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Fuzzy logic based cross-layer design to improve Quality of Service in Mobile ad-hoc networks for Next-gen Cyber Physical System

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ABSTRACT

5G standard by 3GGP has provision for Device-to-Device (D2D) communication over a Wireless Mobile Ad-hoc Network (MANET) framework. Recent research and development in 6G Networks and beyond has support for integration of MANET to the Mobile communication infrastructure to cater services to many potential future-proof applications like Smart Vehicular Networks using Internet of Vehicles (IoV) and Flying Ad-hoc Networks (FANET) for drone networks and military Ad-hoc networks. MANET being an Ad-hoc and infrastructure-less network poses major deployment challenge in resource allocation and management to facilitate strict Quality of Service (QoS) requirements for future Internet of Things (IoT) based Next-generation Cyber Physical System (NG-CPS). Most of MANETs use Contention-based Distributed Coordination Function (DCF) random Access Media Access Control (MAC) and a generic TCP/IP stack implementation. It is a daunting task to have deterministic model of network parameters for specific QoS requirements of IoT applications hence a soft-computing approach would be most viable solution considering network parameters across all five layers of TCP/IP stack that is a Cross-Layer design approach to improve QoS. In this paper, we have proposed a Fuzzy Logic system based Cross-Layer (FLS-CL) design for MANET to improve Network QoS parameters like Throughput, Packet Delivery ration (PDR) and End-to-End (E2E) delay. The proposed system has been implemented using Fuzzy Logic based parameters modeling using MATLAB and the Network simulation study using QualNet® simulator. The results are promising with average 27.64 % improvement in PDR and 76.04 % less E2E delay for connection-less UDP-based CBR applications and 3.28 % improvement in PDR and 58.81 % less E2E delay for connection-oriented TCP-based FTP applications. The QoS improvements are achieved with proposed FLS-CL as compared to state-of-the-art IEEE 802.11 based MANET without any FLS cross-layer optimization.

1. Introduction

Ad-hoc networks are the wireless networks dedicated for a specific function. Mobile Ad-hoc Network (MANET) architecture is imperative for any critical communication scenario especially in the context of Internet of Things (IoT) based Next Generation Cyber-Physical Systems (NG-CPS). It supports infrastructure less and highly scalable wireless sensor network. However, MANET architecture has many deployment challenges for resource management to ensure the typical application specific Quality of Service (QoS) requirements. 5G standards given by 3GPP and next generation mobile communication like 6G support MANET architecture with Device-to-Device (D2D) framework for many potential IoT-based applications such as Internet of Vehicles (IoV), Flying ad-hoc networks (FANETs) etc. The major challenge in the deployment of MANET is ensuring QoS requirements. Most of the MENET's TCP/IP protocol stack implementation suggests an IEEE standard that works on

1) Wireless Physical layer (Layer-I)
2) Ad-hoc communication framework of Distributed Coordinated Function (DCF) based (Layer-II) Media Access Control (MAC)
3) Network layer (Layer-III) with IPv4 / IPv6 based Logical address and routing
4) Transport Layer (layer-IV) supporting either TCP or UDP
5) Application Layer (Layer-V) protocols for specific End-to-End service requirements.

MANET is the combination of a group of self-organized nodes. There is no central management between the nodes. Each node is

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equipped with a transceiver which enables it to act as a router as well as a host. Each node supports variety of applications. These nodes enjoy the advantage of adaptability that makes MANET a multi-functional network. MANET is suggested strongly for IoT applications as the conventional networks can't provide its services [1,22]. Scarcity of bandwidth, constrained power resources, limited transmission range, mobility of the nodes and storage imitation are considered as weakness of MANET. These weaknesses are important aspects to support QoS. Clustering the network provide a solution to enhance QoS [3]. However, clustering the network increases the complexity of its working mechanism.

Cross-layer can be defined as the infrastructural layer of the TCP/IP stack that optimizes different parameters across the five layers. It is one of the proposed solutions in MANET for its developing requirements, addressing the shortcomings and coping with the resources. It is the strict and fixed design of the TCP/IP stack that cannot cope with the dynamic structure of MANET. It is not just any one layer of TCP/IP stack which is sufficient to address the challenges of performance optimization of MANETs strictly as per the QoS requirements of the scenario specific applications. However, a Cross-layer design will provide the best results in terms of performance enhancement as we are tuning relevant network parameters associated with multiple layers of TCP/IP stack. Cross-layer provides solutions for the difficulty in MANET design by minimizing the energy consumption and makes enhancements in QoS [2,4,5].

Due to random access MAC and other stochastic components of MANET, it is not viable to model the overall QoS requirements with help of deterministic modeling to ensure network performance. The research question then is: How to address this challenge of uncertainty in designing the cross layer? Under this circumstance, it is evident to use soft-computing techniques to model the MANET as a Cross-layer design problem. Recently there have been tremendous development in the field of Artificial Intelligence (AI) and Machine Learning (ML) due to more computational resources of recent processors (CPU/GPU). However, these AI and ML based techniques depends on huge data-sets and are processor as well storage hungry applications. Without large amount of training data these techniques do trade-off with accuracy. However, Fuzzy Logic System (FLS) is simple to implement as compared to AI and ML based techniques. Fuzzy logic is based on formulation of fuzzy set and a rule-based inference model with the help of linguistic variables and Membership function (MF). FLS uses antecedent and consequent variables and those are relatively easier to model especially for constraint power mobile computational units like MANET nodes. In this paper, we have considered FLS for modeling our Cross-layer design of MANET for improvements in QoS parameters like Throughput, Packet Delivery Ratio (PDR) and End-to-End (E2E) delay. We have included many parameters across the TCP/IP stack. Different parameters are considered from all the five layers of TCP/IP stack implementation. These parameters are used to model the fuzzy logic system to enhance the overall network performance. Fig. 1 shows Fuzzy Logic System based cross-layer design approach in MANET for QoS sensitive IoT-based applications for Next-generation Cyber Physical System (NG-CPS).

This paper introduces a Fuzzy Logic System based cross layer (FLS-CL) for MANET. Further, we have implemented part of our proposed system using Fuzzy logic toolbox in MATLAB. The results of the FLS-CL system are used on a QualNet® network simulator environment for testing, validation and evaluation of network performance. The results of our proposed FLS-CL design for MANET shows major QoS improvements and results are quite promising. MANET performance after cross layer optimization has been enhanced remarkably as compared with its performance without cross layer. The performance was tested using PDR, throughput and end to end delay.

The rest of this paper is organized as follows. Section 1 includes the introduction. Section 2 presents the related work. Section 3 discusses proposed FLS-CL System model. Section 4 presents simulation study. Section 5 presents results and analysis of results obtained is inferred with discussion in section 6. Finally, section 7 concludes the paper with future research directions.

2. Related work

MANET captures the interest of many researchers due to its suitability in many applications. Many researchers have discussed different methodologies for QoS performance enhancement of MANET [6,7]. One of these methodologies is the cross-layer design.

Anish et al. proposed a cross-layer scheme that links the physical and MAC layer to optimize the power consumption through controlling packets (RTS/CTS) [8]. When the transmitter senses the failure of RTS, it changes the minimum transmitting power. Optimization of energy consumption and enhancement in QoS are the target of this work. Asha et al. proposed a cross-layer scheme for efficient frequency selection. Channel modeling helps to estimate radio resource allocation [11]. A node selects a channel to transmit the data depending on channel frequency, path loss, channel gain, and PDF of each flow. This approach provides an enhancement of throughput and minimizing end to end delay for video transmission. Dhakad et al. proposed a fuzzy logic system (FLS) to enhance Ad-hoc On-demand Distance Vector (AODV) performance in MANET [9]. The rules of the FLS were set to optimize End-to-End Delay, throughput, and Packet Delivery Ratio concerning network size. They have obtained promising results with QualNet® 6.1. Sarao et al. proposed an ANFIS system for optimizing packet size [10]. The fuzzy logic system of 4×1 interfaces used throughput, normalized routing load, the data packet received, and end-to-end delay as antecedent variables with packet size as consequent variable. A new model for QoS calculation was proposed considering Stable Energy Aware Ad hoc Routing protocol (QSEAAR) [12]. They have used Fuzzy Logic system tool box in MATLAB and NS-2 for their work.

Recent state-of-the-art in MANET research is QoS-aware routing protocol presented by Singal et al. [45]. Some QoS enhancement research suggest techniques like Deep/Machine Learning schemes. Cross-layer design based Deep reinforcement learning is proposed by Nguyen et al. in 2021 [44]. Cognitive Radio MANETs Deep Q-Network design for QoS improvements proposed by Tran et al. in 2021 [43]. Hasan et al. in 2022 have proposed cross-layer optimization aspects of MANETs for QoS sensitive IoT applications [46]. Table 1 provides a comparison between some cross-layer models.

