Multistate Active Combined Power and Message/Data Rate Adaptive Decentralized Congestion Control Mechanisms for Vehicular Ad Hoc Networks

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Abstract. Vehicular ad hoc networks (VANETs) have emerged in time to reduce on-road fatalities and provide efficient information exchange for entertainment-related applications to users in a well-organized manner. VANETs are the most instrumental elements in the Internet of Things (IoT). The objective lies in connecting every vehicle to every other vehicle to improve the user’s quality of life. This aim of continuous connectivity and information exchange leads to the generation of more information in the medium, which could congest the medium to a larger extent. Decentralized congestion control (DCC) techniques are specified to reduce medium congestion and provide various safety applications. This article presents two DCC mechanisms that adapt message rate and data rate combined with transmit power control mechanism. These mechanisms are developed under multi-state active design proposed by the standard. The proposed methods deliver better performance over other mechanisms in terms of power, channel load, and channel utilization using real-time-based scenarios by simulation in SUMO.

1. Introduction
Intelligent transportation system (ITS) standards have defined various safety measures to minimize catastrophes caused due to surrounding environment and certain road conditions. Vehicular ad-hoc networking (VANETs) is used to tackle the above situations in a well-organized manner and improve users’ comfort level [1],[2]. The regular exchange of safety and alert messages, also called cooperative awareness messages (CAMs), leads to a congested medium. DCC adapts various transmission parameters based on the current situation as well as surrounding constraints. It works by considering parameters at different layers, and hence DCC is a cross-layered approach for decreasing congestion in the communication medium. European telecommunications standards institute (ETSI) defined various components under cross-layered DCC function and location, and links between these components are defined in [3]. The defined access layer mechanism by ETSI are transmit data-rate control (TDC), transmit power control
(TPC), transmit rate control (TRC) which adapts the rate of the message transmitted, power, and data-rate respectively. Clear channel assessment (CCA) solves congestion in the primary channel under DCC sensitivity control (DSC). High-priority packets such as critical safety information need to be communicated with minimum delay. These kinds of messages with minimal limitations are due to transmit queue concept and transmit access control (TAC).

ITS-G5 defines a set of protocols along with various parameters for highly dynamic VANETs specified by ETSI. ITS-G5 radio takes networking and transport layer decisions based on the available information regarding medium and various transmission parameters [3],[4]. The DCC has a decentralized way that follows relaxed, active, and restrictive states, depending on channel congestion. Congestion is measured according to available channel load (CL), and depending on present channel load DCC adapts transmission parameters. The process is in the active state when present CL is more than the defined minimum CL (minCL) and less than the defined maximum CL (maxCL). If the congestion is very low, the process is in a relaxed state, i.e., the CL is less than minCL in a relaxed state. Once current CL exceeds the threshold value of CL (i.e., maxCL), it is expected that the system is congested, and the CL beyond maxCL, can't be handled efficiently; hence it is called as the restrictive state. Figure 1 shows the state transition diagram for DCC_access layer with the states discussed above.

Variable like transmitted power is evaluated on line of sight (LOS) propagation path and reflections from non-line of sight (NLOS) propagation paths measurements on the medium. It affects the communication range, message reception based on receiver sensitivity and channel interference. The data rate and message rate are the link-layer parameters that are controlled based on the required application. Safety messages are frequently transmitted messages or beacons; hence message/beaconing rate control is used for safety purposes. The main intention behind controlling two parameters to reduce congestion is to handle channel load more efficiently and utilize the channel to more extent on the availability of channel congestion.

Here we follow a two-state active DCC structure and checking the performance for our proposed mechanisms i) combined power and data-rate control and ii) combined power and message rate control. The power control and other parameters are used to consider channel variation's effect on protocol performance. Rest of the paper is arranged with section 2 focused on various works done in this domain, section 3 illustrating our proposed mechanisms, results are discussed in section 4, and finally, section 5 concludes.

