An AI-Based Transmission Power-Control Certificate Omission in Vehicular Ad-Hoc Networks

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Abstract. Fundamental to achieving cooperative awareness amongst vehicles is the periodic dissemination of beacons. However, ensuring the secure dissemination of these beacons has over the years become an issue of importance as these beacons often than not contain some level of safety-critical information which are susceptible to attack. Consequently, researchers have proposed in the literature the use of digital certificates issued by a trusted authority as means of ensuring beacon authenticity and the use of a digital signature as a means of ensuring beacon integrity. Nonetheless, this security method is characterized by an increase in communication overhead caused by the increase in the beacon payload size. To address this issue, some researchers have in recent years proposed approaches like the Neighbor-based Certificate Omission (NbCO) and Transmission Power-control Certificate Omission (TPCO) strategy that uses a certificate omission technique to control channel congestion. Upon evaluation, these strategies have proved to be promising as they focus on tuning the beacon payload size which has a direct impact on the communication channel load and hence reducing channel congestion. Despite the benefits of these strategies, they face the general issue of how to maintain a steady and minimized number of Cryptographic Packet Loss (CPL) and Network Packet Loss (NPL) even as the traffic congestion situation in a vehicular environment increases (***i.e.***: *CPL are beacons dropped because they are unverifiable due to the absence of a corresponding certificate and NPL are the beacons dropped over the network due to congestion*).

Therefore, we propose in this work an Artificial Intelligence-based Transmission Power-Control Certificate Omission (AI-TPCO) scheme which allows vehicles to demonstrate an efficient control over communication channel load by intelligently tuning their transmission power using fuzzy logic and also reactively adapting their beacon size using NbCO strategy. Our obtained simulation results prove that our proposed AI-TPCO scheme is able to attain a steady and minimized number of CPL and NPL even as the traffic congestion situation in a vehicular environment increases and as such maximizing cooperative awareness amongst vehicles.

Keywords: VANET · Security · Certificate omission · Congestion · Fuzzy logic

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1 Introduction

In the early 1800s, the world of mobility observed a paradigm shift which was termed as the “Horseless carriage” [1] and this paradigm shift spearheaded the transitioning of mobility by animals (horses) to mobility by vehicles. Many years on, vehicles have become a significant part of our everyday life and as such, the number of vehicles on our roads has increased significantly. According to the US Car Ownership Statistics report in 2021 [2], about 91.3% of households in the US is reported to own at least one vehicle. Hence, as the rate of vehicle ownership in our world today increases at a study pace, the issue of road accidents and traffic congestion has become even more alarming. To curb these issues, the world is currently observing another paradigm shift in mobility called “Autonomous Vehicles” [3] which will be steered by some technologies like Vehicle to Vehicle (V2V) communication.

V2V communication is characterized by the periodic broadcast of beacons among vehicles on the road to enable them to take proactive safety decisions like slowing down in time when approaching a construction site or an accident scene. Often than not, these periodic beacons contain some level of safety critical information which requires that we authenticate the message itself as well as its source. And to do so, some researchers have proposed the use of a digital certificate issued by a trusted certificate authority.

Despite the benefits of the proposed security mechanism, it raises the issue of high communication overhead as it causes the size of the beacon payload to increase by over 200 bytes [5] and consequently leading to a congestion in the communication channel when vehicle density is high. To combat this issue, researchers have proposed in the literature several congestion control algorithms. Peculiar to our interest in this work is the beacon size control strategies (certificate omission schemes) proposed in the literature [6–9]. The general idea of these certificate omission schemes is to adapt the beacon payload size whenever the communication channel is observed to be congested by omitting the digital certificate attached to the beacons. However, these strategies are faced with the issue of how to significantly minimize and maintain a steady packet loss (NPL and CPL) even as traffic congestion in the vehicular environment increases.

In this paper, we tackle the aforementioned issue by proposing an Artificial Intelligence-based Transmission Power-Control Certificate Omission (AI-TPCO) scheme which is a Beacon Size Control (BSC) strategy supplemented with an intelligent Transmission Power Control (TPC) strategy. In this work, we perform an intelligent adaptation of vehicle transmission power by using an Artificial Intelligence (AI) algorithm like fuzzy logic and an NbCO [7] strategy to tune beacon size in order to effectively control channel congestion.

The structure of the paper is as follows: Sect. 2 presents a literature review of some closely related works. Section 3 covers a detailed explanation of the features and working procedure of our proposed AI-TPCO scheme. Section 4 covers the simulation configuration and implementation. Section 5 presents the performance evaluation of our proposed AI-TPCO scheme against the Periodic Omission of Certificates (POoC) and NbCO schemes. Section 6 covers the conclusion of this work.

