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Enhancing the Reliability of Cognitive Radio Vehicular Ad-Hoc Network using Markov Chain Modeling Process and Determine Radio Transmission Range

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Abstract— As a part of an intelligent transportation system, a Vehicular Ad-Hoc Network (VANET) requires reliability by way of an essential need. Timely and accurately delivering safety messages in VANET is one of the reliability issues affected by different factors such as the lack of frequency spectrum as well as nodes' inabilities or misbehaviors. To overcome spectrum shortage, Cognitive Radio (CR) has been proposed while employing a trust mechanism can lessen any damage caused to reliability by incapable or misbehaver nodes. An effective trust management system can analyze 'agree' and 'disagree' messages and decide about an event to increase reliability. However, message transmission based on trust assessment imposes an extra decision delay causing a reliability cutback, especially in delay-sensitive safety messages. In this research, an effective trust management system for CR-VANET is proposed and analyzed based on a Birth and Death Process (BDP) model to evaluate the average delay imposed by the decision-making process. The probability of event occurrence is also derived in terms of arrival message rate. Moreover, the minimum and maximum permissible range of radio transmission to reach an acceptable degree of reliability, based on the above analysis, is determined. Simulation results show that, using the proposed radio transmission range, reliability can be improved by increasing the accuracy of event detection while reducing decision-making and safety message delivery delays.

Keywords: Vehicular Ad-Hoc Networks, Reliability, Trust Management System, Birth and Death Process, Radio Transmission Range

I. INTRODUCTION

VANETs (vehicular ad-hoc network) are created by applying the principle of mobile ad-hoc network. VANETs as a subset of mobile ad-hoc network attracted the attention of numerous researchers [1]. They involve different property according certain aspects, which include specialized applications, unrestricted energy, convenient access to GPS, multi-hop communication and communication with road side units (RSUs).

There are three type application of VANETs: safety, non-safety and entertainment. One of the most important goals of a VANET is to increase the reliability of safety application, and using an efficient MAC protocol is too necessary in achieving this goal [1]. All of these applications, however, jointly use the available bandwidth [2]. To this extent, safety packet forwarding, only after evaluation, is a good way to optimize channel usage and increase reliability.

On the other hand like enhancing the reliability of a VANETs using CR has been demonstrated. CR can reduce the contention period and safety packet delivery delay in adding to enhancing the reliability. In this way, considering this parameter in trust management system design and reliability evaluation is among the contribution of that research.

Many different definitions have been proposed for reliability of MAC layer. Some definition of reliability are careful with right safety message delivery timely delivery of safety message and end to end delay, or average percentage of vehicle to receive a safety message [10]. In order to ignore a multiplicity of reliability definition, the definition adopted here is similar to the capability to take away out the fixed task within the constraints of desired frequency.

So for, abundant activity has been carried out to enhancement networks reliability although nothing noticeable has been conducted to examine the fact of trust management system on reliability [12]. The existence of malicious and selfish users, or those who cannot send safety message due to software or hardware failure, can burden the arrival of 'agree' message. It make it problematic for the receiver to vaticinator to occurrence of an event before forwarding them is proposed in [14]. Thus considering the required level of reliability in trust management system design is another innovation of our work. We designed a trust management system which can decide upon safety message forwarding depending on nodes' misbehavior and increase the reliability requirements. The proposed trust management system is based on the Markov process. In the course of determining the average decision delay of the proposed model, the maximum radio transmission range to achieve an acceptable level of reliability is also specified in this paper. Simulation results show that using the proposed transmission range can bring reliability to an acceptable level.

Thus, in Section 2, we review some related trust management systems and their challenges. In Section 3, the proposed trust management system is described. Section 3 also discusses the corresponding Markov chain analysis, average decision-making delay and relative probability calculations, while the analytical results and determination of the radio transmission range are presented at the end of this section. Section 4 presents a sample scenario with the simulation results for proposed radio transmission ranges, and we conclude the paper in Section 5 with some suggestions for future study.

II. TRUST MANAGEMENT SYSTEMS

VANET trust management systems are divided into two general categories: static and dynamic [15]. Static models are concerned with privacy while dynamic models deal with trust in relation to entities, data, or both. The authors in [14] proposed a system to analyze different messages about an event before packet forwarding. Their analysis was based only on packets' spatial and temporal similarities and did not consider the required reliability level. The proposed method in [2] divides nodes into reliable and unreliable categories. It also examines the effect of trust on decision-making delay, showing that the consideration of trust values can decrease the message error rate and increase accuracy; however, it is not a good system for a dense network nor does it calculate the amount of decision-making delays and their effect on reliability.