2. Related Work
Cooperative awareness messages (CAMs) and various safety information are frequently exchanged between vehicles. In denser networks, this can cause congestion and can lead to different consequences. ETSI has mentioned numerous mechanisms for DCC that focus on improving congestion and fairness. The functionality and the limitation with usage for the cross-layer DCC architecture in ITS-G5 are mentioned in [4], it highlights on DCC linking for the functionality of management. The DCC gatekeeper does the function of traffic configuration for the access layer. The limitation with accessing a specific channel was on the outcome of results from the DCC algorithm. These concepts detailed in [4] along with other corresponding elements are confirmed in [5]. The DCC algorithms focused on keeping important parameters
like bounded stability when outlining the design for transmission of data rate. D-FPAV, an efficient distributive transmit power control mechanism, is proposed in [6] provides fairness to each communicating node and also raises one-hop reception probability of cyclic beacons and circumstantial driven messages. Maximum beaconing load (MBL) is the constraint used for increasing minimal power levels over entire designated transmission levels of power. Active safety communication requirements in D-FPAV are satisfied with the help of emergency message dissemination for vehicular environments (EMDV). EMDV is one of the fast and effective multi-hop data distribution mechanism uses contention-based medium access. For successful operation, EMDV uses channel load requirements specified by D-FPAV, and this combination gains synergy. DR-DCC, a data-rate an adaptive congestion control framework is analyzed in [7], aims to avoid congestion of safety messages under various traffic densities. Different data rate levels defined by the standard are selected based on the available channel load to control data transmission rate. Beacon and safety messages are prioritized and transmitted at higher rates; this data rate control scheme used in DR-DCC also improves channel utilization. The data rate is the one element considered in DRDCC, and its performance for DCC parameters is not evaluated.

Fairness is not always promised in rate-based congestion control methods if it does not sync with the two-hop piggybacking process. Periodically updated load sensitive adaptive rate control (PULSAR) is mentioned when the transmission rate-adaptive protocol mentioned in [8] is content with awareness and safety measurements. It is accepted that all nodes are in sync during the gap time, and the allotted gap time is utilized to make the right choice and channel observation in every node. The fairness in PULSAR is gained with adjustment in convergence interval and by rescheduling some significant transmissions. The linear message rate integrated control (LIMERIC), a linear adaptive congestion control algorithm, is presented in [9] for DSRC based safety communications. The performance of LIMERIC is tested under various scenarios for analyzing stability and convergence, and it is observed that LIMERIC is adaptive to gain saturation. In noise-free environments, LIMERIC perfectly converges and achieves fairness and a significant improvement over the binary control limit cycle. The effect of DCC mechanisms and the combined result of these mechanisms on the performance of the system are evaluated in [10], taking account of PDR to acknowledge system response. It is inferred that the reduction of congestion level in channel and a common effect in system response could not be made by DCC mechanisms.

The decentralized fair adaptive beaconing rate for intervehicular communications (FABRIC) algorithm is proposed in [11] which follows gradient optimization techniques for beacon rate control. This beaconing rate control problem is modeled as network utility maximization (NUM) concern under different static and dynamic traffic cases. Fairness parameter \( \alpha \) is defined for allocating beaconing rates, and each vehicle is allocated different rates by choosing \( \alpha \) value based on available channel load and vehicle requirements. There are two rate allocation types in FABRIC, namely synchronous and asynchronous. FABRIC converges faster in synchronous case, whereas asynchronous case results in some oscillations while rate allocation. These oscillations are controlled using the proposed anti-flapping technique. Based on active time for each route, the traffic signal offset is determined, which reduces the risk of congestion in urban traffic network [12]. Traffic flows are computed through constrained optimization problems with the help of results in consensus and economic dispatch (ED) problems. The DCC Gatekeeper introduces additional queuing delay under high network load, the multi-hop forwarding with DCC Gatekeeper and LIMERIC is studied for rate adaptation algorithm [13]. The CBF operation is performed more efficiently, and communication reliability and latency are improved for mixed data traffic under this congestion-enabled forwarding scheme. The boundary conditions are derived for CBF and DCC Gatekeeper.

Unsafe and unreliable driving situations can cause variable data rate allocations since vehicles with lower data rates become less visible in the network. The algorithm for packet counting based
decentralized data rate congestion control (PDRDCC) presented in [14], which is fair and offers improved application reliability for the selection of analog data rates. Fairness achieved in PDRDCC is self-reliant on time used up by the vehicle in its monitoring range. It outperforms other standard protocols in awareness range, application reliability, and fairness. It also suggests the adaptation of various parameters such as data rate, power, message rate, which helps to improve the reliability of packet count-based approaches to a further extent. Environment and context-aware combined power and rate control protocol (ECPR) proposed in [15] adapts transmit rate by controlling power based on environmental effects and awareness distance. This combined power and rate control mechanism in ECPR presents feasibility analysis for the environment and context-aware scenarios. The frequency reuse can be possible because of transmitting power adaptation in ECPR compared to rate-control algorithms.

