BEFLAB: Bandwidth Efficient Fuzzy Logic-Assisted Broadcast for VANET

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***Abstract*—Multi-hop broadcast communication is extensively used as the main communication scheme to enable safety and non-safety applications for Vehicular Ad hoc Networks (VANETs). In order to design a bandwidth efficient VANET broadcast protocol, we propose a fuzzy logic-assisted intelligent receiver-based scheme. A receiver vehicle uses a fuzzy logic system , which relies on mobility and coverage factors, to determine the rebroadcaster candidate vehicles, and then based on the distance-to-mean parameter of each vehicle in this candidate set, the receiver vehicle decides to rebroadcast or drop the message. Ns-3 simulations have been developed to investigate the effectiveness of our proposed system in terms of reachability, the average number of rebroadcasts per covered node, and bytes sent per covered node. The proposed protocol performance is compared to DTM, DADCQ, SLAB, FLB, and CSBD protocols. The proposed protocol is shown to have bandwidth efficiency advantage over all the other protocols while maintaining an acceptable reachability level.**

***Index Terms*—Wireless broadcast, fuzzy logic, VANET**

I. Introduction

Vehicular Ad hoc Network (VANET) is a major component of wireless communication technologies which has a great potential to improve Intelligent Transportation Systems (ITS). Since safety related message dissemination is one of the most important VANET applications, which has a significant role in accident avoidance and life saving, a reliable multi-hop broadcast protocol is required to support many safety applications such as accident detection warning, road condition warning, emergency vehicle at scene warning, etc [1]. Flooding is the simplest wireless broadcasting method, in which all nodes that receive the broadcast message thoughtlessly rebroadcast it. Obviously flooding leads to exponential growth of number of transmissions, broadcast storm, and wastes a significant amount of bandwidth [2]. Since in VANET, broadcast is mostly used as a means of safety related communication, solving the broadcast storm problem is an essential task.

Based on how the next forwarder node is selected, we classify VANET broadcast protocols into three main classes:

- Cluster-based
- Transmitter-based
- Receiver-based

In cluster-based network protocols, vehicles near each other form a cluster and a virtual network infrastructure is created in order to provide scalability. Each cluster can select a cluster head, which is responsible for intra-cluster and inter-cluster coordination in the network management functions. Vehicles inside a cluster communicate via direct links. Inter-cluster communication is performed via the cluster heads. In [3], a distributed proactive clustering scheme is proposed for VANET broadcast. The proposed system dynamically establishes a virtual backbone infrastructure, taking robustness and lifetime of connections among backbone members into account. In [4], a mathematical modeling and analysis for a cluster-based safety message broadcasting in highway environment is presented. Due to constant topology changes in VANET, cluster formation and cluster head selection lead to an inefficient performance in terms of message overhead.

In transmitter-based protocols, based on the exchanged hello messages information, each sender node selects the next relay node. In [5], [6], [7], and [8], the farthest neighbor from the sender node is considered the most suitable candidate for being the next forwarder node. Since all the nodes between the sender node and its farthest neighbor have already received the broadcast message, selecting the farthest neighbor as the next relay node can result in covering more area ahead or behind (depends on forward or backward messaging pattern). Obviously, geographical position information is used to evaluate this criterion. Due to the impact of wireless channel condition, the farthest node may not be considered the best relay node. Therefore, in [9] and [10], the transmitter node uses channel quality metrics (i.e. received signal strength) to evaluate the most suitable next relay node. In [11], a fuzzy logic-based system is applied to select backbone nodes which considers the vehicle velocity, the number of neighboring vehicles moving in the same direction and the antenna height. Transmitter-based broadcast methods suffer from latency and higher overall end-to-end delay.

The third type of broadcast methods is receiver-based in which each receiver node itself determines how to act, rebroadcast the received message or remain silent [12], [13], [14], [15], [16], [17]. Receiver-based broadcast protocols enjoy high packet delivery ratios. A detailed discussion about receiver-based broadcast protocols is provided in the next section.

Fuzzy logic technique, is one of the most satisfactory soft computing tools for solving problems in systems with rapidly changing characteristics and uncertainties. In VANET, fuzzy logic has improved the decision making process and has reduced delays in computation.

In this paper, using fuzzy logic techniques, we propose a receiver-based intelligent multi-hop broadcast protocol for VANET. When a vehicle receives a broadcast message, it uses fuzzy logic-based approach to determine the rebroadcasting or non-rebroadcasting status of itself and its potential forwarding neighbors. Then, after calculating the distance-to-mean parameter for each rebroadcasting candidate, it decides to rebroadcast or drop the message.

The remainder of the paper is organized as follows: Section II provides some related work on broadcasting in VANETs. Section III briefly reviews the structure of fuzzy logic system and its applications in VANET. Section IV presents our proposed broadcasting protocol. In Section V we discuss our results. Finally, in Section VI we conclude the paper.

