Fuzzy logic controller based priority model for VANET scheduling

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Abstract. Designing a reliable Vehicular Adhoc Network is challenging, due to the critical constraints in providing reliability with ensured data delivery and minimal latency simultaneously. Here, a fuzzy-based congestion control technique, to minimize latency and packet loss for high priority safety messages is proposed. Fuzzy logic is employed to provide multi-level priority assignment to the vehicles contending for channel access. Based on this priority, the queued messages in the Cluster Head are scheduled. NS-2 simulations prove that this technique improves the packet delivery and minimizes packet loss and channel access delay compared to cognitive radio based implementations at largely densed vehicular network.

1. Introduction
VANET - an indispensible part of Intelligent Transport System (ITS) is a network of vehicles communicating either with each other or with infrastructures installed on roads called Road Side Units (RSU). VANET uses specific standards like Dedicated Short Range Communication (DSRC) and IEEE 802.11p Wireless Access in Vehicular Environments (WAVE) [2]. This is to support the two crucial requirements of a vehicular network - low latency and high reliability. The network congestion and inefficient spectrum utilization are the major challenges in designing a reliable communication for high density vehicular networks. Network quality degradation is a consequence of increased packet loss and increased latency for safety messages. In a congested network, suitable queuing and scheduling strategies can mitigate these issues by prioritizing vehicles that access channels.

Fuzzy-based algorithms are emerging techniques that provide optimal solutions for load balancing in a congested network [2]. Hence, in the proposed algorithm, the concept of fuzzy logic is employed to provide multi level priority assignment to vehicles to avail channel access. The inputs for Fuzzy Logic controller (FLC) are Channel Request Rate (CRR) and Payload Size (PS). The channel request messages queued in Cluster Heads (CH) are then scheduled according to the optimum priority obtained from FLC output. The rest of the paper is organized as follows. Section 2 provides the related work. In Section 3, the design of the proposed fuzzy logic based algorithm is discussed. Section 4 evaluates the efficacy of the proposed technique through simulations. Finally, Section 5 summarizes the work.

2. Related Work
For congestion control in VANET, the end to end strategies are unsuitable due to their unaccounting of intermediate node contexts such as collisions, interferences and transmission problems [2]. Though, the hop by hop strategies can locally control the congestion for specific set of nodes, they fail with
heavy communication and computation overheads for large scale network. The proactive strategies are open loop control solution, where the estimation of propagation conditions during the dynamic movement of vehicles is very difficult [5]. The reactive strategies control the channels after detecting congestion through closed loop feedback. However, the network recovery decays the performance of safety applications in critical situations.

The Prioritizing and scheduling strategies control the congestion by assigning priority to the messages and scheduling them to get transferred in control and service channels. This enables the transfer of safety messages with less delay. The prioritizing and scheduling algorithms that are employed in VANET [4,6,7,8,10,11] are First–In-First-Out (FIFO), Longest Wait Time (LWT), Maximum Request First (MRF), First Deadline First (FDF), Smallest Data size First (SDF), Longest Total Stretch first (LTSF), Maximum Quality Increment first (MQIF) and Least Selected First (LSF).

FIFO serves the earliest arrival request. LWT gives higher priority to the messages that wait longer in the queue. MRF assigns higher priority to the messages that are more requested by various services. In FDF, the messages are scheduled based on the remaining time to their deadlines. SDF [9] determines the highest priority for the messages with lower size. LTSF aims to optimize the stretch metric (ratio of request response time and request service time) to reduce message waiting time in the queues. But its performance is poor, while broadcasting large number of messages. In MQIF, message transfer is based on QoS metrics. D*S algorithm [9] determines the priorities based on Deadline (D) and Size (S) of messages.

To control congestion for safety applications, Context Awareness Weight Beacon Scheduling (CABS) [1] strategy decreases the beaconing rate during congestion. But its MAC layer internetworking is not considered to allocate proper TDMA time slot to different transmissions. The dynamic scheduling of messages based on their priorities is presented in [3]. Here, the static and dynamic factors which are based on the message context and network conditions respectively are used to fix the priority.

3. Proposed Model
Fuzzy logic based queuing and scheduling approach is proposed and its flow diagram is shown in figure 1. The vehicles (nodes) entering the road way start to beacon with its ID and its present location (X&Y) coordinates at regular interval of time, to establish its presence in the network.
From the positional and velocity information, the nodes with similar speed range and same heading range are grouped into a cluster [12]. The node nearest to the central position of the cluster is elected as the Cluster Head (CH) by the Cluster Members (CM). CH is responsible for the allocation of the DSRC channels to its CMs and it keeps track of the channels used by the CMs and their channel utilization time. Every CM is allotted with a channel by its CH through a Channel Request Message (CRM). Also the CH assigns Fuzzy logic based priority to any CM based on demanded arrival rate and payload size. The fuzzy inference system for priority calculation is shown in figure 2. The crisp Channel Request Rate (CRR) and Payload Size (PS) extracted from every node are fuzzified to fit inside the fuzzy range. The weight or degree of membership of fuzzy CRR and fuzzy PS to each fuzzy bin is calculated for all the rule pairs, the values fall into. After calculating the output weight through if – then rules, the output priorities are aggregated and de- fuzzified using Sugeno Max-Prod implication and Weighted Average / Sum methods to get the optimum priority level. The calculated output priority is used to schedule the CMs in a Cluster Head’s buffer. On arrival of new CRM from the same nodes, the latest CRM’s PS and CRR are taken in order to prevent ambiguity and redundancy in the buffer.