3. Proposed fuzzy logic based cross-layer (FLS-CL) design: System model

MANET is a wireless ad-hoc network comprising of mobile nodes. MANET works on a non-infrastructure, decentralized network architecture. Each node has the ability to control and adjust data transmission to work as a router or relaying node or as an end node. When a node is added to the ad-hoc network, the node needs to establish a route dynamically with the other adjacent nodes. Contribution in the transmission process is affected by the degree of closeness to the destination and depending on the utilized routing algorithm. The dynamic network condition in MANET has many technical challenges especially the resource allocation due to ad-hoc and infrastructure-less operation hence conventional TCP/IP stack implementation becomes much difficult and may not provide optimized QoS. Providing a good QoS is a big challenge in MANET regarding the type of application like on demand

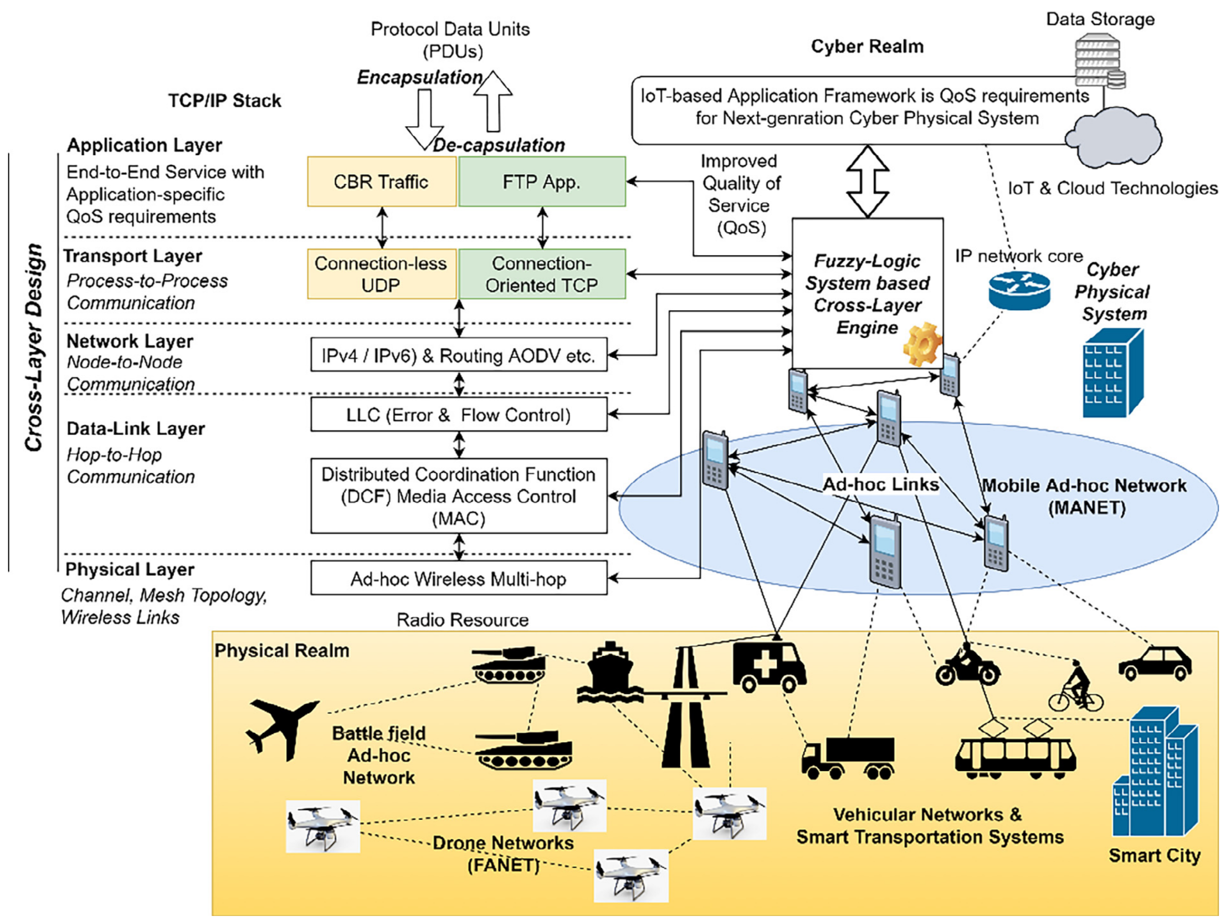

Fig. 1. Fuzzy Logic System based Cross-Layer design for Next-gen Cyber Physical System.

Table 1
Comparison of Cross-layer schemes in MANET.

Methodology Used	Advantages	Limitation	Network Performance and changing ratio %	Application Type
Bottom-up Cross-layer	Flexible and simple to implement	Limit network size	71.85 % reduction in E2E delay32.52 % increase in throughput	Real time and best efforts Denko et al. [13]
Modified AODV MAODV	Good utilization of the Available Bandwidth	Continuous and seamless connection is required and a Base-Station is deployed as a helper node	Improves throughput and PDR and reduces E2E delay	Multimedia (Video) Applications Patil et al. [14]
CCDRA+ DEL-CMAC	Proper for large scale networks	Does not satisfy the QoS requirements as it decreases throughput and increases the E2E delay	Decreased the throughput by 8.02 % and increased the E2E delay by 7 % with prolonged Network life	Generic Application Priya et al. [15]
LEMO	Efficient utilization of the time by giving priority to packets those are closer to their destination.	Increase the delay for the far destination	2 % increment in PDR & 27 % decrease in E2E delay	Constant Bit Rate (CBR)Walia et al. [16]
Service selection and service Discovery	Cost reduced and accuracy increased	More complex compared to other technique	Increased Throughput	Constant Bit Rate (CBR)Varshavsky et al. [17]

applications [18]. The mobility of the nodes gives the link non-stability with time, which requires more tracking of the adjacent nodes and periodic update of the available routes [19]. The wireless medium shared between the nodes increases the challenges through contention and congestion issues as it used contention-based media access control schemes due to ad-hoc network. The limited resources contribute in reducing network life span and degrading the performance of MANET. All these factors together affect the QoS parameters, End to End (E2E) delay, Packet Delivery Ratio (PDR), and Throughput. Cross layer provides a vital solution that MANET needs to for its stable performance. Cross-Layer design is motivated for considering parameters across many layers of TCP/IP reference model.

3.1. Cross-layer design approach in MANET

The layered scheme of TCP/IP stack isn't flexible for MANET design, and may weaken its performance. Each layer has a bidirectional inter-layer communication with the adjacent layers. Non-adjacent layers don't interfere with the other layers' processes [20]. The need for adaptation of each layer to cope with the variations in MANET nature based on a time scale is a big necessity that suggests cross layer. What can come as an emergent solution to makes TCP/IP stack supports MANET design. Cross layer enables lower layers to control the parameters of the higher layers and adapt them with the changes in the network (Mobility, signal strength, channel characteristics etc.) [21]. Cross layer is designed to meet QoS requirements and improve the network performance. It enables non-adjacent layers to adjust their parameters using adaptive methodologies. The Cross-layer design proposed in this paper, is following the adaption required between the layers of TCP/IP stack with some network parameters like mobility, data rates and no. of nodes to provide an optimal value that may adapt to the dynamic deployment scenario of MANET. Generally, cross-layer combines two or more than two layers. The cross-layer design proposed in this paper involves five layers of the TCP/IP protocol stack. Table 2 provides the parameters utilized by our cross-layer model.

3.2. Fuzzy logic system based cross-layer design

Mobile ad hoc networks are automated networks that are designed to support variety of application. As MANET is a battery constrained depending nodes, it's basic matter to have a control scheme for power resource [30]. Hop count affects the end to end delay as MANET has no fixed infrastructure [31]. Performance of MANET depends highly on the routing protocol utilized, with the increase of network size [32]. Application rate has its effect on the performance of the routing protocol and QoS parameters [33]. Retransmission times compensate the enormous received frames at MAC layer cased by wireless links or mobility of the nodes [34]. Selecting the physical layer standard (IEEE802.11b, IEEE802.11a) has its role on transmission process like optimization of energy consumption, error correction, reducing interference and jamming [35]. Fuzzy logic approach is a part of soft computing that interacts with the imprecision and approximate reasoning. It's the formalization of the capability to reason and make rational decisions in an environment of non-precise data with uncertainty, incompleteness, conflicting of its information [36]. Complexities mean that the knowledge about the environment and the decisions' consequences aren't constant and modality. Uncertainty is the concept of non-precise value that may class a type of data in order to satisfy human requirements for some control systems. The fuzzy logic and fuzzy decisions are tools that help taking decisions under the concepts of uncertainty and complexity [37]. The uncertain rule base, is used by our model, forms the controller of the cross layer to adjust the parameters from each layer and to get the optimal value that contribute in enhancing QoS to improve MANET performance. We conclude that the flexibility of fuzzy logic system enables providing cross-layer design for adapting MANET nature. Fuzzy logic system has its efficiency in MANET concerning QoS enhancement, improving the performance of routing protocols, and controlling different parameters of the protocol stack [38,39].

Fig. 2 provides the system model for cross layer (FLS-CL) design. Studying the effects of each parameter on network performance literately and through simulation is represented the first step in this work. In this first stage, we set the network characteristics, the parameters of each layer and the environment to be studied. This stage helped in inferring the rules for fuzzy logic system, and it is done using QualNet® simulator. Next stage included the design of fuzzy logic system (membership function, rule set, ranges of the parameters) for cross layer (FLS-CL) test and implementation. Final stage is the implementation of cross layer based on fuzzy logic by simulating different scenarios of MANET using QualNet®, and applying the values of antecedence to get the optimal values of the consequents and apply it to these scenarios. Finally, a comparative study has been done between with and without proposed FLS-CL for evaluation of MANET performance in the first stage and after applying our proposed FLS based cross layer design.

Fig. 3 provides the block diagram of proposed Fuzzy Logic System based Cross-Layer (FLS-CL) design. Fuzzy logic system provides the adjusting factor to get the optimal value of the consequents depending on the crisp inputs of the antecedents. The fuzzification process converts the crisp inputs to the corresponding fuzzy set. Our cross-layer design is based on Fuzzy logic system. Fuzzification, rule designing, aggregation, and defuzzification are the fuzzy logic processes. In our proposed model we are considering three paraments as our antecedent fuzzy variables 1. Node speed (m/s), 2. End-to-End delay (ms) and, 3. Packet Delivery Ratio (PDR) in %. Similarly, we are considering five consequent variables as: 1. Transmission Power (mW) and 2. Adaptive Modulation and Coding (AMC) form physical layer of TCP/IP layer architecture. 3. Number of Retransmission from data-link layer of TCP/IP layer architecture. 4. Hop count (Number of hops: since it's an ad-hoc network) from network layer of TCP/IP stack and 5. Application rate (packets/*sec.*) as a parameter from application layer of TCP/IP stack.