II. Realated Work

Multi-hop broadcast is the most suitable communication mechanism to deliver safety-related messages in VANET. In this section we briefly review some related existing broadcast methods for VANET. As mentioned earlier, flooding is the simplest multi-hop broadcasting method in which all the nodes that receive the broadcast message will rebroadcast it to their neighbors. However, flooding can lead to the broadcast storm and waste a significant amount of bandwidth. High performing multi-hop broadcast protocols are needed in VANET.

Based on how the next forwarder node is selected, VANET broadcasting methods can be classified into three classes, namely: cluster-based, transmitter-based, and receiver-based broadcast methods. In this paper our focus is on receiver-based broadcast methods.

$Stochastic\ method$:In the stochastic method, when a vehicle receives a new broadcast message, it generates a uniform random number between 0 and 1 and compares it to a predefined threshold value. If this generated number is less than the threshold, the message is rebroadcast. Otherwise, the vehicle drops the message. Besides simplicity, this method reduces the number of rebroadcasting vehicles. External quantities such as traffic density can be use to define a threshold. If the threshold value is too small, there will be too few rebroadcaster vehicles [18].

$Counter-based\ method$: The heuristic underlying the counter method is that if a vehicle's number of transmitting neighbors is high, there will be no benefit by rebroadcasting the message. So, in the counter method, the idea is counting the number of times that the same message is received during a wait time in order to count the number of transmitting neighbors. Based on this observation, if this count is less than a given threshold, the vehicle will rebroadcast the message.

$Distance-based\ method$: Basically, all broadcast schemes attempt to cover as much as possible additional area to improve the performance. In distance method, vehicles can rebroadcast the message if they have not received the message from another vehicles nearby. In other words, more distance between receiver vehicle and transmitting neighbors, more benefit to rebroadcast the message.

$Location-based\ method$: This method, typically, is based on covered area calculation and estimation of the amount of area that would be covered by potential new transmissions. When a vehicle receives a new message, it applies an assessment delay method to observe the location of transmitting neighbors. It then calculates the intersection of those transmitting neighbors' covered areas with its own transmission area. Finally it estimates the potential new area which will be covered if the vehicle rebroadcasts. If this calculated area is greater than a given threshold, the vehicle rebroadcasts the message.

$Distance-to-mean-based\ method$: In [13] and [14], the distance-to-mean broadcast method is proposed and a straightforward broadcast protocol based on this method (DTM) is evaluated. Using positional information, this method calculates the spatial mean of the receiver's transmitting neighbors, and finds the vehicle's distance to that spatial mean. The vehicle will only rebroadcast if the obtained distance exceeds a decision threshold, which is a function of the number of neighbors. This method is shown to outperform the distance method and to have similar performance to the location method, even though it is much easier to calculate than the location method. In [19] a MAC and network cross-layer distance-to-mean-based statistical broadcast protocol with density-adaptive contention window (CSBD) is proposed. In CSBD, the density-dependent information obtained from the network layer is used to adjust the contention window size at the MAC layer.

In the context of receiver-based multi-hop broadcast for VANET, several techniques have been proposed based on statistical methods. The Distribution-Adaptive Distance with Channel Quality (DADCQ) protocol proposed in [15] is a distance-based statistical broadcast protocol that selects forwarding vehicles. The created decision threshold function is simultaneously adaptive to the vehicular traffic density, the spatial distribution pattern and the wireless channel quality. The Statistical Location Assisted Broadcast (SLAB) protocol is presented in [16]. SLAB uses the distance-to-mean method and further enhances DADCQ by utilizing machine learning techniques-based optimization algorithms to automatically create an efficient decision threshold function. In [17], using fuzzy logic techniques, a receiver-based intelligent broadcast protocol is proposed. The fuzzy logic system decides if the vehicle is required to rebroadcast or not. In this paper, we propose a bandwidth efficient intelligent broadcast protocol which aggressively reduces the number of rebroadcasting vehicles while maintaining an acceptable reachability level. The proposed protocol uses fuzzy logic to obtain a set of candidate forwarding vehicles, then based on the distance-to-mean value of each vehicle in this set, the receiver vehicle decides whether to rebroadcast or not.