A voting-based system is also presented in [16]. Nodes are divided into reliable and unreliable categories. Different algorithms are used to obtain the percentage of agree nodes for a reported event, regardless of decision-making delays and their side effects.

Most of the proposed methods specialize in the application layer, without cooperating with MAC and network layers, and therefore they cannot guarantee the timely and accurate delivery of safety messages. Considering decision-making, channel sensing and switching delays, a trust management system is presented in this paper in which reliability can be guaranteed based on the analysis of incoming messages and determining the radio transmission range.

Moreover, a trust management system in a VANET can be faced with the following challenges: vehicle congestion and high-information overload, considering temporal and spatial distance in decision-making delays, scalability [15], being able to make a decision in low-density networks, short-time communications, the existence of misbehaver nodes [16], RSU inaccessibility, and dynamic topology [17]. Thus, the proposed trust management system acts in such a way that it can decide on the happening of an event, regardless of, as far as possible, the above-mentioned challenges. It can access a channel after a reasonable delay following the receipt of a safety message. As such, this system can guarantee the required level of reliability because it can deliver the safety message in a timely and accurate manner to related vehicles.

According to scientific reports, the maximum allowable latency and radio transmission range in single-hop communications are 100ms and 50m~300m respectively [18]. However, to the best of the authors' knowledge, there is no work to date which has focused on the determination of network parameters for multi-hop communication to increase reliability.

III. PROPOSED TRUST MANAGEMENT SYSTEM

When an event occurs various reactions might be triggered. Some vehicles are in an area where they can see the event directly (risk zone). While other vehicle receive the safety message from others (decision area). They should decide on the accuracy on this message and their reaction. In order to be efficient, safety message should not have more than 200 millisecond of delay (18). In CR-VANETs, this time should be the total time needed for message production, channel access (channel sensing and switching), propagation and decision making on the receiver side. Therefore, the event to reaction delay (ERD) can be written as:

$$\mathrm{ERD} = \mathrm{D_{pd}} + \mathrm{D_c} + \mathrm{D_{prc}} + \mathrm{D_{prop}} \qquad (1)$$

In Equation 1, D_{pd} is the message production delay, D_c is the channel access delay, D_{prc} is the message processing delay on the receiver side, and D_{prop} is the message propagation delay. In a CR network with a total no of k =10 channel, each with 10 mbps of achievable data rate and 4 MHz channel space. The average end to end delay is, at most, 20ms [19]. By taking ERD=200, the processing time should be less than 180ms so that a safety message can be delivered to all vehicles in the decision area before 200ms has elapsed. Therefore in order to guarantee the timely and accurate delivery of safety message in CR-VANET, we want to determine R in such a way that ERD is less than 200ms.

A. Markov Chain Analysis

The Markov chain is a tool for optimal decision- making have frequently being used in wireless network [20]. Based on the Markov process we also proposed and analyze a trust management system to enhance the reliability of cognitive radio VANETs. We suppose that the arrival rate of 'agree' and 'disagree' regarding an event are based on the Poisson process with the rate of λ and μ [20] [21]. It is also assumed that the neutral message does not exist, with each vehicle expressing its opinion about an event in terms of either 'agree' or 'disagree'. Therefore in order to determine the event occurrence, we count the number of agree and disagree message using Birth Death Process. Each state in BDP shows the resulting number of disagree message. The markov chain corresponding to this system is shown in figure 1.

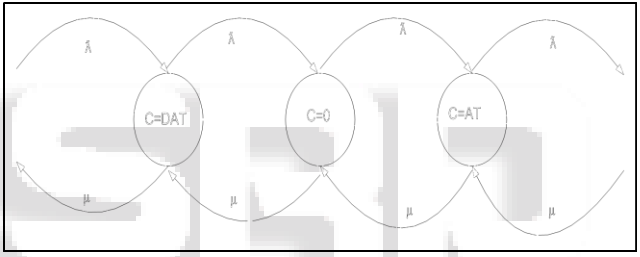


Fig. 1: Markov chain modeling the no of received message

If the total no of 'agree' message crosses the threshold of the agree opinions (AT: agree threshold), the vehicle votes to recognize an event occurrences and enter the channel access phase. If the total no of disagree message crosses the thresholds message crosses the thresholds of the disagree opinions (DAT: disagree thresholds) the vehicle votes to recognized an event non-occurrences and discard the message. Obviously, the value of AT and DAT can differ, depending on the application requirements.