An insight about various DCC algorithms and their analysis is provided in [16], [17]. It is expected that the protocols mentioned under DCC should convey the below-mentioned points to ensure a fair and trustful system.

- Fair allocation of resources to all vehicles needs to be provided, which can help maintain channel load based on the system requirement.
- Providing fast and efficient algorithms that analyze the current situation based on required application and adaptation to keep congestion in specified limits.
- Interference neutralizing methods for carrier sensing power transmission-based methods.

![Figure 2: State transition diagram for 2 state active DCC access](image)

3. PROPOSED WORK

The combined power control, along with other parameters make the DCC technique to be environment and context-aware. ETSI proposed a multi-state active design in which the active state in figure 1 is divided into multiple active states. In this work, the two-state active design shown in figure 2 is used to implement proposed mechanisms. The two-state active design shown above uses two different thresholds for CL under each state. Channel busy ratio (CBR) is the metric utilized to measure congestion in DCC techniques. The message accepted by ego vehicle divided by channel capacity (all represented in bytes per second) results in CBR and is represented in (1) [15]. The overall number of accessible neighbors are $M$, $l_k$ is the length of message received from $k^{th}$ neighbor in bytes per second and $C$ is channel capacity in bytes per second. Ego vehicle is the term used for a particular node in the medium; all analysis and calculations are done with respect to ego vehicle. CBR calculations are done at ego vehicle by analyzing information related to messages received from its neighbors. For the states in our model, we look at the CBR threshold value ranging between 0.2 and 0.43 for active state one, and for active state two, it is considered between 0.43 and 0.6. The system shown in figure. 2 is considered to be in Relaxed state if $CBR$ is less than 0.2, the Active(1) is observed for (0.2 less than equal to $CBR$ less than 0.43), for (0.43 less than equal to $CBR$ less than 0.6) Active (2) state is obtained, finally when $CBR$ is greater than 0.6 it is mentioned to be in Restrictive state.
Value 0.43 is randomly chosen here as a threshold value for active state 1 and active state 2. Instead of center value 0.4, this value intends to keep the system away from congestion for more time (that is, active state 1). Different threshold values lead to different adaptation patterns and variations in CBR. This section proposes two algorithms based on message rate adaptation and data rate adaptation combined with power control.

3.1. Combined Power and Message-Rate Adaptation (CPMRA)

The received power level at a vehicle gives the type of channel and loss in medium. The multi-path fading, reflections, and environment are the factors affecting received power. These effects lead to heavy data loss as density increases, which may cause channel congestion. The use of power adaptation mechanisms based on received power due to environmental and fading effects helps understand channel loss and can eventually reduce congestion. If the density is high, only power control may not solve the issue of congestion; message-rate or data rate control along with power control can help in a much better way to tackle the congestion issues.

\[ ChannelBusyRatio(CBR) = \frac{\sum_{k=1}^{M} \text{message length received from each neighbor (bytes/sec)}}{\text{channel capacity (bytes/sec)}} \]  

\[ = \sum_{k=1}^{M} \frac{l_k}{C} \]  

A combined power and message-rate adaption (CPMRA) mechanism is presented, the power control mechanism is used to consider environment awareness and fading effects, whereas the message rate is controlled based on the value of CBR for efficient and error free transmission. ETSI have specified transmit message rate to be in range of 1 Hz to 10 Hz. In CPMRA mechanism, power and message rate are adapted based on current CBR value so that the congestion is maintained within specified limits. The ego node calculates CBR value using equation 1 based on amount of data received from its neighbors. If CBR is below threshold, CPMRA increases message rate using equation 2 (maximum up to 10 Hz). Similarly, if CBR exceeds the threshold value, message rate is decreased according to equation 3. Here, \( R_i(t-1) \) is the message rate at previous time step, \( R_i(t) \) is the increased message rate and \( R_d(t) \) is the decreased message rate at time \( t \) for the ego node, \( CBR(t) \) and \( CBR_{Th} \) are CBR found by ego node at time \( t \) and threshold CBR respectively. The \( \text{sign} \) function returns +1 if the entity is greater than zero and it returns -1 if the entity is less than zero. Convergence factor \( \alpha \) and adaptive gain factor \( \beta \) are jointly used for algorithm convergence and have converged values to be \( \alpha = 0.1 \) and \( \beta = 1/150 [9] \). X is a threshold saturation gain and is found based on message size, rate, channel capacity and \( \alpha \). In our case, the value of X is 0.00416 and it is calculated as the ratio of message rate to \( \alpha \) multiplied with channel capacity in messages/sec. The target increased rate is \( \min[10, R_i(t)] \) and the target decreased rate is \( \min[10, R_d(t)] \).

