Fuzzy Logic Based On-demand Routing Protocol for Multi-hop Cellular Networks (5G)

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Summary
The Multi-hop Cellular Network (MCN) was proposed to benefit from the advantage of the single hop cellular architecture and the Ad Hoc architecture. Since, the routing is the core of communication in this new architecture, then, it is important to improve the routing protocols in order to improve the performance of the MCN. In this context, we propose a fuzzy logic routing protocol for MCN. This protocol selects an optimal route among the discovered routes based on three parameters: the residual energy of nodes, the SINR and the gain time. Thus, the network's performance is optimized. To achieve such goal, we use a fuzzy logic system to combines the three routing metrics and to keep the synergy between them. The simulation results show that our proposed routing protocol outperforms the Ad Hoc on-demand distance vector protocol (AODV) in terms of average end-to-end delay, Normalized Routing Load (NRL) and throughput.
Key words:
MCN, single hop cellular, Ad Hoc networks, routing, fuzzy logic, AODV, NRL.

1. Introduction

The single-hop cellular networks fail to provide homogeneous and high QoS levels. Thus, the Cellular Multi-hop Networks (MCNs) which is the five generation (5G) is integrated and it gains significant research attention [1,2]. Unlike the Single-hop Cellular Networks, the communication in the MCNs between a source and its target destination is performed through the intermediate relays [3]. An intermediate relay can be a mobile station or a preinstalled Base Station (BS) [4, 5]. However, increasing the number of Base Stations (BSs) is costly in comparison with using mobile stations as relays. For that reason, the integration of mobile stations to retransmit the data from the source to the destination gains significant research attention to achieve the MCNs objectives. Exploiting the mobile stations communications capabilities in a distributed and decentralized manner increases the future perspectives of MCNs. To achieve such potential, it is necessary to overcome some challenge such as the design of optimal routing protocols. In MCNs, the source and its target destination can be in the same cell and so the communication between them uses the Ad Hoc technology. In this case, the routing protocols proposed for Ad Hoc networks can be applied. Many routing protocols were proposed in the literature for Ad Hoc networks such as in [6, 7, 8, 9]. These protocols use one or many metrics in selecting the route to improve network performance such as selecting the route with lowest cost, lowest hop count or lowest node activity. The drawback of these protocols is that the best route selected could be congested later and some of nodes along this path could die. In our research work, we address these problems by proposing an energy and load aware routing protocol for multi-hop cellular networks. To combine these parameters we are based on fuzzy logic controller [10]. Many protocols are proposed in the literature that also based on fuzzy logic technique such as in [11, 12, 13]. However, these protocols are proposed for Ad Hoc wireless networks. Thus, they are not efficient to apply them to establish the communication in a cellular multi-hop network.

This paper is organized as follows: in section I, the introduction highlighted an overview about this work. In section II, we review some related works and their limits. In section III, we describe our proposed routing protocol for MCN in detail. In this section, we introduce the inputs of the protocol, as well as the proposed fuzzy system and the route discovery process. An extensive simulation is detailed in section four based on Network Simulator (NS-2) to evaluate the performance of the proposed protocol. At the last section, we conclude our work and present some future works.

2. Related works

In this section, we describe the research works contributed on optimizing the routing protocols in the multi-hop wireless networks. Indeed, A. Singhal et al. [14] proposed a routing protocol that measures the link and the node stability based on link expiration time and residual energy metrics. These metrics are used to compute the stability level of the discovered route using fuzzy logic technique. In this protocol, the researchers measured the link expiration time based on the signal strengths of the received packets. However, the energy consumption of each node is computed every T second based on the number of received and transmitted packets by this node. As an output of the fuzzy rules, the status of each node of

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the discovered route is considered on the basis of the memberships on the inputs functions. However, this protocol did not consider the load of the nodes. Thus, the battery power will be depleted very early. A. Ghaffari et al. [15] proposed a real time routing protocol based on fuzzy logic technique. To design a fuzzy controller, the researchers determined the available relationships in the system based on smart agencies. The fuzzy rules are applied to estimate the stability of the discovered routes. L. You et al. [16] proposed a heuristic routing protocol for multi-hop wireless networks. The heuristic function used for routing decision is based on the number of hops of each discovered route. However, this metric can result in low quality links of the selected route. Thus, it is important to define a suitable link metric in order to control the link in a discovered route. J. M. Chacko et al. [17] considered this metric by selected a multiple routes based on the Signal to Interference and Noise Ratio (SINR). They proposed a protocol which selects multiple routes with many strong links and less interference links.