In order to conduct a simpler analysis of the proposed decision making system, we should shift the chain in figure 1 to the right side so that the DAT line can be adjusted to the zero state c=0 means that is no event occurrences while reaching state c=T=AT+DAT means that there is an event occurrences. Now this scenario is highly similar to gambler's problem, where each gamblers start his game with n initial cash. The gambler's then win/losses one dollar in each round, and the game ends after all the money (reaching state c=0) has been lost.

We want to find the losing/winning probabilities (probability of an event occurrences or non-occurrences) and the average time period to loss/win (decision making delay). Using these result, we can defined the maximum minimum values of R, such that competition decreases and reliability increases.

At first we need to calculate the probability from going state I to i+1, and vice versa. We call these two probabilities $p = (P_{i,i+1})$ and $q = (P_{i,i-1})$, while we defined a rate metrics (Q) as follows

$$Q = \begin{bmatrix} -\lambda & \lambda_0 & 0 & 0 & ..... \\ \mu & -(\lambda_1+\mu_1) & \lambda_1 & 0 & ..... \\ 0 & \mu_2 & -(\lambda_2+\mu_2) & \lambda_2 & ..... \\ 0 & 0 & \mu_3 & -(\lambda_3+\mu_3) & ..... \end{bmatrix} \quad (2)$$

Based on Kolmogorov forward equations. The transition probability of P (t) is calculated using the following equation:

$$P'(t) = P(t)Q \quad (3)$$

Assuming that $p(0) = I$, we can use the following equation to calculate the exact value of *P (t)*

$$P(t) = e^{Qt} \quad (4)$$

Matrices e^{Qt} can be estinimitated by the following exponential series:

$$e^{Qt} = \sum_{n=0}^{\infty} \left(\frac{Q^n}{n!}\right) = I + \sum \left(\frac{Q^n t^n}{n!}\right) \quad (5)$$

Considering the initial state (primary population, the amount of primary dollar or the initial trust value about a reported event) is very important when analyzing the chain presented in figure 1, given that the opinion of a vehicle is related to its prior experience in an experience based trust management system [17]. This number can be any value bigger than zero, depending on the application requirements; we consider this to be n. in environment where the probability of neighbor's misbehavior is low, the initial value of c can be considered as a bigger positive number, meaning that the decision can be made faster. The same analysis can be made to verify hardware or software failures.

Figure 2 shows the probability of moving to the right on receiving an agree message moving to left and disagree message, and probability of steady state.

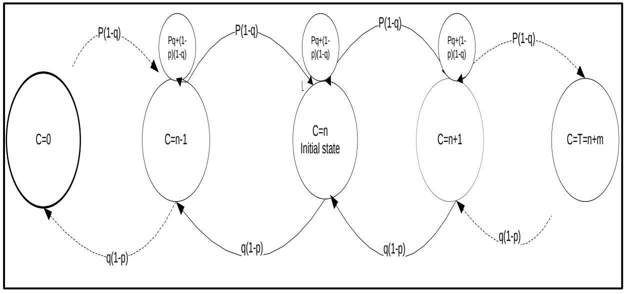


Fig. 2: Markov chain modeling for the proposed trust management system

Using MATLAB symbolic equation toolbox, transition probabilities are derived for a process with three, four and five states. These probabilities will be used to determines the average decision making delay in addition by using these numbers, the maximum and minimum amount of R will be obtained so that reliability can be guaranteed.

States higher than five will not be used be caused firstly it will seems that a five decision making states system represent a good approximation in the [0-1] trust range. Secondly for states higher than five, analytical result show that the decision making delay more than the time required for human reaction (700ms). Thus this system would no longer be efficient. In order to prevent repetition and redundancy, only the two states chain metrics is presented in equation 6, we will only present the result of other states equations:

$$P(t) = \begin{pmatrix} \frac{\mu+\lambda e^{-(\lambda+\mu)t}}{\lambda+\mu} & 1 - \frac{\mu+\lambda e^{-(\lambda+\mu)t}}{\lambda+\mu} \\ 1 - \frac{\lambda+\mu e^{-(\lambda+\mu)t}}{\lambda+\mu} & \frac{\lambda+\mu e^{-(\lambda+\mu)t}}{\lambda+\mu} \end{pmatrix} \quad (6)$$

