# Application of Fuzzy Logic to Cognitive Wireless Communications

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# Application of Fuzzy Logic to Cognitive Wireless Communications

**Issam Trrad, Takialddin AL Smadi,  Hassan Al_Wahshat**

*Abstract: This paper mainly studies data transmission Rate (DTR) in the of fuzzy logic in on Cognitive wireless modern communication improving the use of the radio frequency spectrum and the degree of intelligence of network and subscriber equipment, In this regard, The use of methods of cryptographic protection of information with a public key are convenient in that they do not require an additional communication channel for the exchange of a private key between the sender and the recipient However, they often rely on complex mathematical calculations and usually much less effective than c cryptosystems on a symmetric key. In this article we will focus on implementation of fuzzy logic methods for asymmetric encryption key. Fuzzy logic, in this case, is a problem solving methodology for data transfer that can find its application in various systems.*
*In the present article deals with the encryption method using the theory of fuzzy sets technology of constructing cognitive wireless data transmission systems (WDTS) use of fuzzy logic and fuzzy controllers, Systems a demand of high quality transmission increasing of transmission data speed.*

*Keyword: DataTransmission,OFDM ,Cognitive Radio ,Fuzzy logic*

## I. INTRODUCTION

Wireless communication is the fastest growing sector of the communications industry. It is in this sense that he attracted the attention of everyone in the entire communications market. Analysis has shown that cellular systems are constantly evolving year-round, and now there are about two billion mobile users worldwide. In essence, cell phones have become an important business device and Users.
Wireless Communications has replaced many wired networks in everyday life in professional life. Many types of equipment are available remotely and are controlled by wireless. Since radio frequency is the only spectrum that provides wireless communication between transmitter and receiver, and because of the growing number of users in the radio spectrum, it is not possible to add additional users [1, 2].

We have already adopted many methods to reduce the size of the transmitted packet, cognitive technology (cognitive radio systems and cognitive networks) will lead to improved efficiency in the use of the radio frequency spectrum, improved resource management, improved communication quality, efficient access control and to the new types of services [3]. The term "cognitive" (cognitive) means the property of a communication medium or network expressed in the ability to change its topology autonomously and dynamically, adjust operational parameters, redistribute network resources in accordance with previously accumulated knowledge of the state of the network and with the policy of users service[4].
A promising direction of building cognitive systems is technologies based on the use of fuzzy logic and
artificial neural networks. Fuzzy logic theory provides a way to model the uncertainty of a natural language. Recently, fuzzy logic is used to support intellectual and cognitive systems. The use of fuzzy logic makes it easy to take into account many parameters for decision-making and does not require complex mathematical calculations.
These conditions led to a number of contradictions in the field of wireless network technologies, the most acute of which are: the contradiction between the increasing demand for wireless network services (for operating frequencies) and the natural limitations of frequency resources, the contradiction between the expansion of the range of services provided by wireless networks and the increasing requirements for their quality and the use of traditional (outdated) management technologies.
One of the effective methods for settlement the above contradictions is the use of elements of artificial intelligence in wireless telecommunication systems.
Thus, the technologies for building intelligent (cognitive) radio and cognitive wireless networks are the technological imperative of time. The functions of artificial intelligence in advanced wireless systems and networks can be implemented in different ways.
One of the modern approaches to the implementation of artificial intelligence functions in cognitive wireless systems of networks is the use of fuzzy logic and fuzzy processors.
The data transmission systems are increasing speed, increasing mobility, expanding the coverage area and increasing the intelligence of network and subscriber equipment.

**Revised Manuscript Received on September 15, 2019**
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The evolution of the technical platform of wireless networks is also considered. At the present stage of development, communication networks are at the stage of transition to packet-switched systems and include both circuit-switched systems and packet-switched systems. At the next stage of development, such directions as the expansion of areas of penetration and the ability to adapt to the environment and influence it will become dominant. The ability of the wireless system to adapt to the environment is achieved by the use of cognitive technology at all levels of its construction. This chapter shows modified multi-level model for constructing the cognitive wireless data transmission systems, a feature of which is the introduction of an artificial intelligence plane supporting cognitive functions at all levels of the architecture[5,76,7].

The diverse and effective ways to use cognitive functions are wireless regional networks wireless ad hoc network (WANET), and other types of wireless networks that use many different operating parameters, both in terms of wireless broadcasting and organizing the transceivers in the network.