B. Coll-Perales et al. [18] proposed a location-based routing protocol for MCN. In this proposed protocol, the researchers tried to reduce the energy consumption and the signaling implementation cost. This is achieved by exploiting the location information of the relay devices.

S. Othmen et al. [19] proposed an optimal routing protocol for Ad Hoc networks that takes into consideration the QoS, the energy and the load of the mobile nodes. In this protocol, the source node performs a discovery process of multi-path to find all possible routes to reach the destination. After that, the selection of the best routes is performed based on a new proposed cost function. In [20], S. Tabatabaei et al. proposed a fuzzy logic based on demand routing protocol. This protocol is based on fuzzy technique to select the optimal path using the speed and the battery life of the mobile nodes.

3. Proposed routing protocol

In conjunction with the maturity of the routing protocol design, the growing interest in using the mobile devices like mobiles phones, laptops and tablets had driven to set up an efficient quality of services (QoS). Actually, the QoS is addressed by optimizing one or several routing metrics. In this paper, we use two parameters to ameliorate the QoS: the estimated Signal to Interference and Noise Ratio (SINR) and the Gain Time (GT). Besides to the QoS, a third routing metric is considered which is the stability of the path. This is achieved by taking into account the Residual Energy (RE) of the intermediate nodes. This fact leads to reduce the energy consumption and extend the lifetime of the nodes and so increase the lifetime of the entire network. The route metrics (RM) can be described as three-tuples:

RM(SINR, GT, RE)

3.1. Routing metrics

A route break can occur due to many reasons such as battery depletion. This fact causes the degradation of the network performance. For that reason, in the proposed protocol during route selection process, we avoid the selection of the nodes with low energy. Thus, when an intermediate node receives a route packet, it computes its residual energy as the proposed equation (1). In this equation, we consider the energy expended in emptying the queue to obtain the real lifetime of the discovered path.

$$\mathrm{RE} = \mathrm{E}_{\mathrm{current}} - \mathrm{E}_{\mathrm{emptying-queue}} \quad (1)$$

Where:

- $E_{current}$ is the current energy of the node,
- $\mathrm{E}_{\mathrm{emptying-queue}} = \mathrm{Buffer}_{\mathrm{size}} * \mathrm{trans(p)}_{\mathrm{energy}}$ (2)
- $\mathrm{Trans(p)}_{energy}$ is the energy needed to transmit one packet p.

Moreover, the proposed protocol takes into account the link quality of the selected routes. Therefore, we measure the signal strength of the route from the source to the destination based on the signal-to-interference-plus-noise ratio (SINR) of each link in the route. Let S(r) is the strength of a route r, from a source s to a target destination d, defined as follows:

$$\mathrm{S(r)} = \sum_{(i,j)\in r} \mathrm{SINR(i,j)} \quad (3)$$

Where, SINR(i,j) is the SINR of the link between a node i and the next node j.

The strongest route is the route that maximizes the S(r) value. For the calculation of SINR, we adopt the same approach proposed in [19] for multi-hop cellular network (device to device architecture):

$$\mathrm{SINR}_{i,j} = \frac{\frac{P_{Tx}}{PL_{i,j}} G_{i,j}}{\sum_{k\neq i} \frac{P_{Tx}}{PL_{i,j}} G_{kj} + BW * N_0} \quad (4)$$

Where, k is the interfering link, BW is the bandwidth, N0 represents the thermal noise, PL represents the path loss between the destination and the base station, P_{Tx} is the transmitted power and G represents the beam forming gain. For each discovered route, we compute its GT based on the deadline D_{max} of the packet. This deadline must be met to evaluate whether this route is optimal or not. This means that the packet must reach the destination before the expiration of D_{max}. If a node is congested, the wait time will increase and so D_{max} can expire, which cause the drop of this packet. Therefore, to minimize the congestion, the GT must be counted in during the selection of a route. We propose to compute the GT of the route by computing the GT_k of each node k in this route. In some case, a route contains several nodes which are congested but the other not. Thus, we can benefit from the time gained from the no congested nodes in data transmission. For that reason, we compute the GT of each selected route and select the route with high value.