III. Fuzzy Logic System

This section provides a brief background about the fuzzy logic system which has been utilized in our protocol. Fuzzy

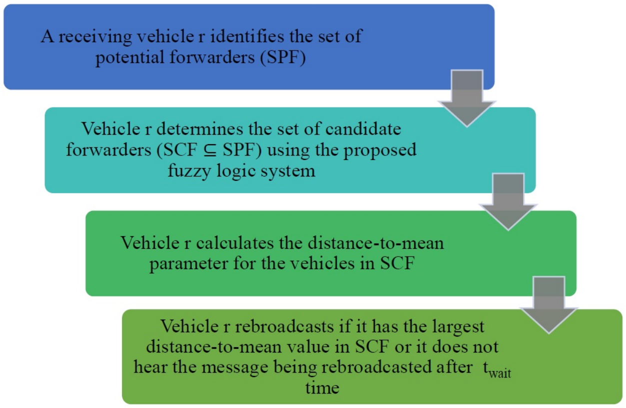

Fig. 1: BEFLAB System Modules

Algorithm 1 BEFLAB Broadcast Method

```
procedure REBROADCASTING DECISION
    if Vehicle r receives a message with a seq. number which was
      previously received then
        It drops the message
    else
        It uses a random assessment delay mechanism to find the
      transmitting neighbors
        It identifies SPF
        It calculates its MF and CF
        It uses fuzzy logic system to determine its rebroadcasting status
        if Vehicle r is not qualified to rebroadcast then
            It drops the message
        else
            It determines SCF and calculates distance-to-mean parameter
      for the vehicles in SCF
            if Vehicle r has the largest distance-to-mean value in SCF
  then
                It rebroadcasts
            else
                It waits for t_wait time
                if Vehicle r hears the message being forwarded during t_wait
  then
                    It drops the message
                else
                    It rebroadcasts
                end if
            end if
        end if
    end if
end procedure
```

Fig. 2: BEFLAB System Algorithm

logic, introduced by Lotfi zade in 1965, accepts a range of values and returns estimated results. Generally, each fuzzy logic system has three main components:

- Fuzzifier
- Inference engine
- Defuzzifier

The fuzzifier maps the crisp input into fuzzy set. Inference engine is implemented by the fuzzy logic rule-based processor to obtain the solution based on IF-THEN sets of rules.

Finally, The defuzzifier is used to transform the solution to the crisp output. Three defuzzification techniques are commonly used: Center of gravity method, Mean of Maximum method, and Height method.

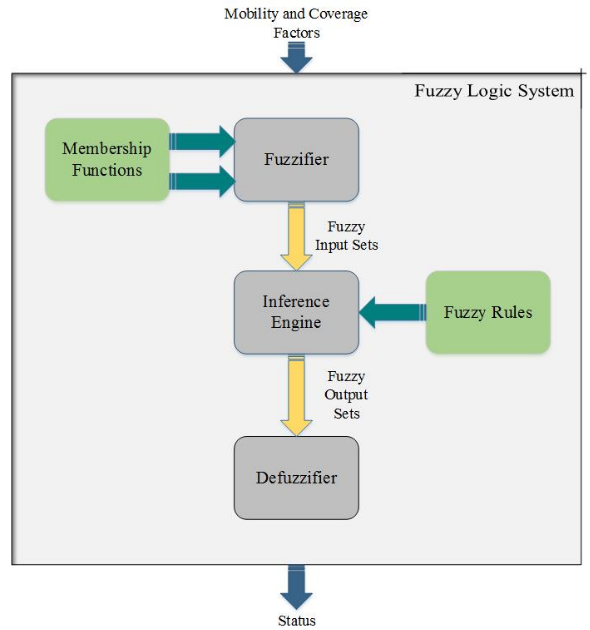

Fig. 3: Fuzzy Logic System Structure

In VANET, fuzzy logic has been used to improve the decision making process and reduce computation delays. Some of the areas that fuzzy logic has been applied to are:

- Routing algorithm
- Broadcasting
- Cluster head selection
- Localization

In [20], a novel stability and reliability routing protocol is presented. This routing mechanism uses fuzzy logic with geographical routing in making packet forwarding decisions. Direction and distance are considered as fuzzy system inputs to select the best neighboring vehicle. In [11], fuzzy logic technique is utilized to select the backbone node in a cross-layer broadcasting method. This method considers the vehicle velocity, the number of neighboring vehicles moving in the same direction, and the antenna height as fuzzy logic system inputs. Also in [17], a receiver-based intelligent broadcast protocol using fuzzy logic is proposed in which each receiver vehicle decides whether or not to rebroadcast a broadcast message. In the cluster head selection method presented in [21], cluster heads are selected according to their speed and distance from the cluster members. The fuzzy logic inference system predicts the future speed and position of cluster members to improve cluster head lifetime and more stable topology. In [22], a fuzzy logic-based localization for VANET is presented. In this method, fuzzy logic and weighted centroid localization (WCL) are combined. Two input parameters are fed to the fuzzy logic system, distance between the neigh- boring vehicles and heading information. Periodic messages (beacons) are used to exchange such information. The output of the fuzzy logic system is weight values. Using WCL, each neighboring vehicle will be assigned a weight value. The weighted coordinates of