2 Related Work

In this section, we review some closely related works.

2.1 Certificate Omission Schemes

Periodic Omission of Certificates (POoC); as the name implies, a POoC [6] strategy operates by attaching a certificate to beacons only on periodic bases. Thus, if a vehicle is expected to send ‘n’ number of beacons within a second, the POoC strategy will require that a certificate affixed to only the ‘nth’ beacon and omit the certificate from the remaining ‘n-1’ beacons it broadcast. Upon evaluation, the performance of this scheme is noticed to be context dependent as CPL increases under situations where vehicle mobility is high and beacon transmission frequency is low and as such compromising vehicle cooperative awareness.

Neighbor-based Certificate Omission (NbCO); in VANETs, vehicles are made aware of other neighboring vehicles through the reception of periodic beacons. And a vehicle upon identifying a new neighbor, records the details of this new neighbor into a neighboring table for reference purposes. Employing the neighboring table concept, the NbCO [7] strategy controls channel congestion by attaching a certificate to a beacon only when it observes an update in its neighboring table. Upon evaluation, the scheme produced promising results as it was able to reduce packet loss. However, its performance was also demonstrated to be context-dependent as it reduced NPL significantly only in situations where vehicle mobility is low and also reduced CPL significantly only in circumstances where vehicles mobility is high. From this, we observe that the NbCO strategy is unable to attain a fair balance between CPL and NPL as its performance conditions are contradictory.

Congestion-based Certificate Omission (CbCO); the Congestion-based Certificate Omission (CbCO) scheme was proposed by [8] to control channel congestion based on the observed Channel Busy Ratio (CBR). As such, the CbCO scheme upon sensing the communication to be free attaches a certificate to all beacons transmitted so as to reduce CPL and when it senses the communication channel to be congested, it omits certificates from subsequent beacons in an aggressive manner by using a POoC strategy. Upon evaluation, the CbCO scheme proved promising as it was able to reduce the total number of packets that were lost (NPL + CPL) within the simulation time. However, when we consider the individual packets that were lost (NPL and CPL) we observe that its performance is no better than previously proposed schemes.

Transmission Power-control Certificate Omission (TPCO); a TPCO strategy was proposed by [9] to maximize cooperative awareness amongst vehicles by minimizing CPL and NPL. The scheme merged the NbCO strategy and a Distributed Transmission Power Control (D-TPC) strategy to efficiently manage channel congestion. And as such, the NbCO strategy was used as a proactive means of preventing channel congestion whereas the D-TPC strategy was used as a reactive means to help vehicles cooperatively reduce channel congestion upon receiving a distress signal. Although this scheme was able to significantly reduce the number of incurred NPL through its reactive congestion control strategy, it was unable to significantly reduce the number of incurred CPL when evaluated against the NbCO strategy since the performance margin between them can be considered negligible.

We consider it worth mentioning that to the best of our knowledge, these were the only works we found in the literature regarding certificate omission strategies.

2.2 Transmission Power Control (TPC) Schemes

As discussed in previous sections, researchers have proposed in the literature many congestion control approaches, an example being the TPC approach. Generally, this kind of approach controls channel congestion by tuning vehicle transmission power in situations where the contention for channel acquisition is high.

A Distributed Fair Power Adjustments for Vehicular environment (D-FPAV) was suggested in the work [10] to maintain the load of the communication channel beneath a predefined value to avoid packet collision in situations where vehicle density is high. In so doing, the transmission power of vehicles is dynamically adjusted upon receiving information on the status of its neighbouring vehicles indicating that the channel load is high. Chang et al. [11] in their work proposed a D-TPC approach to manage channel congestion, without sacrificing cooperative awareness among vehicles. In his approach, vehicles within communication range cooperatively adjust their transmission power upon sensing the channel to be congested or receiving a distress signal from neighbouring vehicles. In [12] the author proposed a Vehicle Density-Based Power Control (VDBPC) strategy that takes in to account the density state of vehicles in the network. In this work, vehicle density was classified into three states (sparse, moderate and dense) and based on the estimated density state, a vehicle adjusts its transmission within the range of high, medium and low transmission power respectively. However, this strategy may be considered as inefficient as the density of vehicles based on which transmission power is adjusted is randomly assumed.