Assume that a route r is composed by hop_count nodes, the estimated local deadline dr,n of a packet in each intermediate node n in the route r is:

$$d_{r,n} = \frac{D_{max}}{hop\_count_r} \quad (5)$$

Some intermediate nodes which are not loaded can transmit the packets before the expiration of the estimated local deadline $d_{r,k}$. The residual time before the expiration of $d_{r,k}$ is called GT_k of node k. We can benefit from this GT by adding it to the local deadline of the next node (k+1). The GT of a node k is calculated as follows:

$$GT_k = d_{r,n} - (D_{K,p} - A_{k,p}) \quad (6)$$

Thus, the local deadline of the next node is as following:

$$GT_{k+1} = d_{r,n} + GT_k \quad (7)$$

Where, $D_{k,p}$ is the departure time of the packet p from node k and $A_{k,p}$ is the arrival time of the packet p at the current node k.

($D_{k,p}$ - $A_{k,p}$) includes the waiting time *w* of the packet p at node k and the time needed to handle this packet. *w* includes the time spent by the node k in serving the set of packets that has higher priority than the current packet. It is computed as follows:

$$w_{k,i}^{h_{k,n}} = \sum_{p=1}^{h_{k,p}} D_{tr,p} \quad (8)$$

Where, Dtr,p is the transmission delay of the packet p and hk,p is the set of packet in the buffer of node k. The transmission delay represents the necessary time to transmit a packet p from its first bit to its last bit over the communication link:

$$D_{tr,p} = T_{tr} * ETX \quad (9)$$

Where, T_{tr} is the transmission time that computed by dividing the packet size by the estimated bandwidth of each link. ETX is the expected transmission count which represents the expected number of transmissions needed by a node to transmit successfully a packet to its neighbours.

After computing the GT_k in each intermediate node, the total GT of a route r is computed as follows:

$$GT_r = \sum_{k=1}^{k=hop-count} GT_k \quad (10)$$

3.2. Proposed fuzzy system

The proposed protocol is based on fuzzy logic system to determine the most stable and optimal route among the discovered routes. The structural design of the proposed system is shown in figure (1). The first step in building this system is to determine the inputs (GT, SINR, RE) that affect the route status.

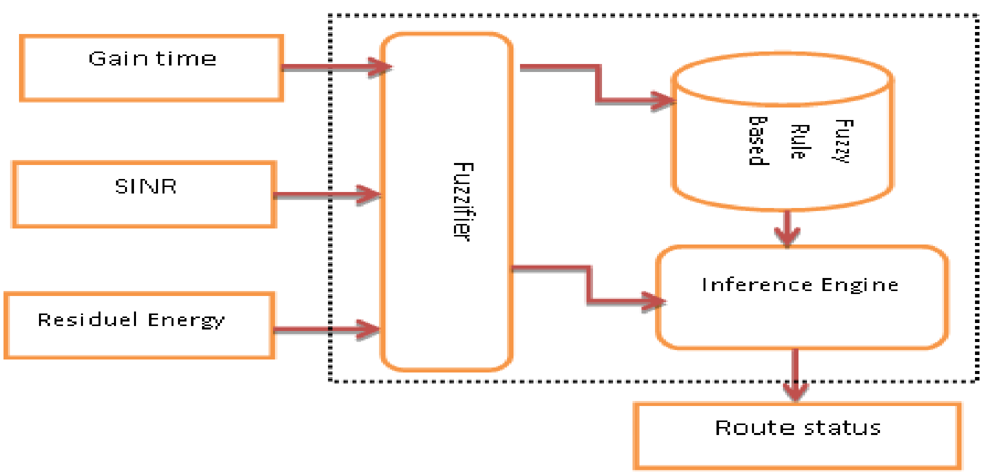

Fig. 1 Fuzzy system architecture

The second step is inputs/output fuzzification i.e. turns the crisp values to fuzzy one. Crisp values are mapped to membership values by using exquisite Membership Functions (MF).