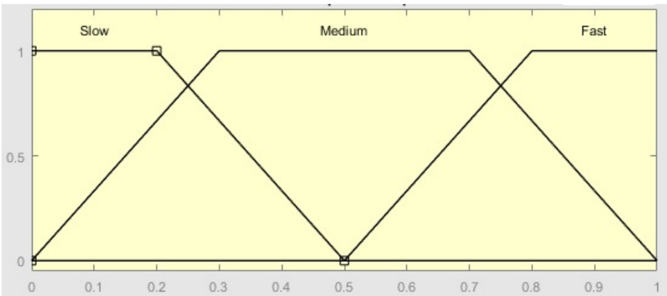

Fig. 4: Membership Function for Mobility Factor

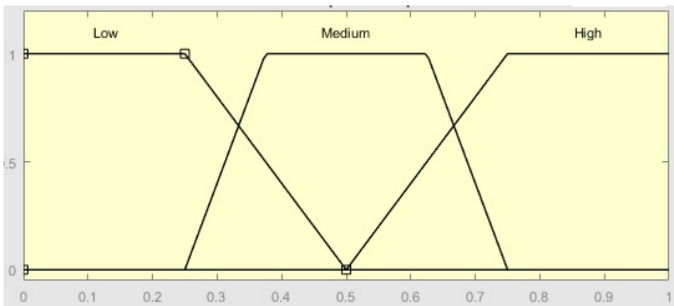

Fig. 5: Membership Function for coverage Factor

the neighboring vehicles are then used to estimate the location of the vehicle.

IV. Proposed Scheme

In this section we describe the proposed Bandwidth Efficient Fuzzy Logic-Assisted Broadcast (BEFLAB) scheme. A receiver vehicle identifies a set of potential forwarders and uses a fuzzy logic system, which relies on mobility and coverage factors, to determine a set of candidate forwarding vehicles, and then based on the distance-to-mean value of each vehicle in this set of candidate forwarders, the receiver vehicle decides to rebroadcast or drop the message. Fig. 1 shows the proposed broadcast system modules.

TABLE I: Fuzzy Rules

	Mobility	Coverage	Status
Rule 1	slow	low	non-rebroadcasting
Rule 2	slow	medium	rebroadcasting
Rule 3	slow	high	rebroadcasting
Rule 4	medium	low	non-rebroadcasting
Rule 5	medium	medium	rebroadcasting
Rule 6	medium	high	rebroadcasting
Rule 7	fast	low	non-rebroadcasting
Rule 8	fast	medium	non-rebroadcasting
Rule 9	fast	high	rebroadcasting

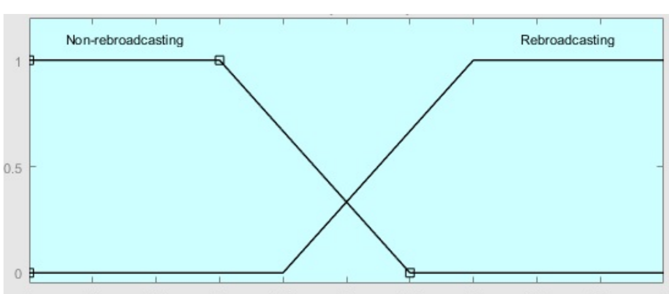

Fig. 6: Output Membership Function

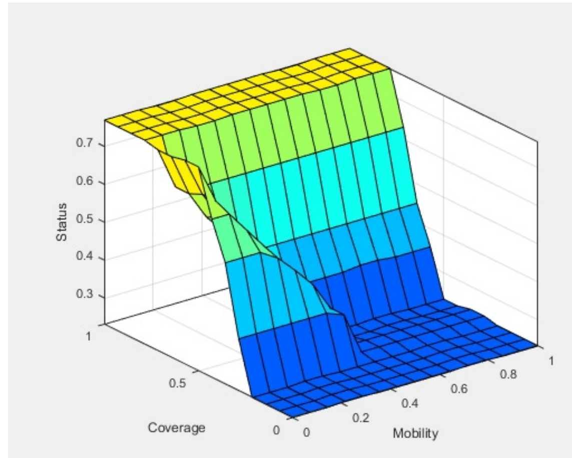

Fig. 7: Correlation Between the Input Factors and the Output

A. Assumptions

We assume all the vehicles are equipped with a Global Positioning System (GPS), so each vehicle is aware of its position and moving velocity information. Each vehicle is able to keep track of its neighboring vehicles using periodic hello messages. These broadcasted hello messages contain position, velocity and vehicle's ID information. Based on the received hello messages, vehicles construct and update their own neighbors information tables.

We assume that each vehicle before broadcasting a message, includes the IDs of its neighbors in the header. After receiving the message, the next rebroadcaster vehicle updates this header to include its neighbors' IDs before it transmits.