In our FLS-CL system modeling we have considered three antecedent fuzzy variables from physical, transport and application layer of TCP/IP stack and five consequent variables from physical, data-link, network and application layer of TCP/IP stack. As multiple layers of TCP/IP stacks are involved in modeling the Fuzzy logic system to enhance the overall QoS performance of the MANET we

Table 2
Cross-layer Parameters considered for Fuzzy Logic System Implementation.

Layer		Parameters	Discussion	Major work
Cross Layer	Application Layer	Application rate (Packets/*sec.*)	Application rate affects the transmission process regarding queuing, storage and power consumption.	Sadagopan et al. [23]
	Transport Layer	TCP/UDP	Determining the relation of connection-less UDP and connection-oriented TCP protocols on the performance	V. Sharma et al. [24]
	Network Layer	Hop Count (No, of hops)	Hop count determines path links that the packet needs to transient through. This affects the overall delay in the network.	Sahu1 et al. [25]
	Data-Link Layer	Number of Retransmission	Retransmission times affects the probability of receiving the packets, since the packet will be dropped after limit number of retransmissions	Jabbar et al. [26]
	Physical Layer	Transmission Power (mW)	MANET is a constraint power resource network, enhancements of energy consumption are one of the goals of the cross layer	Li et al. [27]
		Adaptive Modulation and Coding (AMC)	The utilization of IEEE 802.11a comes to provide higher transmission rates utilizing OFDM	Daisuke Takedal et al. [28]
		Mobility -Node speed	To adjust the overall connection session with the mobility of the nodes	B. Divecha et al. [29]

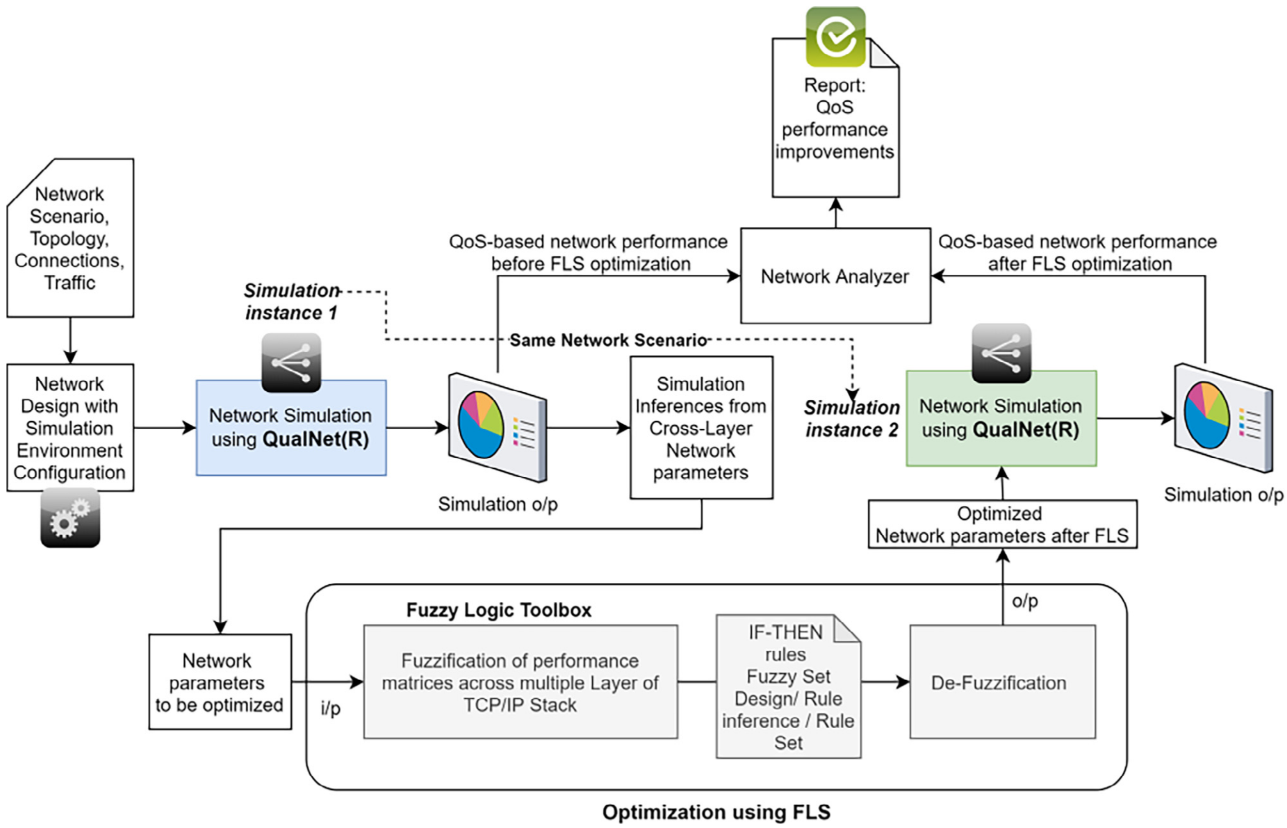

Fig. 2. System model for Fuzzy Logic System based Cross-Layer (FLS-CL) design for QoS improvement in MANET.

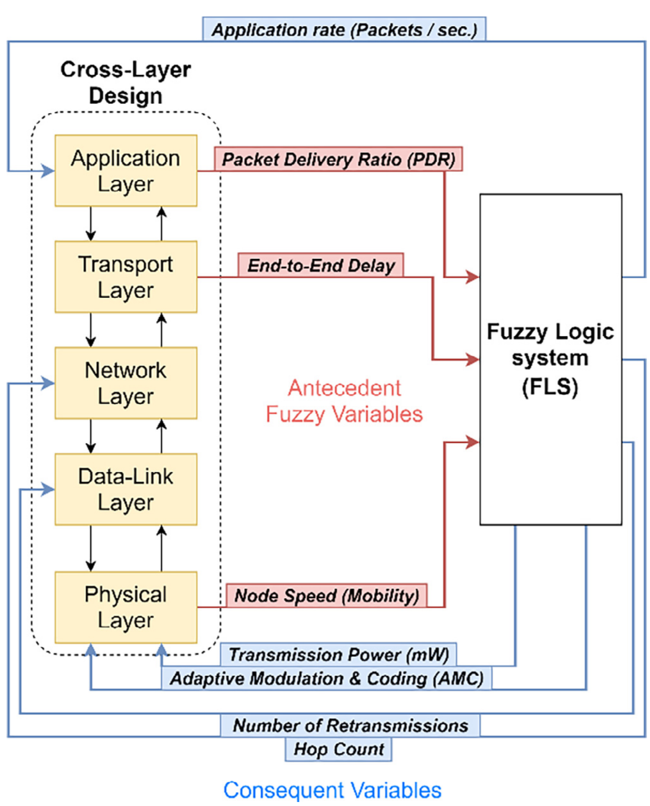

Fig. 3. Proposed Fuzzy Logic System based Cross-Layer (FLS-CL) design.

may term it as a fuzzy logic system based cross-layer design to improve QoS in MANET. Fig. 4 shows Block diagram of fuzzy logic design used for cross layer.

The proposed FLS-CL model adjusts the consequents based on Node speed, End to End delay (latency) and Packet Delivery Ratio (PDR) as they are influencing the QoS evaluation of overall network performance. These parameters are the inputs of cross-layer model which we will mention as antecedents. FLS-CL adjusts transmission power, AMC, number of retransmissions, hop count and application rate for a MANET which are the consequents variable considered in our fuzzy logic system.

In our model, interference engine is based on the QoS parameters with three antecedent fuzzy variables and five consequents variable. The fuzzification process converts the crisp inputs to the corresponding fuzzy sets as shown in Table 3. We used triangular and trapezoidal membership function to represent the fuzzy sets of antecedent variables. In the antecedent variables we have three fuzzy levels (Low, Moderate and High).

Table 4. We used triangular and trapezoidal membership function to represent the fuzzy sets of consequent variables. Here we have nine fuzzy levels: 1. High Increase (HI), 2. Medium Increase (MI), 3. Low Increase (LI), 4. Very Low Increase (VLI), 5. No Change (NC), 6. Very Low Decrease (VLD), 7. Low Decrease (LD), 8. Medium Decrease (MD) and 9. High Decrease (HD). These are considered to be our linguistic variables.

Aggregation is done based on Max-min composition [40]. Defuzzification is based on the centroid of area (COA) method. Each antecedent has 3 fuzzy sets that combine the fuzzy rule set of $3 \times 3 \times 3 = 27$ rules. The rule base is given in Table 5. For example, he following rules are used in the fuzzy inference system for the fuzzy variable 'retransmission'. Similarly, all the rules can be written alike.

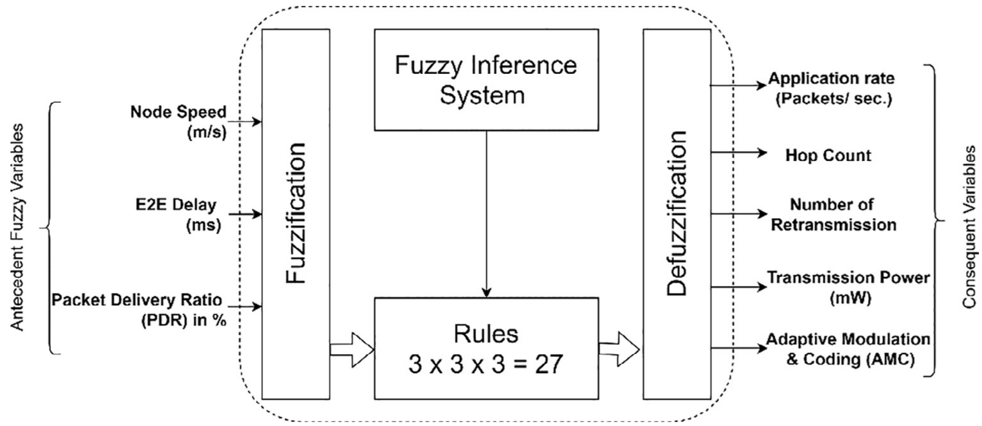

Fig. 4. Fuzzy Logic System for Cross layer.