WANET is a peer-to-peer wireless data network with a variable topology and lack of a clear infrastructure, where each node can perform the functions of a router and participate in the retransmission of data packets. Such network must understand the objectives of the application, and the application is able to understand the capabilities of the network at any time. This will allow the network, by examining the application's basic requirements, to use the new capabilities and dynamically select the compliant network protocols.

## II. FUZZY ADAPTIVE CONTROL OF THE MODULATION SCHEME IN THE OFDM SYSTEM

In fact for purpose of noise immunity at different distances from the transmitter of the radio network node, different signal modulation schemes are used. We also take into account the direction and speed of movement of the WANET nodes relative to each other in the task. The distance transmitter and receiver is determined by the received signal power, and the speed and direction of the distance change is determined by the signal power change [8, 9, 10].

To solve this problem, a relationship is established between the energy of the received signal and the data transmission rate; on the basis of it, the coverage area of the radio network node can allocate areas where different transmission speeds are provided. Adaptive modulation is used to control the transmission rate in the node's coverage area. Adaptive modulation in cognitive wireless ad hoc networks (CWANET) allows the nodes to adapt the signal modulation scheme to the signal-to-noise ratio (SNR) level in the radio channel. The modulation scheme for transmission of the next orthogonal frequency-division multiplexing

(OFDM) symbol is selected due to the SNR receiver testing when receiving the current OFDM symbol [11,12]. The existing methods for Signal-to-noise ratio (SNR) testing in the OFDM system are based on the analysis of the sequence of pilot signals. Despite their effectiveness, in some cases these methods are difficult or hard to implement. In addition, the main disadvantage of such methods is the need to transmit a relatively large amount of overhead information on the return receiver-transmitter line, which is a significant limitation for their practical application. Therefore, this paper proposes a channel adaptation method without auxiliary pilot signals for SNR testing the Quadrature amplitude modulation signals in additive white Gaussian noise channels (AWGN)[13,14]. In accordance with the SNR testing, the modulation scheme is controlled [15].Due to the uneven frequency response of the channel, different signal subcarriers attenuate unevenly in the OFDM transmission system. In accordance with the SNR testing, the subcarriers with low gain factors are disabled in the transmitted OFDM symbol and the power is evenly distributed between the subcarriers remaining active. The final power distribution in the transmitter will be:

$$\begin{cases} p_i = \dfrac{p_i}{N_a}(i = 1/N_a) \\ p_i - 0(i = N_a + 1/N) \end{cases} \quad .........................(1)$$

the (p) is the total radiated power of the OFDM system (assumed to be constant), p is the radiated power of the signal on the i-th subcarrier, $N_A < N$ number of active information subcarriers, used to transmit the current packet. When using a uniform distribution of bits over $N_A$ active subcarriers, the data transfer rate (the number of information bits B transmitted by the system per time symbol with the duration $T_S$)can be determined as follows:

$$r(Na, M, R) = \frac{B}{T_S} = \frac{R.m.Na}{T_S} = \frac{R.\log_2 M.Na}{T_s} ............(2)$$

here $R$ - is the code rate, т- is the number of bits transmitted in one $M$- QAM symbol on one subcarrier, and M is the modulation order (M = 4, 16, 64, 128). The probability of bit errors $p_b$ on the receiver of the OFDM communication system depends on the set of SNR values on the active subcarriers. Taking into account the mixing of bits using interleaving, the probability of bit errors ($p_b$) can be represented as the average (over $N_A$ active subcarriers) values of the probabilities of bit errors:

Here $^Y$ is SNR, $*$ is a monotonically decreasing function describing Dependence of the probability of bit errors on the SNR for M-QAM.

$$f_m(g) \approx \frac{2}{m}(1 - \frac{1}{\sqrt{M}}).Q\left[\sqrt{\frac{3m\Upsilon}{2(m-1)}}\right] ........................(4)$$