3 AI-Based Transmission Power-Control Certificate Omission Scheme

In this work, we propose an AI-TPCO scheme to address the aforementioned drawbacks of previously proposed certificate omission schemes. As such, our proposed scheme aims at attaining a well-balanced and minimized number of packet loss (CPL and NPL) even as the traffic congestion situation increases in a vehicular environment and consequently maximizing the level of cooperative awareness attained amongst vehicles. To demonstrate an efficient control over channel load, we designed our AI-TPCO scheme to intelligently tune beacon transmission power using fuzzy logic and reactively adapt beacon size using an NbCO scheme. We also proposed as part of our transmission power control approach, a cooperative adaptation of beacon transmission power to enable the fast convergence of channel load to a reasonable value that is below the predefined channel load threshold. In this section, we will discuss in detail how our proposed scheme works.

3.1 Beacon Size Control (BSC) Approach

As was elaborated in previous sections, the security mechanism adopted in the state-of-the-art for secured beaconing significantly increases the beacon payload size which in turn induces an increase in channel load when vehicle density is high. For this reason, we propose that beacon payload size is reactively adapted through the adoption of an NbCO strategy which is triggered based on the estimated channel load. Thus, when a vehicle estimates the channel load to be high, it aggressively adapts its beacon size by attaching a certificate to beacons only upon observing an update in its neighboring table (i.e.: a new neighbor is found). On the other hand, if the vehicle observes the channel load as low, it will switch to a No omission strategy where it attaches a certificate to every beacon it broadcasts. This will as a result prevent the occurrence of CPL when the communication channel is free whereas the NbCO strategy will significantly reduce NPL when the communication channel load is high. In this work, the NbCO strategy is invoked when the channel is observed to be in a Restrictive state and the No Omission strategy is invoked when otherwise.

$$\text{Estimated\_CL} = \text{N} * \left(\text{beacon\_rate} * \text{M}_{\text{length}}\right) \tag{1}$$

We measured the load of the communication channel using the formula in Eq. (1), with Estimated_CL representing a vehicles estimation of the current load of the communication channel, N representing the total number of neighboring vehicles, beacon_rate representing the total number of beacons a vehicle transmits per second and M_{length} representing the size of the beacon payload. We define in Table 1 the pseudo-code for our proposed beacon size control approach.

Table 1. Beacon size control approach (certificate omission strategy)

Data:	Estimated channel load
Output:	Beacon size control
1:	**If** *Estimated_CL* < 40% **then**
2:	Attach certificate to all beacons (No Omission strategy)
3:	Wait time ‘ΔT’
4:	**Else**
5:	**If** *New_neighbor* == True **then**
6:	Attach a certificate to the next beacon
7:	Wait time ‘ΔT’
8:	**Else**
9:	Omit certificate from beacons
10:	Wait time ‘ΔT’
11:	**endIf**

3.2 Transmission Power Control Approach

As a reactive beacon size control approach is generally not efficient enough to combat congestion, we also suggest the proactive and reactive adaptation of beacon transmission power to minimize channel congestion probability which will, in turn, have a positive impact on the number of incurred NPL and CPL. In so doing, we employed the use of fuzzy logic as a decision-making system to enable vehicles adapt transmission power independently and cooperatively. In this section, we will discuss in more detail how our modelled fuzzy logic decision-making system functions.

Independent Adaptation of Transmission Power

In our proposed scheme, we modelled a Single Input, Single Output (SISO) fuzzy logic system which accepts a single crisp value as input and produces a single crisp value as an output. A fuzzy logic decision-making system is divided in to various stages and the first of these stages is the initialization stage where we initialize our input and output parameters with their corresponding linguistic variables and membership functions. In this work, we chose estimated channel load as our input parameter and beacon transmission power as our output parameter. The terms Relaxed, Active and Restrictive are defined as our input linguistic variables and we defined the range for our input variable in accordance to [13] as illustrated in Table 2. Also, the terms Low, Medium and High are defined as our output linguistic variables (ranging from 0 to 20 mW). Figure 1 and Fig. 2 illustrates our input and output membership functions respectively. The remaining stages of our fuzzy logic decision making system is elaborated below:

Table 2. Mapping of channel state to channel load threshold

State	Estimated channel load
Relaxed	$<15\%$
Active	15% to 40%
Restrictive	$>40\%$

Factors Calculation: Generally, an estimation of channel load is the measure of the amount of load occupying the communication channel at any given point in time and as such, it is an efficient means of detecting the congestion probability of the communication channel. Hence, we considered the estimation of channel load as our crisp input. We used Eq. (1) as our channel load estimation formula. Also, in measuring the degree of membership to a linguistic variable from the membership functions, we used both the triangular and trapezoidal membership functions [14].