Table 3
Antecedent Fuzzy Variables and their respective Membership function (MF).

Variable	Description of Fuzzy levels (Linguistic Variables)	Crisp range	Membership Function Type
Node Speed (m/s)	Low	0–50	Trapezoidal
	Moderate	0–100	Triangular
	High	50–100	Trapezoidal
End-to-End Delay (ms)	Low	0–1	Trapezoidal
	Moderate	0–2	Triangular
	High	1–2.5	Trapezoidal
Packet Delivery Ratio (PDR) in %	Low	0–50	Trapezoidal
	Moderate	10–90	Triangular
	High	50–100	Trapezoidal

Rule 1: If Node speed is Low, End-to-End delay is Low and PDR is Low then retransmission is Low increase.

Rule 2: If Node speed is Low, End-to-end (E2E) delay is Low and PDR is Moderate then retransmission is Very low increase.

The inference system and the defuzzification process is described as below. For ith fuzzy rule, the consequent fuzzy variable i.e. Retransmission is determined using Eqs. (1) and (2).

$$\mu_{Ri}(w) = Min\{\mu_{Ai}(x), \mu_{Bi}(y), \mu_{Ci}(z)\}i = 1, 2, ..., 27 \tag{1}$$

$$\mu_R(w) = max\{\mu_{Ri}(w)\} \tag{2}$$

Where, $\mu_{Ai}(x), \mu_{Bi}(y), \mu_{Ci}(z)$ are the fuzzy sets corresponding to node speed, E2E delay and PDR respectively. $\mu_{Ri}(w)$ is the fuzzy set corresponding to number of re-transmissions. The output fuzzy set after the inference is denoted as $\mu_R(w)$. The de-fuzzification is obtained using Equation (3) as shown below to get the de-fuzzified value as w.

$$w = \frac{\int \mu_R(w)wdw}{\int \mu_R(w)dw} \tag{3}$$

The above process is repeated for the remaining output fuzzy variables (consequents) such as AMC, Transmission power, Application rate and Hop count denoted as $\mu_M(w), \mu_T(w), \mu_P(w), \mu_H(w)$ respectively. The defuzzified value of the output variables are used for the QualNet® simulation of MANET.

This work uses triangular and trapezoidal membership function. The MFs (fuzzy sets) with its crisp range are given in Table 4. The ranges and the linguistic variables of each parameter are provided in the same table. The linguistic variables of the fuzzy set for the cross-layer inputs are low, moderate, and high (Table 3). While the linguistic variables of the consequents are HI, MI, LI, VLI, NC, VLD, LD, MD, HD. For data rates of AMC, we used linguistic variables based on the order of the modulation and coding scheme. The linguistic variables are named: unchanged, BPSK 0.5, BPSK 0.75, QPSK 0.5, QPSK 0.75, 16QAM 0.5, 16QAM 0.75, 64QAM 0.5, and 64QAM 0.75. We used triangular and trapezoidal membership function to represent the fuzzy sets. Fuzzification is based on AND operation. Aggregation is done based on Max process. Based on degree of the rules with membership functions of the input, output respectively corresponding to the rule i, x is the crisp input, 'i' is the order of the rule, and y is the crisp output then the crisp output for k rules can be obtained [41,42]. The crisp output can be obtained from all the rules of the fuzzy sets. We implemented a rule degree as '1'. Different weights result that the rule with less weight will be neglected when firing the rules. In this model all the rules have the same degree of importance which is the unity. Table 5 provides the rule base of fuzzy logic based cross-layer model.

Fig. 5 shows an illustration of fuzzy logic system implementation graphically for two sample rules. The three antecedent fuzzy variables with membership function (MF) are shown and the firing x1, y1, z1 for finding the first crisp output of consequent variable number of re-transmissions is obtained based on one sample rule-1 implementation. Similarly, the second rule is implemented for finding another consequent variable application rate. Point to be noted there are total 27 rules (3 × 3 × 3 based on three antecedent variables) and five consequent variables, hence there are up to (27 × 5 = 135 possible combinations or iterations based on firing). A crisp value can be obtained after de-fuzzification to implement on Network simulator QualNet® to get QoS improvements. This design is based on the Mamdani system. This proposed FLS-CL is implemented based on the If-then rule base set (27 rules). Hence, when crisp inputs are provided the system would generate crisp outputs.

Defuzzification is based on the centroid method. This method is based on calculating the central point of the shape obtained from aggregation process (combining the results in one graphical representation). Table 6 provides the results after fuzzy logic system based cross layer implementation. These results represent the input values to be applied in QualNet® simulations of the next stage. At the node speed of 10 m/s and the simulation time is 50 s, the transmission power is 774 mw, the packet rate is 11 packet/second, the data rate is 18 MHz, the no. of retransmissions is 5 and the number of hop counts used is 18. The results were used in four MANET scenarios small, medium, and large network sizes with different simulation and node speeds. The same results were also used to compare MANET performance with/out cross layer concerning the studying parameters.

Table 4
Consequents variable and their respective Membership function (MF).

Variable	Description of Fuzzy levels (Linguistic Variables)	Crisp range	Membership Function Type
Transmission power (mw)	High Increase (HI)	1200–1500	Trapezoidal
	Medium Increase (MI)	1050–1350	Triangular
	Low Increase (LI)	900–1200	Triangular
	Very Low Increase (VLI)	750–1050	Triangular
	No Change (NC)	600–900	Triangular
	Very Low Decrease (VLD)	450–750	Triangular
	Low Decrease (LD)	300–600	Triangular
	Medium Decrease (MD)	150–450	Triangular
	High Decrease (HD)	0–300	Trapezoidal
Adaptive Modulation and Coding (AMC)	High Increase (HI)	8–10 64QAM_0.75	Trapezoidal
	Medium Increase (MI)	7–9 64QAM_0.5	Triangular
	Low Increase (LI)	6–8 16QAM_0.75	Triangular
	Very Low Increase (VLI)	5–7 16QAM_0.5	Triangular
	No Change (NC)	0–2	Triangular
	Very Low Decrease (VLD)	4–6 QPSK_0.75	Triangular
	Low Decrease (LD)	3–5 QPSK_0.5	Triangular
	Medium Decrease (MD)	2–4 BPSK_0.75	Triangular
	High Decrease (HD)	1–2 BPSK_0.5	Trapezoidal
Number of retransmissions	High Increase (HI)	8–10	Trapezoidal
	Medium Increase (MI)	7–9	Triangular
	Low Increase (LI)	6–8	Triangular
	Very Low Increase (VLI)	5–7	Triangular
	No Change (NC)	4–6	Triangular
	Very Low Decrease (VLD)	3–5	Triangular
	Low Decrease (LD)	2–4	Triangular
	Medium Decrease (MD)	1–3	Triangular
	High Decrease (HD)	0–2	Trapezoidal
Hop count	High Increase (HI)	28–35	Trapezoidal
	Medium Increase (MI)	24.5–31.5	Triangular
	Low Increase (LI)	21–28	Triangular
	Very Low Increase (VLI)	17.5–24.5	Triangular
	No Change (NC)	14–21	Triangular
	Very Low Decrease (VLD)	10.5–17.5	Triangular
	Low Decrease (LD)	7–14	Triangular
	Medium Decrease (MD)	3.5–10.5	Triangular
	High Decrease (HD)	0–7	Trapezoidal
Application rate (packet per second)	High Increase (HI)	16–20	Trapezoidal
	Medium Increase (MI)	14–18	Triangular
	Low Increase (LI)	12–16	Triangular
	Very Low Increase (VLI)	10–14	Triangular
	No Change (NC)	8–12	Triangular
	Very Low Decrease (VLD)	6–10	Triangular
	Low Decrease (LD)	4–8	Triangular
	Medium Decrease (MD)	2–6	Triangular
	High Decrease (HD)	0–4	Trapezoidal

The values of PDR and end to end delay were applied in a fuzzy logic-based cross layer for a particular speed and time. Fuzzy logic, then provided the optimal values of consequents. The discussion of the results is provided in the simulation results and discussion section.

4. Simulation study

In order to validate our proposed FLS-CL, we have created a simulation-based testbed using QualNet® network simulator and used MATLAB for fuzzy logic system implementation. The system implementation using simulation can be classified into three distinct stages. We run them sequentially to validate our design by showing QoS performance improvements through QualNet®. Fig. 6 shows the flowchart of simulation study showing three stages and their working steps.

4.1. First stage

The first stage included MANET simulation when the number of nodes was 50 nodes. We used variable values of the parameters to study their effect on end to end delay, PDR, throughput, and the transmission power. Throughput, PDR and the end to end delay, are calculated as the following:

a) Throughput = Total data size received in bits/ Time spent between Transmission and Reception
b) Packet Delivery Ratio (PDR) = No. of packet received/ Total no. of packet sent
c) End to End Delay (Latency) represents the time that data suffers in its travel from source to destination E2E.

We start our work by studying the effect of the selected parameters on the QoS parameters. In this stage we studied the effect of node speed, AMC, application rate, hop count, and retransmission times on a given transmission power, end to end delay and the PDR. Fig. 7 shows the simulation environment using QualNet®. This figure provides one of the scenarios used to evaluate MANET performance. The other scenarios differed in no. of nodes, and node speed, and the values of the considered parameters.

Depending on the results obtained from this study, we set the rule base provided in Table 3. This study helped in selecting the ranges of the antecedents and consequents. Also, it provided the

Table 5
If-Then (3 × 3 × 3 = 27) Rules for three Antecedent Fuzzy Variables for Cross layer Design of MANET.

