Y_{2q}(k)$dumov, degree truth to this rule is given by:

– activation involves determin$S^{hk} = \max_n S_n^{mk}$, ing function each association during initial conclusions for linguistic variables considered. The calculation by the formula:

$$\mu^{hk}(\overline{w_g}) = \min_h \left\{Z_g^{h}, \mu_g^{h}(\overline{w_g})\right\},$$

where $\mu_r^{zb}(\overline{y}_z)$ – membership function h-th term output variable $\overline{w_g}$; Z_{jr} – the degree of truth in each of conclusions by the formula:

$$Z_g^{h} = S^{hk} \cdot F^{k},$$

where K_r – weight rules.

– accumulation and accumulation will combine operations using max-disjunction [16, 24] degrees of truth in findings for each membership function of the output variables:

$$\mu_g^*(\overline{w_g}) = \bigcup_{k=1}^{k_M}\bigcup_{h=1}^{H}\mu^{hk}(\overline{w_g}).$$

– Defuzzification - where on basis accumulation of all output linguistic variables are received precise (quantitative) value each output variables that can be used subsystems mobile node during its functioning. For Defuzzification used a modified version method form the center of gravity for one point sets:

$$w_g = \frac{\sum_{h=1}^{H} Z_g^h \cdot d_g^h}{\sum_{h=1}^{H} Z_g^h},$$

where y_{zn}^* – Defuzzification result in a clear value of output variable; V_z – total number of active fuzzy rules productions, findings which are under output linguistic variable d_g^h.

Then the data is sent to the sub node, as shown in Fig. 1.