B. Proposed Broadcast Protocol

Here is a detailed explanation of the proposed algorithm shown in Fig. 2. When Vehicle r receives a warning broadcast message (with unique sequence number) for the first time, using a random assessment delay mechanism [2], it identifies the transmitting neighbors from which the message was received. Since the message transmitting vehicles include their neighbors' IDs in the header of the message, receiver vehicle r knows the set of the transmitters' neighbors. Vehicle r identifies the set of common neighbors between itself and the transmitters and treats it as a set of potential forwarders (SPF). Vehicle r utilizes the proposed fuzzy logic system (Fig. 3), which uses mobility and coverage factors as inputs, to determine whether it is qualified to rebroadcast. Vehicle r calculates its mobility factor (MF) and its coverage factor (CF) using Equations 1, 2, and 3.

$$MF = \frac{v_i - v_{min}}{v_{max} - v_{min}} \tag{1}$$

Where v_i denotes the velocity of vehicle i and v_{min} and v_{max} are the minimum and maximum velocity among common neighbors set and vehicle r, respectively. A lower mobility factor indicates a lower velocity and vehicles with lower velocity are more qualified to rebroadcast the message.

To obtain the coverage factor (CF), the distance-to-mean method proposed in [13] is used. The distance-to-mean in our method considers distance from the vehicle to spatial mean of the potential forwarder vehicles.The spatial mean of a set of n points (x_i,y_i) is calculated as:

$$(\bar{x}, \bar{y}) = (\frac{1}{n} \sum_{i=1}^{n} x_i, \frac{1}{n} \sum_{i=1}^{n} y_i) \tag{2}$$

If the vehicle is positioned at (x,y), then the normalized distance to mean variable, CF, can be obtained using Equation 3.

$$CF = \frac{1}{R}\sqrt{(x-\bar{x})^2 + (y-\bar{y})^2} \tag{3}$$

Where, R is the transmission radius. When CF is small, it means the potential forwarder vehicles are distributed evenly around the vehicle, indicating that it should favor not rebroadcasting.

The trapezoidal membership functions of mobility, and coverage factors for this proposed broadcast scheme, are defined in Figs. 4, and 5. A vehicle uses the mobility membership function to calculate which degree the mobility belongs to $\{slow, medium, fast\}$. Similarly, it calculates the degree of coverage, which is $\{low, medium, high\}$. The Max-Min fuzzy inference method is applied which means the fuzzy operator AND takes the minimum value of the antecedents [23]. Based on fuzzy values of input variables and using If-Then rules (as given in Table. I), the vehicle status as being rebroadcaster or non-rebroadcaster is determined. The output membership function is shown in Fig. 6. In this work, we use Center of Gravity (COG), which is the most popular defuzzification technique and widely utilized in actual applications. The correlation between input and output variables is given in Fig. 7.

If vehicle r finds its status as non-rebroadcasting, it drops the message. Otherwise, vehicle r, again using the proposed fuzzy logic system, determines the set of vehicles (in SPF) that are qualified to rebroadcast and treats it as a set of candidate forwarders (SCF). Vehicle r calculates the distance-to-mean of the vehicles in SCF. It rebroadcasts if its distance-to-mean is the largest in the set, or after t_{wait} time it does not hear the message being forwarded by another vehicles. t_{wait} is given by Equation 4.

$$t_{wait} = T_{max}(1 - \frac{d_{min}}{R}) \tag{4}$$

Where d_{min} denotes vehicle r's nearest neighbor distance. In Section V, using simulations, we obtain an optimal value for T_{max}.