Rule Number	Node speed	E2E Delay	PDR	No. of Retransmission	AMC	Transmission Power	Application Rate	Hop count
1	Low	Low	Low	LI	QPSK-0.5	LI	LD	LD
2	Low	Low	Moderate	VLI	NC	VLI	VLD	VLD
3	Low	Low	High	LD	16QAM-0.75	LD	LI	MI
4	Low	Moderate	Low	LI	BPSK-0.75	LI	VLI	VLD
5	Low	Moderate	Moderate	NC	QPSK-0.75	VLD	LI	VLD
6	Low	Moderate	High	LD	BPSK-0.75	LD	VLI	LD
7	Low	High	Low	VLI	QPSK-0.75	VLI	VLD	LI
8	Low	High	Moderate	VLD	16QAM-0.5	VLD	LI	VLI
9	Low	High	High	LD	BPSK-0.5	NC	VLD	VLD
10	Moderate	Low	Low	LI	BPSK-0.75	NC	HI	MI
11	Moderate	Low	Moderate	VLI	BPSK-0.75	VLI	NC	LI
12	Moderate	Low	High	VLD	QPSK-0.5	VLD	MD	VLI
13	Moderate	Moderate	Low	VLI	64QAM-0.5	VLI	LD	VLI
14	Moderate	Moderate	Moderate	NC	QPSK-0.5	NC	VLD	LI
15	Moderate	Moderate	High	VLD	BPSK-0.75	VLD	MI	VLI
16	Moderate	High	Low	LI	16QAM-0.5	NC	NC	LI
17	Moderate	High	Moderate	VLD	16QAM-0.75	VLD	LI	LI
18	Moderate	High	High	LD	BPSK-0.5	NC	LD	VLD
19	High	Low	Low	HI	64QAM-0.75	HI	HI	VLI
20	High	Low	Moderate	MI	QPSK-0.75	MI	HD	HI
21	High	Low	High	VLD	NC	NC	HI	MI
22	High	Moderate	Low	HI	64QAM-0.5	HI	LI	NC
23	High	Moderate	Moderate	VLI	QPSK-0.5	VLI	VLD	HI
24	High	Moderate	High	VLI	64QAM-0.75	VLI	LI	MI
25	High	High	Low	LI	16QAM-0.75	LI	VLD	HI
26	High	High	Moderate	NC	64QAM-0.75	LI	LI	HI
27	High	High	High	VLD	NC	VLI	LD	LI

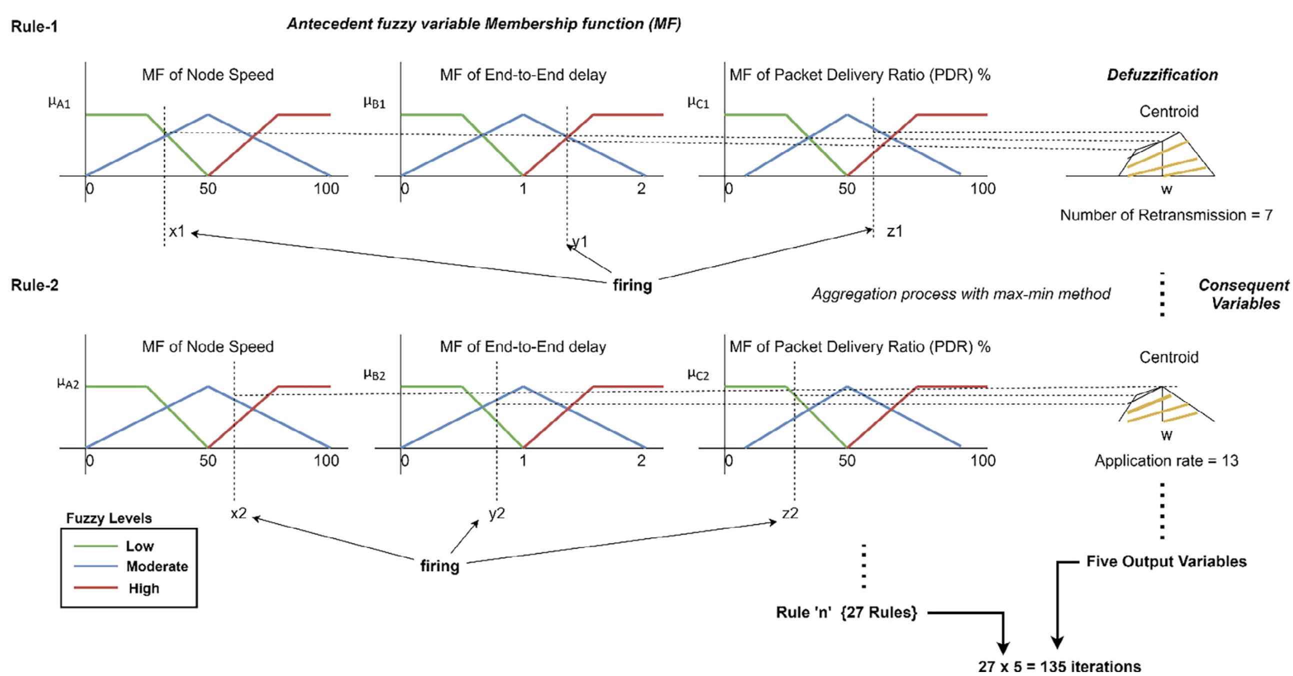

Fig. 5. Rule based Fuzzy logic system implementation in Cross-layer design for MANET.

information on how QoS parameters and the required transmission power change regarding node speed, AMC, retransmission times, hop count and application rate. Based on the obtained data and the analytical study we designed our fuzzy logic system based cross layer (FLS-CL) design.

4.2. Second stage

This stage included MATLAB implementation for fuzzy logic design. It included opting the membership functions for both the antecedents and consequents, designing the rule set base, and setting the aggregation and defuzzification processes.

If-Then rules are applied in the fuzzy logic system to get the crisp values of the consequent variables. The 3-D plots of the consequent variables with respect to the antecedent variables are provided in the Fig. 8.

4.3. Third stage

This stage includes MANET simulation in QualNet® using the obtained values of the consequents. After that, we compared the results of PDR, end to end delay and throughput with their results without cross layer implementation. This comparison proved the capability of our cross-layer model to enhance the QoS in a very

Table 6
De-fuzzification values for adjusting output parameters.

S.No	Node Speed (m/s) Mobility	Transmission Power (mw)	Application rate (Packet/s)	AMC	Re-transmission	Hop count
Case-1						
1	10	774	11	5	5	18
2	25	747	11	3	5	19
3	50	831	10	6	6	24
4	75	1050	10.2	7.82	6.28	32.3
5	100	1050	10.8	8.09	6.07	32.1
Case-2						
1	10	588	4	5	11	20
2	25	594	12.2	3.99	4.1	17.2
3	50	729	10.1	3.42	4.68	22.5
4	75	848	11	5.58	5.65	26.7
5	100	934	11.7	4.9	5.77	29.7
Case-3						
1	10	1050	12	8.61	5.67	32.1
2	25	688	12.1	6.19	4.96	22.5
3	50	674	11.3	5.32	3.69	21
4	75	850	11.6	6.7	4.3	27
5	100	1010	11.4	6.95	4.7	30.3
Case-4						
1	10	838	14.2	4.5	6.74	21.8
2	25	808	15.7	3.99	6.84	23.4
3	50	750	10	6	7	24.5
4	75	921	8.83	6.58	7	29.8
5	100	1050	8	7	7	32.4

interesting result. Discussion of the results is presented in the next section.

5. Results and analysis

This section describes results obtained from implementation of both cross-layer and without cross-layer system to provide a performance comparison. The implementation happens through four different scenarios. Each scenario involves different set of simulations as stated below:

1. Scenario-1: MANET with varying number of nodes (Network Size)
2. Scenario-2: MANET with varying node speed (Mobility)
3. Scenario-3: MANET with varying AMC (Modulation and Data-rate)
4. Scenario-4: MANET with varying number of retransmissions (re-transmission)

The FLS-CL adapted the parameters to make some kind of compensating. This process adjusts the energy consumption in the transmission mode with the other parameters. FLS-CL provided a trade-off between the utilized parameters. This resulted a very remarkable enhancement in QoS comparing with QoS without cross layer. The following sections provides Simulation Results of Fuzzy Logic System based cross-layer optimization for MANET concerning different scenarios.

For the above four scenarios for both connection-less User Datagram Protocol (UDP) based CBR traffic as well as connection-oriented Transmission Control Protocol (TCP) based FTP application traffic have been considered for the simulation study.

Simulation Environment: Simulation environment has been set using QualNet® simulator. Table 7 provides simulation environment parameters for all the four scenarios.

5.1. Scenario-1: MANET with varying number of nodes (Network Size)

Simulation Results: The obtained results for PDR, throughput, and end to end delay were compared with the values obtained when inferring simulation for fuzzy sets for cross layer design. Table 8 provides the numerical results of the simulations. We notice an enhancement in QoS after cross layer implementation.

The following figures provide MANET performance regarding PDR, throughput, and end to end delay with/out cross layer (FLS-CL) optimization concerning the number of nodes.

Fig. 9 shows the impact of our novel Fuzzy Logic based cross layer (FLS-CL) design optimization on PDR for CBR and FTP applications. With increasing network size, PDR increased for FTP. The retransmission of TCP protocol provided high PDR for FTP. For CBR, PDR decreased with increasing network size. For CBR, our proposed FLS-CL has improved the PDR by an average of 17.76 % with respect to without cross-layer case, while for FTP cross layer optimization has improved PDR by an average of 3.09 %.