## 3. Proposed Scheme

As a result, the overall probability of error because of tripping the attenuated subcarriers is significantly reduced due to a small loss in system capacity. In The potential loss of bandwidth can be compensated by applying a high modulation order, in the remaining active subcarriers showing a high (SNR) value.
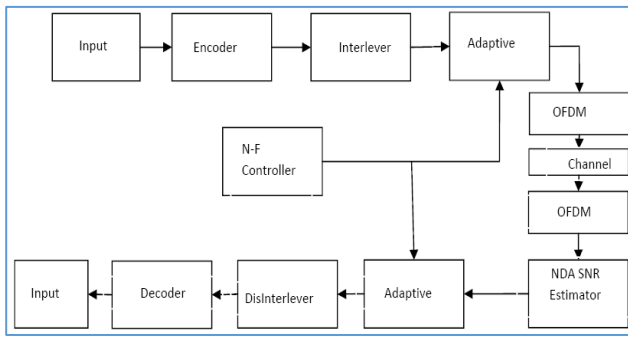
**Fig.1 system under consideration diagram**

(SNR) estimation algorithm for (QAM) signals uses the statistics of a data unit reception. In the fuzzy (SNR) testing subsystem, the imaginary $I_m$ and the real $R_m$ components (Fig. 2). The value of the imaginary and real components is received on the subtraction and comparison units. The comparison unit compares the values of the incoming components with the values stored in the memory, and selects from the memory the values closest to the incoming ones, and transfers them to the subtraction unit. Subtraction unit determines the presence of deviations or discrepancies. Then the processed data is sent to the fuzzier, the element responsible for converting the real parameters of the system to fuzzy logic parameters. In combination with information from the knowledge base, the decision-making device makes a fuzzy inference[16,17].
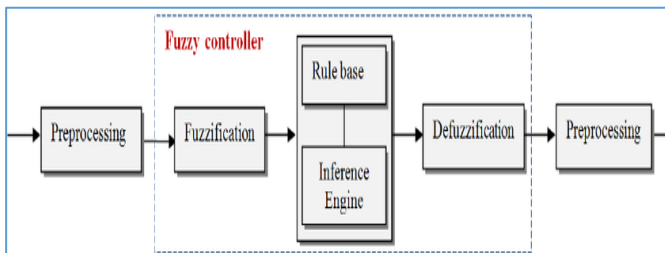


**Fig. 2. The fuzzy logic structure diagram**

In the preprocessor, the inputs in the form of clear values generated from the feedback error and the change in the error were due to multiplication by a constant gain before entering the main control unit. The fuzzification block transforms the input data into a function of degrees of membership and matches the data with the conditions of the rules. From the rules-based commands, the type inference mechanism determined the possibility of determining the extent of the rules used and returned a fuzzy set for the fuzzification block, where fuzzy output data were taken and clear values were returned.

It is convenient to present the totality of all rules in the form of a table where the columns correspond to the conditions of one parameter, the rows to the conditions of another parameter, and the inferences are written at their intersections, Corresponding to these conditions. The fuzzy inference rule base will consist of the following rules:

*If $R_m$ - high (H) and dR - low (L), then y - very high (VH).*
*If $I_m$ - medium (M) and dI - high (H), then y - low (L).*

According to the obtained SNR value *(y)* and its change from the previous estimate of Ay, the fuzzy modulation rate control subsystem (Fig. 3) decides on the choice of the modulation scheme for transmitting the next frame.
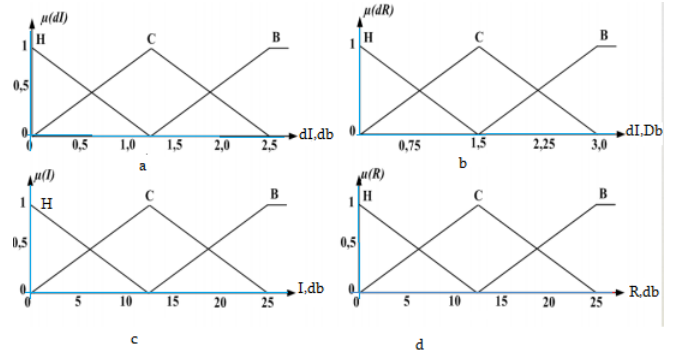


**Fig.3 Membership function: a) -the imaginary component deviations b) - deviations**

Real component; C– imaginary component, d) – real component

The modulation rate (MR) is represented as a linguistic variable, its basic term-set $T_{Mr}$ is defined as the set of possible values:

$T_{uu}=\{4QAM,16QAM,64QAM,128QAM\}$, (6)

here 4QAM, 128QAM designations of possible modulation schemes.

The value *(Mr)* is determined as a logical inference obtained as a result of applying the base of specified *R2* rules.