Fuzzification: at this stage, the input value (crisp value) is converted into a fuzzy input set using the corresponding membership function. Hence, each vehicle uses the input membership function (as defined in Fig. 1) to calculate the degree to which their estimated channel load belongs to the input linguistic variables (Relaxed, Active or Restrictive). This membership degree then becomes our fuzzy input set.

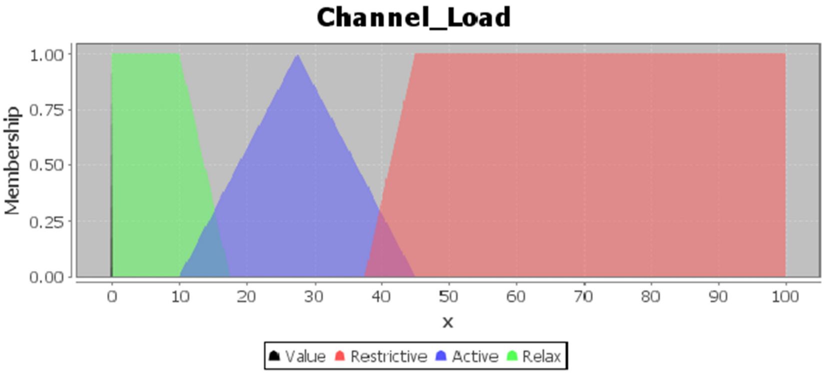

Fig. 1. Membership function for fuzzy logic input parameter (Estimated Channel Load)

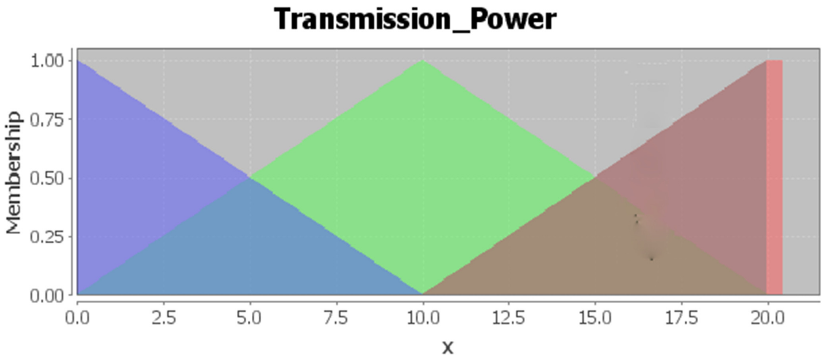

Fig. 2. Membership function for fuzzy logic output parameter (Transmission Power)

Table 3. Fuzzy rule base

	Estimated channel load	Transmission power
Rule 1	Relaxed	High
Rule 2	Active	Medium
Rule 3	Restrictive	Low

Fuzzy Interference Engine: constitutes a list of IF/THEN rules (as specified in Table 3) which forms the decision making brain of the fuzzy system. Here, each vehicle uses the fuzzy rule base to determine to which of the output linguistic variable its fuzzy input value belongs and its corresponding membership degree. As such, a fuzzy output set is generated using the Mamdani fuzzy interference method [15].

Defuzzification: in the defuzzification stage, a crisp output value is generated using the membership function defined for the output parameter (depicted in Fig. 2) and a corresponding degree of membership of the fuzzy output set. In this thesis, we employed the Mean Of Maxima (MOM) method [16] to defuzzify the fuzzy output set. The generated crisp output value then serves as the beacon transmission power of a vehicle.

Cooperative Adaptation of Transmission Power

In addition to the independent adaptation of transmission power by vehicles, we also propose the cooperative adaptation of transmission power (using same fuzzy logic system) upon a vehicle receiving a distress signal from a neighboring vehicle. Thus, when a vehicle estimates its channel load to be high, it generates a distress signal (containing information of the observed channel state) and also piggybacks in to it, its observed number of neighboring vehicles. The distress signal is then broadcast to all neighboring vehicles as a means of informing them of its current state and also soliciting their cooperative support. Therefore, if a vehicle should receive a distress signal, it extracts the piggybacked information (number of neighboring vehicles) and using this information, it estimates the corresponding channel load. Upon estimating the channel load (generated from the piggybacked information), the value is fed into the fuzzy system as input to generate the appropriate transmission power with which it can cooperatively assist in relieving the observed channel condition. Hence, allowing for the effective control of channel load to maximize cooperative awareness amongst the vehicles. Table 4 and Table 5 illustrates the pseudocodes for our proposed transmission power control approach (independent and cooperative transmission power adaptation).

