APPLICATION OF FUZZY LOGIC FOR THE CLASSIFICATION OF INFORMATION FLOWS IN DISTRIBUTED CONTROL SYSTEMS

Oleksandr Ushkarenko[1]

DOI: https://doi.org/10.30525/978-9934-26-672-0-5

Distributed control systems operating in real time, such as automated control systems (ACS) for autonomous electric power systems (AEPS), require strict and precise guarantees for the quality of service (QoS) of network information flows [1, p. 4706]. Such systems are characterized by high requirements for the quality of service of information flows, in particular, for latency, throughput, and data transmission reliability [2, p. 90; 3, p. 48]. During peak loads or emergency situations, traditional deterministic methods of network resource allocation, discussed in [4, p. 6], often prove insufficiently flexible and fail to provide the required level of QoS. In this regard, the use of intelligent methods, in particular fuzzy logic [5, p. 320], which allow for the multi-criteria nature of information flows and the uncertainty of network parameters, is relevant.

Correct network design and flow classification into a small number of priority classes may be sufficient to ensure the normal operation of the ACS. Consequently, the correct allocation of resources during periods of peak load or emergency situations, along with protection from lower-priority flows, will ensure the required level of service. It is proposed to solve such problems in multi-criteria fuzzy distribution using the apparatus of fuzzy logic.

The aim of this research is to develop and validate a technique for classifying information flows in distributed control systems using fuzzy logic, taking into account their quality of service requirements. This allows for increased efficiency in network resource utilization and reduced network congestion under variable load conditions.

Classification is based on the expected flow intensity and flow QoS requirements. The decision to assign a simple flow to a specific service class is based on the proximity of fuzzy estimates of its volumes and the physical location of receivers and packet generators.

The essence of the method is as follows:

– Fuzzification – introducing fuzziness:

1. The linguistic variables necessary for assessing the flow’s quality of service are identified.

---

[1] Admiral Makarov National University of Shipbuilding, Ukraine

2. For each linguistic variable, a number of terms is selected, and the physical values of their boundary conditions are determined.

- A decision on the number of service classes is made.
- Fuzzy rules for processing fuzzy flow estimates are developed.
- Defuzzification rules are developed to eliminate the fuzziness of the result when multiple result terms are present.

To assess the quality of service for a flow using fuzzy logic methods, the following linguistic variables were identified:

- traffic sensitivity to delays;
- rate predictability;
- packet loss sensitivity.

In addition, the following linguistic variables should be determined for the assessment of:

- transmission rate;
- flow intensity distribution over time.

The terms for the linguistic variables are defined in accordance with the classification [5, p. 322].

Traffic sensitivity to delays Fz is expressed over time. The variable can take the value . The linguistic variable "traffic sensitivity" takes the following values (Fig. 1).

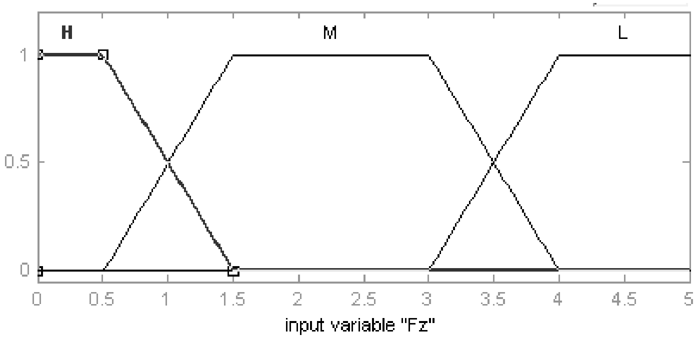
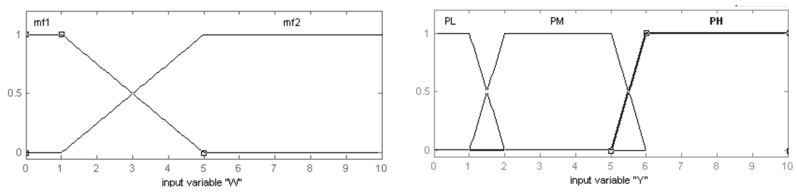


Figure 1 – Definition of the fuzzy distribution function

Using this linguistic variable allows us to derive the distribution of delay parameters: minimum, average, and maximum.

Rate predictability W can be expressed as the ratio of the maximum to the minimum rate. The variable will take on the value $X(W) \in \{1 \div \infty\}$. Using the linguistic variable "rate predictability" it can be derived the maximum and minimum transmission rates for a given average. Based on the predictability criterion, flows can be divided into two broad classes: flows with uniform traffic and flows with bursty traffic.