\[ R_i(t) = (1 + \alpha)R(t-1) + \{\text{sign}(CBR_{Th} - CBR(t)) \times \min[X, \beta(CBR_{Th} - CBR(t))]\} \]  

\[ R_d(t) = (1 - \alpha)R(t-1) + \{\text{sign}(CBR_{Th} - CBR(t)) \times \min[X, \beta(CBR_{Th} - CBR(t))]\} \]  

The active-1 state in state transition diagram is shown in the figure 2, indicates less amount of congestion compared with active-2 state. So, if the system is in a relaxed or active-1 state, it
can still handle the increase in message rate. In an active-2 state, an increase in message rate can lead the system to a restrictive state. In order to maintain the system with active state and congestion within specified limits, the value of \( \alpha \) is chosen as '0.1' and '0.05'. These values are used to increase or decrease the message rate. For a system in the relaxed state, \( \alpha \) is chosen as 0.1, and for a system with active state 1, it is chosen as 0.05 in equation 2. When the system is in a restrictive state, \( \alpha \) is chosen as 0.1 in equation 3. This can help utilize the channel to more extent by keeping the system in active state for more time. The message rate adaptation algorithm is applied to all four states of the two-state active design of DCC.

The power control algorithm is applied at the ego node based on the CBR value and current neighbors and environment conditions. The ego node calculates its distance from each neighbor and selects only those neighbors which are in its target awareness range. The awareness metric measures ego vehicle awareness by neighboring vehicles, and ego vehicle estimates it locally. The ego vehicle calculates the transmit power required at time instant \((t + 1)\) (or the value for next time step) using path loss exponent and path loss for messages received from its neighbors. These metrics give information related to channel conditions and fading due to multipath reflections. The power control algorithm considers the number of neighbors in the target awareness range, and it executes for every simulation time step. If the ego vehicle has the same neighbors as the previous time step and CBR is less than the threshold, the algorithm uses the same transmit power in the next observation interval (or time step). The required power for the next step to reach each neighbor is calculated from equation 4. Here, \( M \) denotes total numbers of neighbors of ego vehicle, \( P_{j\,Rx}^R(t) \) is power received from \( j^{th} \) neighbor for current time interval, \( PLE_j(t) \) is path loss exponent for current time interval, \( \lambda \) is wavelength and \( r(t) \) is target awareness distance of ego node. The received power from every neighbor is calculated, and the maximum value of \( P(t + 1) \) is chosen by considering the effect of target awareness percentage [15].

\[
P(t + 1) = \frac{1}{M} \sum_{j=1}^{M} P_{j\,Rx}^R(t) + 10 \cdot PLE_j(t) \log_{10} \left( \frac{4\pi}{\lambda} r(t) \right)
\]

The working flow of CPMRA for a single time step is shown in figure 3. The available number of neighbors within the target awareness range and received power from each neighbor is calculated at ego node. From these available values, CBR and transmit power required for the next time step are calculated. Once these values are calculated, an adaptation algorithm is applied based on the number of available neighbors and CBR value. The system’s state is obtained from the current CBR value, and the \( \alpha \) value is chosen from the current state of the system. The received power for the current time-step is calculated for some set of available neighbors. The power adaptation is applied for the next step if the CBR value exceeds the threshold value for the same number of neighbors. If the number of neighbors for the next time step is changed, power adaptation is applied for next time-step irrespective of CBR value. The change in neighbors enforce extra processing to set up communication links, hence the power adaptation is applied for that case. The message rate adaptation is applied depending on the values of the current CBR. In the current time step, if the CBR value exceeds the threshold value for a particular state, depending on that DCC state and CBR value, the message rate is selected for the next time step as explained earlier. In every step, the ego node performs the above procedure and accordingly uses newly calculated power and message rate values for the next step.

### 3.2. Combined Power and Data-Rate Adaptation (CPDRA)

The data contained in larger data files or entertainment data, playing online games, need more bandwidth and data rate for communication. In high-density networks, these applications can cause congestion due to their data rate and bandwidth requirements, which can sometimes delay the safety message delivery. The combined power and data-rate adaptation mechanism
are proposed in this section to tackle issues related to infotainment data transfer. The data rate and power are adapted depending on the current congestion situation. The power control mechanism is the same as the CPMRA algorithm, and ego node changes transmit power based on available neighbors and CBR values.