Table 4. Algorithm I: Transmission power control strategy (sending vehicle)

Data:	beacon_rate, M_{length} and N
Output:	Change in channel state, adapted transmission power
1:	Estimate channel load (N = observed no. of neighbors)
2:	**If** *Estimated_CL* > 15% **then**
3:	Set channel state = Active or Restrictive
4:	Broadcast ‘Distress signal’
5:	Generate transmission power (using fuzzy logic)
6:	Wait time ‘ΔT’
7:	**Else**
8:	Set channel state = Relaxed
9:	Generate transmission power (using fuzzy logic)
10:	Wait time ‘ΔT’
11:	**endIf**

Table 5. Algorithm II: Transmission power control strategy (receiving vehicle)

Data:	Distress signal, beacon_rate and M_{length}
Output:	Adapted transmission power
1:	**If** *Distress signal* == True **then**
2:	Estimate channel load (N = no. of neighbors piggybacked in distress signal)
3:	Generate corresponding transmission power (using fuzzy logic)
4:	Wait time ‘ΔT’
5:	**Else**
6:	**Go to** Algorithm I
7:	**endIf**

4 Simulation Configuration and Implementation

As our network simulator, we employed the use of OMNET++ which is an object-oriented modular discrete event network simulation framework that enables the modelling of communication in both wired and wireless networks.

As traffic simulator, we use SUMO is a portable open-source road traffic simulation software that was designed by the Institute of Transportation at the German Aerospace centre to support the simulation of large road networks. In this work, we used SUMO to generate two traffic scenarios. First of which is a 4-way signalized junction as illustrated in Fig. 3 and we imported a real roadmap of Erlangen from Open Street Map as our second traffic scenario as illustrated in Fig. 4. To achieve a dense traffic condition to test the robustness of our proposed scheme, we simulated the communication between 100 to 400 vehicles in each traffic scenario.

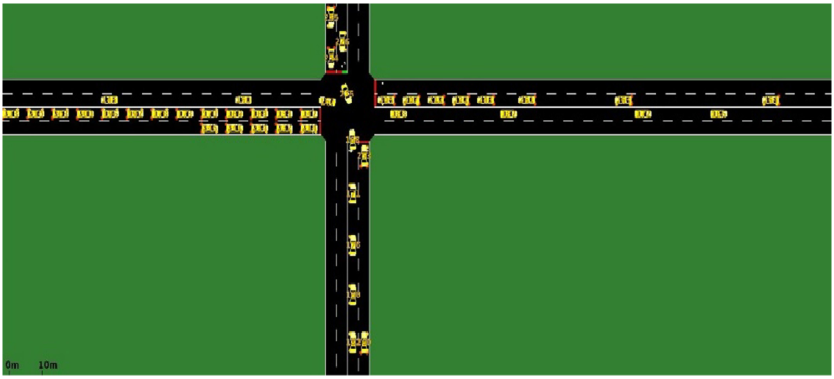

Fig. 3. A 4-way signalized junction

Fig. 4. Erlangen map

Also, we employed the Veins simulation framework which is an open-source VANETs simulation program used to simulate Inter-Vehicular Communication (IVC) by running in parallel the OMNET++ simulator and SUMO simulator. In this work, we extended the Application layer of the Veins framework to model our certificate omission strategy and we also extended the MAC layer of the Veins framework to implement our fuzzy logic based transmission power control strategy.

In Table 6, we present a summary of the network and traffic parameter configurations of our simulation and it is worth mentioning that some of these parameters were configured in conformity with the work of Schoch et al. in [8].

Table 6. Overview of simulation parameters

Parameter	Value	Source location
Number of vehicles	100, 200, 300, 400 vehicles	*.rou.xml
Field size	90 km × 40 km	Omnetpp.ini
Beacon frequency	10 Hz	Omnetpp.ini
Payload size	50 Bytes	Omnetpp.ini
ECC key type	Nistp256, compressed	Omnetpp.ini
Certificate size	125 Bytes	Omnetpp.ini
Signature size	56 Bytes	Omnetpp.ini
MAC	802.11p, 3 Mbit/s	Omnetpp.ini
Max transmission power	20 mW	Omnetpp.ini
Simulation time (sec)	150, 250, 350, 450 s	Omnetpp.ini
Simulation runs	10	Omnetpp.ini

5 Performance Evaluation

In evaluating our proposed AI-TPCO schemes, we performed a comparison between our obtained simulation results and the results obtained from the NbCO and POoC schemes which we considered as the baseline for our comparison. Below are the evaluation metrics we used in our comparison:

- Percentage of CPL: this criterion shows the percentage of CPL incurred during the simulation time. Thereby giving a clear indication of the level of cooperative awareness achieved.
- Percentage of NPL: this metric measures the percentage of NPL incurred during the entire simulation time and as such gives us an estimate of the network performance. As well as the level of cooperative awareness achieved.