We start with a c=n primary population to produce with our analysis, we reiterate that when we reach state c=0 or c=T the result is obtained (event occurrence or non-occurrence) the probabilities of obtaining a occurrences result before a non-occurrences result and expected time decision making to take place, are presented in section 3.1 or 3.2

1) Probabilities of Reaching State Zero before Reaching State

We defines the probabilities of reaching state T (win state or occurrences state) before reaching a zero state by starting from state c=n(W_n) as follows for all states we assume T=n+m:

$$W_n = p\,(1-q)W_{n+1} + q(1-p)W_{n-1} + \big(pq + (1-p)(1-q)\big) \quad (7)$$

$$(p-pq)W_{n+1} + (2pq-p-q)W_n + (q-pq)\,W_{n-1} = 0 \quad (8)$$

By writing the characteristic equation in equation (8), we have:

$$r_1 = 1 \quad (9)$$

$$r_2 = \frac{q(1-p)}{p(1-q)} \quad (10)$$

$$\left\{ \begin{matrix} W_n = A\left(\frac{q(1-p)}{p(1-q)}\right)^n + B\,(1)^n \\ W_0 = 0 \\ W_T = 1 \end{matrix} \right\} \Rightarrow A = -B,$$

$$A = \frac{1}{\left(\frac{q(1-p)}{p(1-q)}\right)^n - 1} \quad (11)$$

Therefore when p and q are not equal, we have:

$$W_n = \frac{\left(\frac{q(1-p)}{p(1-q)}\right)^n - 1}{\left(\frac{q(1-p)}{p(1-q)}\right)^T - 1} \le \frac{\left(\frac{q(1-p)}{p(1-q)}\right)^n}{\left(\frac{q(1-p)}{p(1-q)}\right)^T} = \left(\frac{p(1-q)}{q(1-p)}\right)^{T-n}$$

$$= \left(\frac{p(1-q)}{q(1-p)}\right)^m \quad if\ p \ne q \quad (12)$$

The following is an example of a chain with 4 statuses:

$$\left\{ \begin{matrix} (p_{12}-p_{12}p_{10})W_2 + (2p_{12}p_{10} - p_{12} - p_{10})W_1 + (p_{10} - p_{12}p_{10})W_0 = 0 \\ (p_{23} - p_{23}p_{21})W_3 + (2p_{23}p_{21} - p_{23} - p_{21})W_2 + (p_{21} - p_{23}p_{21})W_1 = 0 \end{matrix} \right\} \quad (13)$$

In the above equation $p_{i,j}$ is calculated using equation 3. These values are substituted in equation 13. Since the values of W_0 are always zero, and the values of W_3 are always 1. Only the values of W_1, W_2 are drawn in figure above.

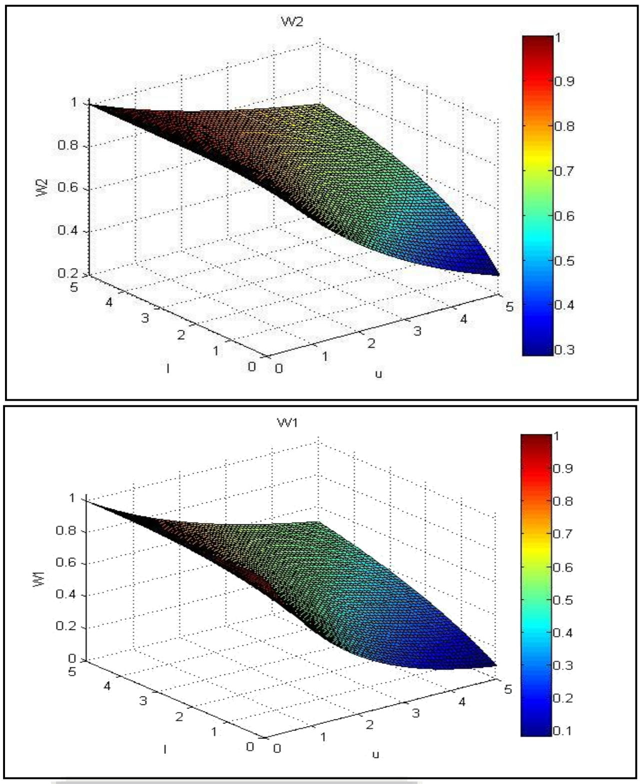


Fig. 3: Probability of obtaining an occurrence result before a non-occurrence result in different states