Fig. 10 shows the throughput with respect to the no. of nodes. For CBR application, our novel Fuzzy Logic based cross layer (FLS-CL) design has enhanced the throughput of the network compared to without FLS-CL. For FTP application, cross layer optimization has provided a good enhancement in the throughput while increasing the network size. An average of 54.4 % increase has been noticed for FTP with proposed FLS-CL Throughput of CBR application increased after applying FLS-CL. In-case of CBR an average of 34.45 % improvement has been noticed in throughput with proposed FLS-CL.

Fig. 11 shows the end to end (E2E) delay with respect to network size. The end to end delay increased with increasing the no. of nodes. The result shows a staggering improvement in case of CBR. The E2E delay has reduced by an average of 99.32 % after applying our proposed FLS-CL design with respect to default value without FLS-CL. However, in case of FTP the improvement is 49.27 % overall reduction of E2E delay after applying FLS-CL.

5.2. Scenario-2: MANET with varying node speed (Mobility)

Simulation Results: The obtained results for PDR, and end to end delay were compared with the values obtained after inferring fuzzy sets and applying cross layer output. Table 9 provides the numerical results of the simulations. Cross layer implementation improves the PDR for both FTP and CBR. It can be remarkably observed that end to end delay is much less after cross layer optimization when considering node speeds. This enhancement includes reducing the delay for both FTP and CBR.

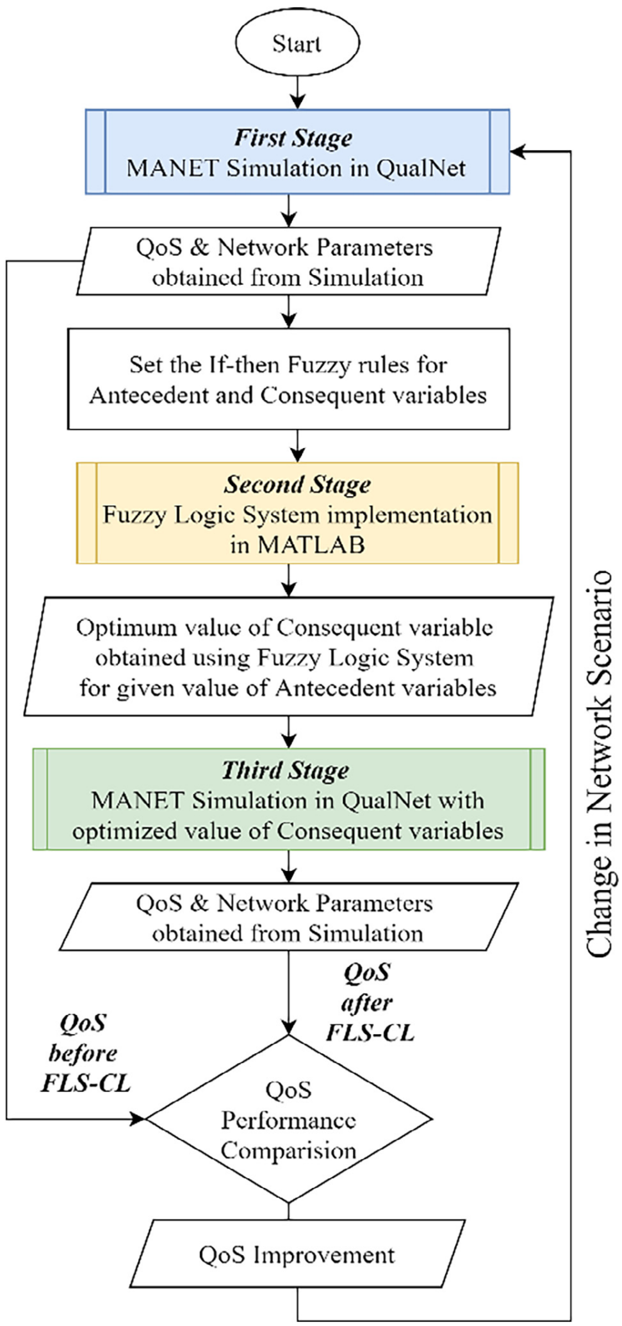

Fig. 6. Flowchart of Simulation Process.

Presentation of the numerical data in Table 9 is given in Figs. 12 and 13. The figures show the effect of our proposed FLS-CL optimization on MANET performance concerning PDR and end to end (E2E) delay. Fig. 12 provides the PDR with respect to node speed. FLS-CL deployment has enhanced the PDR of both FTP and CBR when increasing the node speed. This is a result of cross layer providing a degree of balance between the values of the TCP/IP stack parameters targeting keeping the PDR at high level. For FTP traffic, FLS-CL implementation has improved PDR of an average of 4.37 %. For CBR, FLS-CL optimization increased the PDR by 6.8 % on an average. The overall all performance of the network has enhanced after our proposed FLS-CL.

Fig. 13 shows cross layer optimization in End-to-End delay with respect to varying node speed. FLS-CL optimization decreased the end to end delay for both types of applications. For FTP traffic, end to end delay decreased after cross layer implementation by 91.89 % overall. While for CBR, cross layer implementation has decreased the overall end to end delay by 80.69 %.

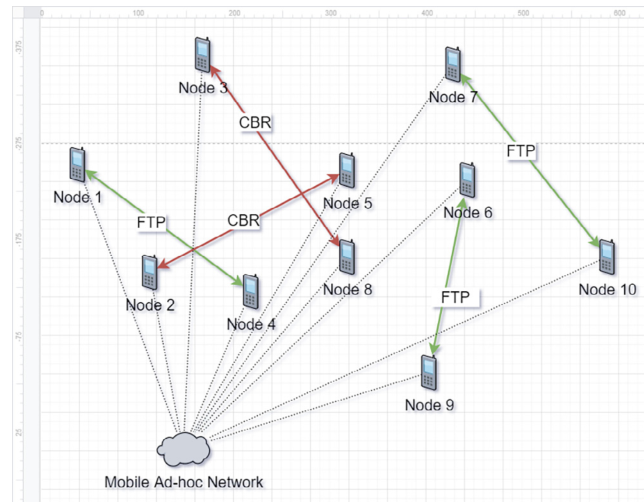

Fig. 7. Sample MANET simulation environment using QualNet®.

5.3. Scenario-3: MANET with varying AMC Data-rate

Simulation Results: The obtained results for PDR, and end to end delay were compared with the values obtained when inferring fuzzy sets and applying cross layer output. Table 10 provides the numerical results of the simulations. Cross layer implementation improves the PDR for both FTP and CBR. It can be remarkably observed that end to end delay decreased after cross layer optimization with respect to data rates. This enhancement includes reducing the delay for both FTP and CBR. The enhancements in PDR and delay values for both applications are summarized at the end of this discussion. Representation of the data provided in Table 10 is given in Figs. 14 and 15.

From Fig. 14 it is evident that, FLS-CL based cross layer optimization enhanced the PDR for both FTP and CBR when increasing the data rates. For FTP traffic, FLS-CL implementation improved the average PDR by 2.05 %. However, the improvement is more in-case of CBR traffic, FLS-CL implementation increased the PDR by 73.04 % overall.

Fig. 15 shows cross layer optimization effect on end to end delay with respect to the data rates. FLS-CL based Cross layer optimization decreased the end to end delay in both FTP as well as CBR traffic. For FTP traffic, average end to end delay decreased after cross layer implementation by 35.67 %. For CBR, cross layer implementation has decreased the average end to end delay by 34.59 %.

5.4. Scenario-4: MANET with varying number of re-transmissions

Simulation Results*:* The obtained results for PDR, and end to end delay were compared with their values without cross layer implementation. Table 11 provides the numerical results of the simulations. Cross layer implementation improves the PDR for both FTP and CBR. End to end delay was decreased after cross layer implementation.

Fig. 16 shows that PDR increases with increasing the number of retransmissions. Proposed FLS-CL based Cross layer implementation enhanced the PDR for both FTP and CBR when increasing the number of retransmissions. For FTP traffic, FLS-CL implementation improved the PDR by an average of 3.6 %. For CBR traffic, FLS-CL implementation increased the PDR by an average of 12.98 %.

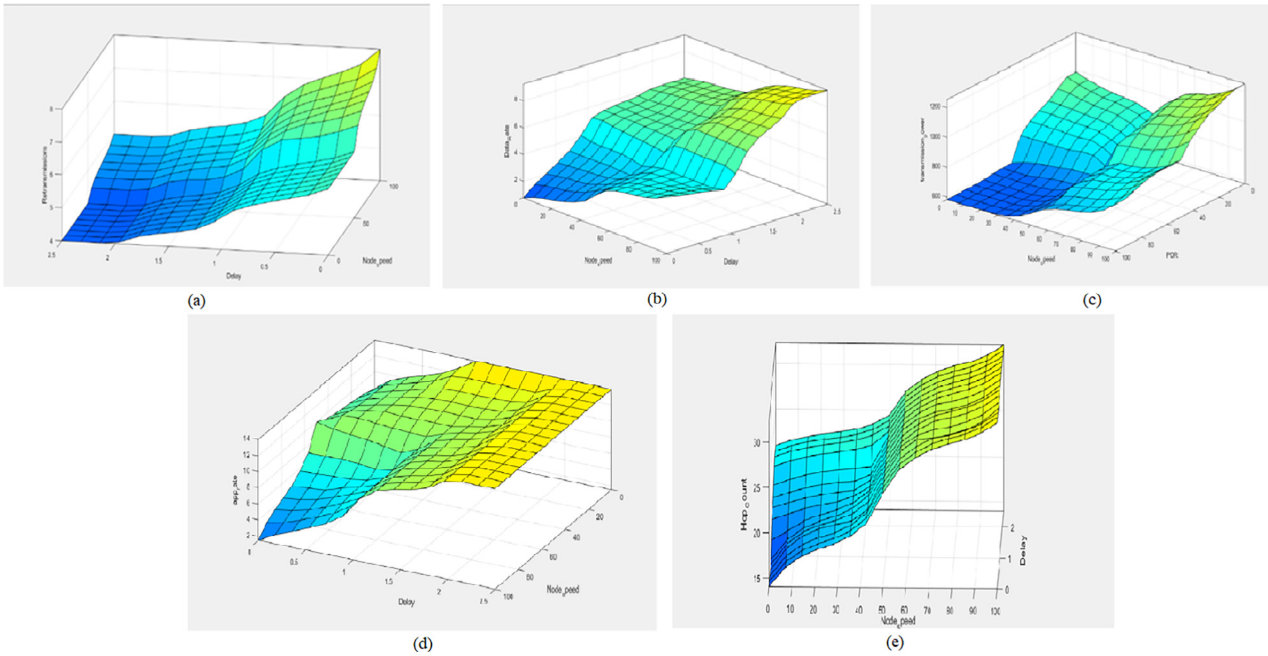

Fig. 8. 3-D plot of (a) No. of retransmissions (b) AMC (c) Transmission Power (d) Application rate (e) Hop count.