$Mr=R2(y,s)$, (7)

where R2 is the base of *modulation rate* value selection rules; *y* is the value of the signal-to-noise,the change in the signal-to-noise ratio, the set of which (Fig. 4b) consists of terms: $\{\pm M, \pm C, \pm 5\}$ (the notation "M"

Change, *"C" is* medium change, "B*" is* a big change, and the signs "+" and "-" mean a positive or negative change in the GSS).

The fuzzy inference rule base will consist of the following rules:

*If y - very high (VH) and Δγ - low ( ±L ), then MS - 128QAM;*

*If y - high (H) and Δγ - positive high (+H), then MS - 128QAM;*

*If y - high (H) and Δγ - low (±L ), then MS - 64QAM;*

*If y - high (VH) and Δγ - negative high (-B), then MS - 16QAM;*

*If y - medium (M) and Δγ - positive high (+H), then MS - 64QAM;*

*If y - medium (M) and Δγ - low (±L ), then MS - 16QAM;*

*If y - medium (M) and Δγ - negative high (-B), then MS - 4QAM;*

*If y - low (L) and Δγ - positive high (+H), then MS - 16QAM;*

*If y - low (L) and Δγ - low (±L ), then MS - 4QAM;*

*If y - low (L) and Δγ - negative*

high (-B), *then* reject the transmission.

*If y* - very low (VL) and Δγ - low ( ±L ), *then* reject the transmission.



$$\mu(MR)$$
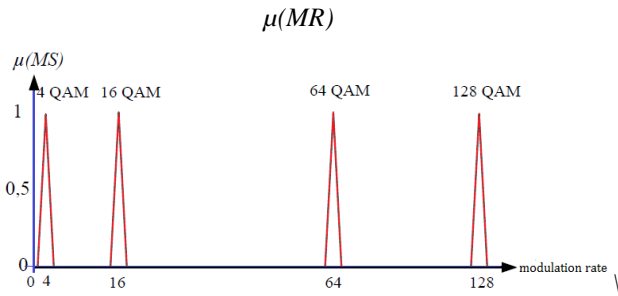
III. **THE MANAGING MULTIPLE MEDIA ACCESS**

From the point of view of channel access, the main problem is the possibility of conflicts of access to a shared resource. The mechanism of conflict is the random simultaneous transmission of several packets on a common channel, which leads to the imposition of transmitted packets and to distort the transmitted information [18].

This chapter analyzes the existing methods of multiple accesses in CWANETs. Based on the analysis, we can say that today there is no ideal method for organizing access to a shared data transmission channel. Therefore, one of the important problems in the field of quality of service in the CWANET is the problem of managing multiple accesses. Behavior and demand users show the fig 4

The fuzzy conclusion itself can be formulated not only in
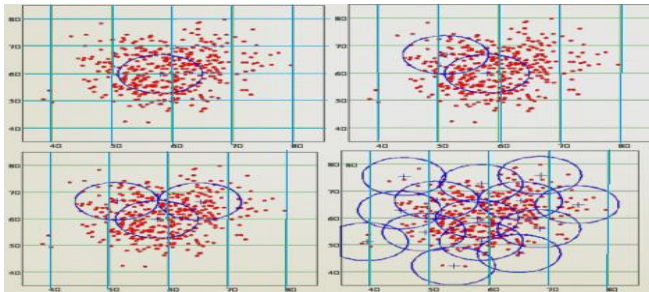


the form of "change modulation", but also in the form of "greatly reduce the transmitter power"
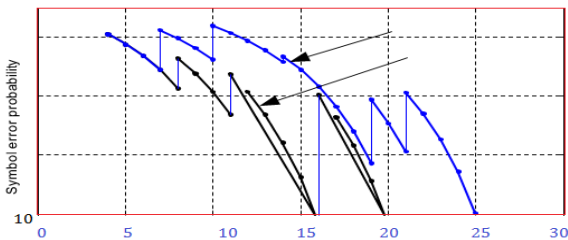


Fig.5 Comparison of fuzzy and classical adaptive modulation

**The subscriber has a buffer for storing one packet.** Each subscriber remembers the moment *x* of the occurrence of its last new packet and keeps the packet in memory until the moment of successful transmission of this packet. For a packet received by this subscriber at time x, this subscriber remembers the sequence

$$v^{(x)}(t) = \{v_l^{(x)}, \quad ... \ v_t^{(x)}\}\ldots\ldots\ldots\ldots \ldots\ldots.....(9)$$

The results of the channel state measurement are sent to a comparison device, it determines the change in the degree of channel utilization (determines how far the channel state has changed at time т compared with the previous state at time $x_r$-.$_1$), the value of the channel status (number of free windows in $x_r$) , the change of channel load and queue delay. This data is fed from the comparison device to the input of a fuzzy controller, which fuzzifies all values and then, in accordance with

the established rule base, performs a fuzzy inference operation. The result of fuzzy output is transmitted to the defuzzifier, which converts fuzzy values into clear decisions that are transmitted to the input of the actuator. In accordance with the result of solving a fuzzy logic, the actuator determines the probability with which the incoming packet will be transmitted to the channel[19].