When considering Equation 11 to 13 and Figure 3, the following results are obtained:

1) Result 1: The smaller the m, the greater the probability of obtaining an event occurrences result.
2) Result 2: when considering the Kolmogorov forward equation, we can see that when i increase, the probability from going state i to state i+1 also increase. Furthermore, as μ increase, the probability from going state I to i-1 also increase, therefore we can conclude that the more μ we have, the less $W_n$probability we have. Similarly, W_n probability can increase with an increase in arrival rate. In other words, the greater the differences betweenλ *and* μ, the closer W_n will be 0 or 1.These results can be useful in environments with very high or low trust, such as urban areas an highway respectively. For example, in urban areas, the probability of communication repeats is high; in that vehicle take precaution with their behaviors. This means that the μ rate decreases. But this is not true for highway with few spectators, such as Road Side Units, where vehicle may act as maliciously or selfishly. Therefore in urban areas with a high λ rate, it is better to choose a lower initial state (lower c) so that we can assure the authenticity of an event. This result can be the basis for a reliability enhancing in the geolocation based trust management system. Some geolocation based trust management system are introduced in [23].
3) Result 3: When the probability of receiving 'agree' and 'disagree' message is equal by increasing n (in fact, by reducing m), an event occurrences result is more probable. In other words, the less m there is, is less probable it is that we will win.

2) *Required Time to Obtain a Result*

We can determine the expected time to obtained a result (event occurrence or the event non occurrences) by starting from state c=n (En) as follows.

$$E_n = p(1-q)(1+E_{n+1}) + q(1-p)(1+E_{n-1}) + ((1-p)(1-q)+pq)(1+E_n) \qquad (14)$$

$$p(1-q)E_{n+1} + \big((1-p)(1-q)+pq-1\big)E_n + q(1-p)E_{n-1} = -1 \qquad (15)$$

By solving the above equation, we have two roots as follows:

$$r_1 = \frac{q}{1-q} \qquad (16)$$

$$r_{2=\frac{p(q-1)-q}{p(1-q)}} \qquad (17)$$

$$E_n = A\left(\frac{q}{1-q}\right)^n + B\left(\frac{p(q-1)-q}{p(1-q)}\right)^n \qquad (18)$$

In order to arrive a particular answer, we assume $E_n = an + b$ to be answer to the equation, while we calculate a and b values by putting the answer in to the equation 16:

$$b = 0 \qquad (19)$$

$$a = -\frac{1}{p-q} \qquad (20)$$

Then the E_n value is calculated as follows
$(p \neq q)$

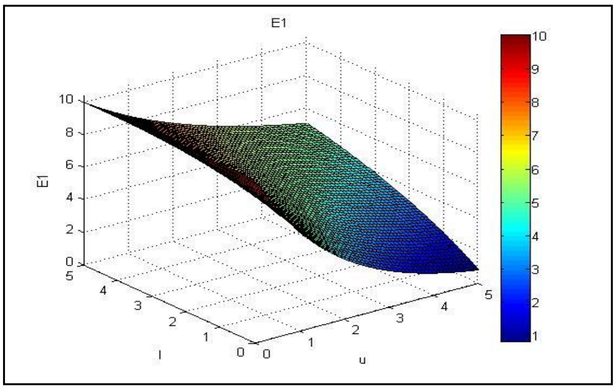
$$\left\{\begin{matrix} E_n = A\left(\frac{q}{1-q}\right)^n + B\left(\frac{p(q-1)-q}{p(1-q)}\right)^n - \frac{n}{p-q} \\ E_0 = 0 \qquad\qquad \to A = -B \\ E_T = 0 \qquad \to A = \dfrac{\frac{T}{p-q}}{\left(\frac{q}{1-q}\right)^T - \left(\frac{p(q-1)-q}{p(1-q)}\right)^T} \end{matrix}\right\} \qquad (21)$$

$$E_n = \frac{T}{p-q}\,\frac{\left(\frac{q}{1-q}\right)^n - \left(\frac{p(q-1)-q}{p(1-q)}\right)^n}{\left(\frac{q}{1-q}\right)^T - \left(\frac{p(q-1)-q}{p(1-q)}\right)^T} - \frac{n}{p-q} \quad if\ p \neq q \qquad (22)$$

4) Result 4: If $p > q$ and $T \to \infty$ then $E_n \to \frac{n}{p-q}$. this case shows that, in situation where λ is low, taking in to account a greater initial trust value or a higher number of steps only increase the decision- making delay.
5) Result 5: If $p > q$ and $T \to \infty$ then$E_n \to \frac{n}{q-p}$. Unlike the previous case, when the probability of receiving an agree message is high, the decision making delay is also limited to a specific value.