The broadcasting network causes flooding for higher data rate values in dense scenarios. The evaluated data rate for the broadcast network is 6 Mbps. The 3 Mbps data rate is mostly chosen for dense broadcast networks. The data rate values are selected depending on current channel congestion so that more data can be transmitted over the channel with minimum data loss.

Table 1 reflects data rates adapted for CBR values under different DCC states. A higher data rate is allocated for the relaxed state because at minimum congestion level, data transferred at higher rate guarantees fast and reliable transmission. In the relaxed state, the number of vehicles in the medium is less, and the channel is almost free so that the data can be transmitted at a higher rate. As the CBR value increases, the data rate is reduced depending on the threshold CBR value and DCC state. This data rate adaptation mechanism adjusts the communication bandwidth to avoid data loss and more data delivery. The probability of failed transmissions as well as

| CBR       | DCC State | Data rate (mbps) |
|-----------|-----------|------------------|
| <0.2      | Relaxed   | 12               |
| >=0.2 & <0.43 | Active1   | 9                |
| >= 0.43 & <0.6 | Active2   | 6                |
| >= 0.6    | Restrictive | 3               |

Figure 3: Flow chart for single time step of CPMRA
long queues can be reduced. An increasing number of neighbors increases possibilities for various calamities, which eventually increases safety messages. Hence, as CBR increases, the data rate is reduced to reduce the possibility of collision between safety messages. Safety and beaconing messages are always transmitted at higher data rates.

The operation of CPDRA is explained in algorithm 1, and data rate adaptation is applied based on the current CBR value and the available number of neighbors. The data rate values are chosen from table 1 for the next simulation time step. The non safety applications involve sharing of larger files as well as infotainment data. This data sharing happens between all neighboring vehicles; hence, the CPDRA algorithm considers the number of available neighbors in every step. It is assumed that for the same number of available neighbors, the data exchange is considered uninterrupted. If the number of neighbors changes, the data exchange may or may not continue due to the absence of a source or destination. Hence, the same data rate is carried to the next step to establish new communication. The value of data rate depends on channel capacity and bandwidth, which affects CBR. The transmit power control mechanism helps to consider fading effects caused by surrounding vehicles and other objects. So, this mechanism of directly choosing data rates based on CBR values is entirely feasible for real-world VANET scenarios.

4. SIMULATION RESULTS
This section presents simulation results for proposed two-state active DCC protocols. From the channel load, these protocols adapt message rate and data rate along with power control mechanism. The two-state active model used for simulation is shown in the figure. 2, and threshold values for each state are presented in table 1. Simulation results are obtained using GEMV\textsuperscript{2} V2V propagation simulator [18]. GEMV\textsuperscript{2} is a computationally efficient propagation model for V2V communications, which considers effects of surrounding objects (e.g. foliage, buildings and vehicles [19]).

Algorithm 1 The adaptation of data rate (DR) in a considered model

Require:
The geographic area is taken from openstreetmap, and the vehicles and mobility is added to this scenario using SUMO
Using GEMV\textsuperscript{2}, find the no. of neighbors and power obtained by every neighbor in above scenario
CBR calculation
if No. of neighbors=No. of neighbors in previous time-step then

if Channel Busy Ratio <0.2 then
   DR = 12 Mbps
else if 0.2 <= Channel Busy Ratio <0.43 then
   DR = 9 Mbps
else if 0.43 <= Channel Busy Ratio <0.6 then
   DR = 6 Mbps
else
   DR = 3 Mbps
end if
else
   DR = Current DR
end if

Realistic mobility traces with Google-earth visualization are generated using simulation of
urban mobility (SUMO), and route files are generated for simulation using these traces [20]. The scenario used for simulation is the area around Mangalore city in India, generated using openstreetmap and SUMO. Figure 4 shows the generated scenario for simulation with 250 to 300 vehicles in the given area. Google-earth visualization is applied in SUMO to get the information about surrounding objects and foliages so that GEMV$^2$ considers all reflections from surroundings and calculates required parameters for the simulation. The filled circle in figure 4 indicates communicating vehicles, and colored lines are multipath reflections received from surrounding objects. Log-Normal model is used in GEMV$^2$ to analyze channels using these multipath reflections. Table 2 shows the default values of some parameters considered in simulations.