Depending on their shapes, membership functions can be represented in different forms; in our proposed system, Trapezoidal and Triangular forms are used to build the MFs in fuzzification step. The trapezoidal MFs is used for fuzzification of the GT input given by the following formula:

$$f(x, a, b, c, d) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right) \quad (11)$$

The triangular MFs used for fuzzification of SINR and RE and the output (route status) is given by the following formula:

$$f(x,a,b,c) = \max\left(\min\left(\frac{x-a}{b-a},\frac{c-x}{c-b}\right),0\right) \quad (12)$$

Where, a, b, c and d are the premise parameters that characterize the shapes of the inputs and output MFs, x is crisp value of input/output variable.

Figure 2 shown the system inputs and output MFs:

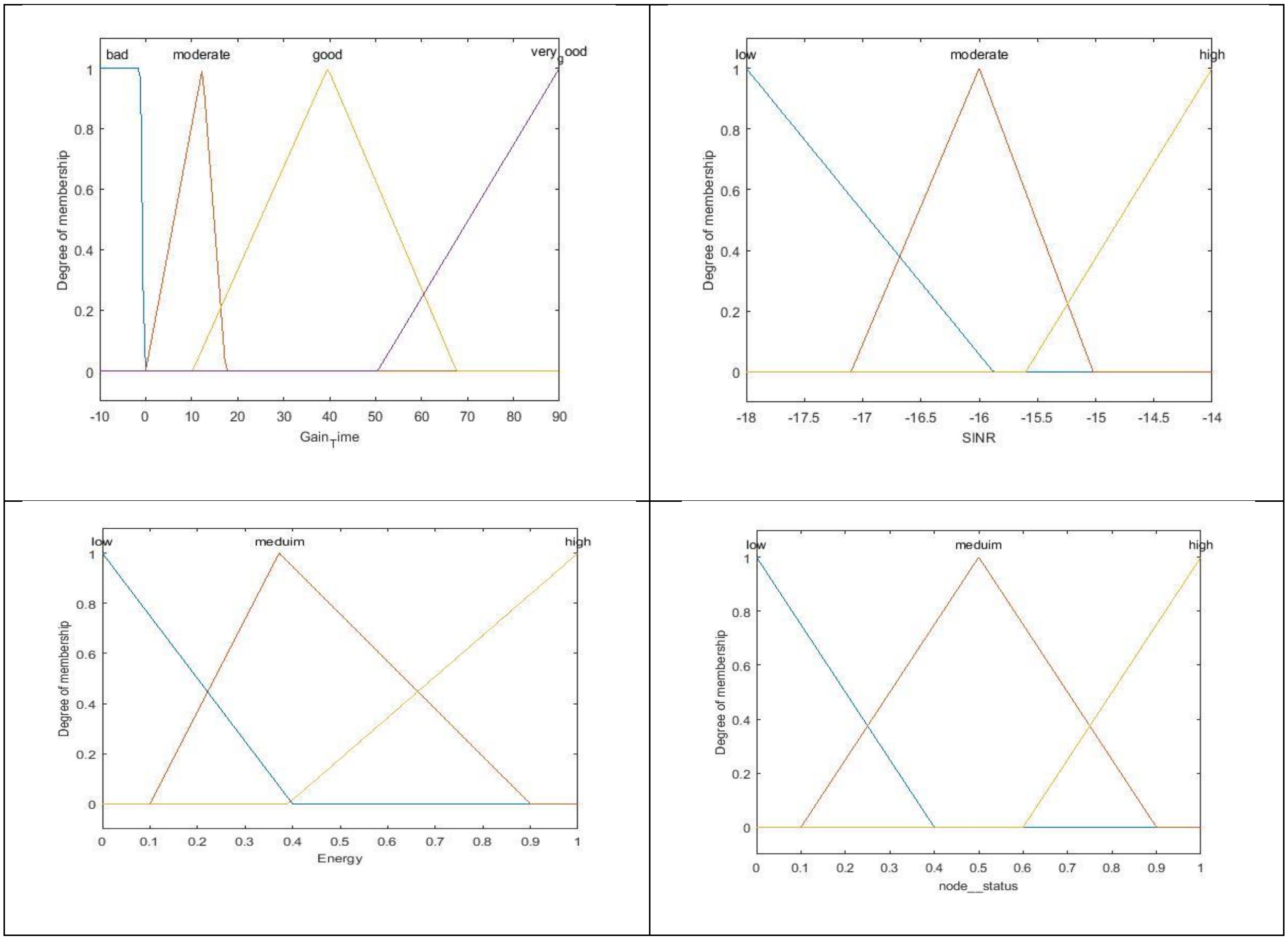

Fig. 2 System inputs/ output membership functions

The third step in our proposed system is the rules construction. Fuzzy rules can take the following form:

IF a1 is A_1 and a_2 is A_2 and .and an is An **THEN** b1 is B_1 and b_2 is B_2 and .... and b_m is B_m.