The input variables in our system:

• **The channel state** " *X* is represented as a linguistic variable, its basic term-set $T_x$ is defined as the set of possible values

$T_X$ ={" *B*" , " *N*" , " *G*" }, here "*B*" - bad channel, Loaded " *N*" - normal channel, " *G*" - god channel, i.e. channel is not loaded;

• **the change rate of the load level of the channel** " *dX / dt*". For

the transition to fuzzy variables of the change rate in the degree of congestion of the channel will take the standard form of the membership function

with terms: $T_{dX / dt}$ = {" *L*" ," *M*" ," *H*" }, here " *L*" - low rate, " *M*" - medium rate and " *H''* - high rate;

• **the queue delay** "d", which also has three terms: small (L), medium (M) and high (H).

The fuzzy inference system is determined by a fuzzy knowledge base, or more specifically, by the production rules used for fuzzy inference construction.

The inference of each R1 implication rule is a linguistic variable "channel rating", the set of values of which consists of five terms *T(R):* very low *(VL),* low *(L),* medium *(M),* high *(H)* and very high *(VH).*

In this case, the fuzzy rules are presented in the form:
*If the channel is in good condition (G)* and its load is reduced compared to the previous state (L) and the queue delay is low (L), then the channel rating will be very high *(VH).* Through fuzzy variables, this rule can be written as follows:

*if X = G and dX / dt = L, and d = L, then R = VH.*

If the channel is in poor condition *(B)* and its degree of congestion will increase *(H)* compared to the previous state and

the queue delay is high (H), then the channel rating will be very low *(VL).* Through fuzzy variables, this rule can be written as follows:

if *X = B u dX/dt = H* adnd *d = H,* then *R = VL.*

The rule of fuzzy implication is given by the Mamdani rule:

$$M_{B'}{}^{(R)} = {}^{max}{}_{k=i...N}{}^{(min[}d_A *{}^{(X)} d_A k\{dX/dt),(d),(r\}, \quad ........ \quad (10)$$

here $X, dX/dt, d'$ respectively, are input variables (state of the channel, rate of change of the channel load level and queue delay), $A_1{}^k$,

$A_2{}^k$ and $A_3{}^k$- their corresponding fuzzy sets, $k=1, ...,N$ - rules of

fuzzy inference, $N$ is the number of fuzzy inference rules (N = 3 * 3 * 3 = 27, since each of the three linguistic variables can take three different values), $R$ is the output variable (channel rating), $B$ is the corresponding set.

### Development routing algorithm

Multicast Routing Protocol Classification of routing protocols and the operation of the protocols used in CWANETs, as well as the features of the functioning of CWANETs. The result of the analysis shows that there is no single routing method that satisfies the QoS requirements and ensures the optimization of all performance indicators of the network operation with fuzzy basic data on the state of radio links.

For routing with prediction of quality of service in the CWANET, it is proposed to use the fuzzy logic-based routing method. The use of fuzzy logic in this method allows to take into account the many parameters of the state of nodes and communication channels when choosing the optimal (in terms of quality of service) data transfer route, and it does not require the construction of an exact mathematical model. The potential data transmission routes, the FAODV reactive routing protocol is considered (Fuzzy Ad-hoc on-demand Distance Vector). The reactive routing protocol was chosen because of its better scalability in large self-organizing networks. FAODV builds the routes using the request-response cycle. Reactive methods do not require periodic updating of the routing tables, while maintaining the bandwidth of the wireless Environment and saving battery power of mobile terminals. Such protocols do not require any unnecessary costs in the event of changes in the topology of the mobile network, and especially if the movement of nodes is negligible.
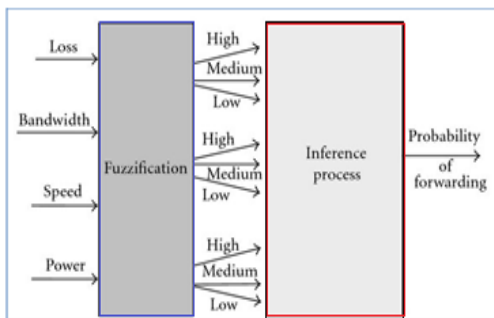