We solve the above equation for a Markova chain with four states, as presented in the charts in Figure.

$$\left\{\begin{matrix} p_{12}(1-p_{10})E_2 + ((1-p_{12})(1-p_{10}) + p_{12}p_{10} - 1)E_1 + p_{10}(1-p_{12})E_0 = -1 \\ p_{23}(1-p_{21})E_3 + \big((1-p_{23})(1-p_{21}) + p_{23}p_{21} - 1\big)E_2 + p_{21}(1-p_{23})E_1 = -1 \\ E_3 = 0 \end{matrix}\right\}$$



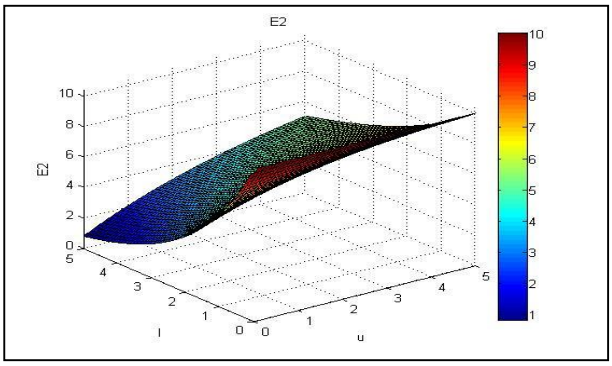


Fig. 4: Average decision delay in a four state Markov chain

According to the equation and figure, we can arrive at the result given below:

6) Result 6: If m→ ∞ *then* $E_n \to \infty$. this state indicate that, as the no of steps increases, or the degree of initial trust values decreases, the amount of time required to obtain a result increases.
7) Result 7: Even if we start with $n = 1$, it is possible to receive massage ad infinitum without ever obtaining a result.
8) Result 8: Starting with c=n and p=q, the probability of non-occurrence of an event is equal to 1. Here is the proof:

for all T:p("non-occurence")>p(reaching "non-occurence\" " before reaching "occurence"

$= 1 - \mathrm{p(reach\ T\ before\ go\ broke)}$

$= 1 - \frac{n}{T} \to 1 \text{ as } T \to> \infty.,$

In this case Kolmogorov equation for steady states cannot be simplified. In other words, neither the transition metrics derivative nor the transition probability matrix is zero when time goes to infinity.

9) Result 9: By considering result 4 and 5 we can conclude that we have two ways to reduce the required time for decision making. The first is to reduce n as much as possible (or reduce to difference between T and n in small Ts) while the second is to increase the difference between p and q as much as possible (or the difference between λ *and* μ respectively). In this respect, we will provide a way for increasing the difference p and q.

IV. DEDICATED RADIO TRANSMISSION RANGE

Since the values of p and q are related to λ *and* μ, the important point is the definition of these two parameter. We defined these two parameter using equation 24 and 25. All parameters definition are stated in table

$$\lambda = \frac{N_{tr} mV}{d} \qquad (24)$$

$$\mu = \frac{N_{tr}(1-m)d}{V} \qquad (25)$$

$$N_{tr} = 2\beta r \qquad (26)$$

We can now rewrite equation 24 as follows:

$$\lambda = \frac{2V\beta Rm}{t} \qquad (28)$$

According to 28 each i increases, the probability of misbehavior increases, and λ decreses. In other words, by increasing the average distance between vehicles, the distance from the event area increases, thus, the agree message arrival rate may decreases while the possibility of misbehavior increases. The ratio of well-behaved nodes can be estimated based on the quality of previous relationship

Name	Definition
λ	Agree message arrival rate (in 100ms)
μ	Disagree message arrival rate (in 100 ms)
N_{tr}	The average no of nodes in a nodes range
B	Nodes density in network (in vehicle per meter)
R	Radio transmission range
M	Nodes well behavior ratio
V	The average vehicle speed
D	The average distance between vehicle
T	Time to travel d meter by speed V
AT	The no of required agree message for decision
DAT	The no of required disagree message for decision

Table 1: Parameters definition

According to result 9 and equation 28, there are four possible ways to increase the difference between λ *and* μ: by increasing the value of β, R *and* m, or decreasing the value of t. as we assume the values of β, m and t to be constant, the only remaining way is to increase R, but what are the preferred minimum and maximum value for R. Allowable communication range for safety in a single hope is determined as 50-300 in [18]. Bat, as we will show in section 4, a constant radio transmutation range cannot guarantee the reliability parameter in a long platoon.