Where, ai and bj are input/output variables, A_i and B_j are linguistic variables.

These rules are created using two conditions: "IF" and ‘"THEN" consequent action mechanism, which established for development of a Fuzzy Logic System to identify the priority index. The number of fuzzy rules base will be equal to 33 = 27 rules since we have three variables and the output which is the route status will be divided into four classes (bad, medium, good, very good).

Also in the third step, we compute the weighting factor for each rule. The weighting factor has the expression ωk and it is determined by evaluating the linguistic expressions membership in the antecedent of the rule. This is accomplished by converting the input values to fuzzy membership values using the input MFs in the step1 and then applying the “and” operator that gives minimum value from these membership. The “and” operator corresponds to the multiplication of input membership values. Hence, the weighting factors of the rules can be computed as follows:

ω1= M11(W) M21(L) M31(h) M41(ε_r)
ω2= M11(W) M21(L) M31(h) M42(ε_r)
ω3= M11(W) M21(L) M31(h) M43(ε_r)
ω4 = M11(W) M21(L) M31 (h)M44(ε_r)

The implication of each output MF is computed by:

$$M_{imp,k} = w_k z_k \quad , k = 1, \ldots, n \qquad (13)$$

Where, ωi represent the variable weight, M_{ij}, z_k and M_{ok} represent the j^{th} MF of the i^{th} input, the output of the k^{th} rule, and the k^{th} output MF, respectively.
Some possible combinations of different membership functions of the proposed protocol are listed below:

Rule 1: If (Gain_Time is Meduim) and (SINR is low) and (Energy is low) then (Route_status is Bad)

Rule 2: If (Gain_Time is Meduim) and (SINR is Meduim) and (Energy is low) then (Route_status is Bad)

Rule 3: If (Gain_Time is Meduim) and (SINR is high) and (Energy is low) then (Route_status is Bad)

Rule 4: If (Gain_Time is Meduim) and (SINR is high) and (Energy is meduim) then (Route_status is Meduim)

Rule 5: If (Gain_Time is good) and (SINR is low) and (Energy is high) then (Route_status is Meduim)

Rule 6: If (Gain_Time is very_good) and (SINR is high) and (Energy is meduim) then (Route_status is Good)

Fig. 3 Some proposed rules

The model's surface is illustrated in figure 4.

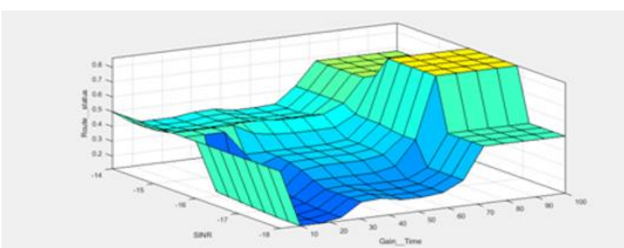

Fig 4. Fuzzy model surface

In step 4, the aggregation is established to produce an overall output MF, represented by Mo(z). This can be done by using the union operator:

$$M_o(z) = \bigcup_{k=1}^{n} M_{imp,k} = \bigcup_{k=1}^{n} w_k Z_k \qquad (14)$$

Where, $M_o(z)$ represents the overall output MF, $M_{imp,k}$ represents the overall inputs MF, w_k represents the variable weight and Z_k is the output.

The two types of the output MFs (M_{ok}) are trapezoidal and triangular. Hence, the "*union*" operation is performed by using the "and" operator.
In step 5, the defuzzification is performed by the most widely used defuzzification method which is centroid of area:

$$z = \frac{\sum_j^q z_j u_c\,(z_j\,)}{\sum_j^q u_c\,(z_j\,)} \qquad (15)$$

Where, q is the number of variables, z is the center of mass and u_c is the membership in class c at value zj.