Table 7
Network simulation parameters.

Parameter	Configuration with Cross-Layer				Configuration without Cross-Layer			
	Scenario-1	Scenario-2	Scenario-3	Scenario-4	Scenario-1	Scenario-2	Scenario-3	Scenario-4
Routing protocol	AODV							
Network size	Variable	1500x1500 (m^2)			Variable	1500x1500 (m^2)		
Mobility	Random Way-point							
Node speeds	50 m/s	Variable (m/s)			50 m/s	Constant (m/s)		
Simulation time(s)	200	Variable			50			
Number of Nodes	Variable	50	Variable		Variable	50		
Number of Sources	30 % of the No. of nodes							
Applications	CBR and FTP							
Network protocol	IPv4							
MAC protocol	IEEE 802.11							
Physical Layer Standard	IEEE 802.11a	Variable depends on cross layer values			IEEE 802.11a	IEEE 802.11a 9 MHz	IEEE 802.11a with AMC	
channel frequency	5 GHz							
Path loss model	Two-ray ground							
Packet sizes (Bytes)	2048				512			
Number of packets	500				100			
Shadowing model	Constant							
Propagation shadowing mean	4.0 dBm							
Node placement	Random							
No. of Hop counts	Variable				35			
No. of Retransmissions	Variable				Constant −4			
Energy Model	Generic	Variable according to the FLS			Generic Constant			

Fig. 17 shows our proposed FLS-CL based cross layer optimization effect on end to end delay with respect to the number of retransmissions. End to end delay decreased with increasing the number of transmissions. Cross layer optimization decreased the end to end delay. For FTP traffic, the average end to end delay has decreased after FLS-CL cross layer implementation by 58.49 %. For CBR traffic, FLS-CL implementation has decreased the average end to end delay by 89.55 %.

5.5. Result Summary: QoS performance improvements with proposed FLS-CL design for MANET

Here we are summarizing our results for four scenarios for both connection-less User Datagram Protocol (UDP) based CBR traffic as well as connection-oriented Transmission Control Protocol (TCP) based FTP application traffic. The result shows that CBR is getting more QoS performance boost as compared to TCP. Table 12 shows the Result summary of cross layer optimization on Packet Delivery Ratio (PDR) and End-to-End (E2E) delay.

Table 8
Simulation Results. PDR, throughput, E2E-delay for different network size with/out Proposed FLS-CL.

PDR (Number of Packet Received/Sent)				
	CBR		*FTP*	
Number of Nodes	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
0	0.00	0.00	0.00	0.00
30	30.50	31.40	95.70	98.20
50	72.40	76.40	96.00	98.50
100	57.19	61.68	95.10	98.30
250	2.40	21.87	95.30	98.90
Average	32.50	38.27	76.42	78.78
Throughput (Kbps)				
	CBR		*FTP*	
Number of Nodes	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
30	156.86	260.39	2626.46	4619.33
50	292.86	1004.54	3647.48	4305.78
100	1285.47	1769.47	2105.84	2533.89
250	2146.77	2185.11	12296.55	20465.32
Average	970.49	1304.87	5169.08	7981.08
End-to-End Delay (ms)				
	CBR		*FTP*	
Number of Nodes	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
0	1.00	0.00	0.00	0.00
30	0.50	0.47	0.15	0.12
50	21.00	0.03	0.05	0.05
100	47.00	0.04	2.40	1.34
250	44.40	0.24	0.50	0.06
Average	22.78	0.16	0.62	0.31

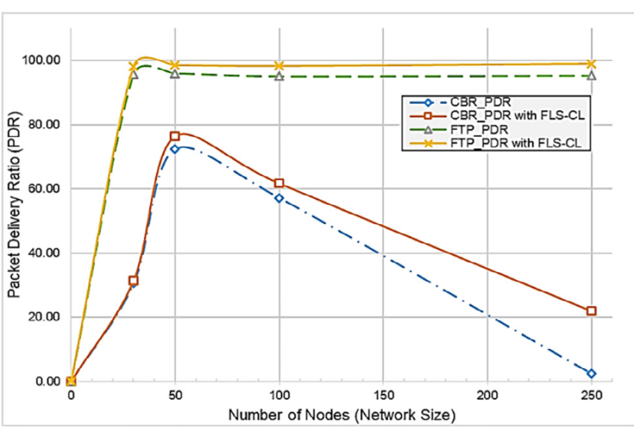

Fig. 9. Packet Delivery Ratio (PDR) for different Network Size.

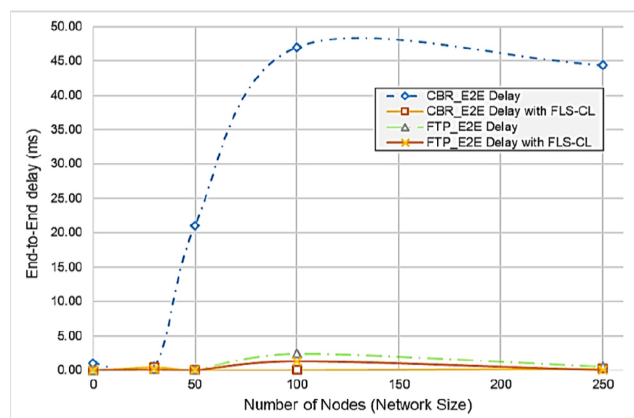

Fig. 11. End-to-End Delay for different Network Size.

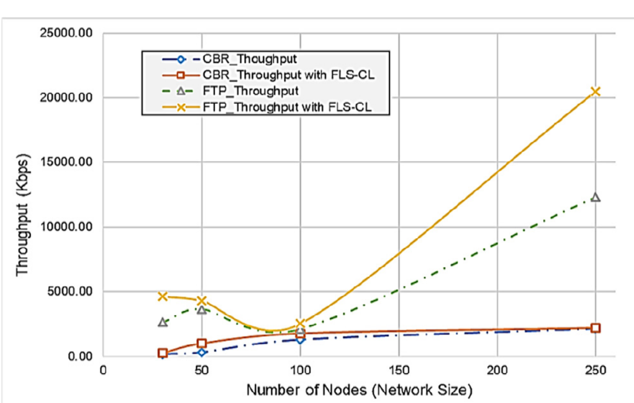

Fig. 10. Throughput for different Network Size.

6. Discussion

We summarized that, our results are quite promising after implementation of proposed FLS-CL based cross layer design for all the four scenario of network deployment. This proves the effectiveness of Fuzzy-Logic based soft-computing technique for optimization of overall network performance by enhancing the QoS parameters. The most important outcome of this research work is to validate the proposed FLS-CL design for four different scenarios by taking key- network configurations as variables and validating the impact of our proposed novel FLS-CL design.

In a nutshell, our proposed FLS-CL has performed better for connection-less User Datagram Protocol (UDP) based Constant bit rate (CBR) traffic than the connection-oriented counterpart i.e. Transmission Control Protocol (TCP) with the File Transfer Protocol (FTP) as the test application protocol. In case of CBR traffic over UDP results show an improvement of 27.64 % in PDR on an average for all four scenarios and reduced the average

Table 9
Simulation Results. PDR, E2E-delay for varying Node Speed with/out Proposed FLS-CL.

PDR (Number of Packet Received/Sent)				
	CBR		*FTP*	
Node Speed (m/s)	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
0	0.00	0.00	0.00	0.00
10	84.30	85.70	91.70	97.90
50	76.40	82.00	94.80	98.50
100	77.90	87.12	95.68	98.10
Average	59.65	63.71	70.55	73.63
End-to-End Delay (ms)				
	CBR		*FTP*	
Node Speed (m/s)	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
0	0.00	0.00	0.00	0.00
10	0.50	0.29	3.03	0.52
50	0.60	0.03	2.50	0.05
100	0.63	0.01	1.80	0.03
Average	0.43	0.08	1.83	0.15

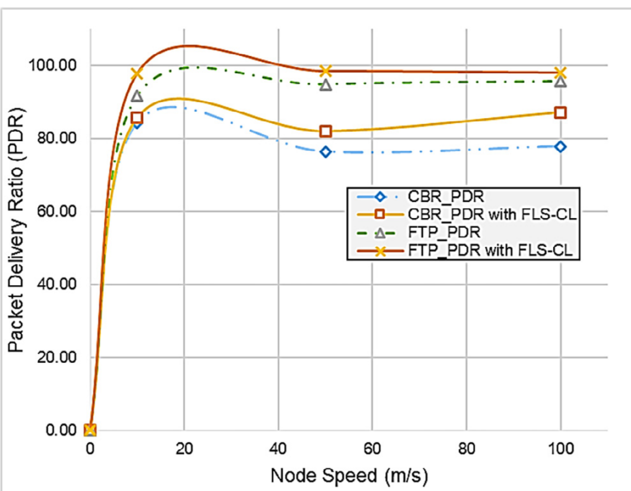

Fig. 12. Packet Delivery Ratio (PDR) for different Node Speed.