Figure 5 and Fig. 6 show the evaluation results in the 4-way signalized junction scenario, whereas Fig. 7 and Fig. 8 show the evaluation results in the Erlangen map scenario.

From Fig. 5, we noticed that when the vehicle population is 100, the POoC, NbCO and AI-TPCO schemes incurred an NPL percentage of 16.06, 8.28 and 12.26 respectively. Here, we observe that our AI-TPCO scheme performed slightly poor as it incurred 3.98 of NPL more than the NbCO strategy. This we believe is a result of the No Omission strategy we perform when channel load is observed to be below a defined threshold. However, as the number of vehicles begins to increase from 100 to 400, the simulation results show that our AI-TPCO strategy outperforms both the POoC and NbCO strategies. When the number of vehicles is 400, we see that our AI-TPCO scheme incurs an NPL percentage of 19.49 which is approximately two times lower than that of the NbCO scheme and approximately three times lower than that of the POoC scheme. Implying that our AI-TPCO scheme can reduce NPL drastically even as channel load or vehicle population increases. We, therefore, attribute this efficient channel control performance demonstrated by our AI-TPCO scheme to the proactive and reactive strategies we adopted in our scheme.

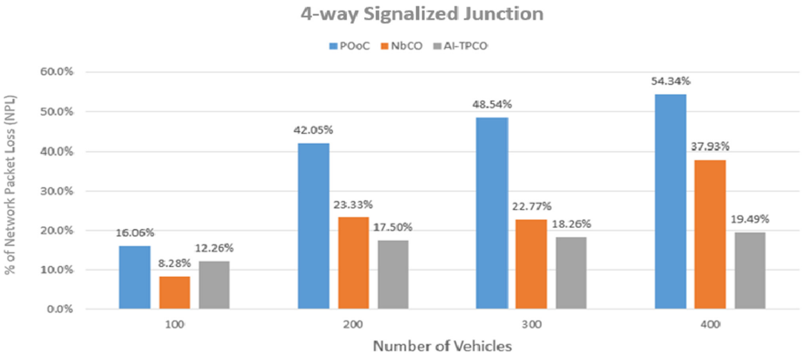

Fig. 5. Percentage of NPL (4-way signalized junction)

Figure 6, depicts the variations in CPL with vehicle population for each congestion control strategy. We compared the percentage of CPL incurred in POoC, NbCO and AI-TPCO schemes as we gradually increase the vehicle population from 100 to 400. The simulation results prove that our proposed AI-TPCO scheme is more efficient at decreasing CPL as it recorded a CPL percentage of 1.85, 2.74, 2.72 and 2.67 (as vehicles increases from 100 to 400 respectively) which is approximately three times lower than that of POoC and NbCO. Hence, making our AI-TPCO scheme the first certificate omission scheme to significantly outperform the NbCO scheme at reducing CPL.

However, when vehicle population is 200 we observe that our proposed AI-TPCO scheme and the POoC scheme incurred its highest CPL and this is because of the indirect impact NPL has on CPL. Thus, depending on the kind of beacon (with certificate or without certificate) that is dropped during a NPL, there may be an effect on CPL. Hence, we deduce that majority of the beacons that were dropped in NPL when vehicle population is 200 were possibly beacons with certificates attached and as such affecting the incurred number of CPL in these schemes when vehicle population is 200.

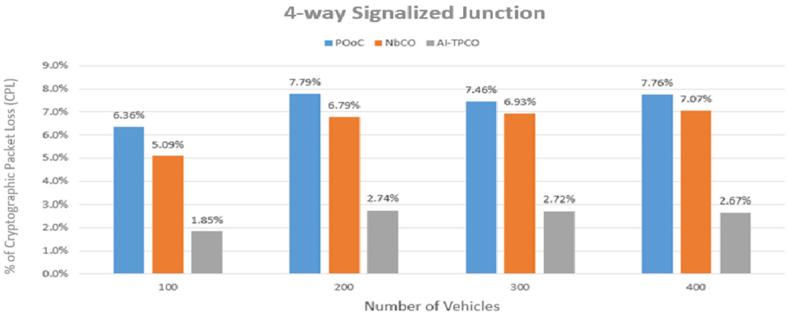

Fig. 6. Percentage of CPL (4-way signalized junction)