3.3 Route discovery

The proposed protocol is on-demand routing protocol. It is divided into two principle phases: the route request and the route reply phases.

3.3.1 Route request phase

When a source node wants to communicate with a target destination for which no information is maintained in its routing table, it initiates the route
discovery process. Thus, it broadcasts a request packet called RREQ to its neighboring nodes.
When an intermediate node receives a RREQ packet, it checks the sequence number (*seq-Nb)*. If it has received already a packet with the same *seq-Nb*, the new packet is discarded. Otherwise, the node computes its *RE* using function (1).
If its energy is lower than a threshold *S*, it discards the packet. Otherwise, it broadcasts this packet until it reaches the destination. By this way, the nodes with low energy cannot participate in data transmission and so their lifetimes increase.

3.3.2 Route reply phase

When the destination receives the RREQs packet, it generates for each one a RREP packet. The format of RREP is as follows:

RREP :{ ID_S, ID_D, *Seq-Nb*, *HC*, *GT*, *SINR*, *RE*}.

Where, ID_S represents Source Address, ID_D represents Destination Address, *Seq-Nb* is the Sequence Number, *GT* is the Gain Time, *SINR* is the Signal Inference and Noise Ratio, *RE* is the Residual Energy.
When an intermediate node receives a RREP packet, it performs the following tasks:

- It computes its *RE* as function (1) and compares this value with *RE* field. Then, it initiates the *RE* field with the smallest value among these two compared values.

- It computes the estimated *SINR* of its link as function (4) and adds this value to *SINR* field to obtain the signal strength of the discovered route,
- It computes its *GT* as function (6) and adds this value to *GT* field using function (10),
- It sends the RREP packet to the corresponding next node,

When the source receives a RREP packet, it waits the arrival of other packets for a predefined time. This increases the chance to find more number of optimal routes.

The selection of the optimal routes is performed by the source node based on the proposed fuzzy system. This is achieved by extracting the three inputs (*GT*, *SINR* and *RE*) from the RREP packet and then they are delivered to the fuzzy logic system. These values are as crisp values. Then, the system converts them into fuzzy values, this step is called fuzzification. After that, in the aggregation process, the inference engine computes the output based on the fuzzy values and the proposed rules base (see Figure 3). Last step in our system is the defuzzification. In this step, the system, convert the fuzzy output to crisp values which represent our output (route status). The output of the fuzzy logic system indicates the status of the discovered routes. Thus, the source should select the routes that have "very good" status, if there is no route with this status, it selects the next status.

4. Simulation results

In this section, extensive simulations are performed to compare our proposed protocol with the well known AODV protocol. A NS2 simulator is applied to simulate our proposal. The network is modeled by the simulator in 1000 meters * 1000 meters area with 30 nodes.

The parameters of the simulation are summarized as the following Table:

Table 1: Simulation Parameters

Parameters	Value
Routing protocols	AODV, proposed protocol
Simulation time	300 seconds
Simulation area	1000*1000
Traffic type	Constant Bit Rate (CBR)
Packet size	512 bytes
Queue length	250 packets
MAC protocol	MAC/802.11
Mobility model	Two Ray ground
Initial energy	100J
Reception energy	0.395 W
Transmission energy	0.660 W

The simulations scenario consists of varying the number of mobile nodes to show the effect of load on the network. The nodes exchange different type of packets during simulation time. So, increasing the number of mobile nodes lead to increase the congestion in the network. This fact influences the stability of links as well as the energy of the nodes in the network. We are based on three parameters to evaluate our proposed protocol: the average end-to-end delay, the Normalized Routing Load (NRL) and the throughput.

4.1 Average end-to-end delay

The end-to-end delay is computed based on the number of successful received packets. It is the delay from the origination of the packet by the source to its reception by the destination.