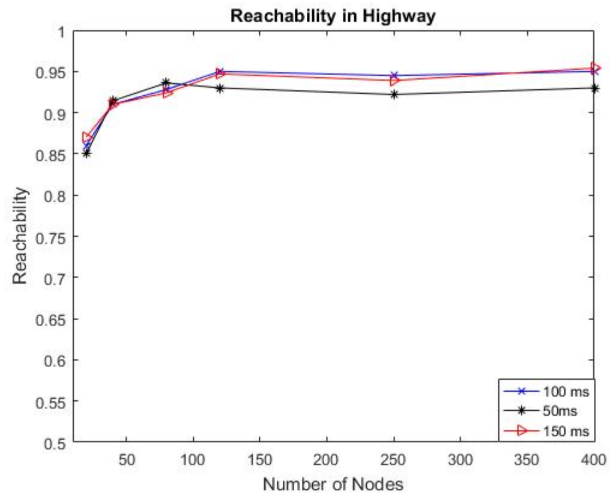

Fig. 8: Reachability for Different T_{max}

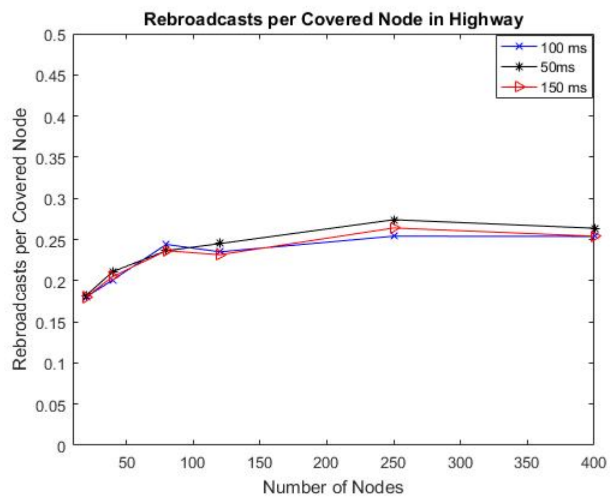

Fig. 9: Rebroadcasts per Covered Vehicle for Different T_{max}

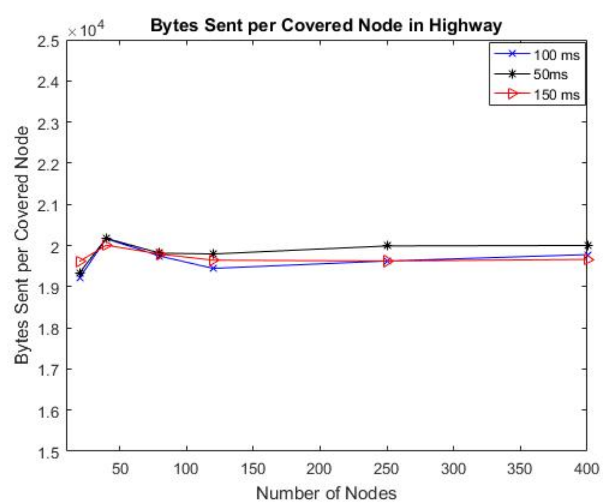

Fig. 10: Bytes Sent per Covered Vehicle for Different T_{max}

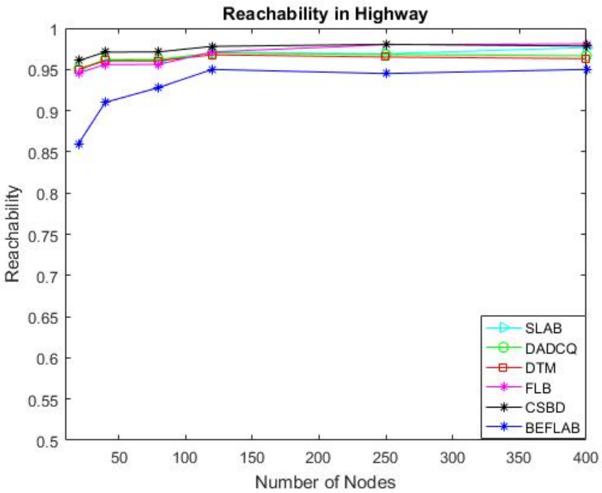

Fig. 11: Reachability in Highway Environment in Highway

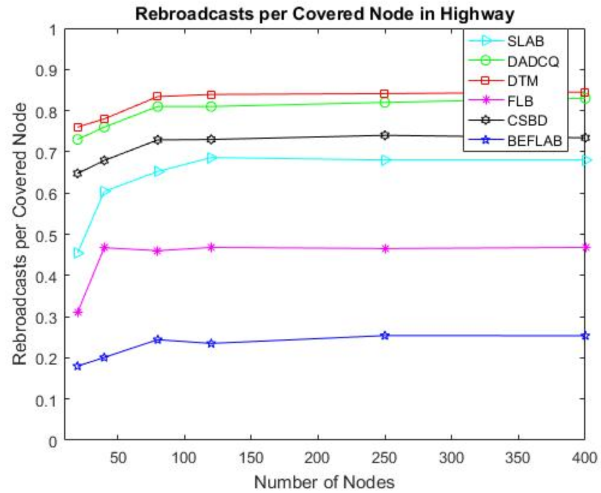

Fig. 12: Number of Rebroadcasts per Covered Vehicle in Highway

V. Simulation and Results

To determine the performance efficiency of our proposed broadcast protocol, we use ns-3.24 [24]. The network simulation is set up to have an active period of 1800 seconds and communication range is considered as 250 meters. The data size of each packet is 500 bytes. Signal propagation is modeled with Nakagami propagation. We use the WAVE model [25], which is the overall system architecture for vehicular communications implemented in ns-3 and also use IPv4 layer 3 addressing. Three sets of results are presented for each protocol using the following metrics: reachability, rebroadcasts per covered vehicle, and number of bytes sent per covered vehicle. Reachability is measured as average fraction of vehicles that receive source messages. Messages rebroadcasts per covered vehicle metric is defined as the ratio between number of retransmissions to number of vehicles that receive the message (ignoring overhead from hello messages) is calculated. Finally, bytes sent per covered vehicle is calculated as a ratio of total number of bytes sent to number of vehicles that receive the message (including overhead from hello messages). In order to assess scalability, we run the simulation for low, medium, and high traffic densities.