The minimum value should be determined in such a way that the sum of decision making delay and the average E2E delay for safety message is less than the human reaction time. The minimum value of R should be at least S*d, which means that we need to make sure that AT or DAT message are received in a reasonable time.

In order to find the maximum value of R, we choose λ im such a way that the decision making delay is lower than 180ms. According to equation 28, by assuming constant value for β and m in a specific period of time in the network, R can be determined as follows:

$$R = \frac{\lambda \times t}{2V\beta m} \qquad (29)$$

In equation 29, choosing the maximum value of λ depend upon the no of states Markova chain. According to figure 5 and 6, we choose the maximum value of λ equal to 30 and 5 respectively. Where λ is greater than these two value, the decision making delay may greater than 180ms as for as safety message may not be effective.

Table II presents a selection of proposes Rs according to equation 29, different densities and misbehavior probabilities. Distance between vehicle are selected in such a way the time distance between each vehicle is less than the human reaction time, meaning that we can evaluate the reliability and efficiency of the proposed trust management system. A comparison between the analytical and the simulation result is made in the next section

Vehicle Avg. distance	Related β	Avg. vehicle speed	Max derivative R
10	0.1	20	75
20	0.05	20	300
30	0.03	20	750
40	0.025	20	1200

Table 2: proposed R in a four state decision making system V=20m/s $\lambda_{max} = 30$

V. PERFORMANCE EVALUATION

This section chose how choosing optimum radio transmission range can increase the reliability of network and accuracy of a trust management system. Consider a platoon of a 100 cars travelling on a highway with an average speed of $V=20\frac{m}{s}$. Figure depicts this scenario.

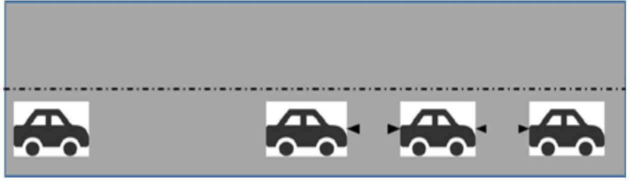


Fig. 5: The scenario considered in simulation

VI. RESULTS AND DISCUSSIONS

We suppose that the head of the platoon (V99) sees an event after a certain period of time. The head of the platoon immediately decrease its speed at the rate $8\frac{m}{s^2}$ and sends safety packet with a high rate value to the other vehicle. Each vehicle uses a trust management system with four statuses as mentioned in section 3. A packet with trust value between 0.5 and 1 means that it agrees with an event. While a trust value between 0 and 0.5 means it disagree with an event. In each situation a malicious vehicle may involve, which sends the reverse its decision about an event to the others. Each vehicle should make a determination with in 180ms.

If the resulting number of agree and disagree message is less than the specific threshold, after 180 MS, we should only judge on the basic of the number of received message. In other words, if the no of received agree message is positive, we can announce an event occurrence and vice versa. Other simulation parameter in table III .as cognitive radio framework is used here to simulate the network and evaluate the reliability. Using Macon each vehicle can chose a channel randomly from k =10 available channel. Figure 8 present a comparison between two different decision making systems.

Feature	Value
Simulation run for each configuration	3
MAC protocol	Macon
Type of road	Highway with single lane
Vehicle speed	70km/h
Distance between vehicle	10,20,30,40 m
Transmission range	50-1200 m
Accident detection	Distance less than 4 meter

Table 3: Simulation configuration

In all states the result for low constraints are equal to, or better than, those for high constraints. In other words increasing the decision making time has a negative impact on system reliability. Thus we choose the low constraints to increase the reliability parameter in the next simulator.

According to the derived R in Table II, Figure 15 shows the Comparison between numbers of hands-off vs. number of nodes safety message to the last vehicle in the platoon.