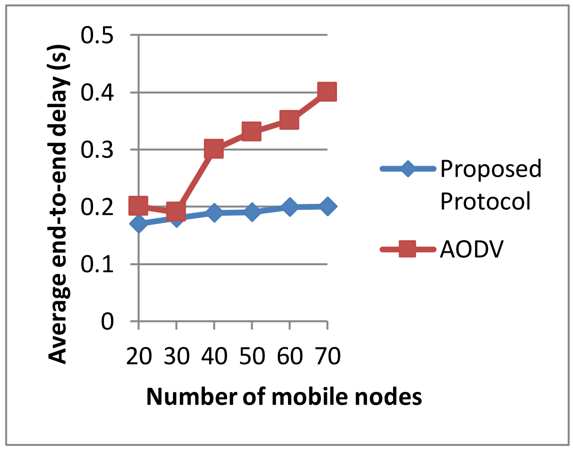

Fig. 5 Average end-to-end delay versus Number of Nodes

Although the AODV protocol selects the shortest route to forward data, our proposed protocol has less average delay. This ensures that the shortest route is not a sufficient metric to select an optimal path. Our proposal selects the route based on three routing metrics. Through these metrics, the fuzzy logic system can determine the status of the selected route. Indeed, it selects the route with more gain time and so reducing the buffering and handling times.

4.2 Normalized Routing Load (NRL)

Normalized Routing Load (NRL) is the number of routing control packets that is exchanged in the network. It is computed as the ratio of the received routing packet to the received data packets. As shown in figure 4, our proposed protocol has lower routing overhead than AODV. This is because our proposal selects the most stable and shortest path based on the proposed routing metrics, which leads to decrease the number of exchanged control packets.

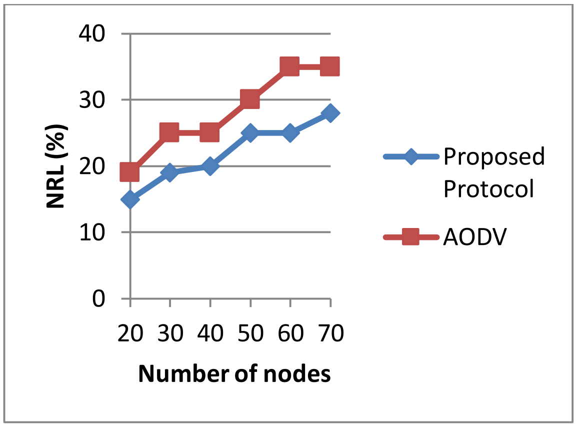

Fig. 6 Normalized Routing Load versus Number of Nodes

4.3 Throughput

Throughput represents the average of the data received by the destination among the data sent by the source. The throughput in our proposed protocol is more important than AODV protocol. This is because our proposal uses a fuzzy logic system that selects a route with stable links to transmit data. Thus, if the links are strong the nodes in the selected route are able to exchange data successfully. Moreover, the gain time of the selected nodes is considered and so the loaded nodes are avoided from participating in data transmission. This fact can also increase the throughput of our proposal. AODV protocol selects the shortest path which can be destroyed as the energy of nodes is not considered. However, in our protocol, the stability of path is considered by selecting only the nodes with high energy and low load (gain time). Therefore, the throughput is improved.

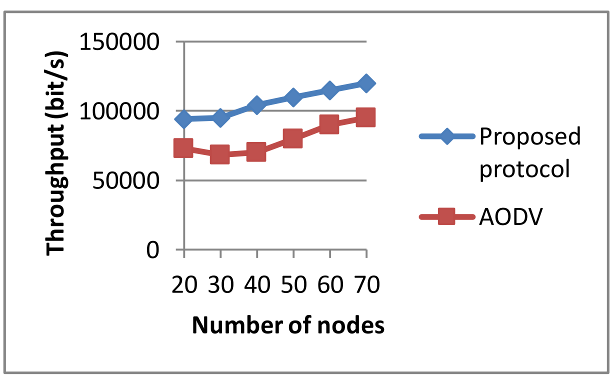

Fig. 7 Throughput versus Number of Nodes

5. Conclusion

In this paper, we proposed a fuzzy based routing protocol for 5 generation (MCN) with proper defined rules. Based on fuzzy logic system, our proposal selected the most stable routes by maximizing the links stability among the discovered routes. Three parameters are considered: the gain time, the residual energy and the SINR. Simulations results showed that the proposed protocol outperforms the AODV protocol in terms of average end-to-end delay, Normalized Routing Load and Throughput. This is because; we used a fuzzy logic system that determines the status of the discovered routes.
The participation of mobile devices in routing data makes the MCN architecture vulnerable against many types of attacks. Thus, as a future work, we plan to secure the communication inside the proposed routing protocol.

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