In the Erlangen scenario, our proposed AI-TPCO strategy is evaluated using the same evaluation metrics as was used in the highway scenario. Figure 7 and Fig. 8 illustrates the results obtained from this scenario. From Fig. 7, we observe that as the vehicle population increases, the percentage of NPL continues to increase across all the omission strategies under study. For instance, using POoC, NbCO and AI-TPCO, the percentage of NPL are 22.63, 23.45 and 9.59 respectively when the population of the vehicles is 200. And 49.76, 37.08 and 11.99 respectively when the population of vehicles is 300. From the given example, the difference between the two results is 27.13, 13.63 and 2.4 respectively. With this difference, we deduce that our proposed scheme better improves network performance as it can suppress NPL significantly even as the vehicle population increases.

When vehicle population is 300 we observe that all the schemes incurred their highest NPL and this we attribute to the random assignment of routes to vehicles. Thus, in our simulation routes were randomly assigned to the vehicles on the map and as such, the routes vehicles take when their population is 100 is different from the routes the vehicles will take on the same map when their population is 200. Hence, we deduced that due to this random assignment of routes, vehicles experienced higher clustering when their population was 300 which consequently increased traffic congestion and as a resulting affecting the number of NPL incurred.

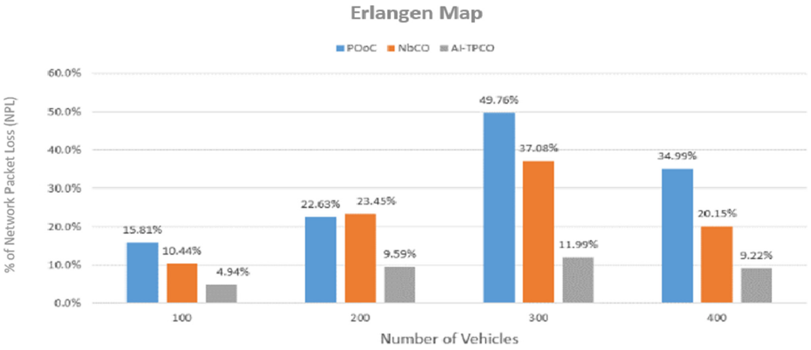

Fig. 7. Percentage of NPL (Erlangen Map)

The results in Fig. 8 show that our AI-TPCO scheme was able to outperform the POoC and NbCO schemes significantly by a performance margin of 4.83 and 3.35 respectively when the vehicle population is 100. And this performance margin is seen to be maintained even as the vehicle population increases from 100 to 400. Hence, comparing the results obtained from the 4-way signalized junction and the Erlangen map scenarios, it is clear that our proposed scheme is consistent at maintaining its performance (of decreasing CPL) regardless of the traffic scenario underuse. Once again, when vehicle population is 300 we observe that the POoC scheme and the NbCO scheme incurred its highest CPL and as we previously explained, we attribute this to the indirect impact NPL has on CPL.

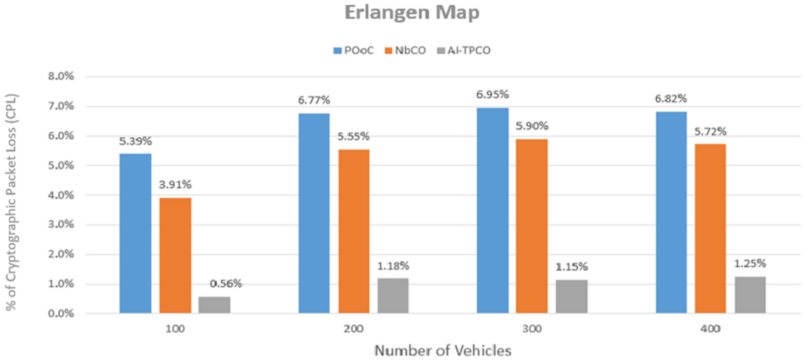

Fig. 8. Percentage of CPL (Erlangen Map)

Comparing results obtained from both traffic scenarios (4-way signalized junction and Erlangen map) we can conclude that our proposed AI-TPCO scheme significantly outperforms the other strategies as it is able to demonstrate effective control over the communication channel even as the vehicle population increases. Thereby maximizing cooperative awareness amongst vehicles.