We run the simulation for three different values of T_{max} in Equation 4 as 50,100, and 150 milliseconds, to select the one with the best performance. According to the results shown in Figs. 8, 9, and 10, we decide to pick the value 100 milliseconds as T_{max}.

A. Highway Environment

The vehicle's mobility is generated based on ns-3.24 constant speed mobility model and the position allocation is based on ns-3 random rectangle position model, which places vehicles uniformly on a straight line (highway road scenario). The performance of our proposed protocol, BEFLAB, is compared with the distance-to-mean broadcast (DTM) protocol [13], Distribution Adaptive Distance with Channel Quality (DADCQ) protocol [15], Statistical Location Assisted Broadcast (SLAB) [16], Fuzzy Logic-based Broadcast (FLB) [17], and Cross-layer Statistical Broadcast with Density-adaptive CW (CSBD) protocols. According to Fig. 11, BEFLAB ability of successful message delivery in terms of reachability is shown. BEFLAB reaches more than 90% of vehicles in the network for almost all density scenarios. Fig. 12 proves that BEFLAB significantly reduces number of retransmission for various numbers of vehicles. Fig. 13 demonstrates bandwidth consumption in terms of bytes sent per covered node. It is observed that BEFLAB, for all densities, has the lowest bytes sent in comparison with other protocols.

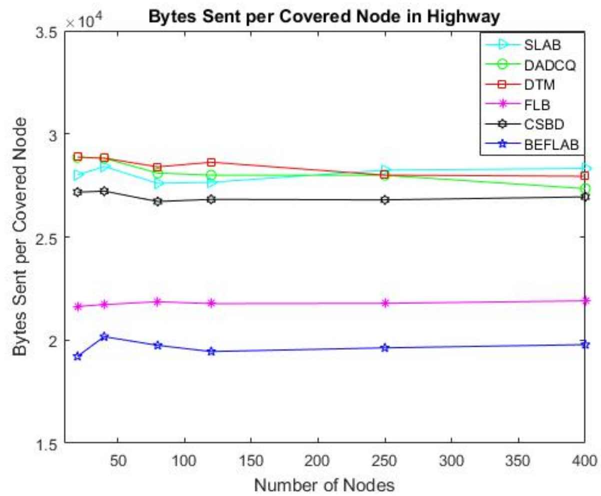

Fig. 13: Number of Bytes Sent per Covered Vehicle in Highway

B. Urban Environment

To get results for the urban environment, we generate vehicle's mobility using Simulation of Urban MObility (SUMO) [26]. In our simulation, the road network uses a 3x3 Manhattan Grid as shown in Fig. 14 with an edge length of 1km and an equal distance between any two neighboring