Table 2: Simulation Parameters

| Parameter                          | Value          |
|-----------------------------------|----------------|
| Beaconing rate                    | 10 Hz          |
| Message size                      | 250 Bytes      |
| Carrier sense threshold           | -90 dBm        |
| Threshold Channel Busy Ratio      | 60% (0.6)      |
| Measurement interval              | 200 ms         |
| Transmit power                    | 23 dBm         |

The two-state active system shown in figure 2 is used to simulate proposed CPMRA and CPDRA mechanisms, and results are compared with available standard DCC protocols. The performance is evaluated based on variations in CBR, transmit power, and message rate. The performance of CPMRA and CPDRA is compared with ECPR, TPC, TRC, TDC, and without DCC mechanisms. In recent papers, the results based on CBR are not presented. Hence we compared our algorithms with the schemes mentioned above. CBR is calculated in each measurement interval, and the adaptation is applied based on the present channel load for all mechanisms. Figures 5, 6, and 7 show simulation results obtained for all mechanisms for the scenario shown in the figure 4. Results are obtained for the set of initial transmit power and target awareness distance [23dBm, 90m] and [10dBm, 150m]. Figure 5 shows results obtained
for CBR and adapted message rate values for initial transmit power of 23 dBm and target awareness distance of 90m. Figure 6 shows results obtained for CBR and adapted message rate values for initial transmit power of 10 dBm and target awareness distance 150m. All results are obtained for target awareness of 85%. Results show that both the proposed mechanisms keep the channel load of the system within specified limits. The rate adaptation in CPMRA has various oscillations because of different \( \alpha \) values chosen for two active states. This oscillatory change in message rate in CPMRA utilizes more channel resources along with congestion control. The message rate control mechanism is not applied to CPDRA, TDC, and TPC; hence, a maximum rate of 10 Hz is used during simulations. TRC and TDC mechanisms have used fixed initial transmit power to each node for all time simulation steps.

Data rate adaptation mechanisms TDC and CPDRA use higher data rates at lower CBR values or in a relaxed state of the DCC system. Since channel capacity is directly related to data rate, data rate adaptation schemes have higher CBR values than other mechanisms in a relaxed state. As the data rate starts changing with respect to the current CBR value, the number of available neighbors and feasible communication links starts changing for every step due to adapted values. This mechanism restricts CBR from crossing the threshold value specified by the standard. The initial value of message rate in the CPMRA mechanism is chosen to be 5 Hz, and the adaptation of message rate is shown in the figures. 5(b) and 6(b), variation in message rate is in the range \([1, 10]\). This variation in message rate keeps channel load in specified limits, and proper channel utilization is achieved. The proposed CPMRA mechanism can be
used for safety applications, and CPDRA can be used for safety and infotainment applications. Figure 7 shows transmit power adaptation applied to various DCC mechanisms. For initial

![Figure 7: Variations in transmit power with 85% of target awareness](image)

(a) Transmit power=23 dBm and target awareness distance = 90m (b) Transmit power=10 dBm and target awareness distance = 150m

transmit power of 23 dBm, the target awareness distance is chosen to be 90 m and for 10 dBm initial transmit power, it is chosen to be 150 m. This combination is selected to find an equivalent amount of neighbors for both cases and avoid data loss due to collision. Transmit power plots show that transmit power is either increased or decreased depending on available channel load and awareness distance to cover the awareness area considered for ego vehicle. In order to control channel load and avoid data loss due to increased load, we consider the adapting power. For the initial transmit power of 23 dBm, the decrease and increase in transmit power of CPMRA is because of variations in message rate, which also indicates more channel utilization by CPMRA. In CPDRA, the transmit power adaptation starts once CBR crosses the threshold value or changes the number of neighbors.

5. CONCLUSION

The variations in topology, non-linearity in road structures, higher mobility, traffic rules and regulations, communication environment, and many other constraints are to be considered during the design of vehicular networks. These constraints add some distinctive challenges in designing various protocols for VANETs. This paper presented two mechanisms, message-rate and data-rate adaptation combined with power control mechanisms, called CPMRA and CPDRA. ETSI presents two active state designs used while designing these mechanisms and tested under real-world scenarios generated using SUMO. The message-rate adaptation and power control in CPMRA help utilize channels to more extent than other techniques by maintaining congestion in specified limits. Data-rate adaptation and power control mechanisms in CPDRA always keep channel load below the specified threshold. The power control mechanism works by considering environment variables and their effect on the channel. As the continuation of this work, we will be working on resource allocation and fairness performance for our proposed mechanisms.

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