**Fig.5probability of caching or forwarding**

The proposed routing method includes three steps:

a) *The detecting procedure of possible routes to the destination node is started*, while the routing control packets also transmit the state parameters of the nodes and communication channels. After completion of this procedure (by timer), the collected data are fed to the input of the fuzzy logic controller.

b) *At the second stage, for each of the detected routes*, its rating is calculated. The values of the state parameters of each route are fed to the input of a fuzzy logic controller, which fuses all values and then, in accordance with the established rule base, performs a fuzzy output operation. At the controller output, a clear (numerical) rating of each route is obtained. The route with the highest rating is considered optimal.

c) *Choosing the optimal route*, from the set of other detected routes; two more routes with the highest rating are selected, which become alternate routes[20].

After selecting the optimal route, the node writes this route to the routing table for a certain period of time (caches the route).

If a new connection request arrives, and the destination address is contained in the table, a new Route Request is not generated, and the data is sent via a previously saved route. In addition, to ensure the resilience of failures of nodes on the selected route, in addition to the optimal route, two spare ones are selected. The following algorithm selects them:

- The results of the route evaluation pass through the decision block, where their rating is calculated.

All routes are recorded with their corresponding rating in a temporary table.

- Then all the rows of the table are walked through, and the routes are marked, the set of intermediate nodes of which do not intersect with the set of intermediate nodes of the selected optimal route. Thus, we find a set of non-intersecting routes. This is important because it reduces the probability that a node that fails on the optimal route will affect the operation of two alternate routes.

- From the set of marked routes, two routes with the highest rating are selected, which become alternate routes.

- If the set of marked routes is empty, we repeat the procedure for selecting alternate routes, but we note those routes that intersect with the one selected in one node.

In the process of maintaining information exchange, a dynamic assessment of the working route is carried out. If its characteristics decrease below the threshold value (the application defines it) due to the increased mobility of nodes or due to bad weather conditions, or if a node or part of the nodes leaves the route, the characteristics of the two remaining (spare) routes are specified and the best one is selected.

If one of the remaining (spare) routes is not suitable for quality, the connection (three-step) is repeated [21].

Thus, the proposed algorithm (unlike, for example, from the well-known AODV) allows forming several routes (three in this case) at the connection establishment stage, which provides a significant increase in the

continuity of service to CWANET's subscribers.

For the method of routing under developing, the following parameters of the state of the nodes and the communication channel were selected: throughput, transmission delays, jitter delay, load (free queue size) and the number of "jumps" (number of nodes). The network is represented by an undirected graph $G=(V,E),$, here $V$ is the set of nodes; $E$ is the set of channels. Denote the cyclic route $p$ в $G$ as a sequence of nodes.

We define the parameters of the state of nodes and communication channels for each $p$ route:

**The bandwidth** of the entire route is considered to be the minimum bandwidth among all channels on route p:

$i=L$

**The packet transmission delay** for all intermediate communication channels is summarized:

$$d(p) = \overset{n=1}{\text{å}} d(v_1, v_2, n) \dots \dots \dots \dots \dots \dots \dots (11)$$

$$\mathrm{D}d(p) = \max\left\{(\mathrm{D}d(v_i, v_{i+1})\right\} \dots \dots \dots \dots \dots \dots (12)$$

$$b(p) = \min_{i\bar{1}\ p}\left\{(b(v_i, v_i + 1)\right\} \dots \dots \dots \dots \dots \dots (13)$$

**The jitter of the entire route** is considered the maximum jitter among all the channels on the route:

**Load of packet node buffer.** The relative load of packet nodes buffers on the route is calculated as:

$$l = \overset{n}{\underset{i=1}{\text{å}}} li * /_1 \dots \dots \dots \dots \dots \dots \dots (14)$$

here $l$ is the buffer load of $i$-th node; \ - weighting factor of the i-th node; $n$-number of nodes in the route.

### 4.  Intermediate nodes and result

This parameter is additive, its value is easy to calculate, since the response to the routing request contains a list of all intermediate nodes to the destination node.