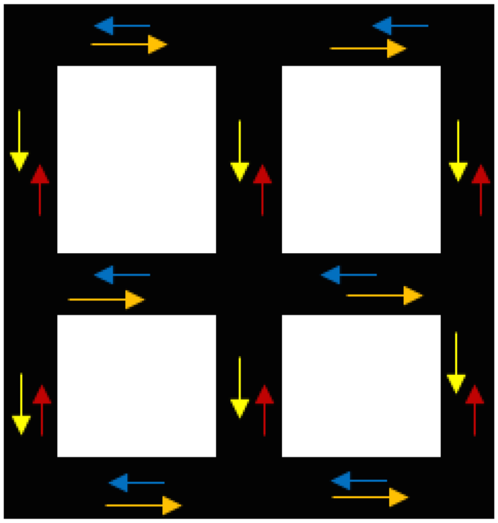

Fig. 14: 3x3 Manhattan Grid Road

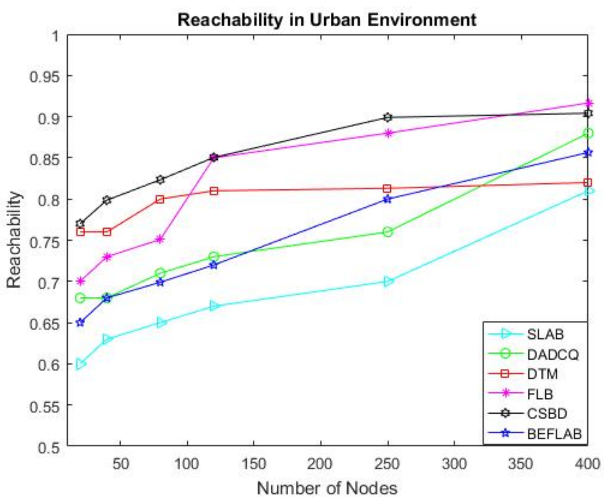

Fig. 15: Reachability in Urban Environment

intersections. Vehicle movement uses Intelligent Driver Model and vehicle speeds are computed using the car-following model in which each vehicle speed is adaptive to the leading vehicle speed. Vehicles distribution is a random process and routes are randomly generated. For each traffic scenario, ns-3 generates vehicle mobility based on mobility traces created by SUMO. The simulations are run using the parameters as mentioned before. The simulation results for urban environment are shown in Figs. 15, 16, and 17. Fig. 15 proves that BEFLAB can exceed an acceptable percentage of reachability in urban environment. For sparse networks it achieves less level of reachability than CSBD, FLB, and DTM. As the network density increases BEFLAB can reach more vehicles than SLAB and DTM. From Figs. 16 and 17, BEFLAB outperforms the other protocols in terms of number of rebroadcasting

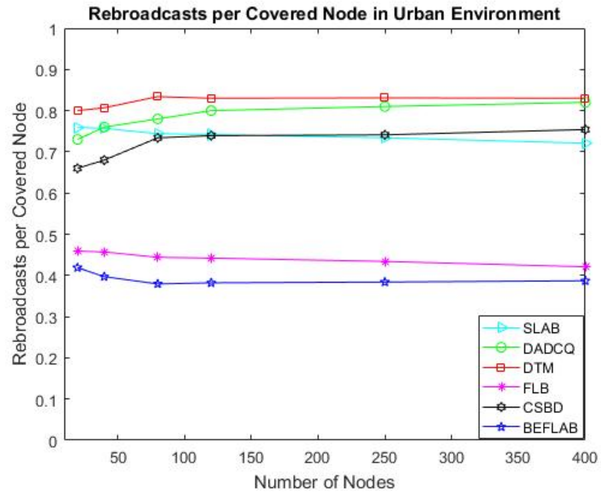

Fig. 16: Number of Rebroadcasts per Covered Vehicles

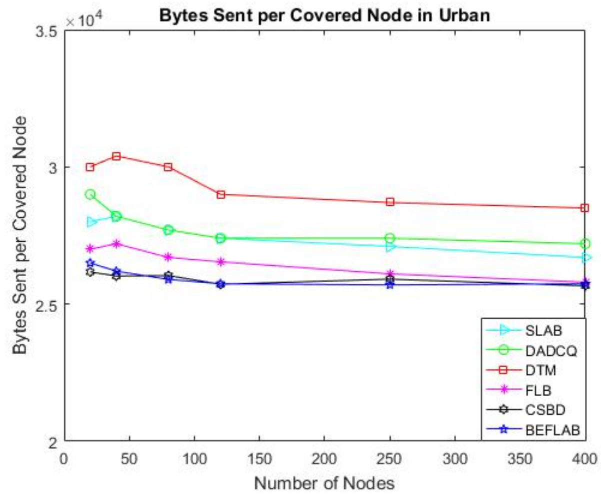

Fig. 17: Number of Bytes Sent per Covered Vehicles

vehicles and number of bytes sent. It can be attributed to the aggressive behavior of BEFLAB.

VI. Conclusions

We proposed a bandwidth efficient fuzzy logic-assisted broadcast protocol for vehicular ad hoc networks. In the proposed protocol, each vehicle after receiving a broadcasted warning message, considers its common neighbors with the transmitting vehicles from which the message is successfully received, as the set of potential forwarders (SPF). Relying on mobility and coverage factors, the proposed fuzzy logic-based decision making system determines whether a receiver vehicle is qualified to rebroadcast. If the vehicle is qualified to retransmit, using the fuzzy logic system the status of other vehicles in SPF will be determined and the set of candidate forwarders (SCF) will be obtained. Vehicle r calculates the distance-to-mean parameter for each vehicle in SCF. Vehicle r rebroadcasts if it has the largest distance-to-mean value in the SCF, or it does not hear the message being rebroadcasted after t_{wait} time. The goal of this work is to propose a broadcast scheme that aggressively reduces the number of rebroadcasting vehicles which leads to saving bandwidth. The simulation results confirmed the advantage of the proposed method over DTM, DADCQ, SLAB, FLB, and CSBD in terms of bandwidth consumption for both highway and urban environments and its comparable reachability performance. Clearly, for dense networks BEFLAB should be the protocol of choice, since it aggressively reduces the number of rebroadcasts while maintaining an acceptable reachability level.

Our future work will focus on improving BEFLAB's reachability performance in both highway and urban environments.

VII. Acknowledgment

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