![Diagram](image)

**Figure 2.** FLC flow for priority calculation

### 3.1. Queuing Model

A high density vehicular network can be modelled as a Poisson network and every Cluster Head is modelled as an M/G/1 queue with infinite buffer space and is shown in figure 3.
Figure 3. M/G/1 queue model at Cluster Head

If at every Cluster Head, the arrival rate is $\lambda$ messages / second and the Service rate is $\mu$ ($\mu = 1/$ Data size for M/G/1 queue model) with the variance as $\sigma^2$ then, the queue is governed with the following equations.

Traffic flow density is, $\rho = \frac{\lambda}{\mu}$ \hspace{1cm} (1)

Average number of messages in Queue is, $L_q = L - \rho$ \hspace{1cm} (2)

Average number of messages is,

$$L = \rho + \frac{\rho^2(1 + \sigma^2\mu^2)}{2(1 - \rho)} \hspace{1cm} (3)$$

Average waiting time in system is, $W = \frac{L}{\lambda}$ \hspace{1cm} (4)

Average waiting time in Queue is, $W_q = W - \frac{L}{\mu}$ \hspace{1cm} (5)

3.2. Scheduling Technique

The queued messages of CH buffer are scheduled using Multi Level Priority (MLP) based scheduling algorithm. MLP is calculated using the concept of Fuzzy logic inference attained through Fuzzy Logic Controller (FLC). The primary steps of FLC include Fuzzification, Inference Engine and Defuzzification. The functional block diagram of FLC is shown in figure 4.

Figure 4. FLC block diagram

Fuzzification, the process of transforming crisp inputs into fuzzy inputs has Channel Request Rate (CRR) and Payload Size (PS) as inputs for FLC. CRR is proportional to the priority of payload message to be sent, when the channel allocation is done and it varies from 100ms to 1000ms, to cover the required fuzzy range. CRR is fuzzified to map into the categories as shown in figure 5.

$\text{CRR}_c = \{\text{Rapid, Fast, Medium, Slow, Very Slow}\}$
PS is the size of the message to be transmitted upon allocation of channel and it varies from 50 bytes to 500 bytes. It is fuzzified to map into the categories as shown in figure 6.

\[ PS_f = \{\text{Very Small, Small, Medium, Large, Very Large}\} \]

**Fuzzy inference** is the process of formulating the mapping from a given input to an output using fuzzy logic. This process involves membership functions, fuzzy logic operators and if-then-else rules given in Table 1. The inference system used is Sugeno type, due to the Singleton nature of outputs. The if-else rules of the FLC are defined using max-min method.

| Table 1. If-Then- Else Rule base. |
|----------------------------------|
| PS \[\rightarrow\] CRR \[\rightarrow\] Micro | Very Small | Small | Medium | Large | Very Large |
|----------------------------------|------------|-------|--------|-------|------------|
| Rapid                            | Highest    | Highest| High   | Default| Default    |
| High                             | Highest    | High   | Default| Low   | Default    |
| Medium                           | High       | High   | Default| Low   | Low        |
| Slow                             | Default    | Default| Low    | Lowest| Lowest     |
| Very Slow                        | Default    | Default| Low    | Lowest| Lowest     |

**Defuzzification** of priority \( Prio_k \) is done using Sugeno max-prod method. The calculated priorities are assigned to weigh and schedule the CRMs in the CH queue. The fuzzy output variable is singleton function categorized as in figure 7.

\[ Prio_k = \{\text{Lowest, Low, Default, High, Highest}\} \]

Out of the two methods available for Defuzzification as Weighted Average (WA) and Weighted Sum (WS), the WA is used here. The final crisp priority value from defuzzified output (Z\( _{pri} \)) is then calculated, where \( Z_i \) represents the values of the linguistic variables for the output and \( W_i \) represents the resulting values of the weights calculated at the inference stage. FLC flow for priority calculation is given in figure 2.
4. Simulation and Results

The mobility source file exported from SUMO and Open Street maps are fed to NS2 during simulation. The channel congestion is created by generating CRM at random rates from 100ms to 1000ms at varying payload of 50 to 512 bytes. The performance is evaluated for varying vehicular speed and vehicular densities at varying priorities and payload of CRMs.

4.1. Average Channel Access Delay (CAD)

It is the time lapse between a message arrival at CH and channel assignment. Figures 8 and 9 show the plot of CAD for Weighted Average Defuzzifier (WAD) and Weighted Sum Defuzzifier (WSD). The results are noted for highest priority messages with constant access delay, even at increased vehicular densities. The WAD performs better than WSD.

4.2. Packet Delivery Ratio (PDR)

Figures 10 and 11 infer that PDR of 90% is obtained, when fuzzy based queuing is used. An approximate difference of 25.7% and 20.1% is observed between WAD and WSD respectively.
4.3. Packet Loss Ratio (PLR)

Figures 12 and 13 show the PLR obtained at varying priorities and vehicular densities with WAD and WSD. An average PLR of 15% is observed with the fuzzy queuing. The PDR difference is 10.7% and 15.1% for WAD and WSD respectively.
5. Conclusion
A novel fuzzy based closed loop congestion control algorithm for high vehicular density VANET is developed to provide multi level priority based DSRC channel access to vehicles contending for congested channels. The multi level priority is used for queuing and scheduling of all types of messages to improve the QoS of the network. The cooperation extended awareness for vehicles that leads to reliable and faster dissemination of messages. CAD, PDR and PLR are the critically analyzed parameters to confirm the highest priority assignment of safety messages during congestion. In future, the altering of Fuzzification categories to further optimize priority settings and usage of different combinations of if-then rules, to check for fair channel access messages need to be developed.
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