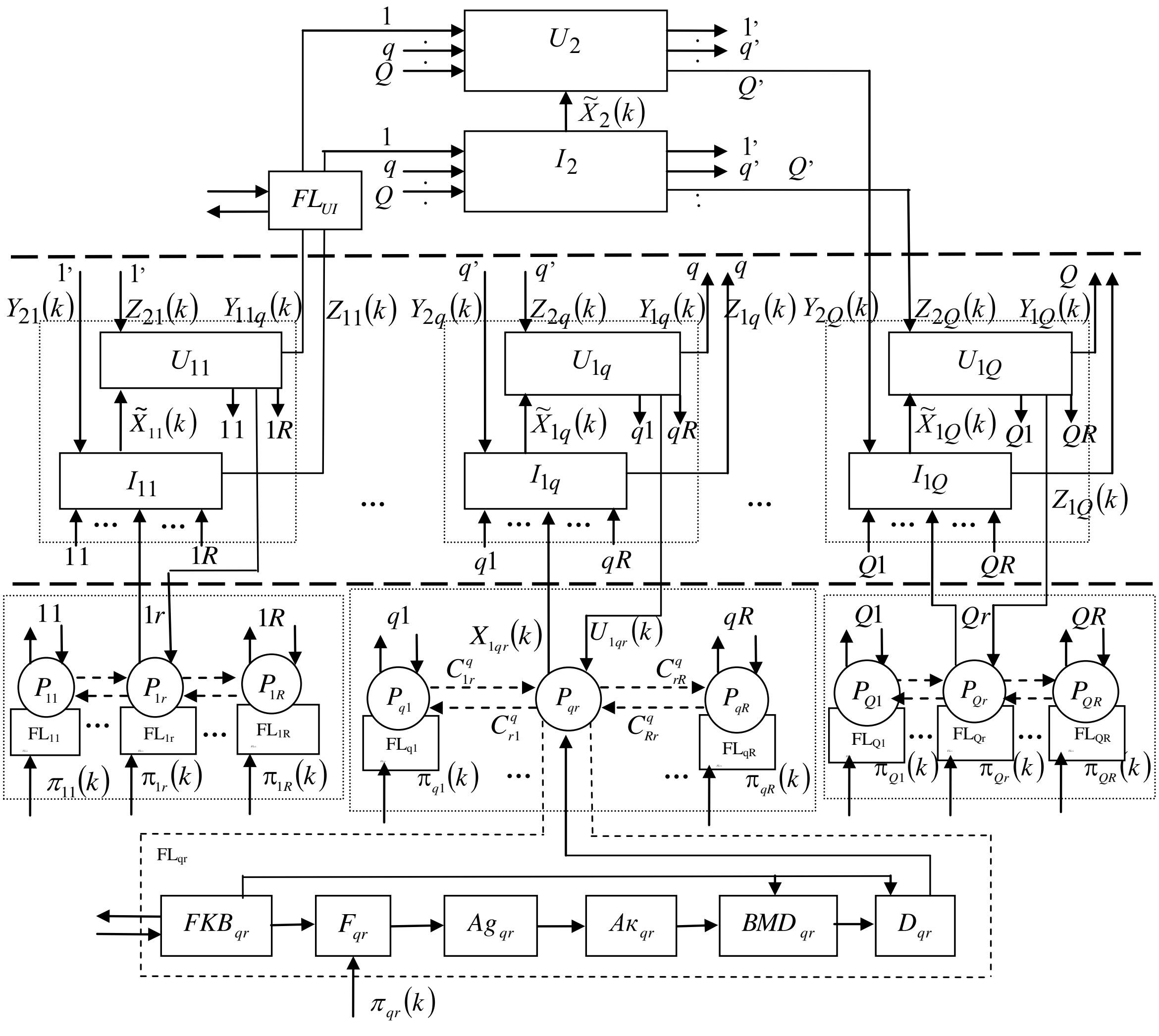

Fig. 1. The hierarchical WSN control system model

During those time intervals every element of the radio network control system implements corresponding methods and algorithms of hierarchical control system using fuzzy logic control, from mathematical methods and algorithms of link control (physical level of OSI model) to methods and algorithms of application level control (security control, power consumption control, QoS control, etc.).

Thereby, to respond to the features of the management in the MANET class mobile networks, the management system must have intellectual capabilities to recognize and analyze the situations in the radio network, and based on this, make management decisions to control the node and network resources. To design such management system it is proposed to use the technology of intellectual agents and multiagent systems, that suggests that all subsystems of node ICS are implemented using multiple IA, that are defined by management functions depending n the level of the OSI network model.

To combine different IA in an intellectual network control system a hierarchical model of IA interaction was proposed in this article, whose essence lies in describing the network ICS as a hierarchical structure with vertical links, that indicate the subordination of management tasks.

The novelty of the model lies in using the graph theory to make a formal description of the functional subsystems of the network ICS (vertices of the graph) and their interaction processes (edges of the graph). Using the proposed model can accelerate and systemize the network design process considering their functioning environment and hierarchical structure of their ICS. Using the intellectual agents technology and multiagent systems allows to minimize the service traffic and use network and node resources more efficiently.

IV. Conclusions

Thereby, to respond to the features of the MANET management, the network control system must have capabilities to recognize and analyze the situations in the network fuzzy activity, and based on this, make management decisions to control the node and network resources without human intervention. To design such control system it is proposed to use the technology of intelligent agents and multiagent systems that suggests that all subsystems of networks control system are implemented using multiple IA, that are defined by management functions depending on the level of the OSI network model.

To combine different IA in a network control system hierarchical control system model of wireless networks that use fuzzy logic was proposed in this article. The model essence lies in describing the network control system as a hierarchical structure with vertical links that indicate the subordination of network management tasks.

The novelty of the model lies in using the graph theory to make a formal description of the network control system functional subsystems (vertices of the graph) and their interaction processes (edges of the graph), and use fuzzy logic for operation in fuzzy network activity.

Using of the proposed model can accelerate and systemize the wireless networks design process considering their functioning environment and hierarchical structure of their CS. Using the fuzzy logic, intellectual agents technology and multiagent systems allows to minimize the service traffic and to use network and node resources more efficiently.

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