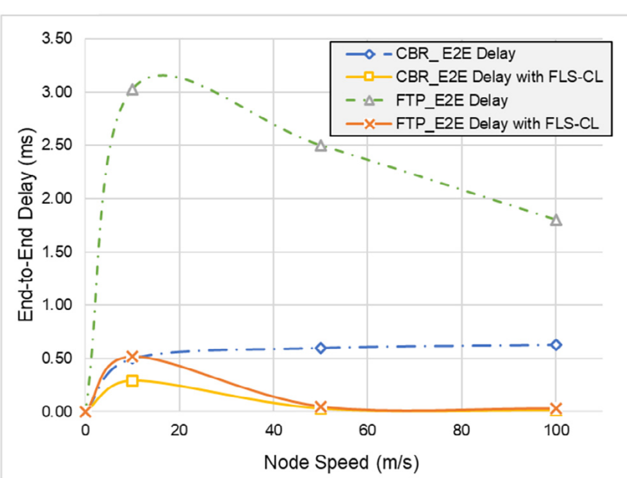

Fig. 13. End-to-End (E2E) Delay for different Node Speed.

E2E delay by 76.04 % considering all four scenarios. However, in case of FTP over TCP there is an average improvement of PDR by 3.28 % and a reduction of average E2E delay of 58.81 % considering all four scenarios.

Table 10
Simulation Results. PDR, end to end delay for Varying AMC Data Rate with/out Proposed FLS-CL.

PDR (Number of Packet Received/Sent)				
	CBR		*FTP*	
AMC Data-rate	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
0	0	0	0	0
9	13.05	84.28	96.6	98.8
12	31.4	92.65	95.9	98.2
18	76.4	89.85	96.23	98.5
24	82.85	85.7	96.75	97.9
Average	40.74	70.50	77.10	78.68
End-to-End Delay (ms)				
	CBR		*FTP*	
AMC Data-rate	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
0	0	0	0	0
9	0.42	0.4	1.94	1.123
12	0.67	0.47	1.74	1.03
18	0.24	0.05	1.5	1.03
24	0.52	0.29	1.4	1.05
Average	0.37	0.24	1.32	0.85

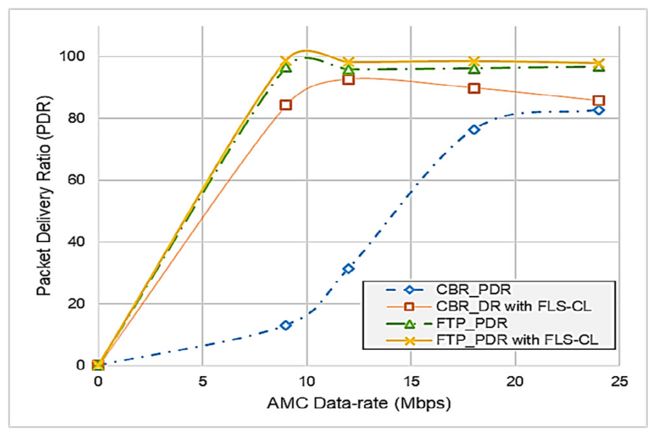

Fig. 14. Packet Delivery Ratio (PDR) for varying AMC Data rate.

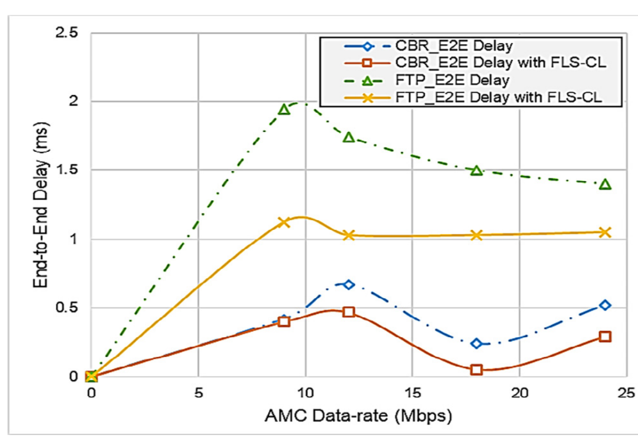

Fig. 15. End-to-End (E2E) Delay for varying AMC Data rate.

We can conclude our FLS-CL design would be very much effective and adequate to deploy over a MANET to improve the QoS parameters like overall Packet Delivery Ration (PDR) and End-to-

Table 11
Simulation Results. PDR, end to end delay for varying number of re-transmissions with/out Proposed FLS-CL.

PDR (Number of Packet Received/Sent)				
	CBR		*FTP*	
No. of Retransmissions	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
0	0.00	0.00	0.00	0.00
4	56.50	85.70	94.00	97.90
5	69.18	74.50	94.30	97.20
6	75.10	77.96	94.45	98.50
11	90.75	91.20	96.00	98.80
Average	58.31	65.87	75.75	78.48
End-to-End Delay (ms)				
	CBR		*FTP*	
No. of Retransmissions	Without FLS-CL	With proposed FLS-CL	Without FLS-CL	With proposed FLS-CL
0	0.00	0.00	0.00	0.00
4	1.50	0.29	6.69	2.52
5	0.95	0.06	3.05	1.29
6	0.80	0.03	2.70	1.05
11	0.49	0.01	1.70	1.01
Average	0.75	0.08	2.83	1.17

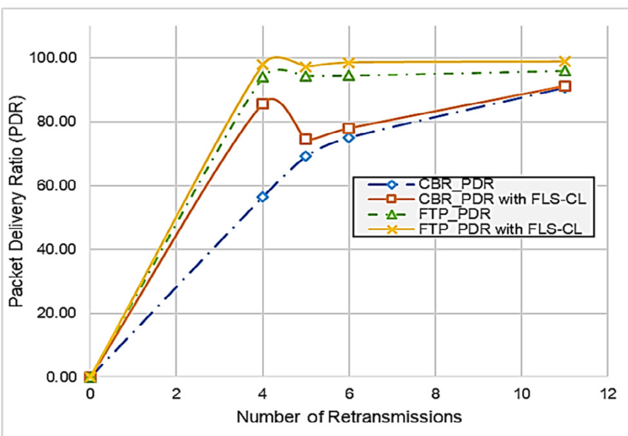

Fig. 16. Packet Delivery Ratio (PDR) for varying number of re-transmissions.

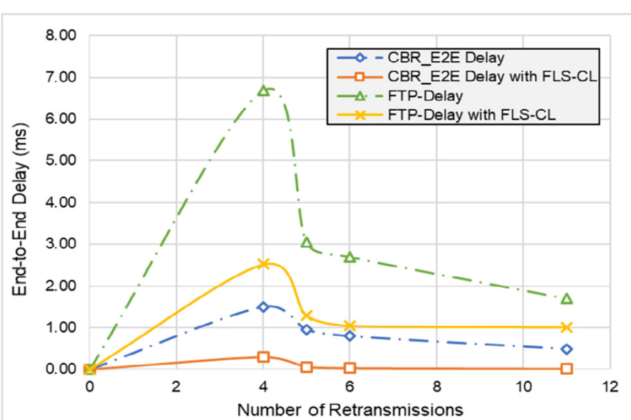

Fig. 17. End-to-End (E2E) Delay for varying number of re-transmissions.

End (E2E) delay in all the possible deployment scenarios. This comes from flexibility that FLS-CL provides to cope the mobility and the increase in network size. It performs that through utilizing the optimal values of the selected parameters.

This comes from flexibility by following:

Table 12
QoS Performance Improvements Result summary of Proposed FLS-CL design for MANET.

Scenarios	After implementation of proposed FLS-CL design in MANET			
	Percentage increase in PDR (CBR)	Percentage increase in PDR (FTP)	Percentage decrease in E2E delay (CBR)	Percentage decrease in E2E delay (FTP)
No. of Nodes (Network size)	17.76 %	3.09 %	99.32 %	49.27 %
Node speed	6.80 %	4.37 %	80.69 %	91.81 %
AMC Data-rate	73.04 %	2.05 %	34.59 %	35.67 %
Retransmission time	12.98 %	3.60 %	89.55 %	58.49 %
Average	27.64 %	3.28 %	76.04 %	58.81 %

1) Adjusting the ratio of the application from application layer
2) Improving network performance by reducing the end to end delay in the network
3) Managing energy consumption in the communication process between the nodes
4) Controlling the number of hops in the network between source destination pairs
5) Adjusting the data rates in the first layer
6) Controlling the number of retransmissions in the MAC layer.

Most importantly the result obtained here would be helpful in design and deployment of real-world MANETs with cross-layer design approach to enhanced QoS performance keeping in mind the strict QoS parametric requirements of any IoT applications which has Ad-hoc network requirements specifically designed for creating Mobile Ad-hoc communication framework support for Next-generation Cyber Physical System [47].

7. Conclusion

Cross-layer is the transparent layer that use the parameters across more than one layer (or several/multiple layers as per scenario specific network requirements) of the TCP/IP stack. Fuzzy logic approach is a part of soft computing that interacts with the imprecision and approximate reasoning. FLS adjusts the parameters of TCP/IP due to adaptive nature of MANET. The results demonstrate the effectiveness of the proposed FLS-CL design in improving the network performance compared with the constant parameters (deterministic model) of the network configurations. Most importantly the result obtained here will be helpful in design and deployment of real-world MANETs with cross-layer design approach specifically designed for creating Mobile Ad-hoc communication framework support for Next-generation Cyber Physical System. This work can be extended by considering more complex and dynamic network configurations as well as parameters and even multi-objective functions based constrained optimization problem can be formulated and scope of various promising optimization techniques like Nature Inspired algorithms / evolutionary algorithms-based techniques can be explored for Cross-layer design for MANET in the context of providing mobile ad-hoc communication framework for future IoT-applications and Next-generation Cyber Physical Systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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