As a result, after the source has received a response to the routing request, the values of the listed parameters are extracted from the packet and fed to the input of the fuzzy logic controller. Each input parameter of the fuzzy controller is associated with a linguistic variable that has five terms: very low, low, medium, high, very high The functions of linguistic variables LV) (symbols of the LV: VL- "very low", L- "low", M- "medium", B "big", VB- "very big", VS- "very small", OB- "very high")The inference of each implication rule is the linguistic variable "route rating R (p)", the set of values of which also consists of five terms from "very low" to "very big". The functioning logic of the fuzzy logic controller is very simple: for each detected route its exact rating is calculated in accordance with the rule base. The best route is the route with the highest rating. For a more visual display of the operation of a fuzzy controller in accordance with this method, a graph  (Fig. 15) shows the dependencies of the output variable on the input. The input variables $B(p)$, $d(p)$, $Ad(p)$, $N(p)$ and $l(p)$,  are deposited along the axes, and the corresponding $R(p)$ value along the vertical axis. The resulting graph represents the defused surface of the fuzzy route rating.

To obtain a graphical display of this function, a model was built in the program package. Due to the large size of the rule base (3125 rules), for simplification, only 25 rules were given in the model.

The simulation results in fig. 6. Show that when the number of nodes in the networks a tenth of delivered packets increases to 5.07%, the average packet delay on the route decreases by 49.517%, and with 20 nodes the amount of delivered packets increases to 4.96%, the packet delay on the route decreases by 45.32%.

delivery package (%)

Delay
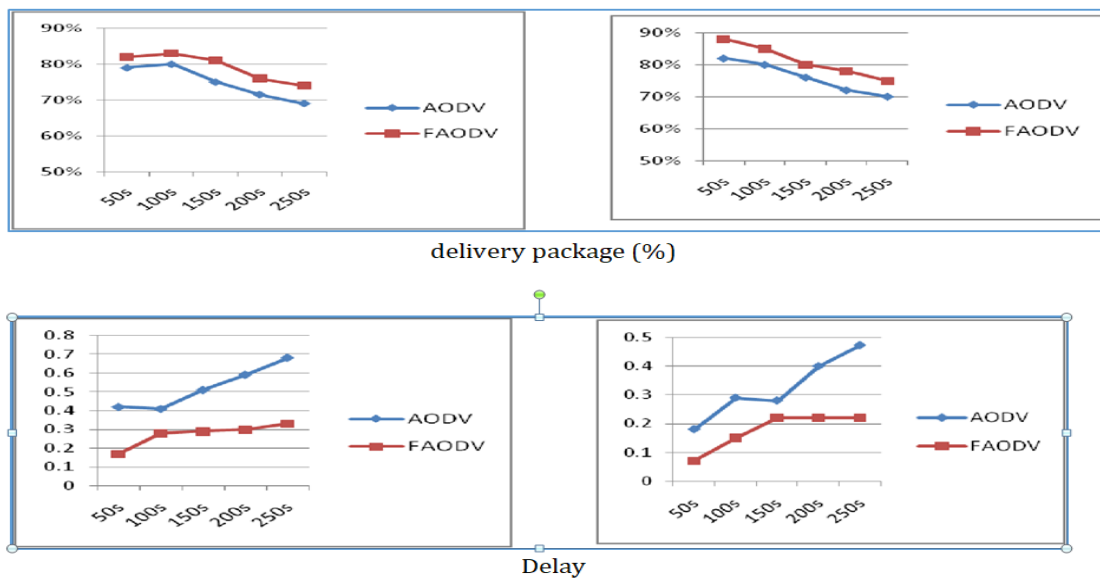
### IV.   CONCLUSION

Adaptive modulation in a transmission that maximizes spectral efficiency while maintaining an acceptable BER. Fuzzy logic based adaptive modulation provides the best conventional logic based adaptive modulation for an OFDM system. The models and methods of applying fuzzy logic in cognitive wireless data transmission systems are developed and investigated here.

The main results of the work are The Wireless data networks are developing in Building of promising cognitive data networks which provide for the widespread use of elements of artificial intelligence at all levels of the architecture. For Applying artificial intelligence based on physical fuzzy logic on allows to improve the quality of adaptive OFDM modulation control.

The use of fuzzy computing at the network level improve the stability of the network as a whole and The use of fuzzy logic is one of the promising technologies for building cognitive wireless networks.

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