6 Conclusion

In this paper, we addressed the drawbacks of existing certificate omission strategies and as such we investigated how to significantly decrease CPL and NPL incurred. And we did this with the ultimate aim of maximizing cooperative awareness amongst vehicles even as traffic congestion increases in the vehicular environment. In so doing, we proposed an AI-TPCO scheme that combines the strengths of both a TPC and BSC strategy to effectively control channel congestion in VANETs. To detect congestion, the proposed scheme estimates channel load and uses the TPC and BSC strategy to respectively control channel congestion proactively and reactively. The TPC approach of our proposed scheme controls congestion by tuning the transmission power of vehicles independently or cooperatively using fuzzy logic, whereas the BSC approach of our scheme controls congestion by tuning the beacon size using a No omission or NbCO strategy.

The obtained simulation results justify our claims that the proposed AI-TPCO scheme can incur a significantly low and balanced number of NPL and CPL even as the traffic congestion increases. Thereby justifying consequently that the scheme can maximize cooperative awareness amongst vehicles and also exhibit an effective mastery over the communication channel in both traffic scenarios used.

In conclusion, we have demonstrated through our work that when a beacon size control strategy is supplemented with an intelligent transmission power control strategy, the strategy gains mastery over the communication channel and as such maximizes vehicle cooperative awareness.

References

1. Williams, J.: Horseless Carriages: Road Vehicles. The Electric Century, pp. 136–146 (2017)
2. Peterson, B.: Car Ownership Statistics (2021 Report). ValuePenguin (2021). https://www.valuepenguin.com/auto-insurance/car-ownership-statistics. Accessed 7 Sept 2021
3. Litman, T.: Autonomous vehicle implementation predictions: implications for transport planning. Trid.trb.org (2021). https://trid.trb.org/view/1678741. Accessed 7 Sept 2021
4. Liu, X., Jaekel, A.: Congestion control in V2V safety communication: problem, analysis. Appr. Electr. **8**(5), 1–24 (2019)
5. Feiri, M., Petit, J., Kargl, F.: Evaluation of congestion-based certificate omission in VANETs. In: 2012 IEEE Vehicular Networking Conference (VNC), pp. 101–108 (2012)
6. Calandriello, G., Papadimitratos, P., Hubaux, J., Lioy, A.: On the performance of secure vehicular communication systems. IEEE Trans. Depend. Secur. Comput. **8**(6), 898–912 (2011)
7. Feiri, M., Petit, J., Kargl, F.: Congestion-based certificate omission in VANETs. In: Proceedings of the ninth ACM International Workshop on Vehicular Inter-Networking, Systems, And Applications - VANET 2012, pp. 135–138 (2012)
8. Schoch, E., Kargl, F.: On the efficiency of secure beaconing in VANETs. In: Proceedings of the third ACM Conference on Wireless Network Security - WiSec 2010, pp. 111–116 (2012)
9. Dapaah, E., Memarmoshrefi, P., Hogrefe, D.: Transmission power-control certificate omission in vehicular ad hoc networks. In: Ad Hoc Networks, pp. 164–176 (2021)

10. Torrent-Moreno, M., Santi, P., Hartenstein, H.: Distributed fair transmit power adjustment for vehicular ad hoc networks. In: 2006 3rd Annual IEEE Communications Society on Sensor and Ad Hoc Communications and Networks (2006)
11. Chang, H., Song, Y., Kim, H., Jung, H.: Distributed transmission power control for communication congestion control and awareness enhancement in VANETs. PLoS ONE **13**(9), 1–25 (2018)
12. Akinlade, O.: Adaptive transmission power with vehicle density for congestion control. Scholarship at UWindsor (2021). https://scholar.uwindsor.ca/etd/7420/?utm_source=scholar.uwindsor.ca/etd/7420&utm_medium=PDF&utm_campaign=PDFCoverPages. Accessed 7 Sept 2021
13. Anon, n.d. https://www.etsi.org/deliver/etsi_ts/102600_102699/102687/01.01.01_60/ts_102687v010101p.pdf. Accessed 7 Sept 2021
14. eMathTeacher, n.d. Mamdani's fuzzy inference method - Membership functions. http://www.dma.fi.upm.es/recursos/aplicaciones/logica_borrosa/web/fuzzy_inferencia/funpert_en.htm. Accessed 7 Sept 2021
15. Mamdani Fuzzy Model (n.d.). http://researchhubs.com/post/engineering/fuzzy-system/mamdani-fuzzy-model.html. Accessed 7 Sept 2021
16. Coursehero.com. (n.d.) Chapter 5 Defuzzification Methods.pdf-Chapter 5 Defuzzification Methods Fuzzy rule based systems evaluate linguistic if-then rules using fuzzification|Course Hero. https://www.coursehero.com/file/52969005/Chapter-5-Defuzzification-Methodspdf/. Accessed 7 Sept 2021