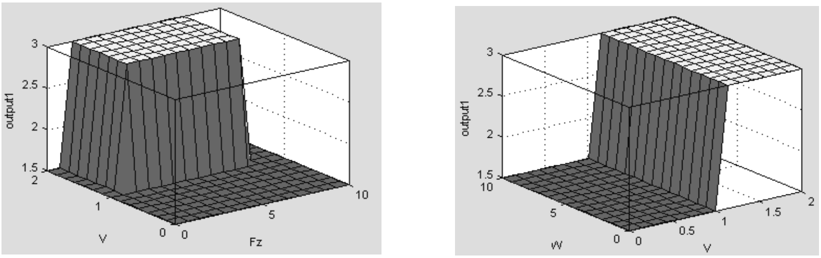
a b

Figure 2 – Membership functions for the terms of the input linguistic variable: a – "rate predictability"; b – "loss sensitivity estimate"

The packet loss sensitivity estimate *Y* is expressed as the percentage of acceptable packet loss. The variable will take on the value $X(Y)\in\{0\div100\%\}$. The transmission rate V is expressed in bits/s and can take the value:

$$X(V)\in\{0\div115kBit/s;115kBit/s\div1MBit/s;1MBit/s\div10MBit/s\}.$$

Figure 3 shows fuzzy inference surfaces that allow us to determine the value of the output variable from the values of the input variables of the fuzzy model.



a b

Figure 3 – Fuzzy inference surfaces: a – "traffic sensitivity to delays"; b – "speed predictability"

The result of fuzzy rule generation is the assignment of the flow under consideration to a specific service class with priorities 1, 2, and 3 (Fig. 4).

Three groups of parameters are used to characterize the required class of service:

- throughput parameters;
- delay parameters: average and maximum delay values;
- transmission reliability parameters: percentage of lost data packets.

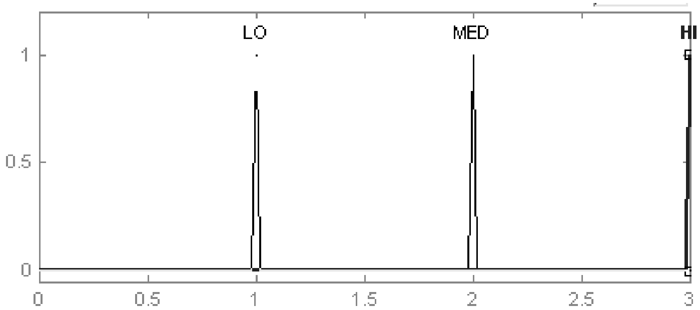


Figure 4 – Membership functions of the output variable

These parameters are measured over a specific time interval. The shorter this time interval, the more stringent the requirements for the network, and therefore for all elements, since packet transmission requires cooperation from all nodes along the flow path and is determined by the reliability and performance of the slowest node. After dividing flows into classes, an overall picture of the network flows can be obtained. Flows belonging to the same class are combined, and the network structure is simplified by eliminating elements irrelevant to the calculations using structural composition methods. Consequently, using fuzzy logic, network congestion can be reduced.

References:

1. Poza-Lujan J.-L., Posadas-Yague J.-L., Simo-Ten J.-E., Simarro R., Benet G. (2015) Distributed Sensor Architecture for Intelligent Control that Supports Quality of Control and Quality of Service. Sensors, vol. 15 (3), p. 4700-4733. DOI: https://doi.org/10.3390/s150304700

2. Aziz Glena, Zeebaree Subhi. (2021) Evaluation of QoS in Distributed Systems: A Review. *International Journal of Science and Business*, vol. 5, issue 2, p. 89–101. DOI: https://doi.org/10.5281/zenodo.4462245

3. Al-Quteimat A.M., Al-Soud M.M., Eial Awwad A.M., AlHawamleh A., Zeidan M., Ushkarenko O., Dorohan O. (2020) Research of the data exchange processes during the automated control of autonomous electric power systems. *Journal of Electrical and Electronics Engineering,* vol. 15 (2), p. 48–52. DOI: https://doi.org/10.9790/1676-1502024852

4. Henrik Austad, Erling Rennemo Jellum, Sverre Hendseth, Geir Mathisen, Torleiv Haland Bryne, Kristoffer Nyborg Gregertsen, Sigurd Morkved Albrektsen, Bjarne Emil Helvik. (2023) Composable distributed real-time systems with

deterministic network channels. *Journal of Systems Architecture*, vol. 137, p. 1–18. DOI: https://doi.org/10.1016/j.sysarc.2023.102853

5. Vincent Bombardier, Jean-Philippe Georges, Eric Rondeau, Idriss Diouri. (2018) Using fuzzy rules for network behavior identification: application for differentiated services in an Ethernet network. *International Journal of Computational Intelligence Systems*, vol. 11, issue 1, p.316–329. DOI: https://doi.org/10.2991/ijcis.11.1.24