Each vehicle may either detect an event correctly (TP: true positive) or mistakenly detect an event (FN: false negative). In turn, we can calculate the accuracy of the trust management system in relation to event detection as follows:

$$\text{Accuracy} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

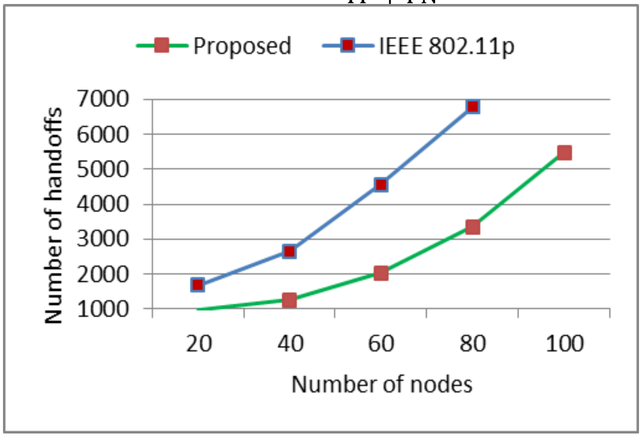


Fig. 6: Comparison between numbers of hands-off vs. number of nodes

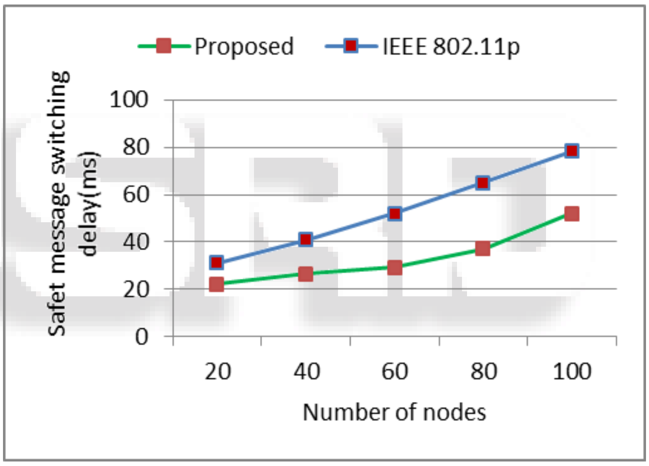


Fig. 7: Comparison between numbers of safety message switching delay vs. number of nodes

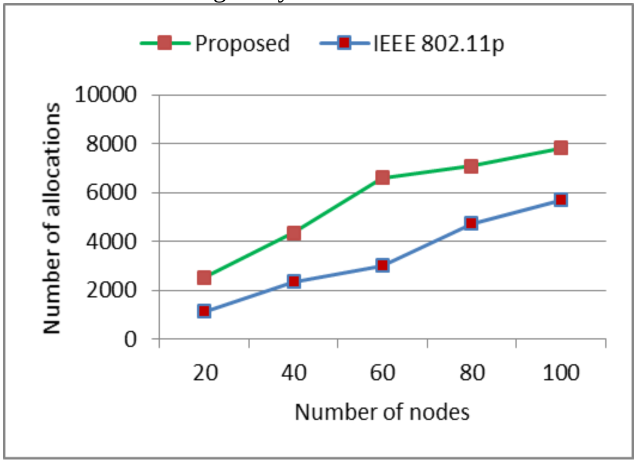


Fig. 8: Comparison between numbers of channel allocation vs. no of nodes

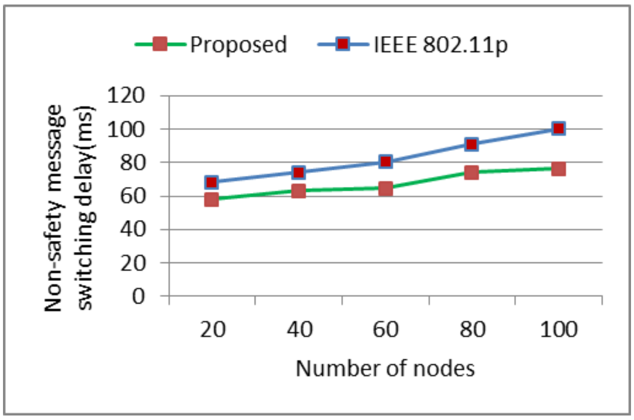


Fig. 9: Comparisons between number of non safety message switching delay vs. no of nodes

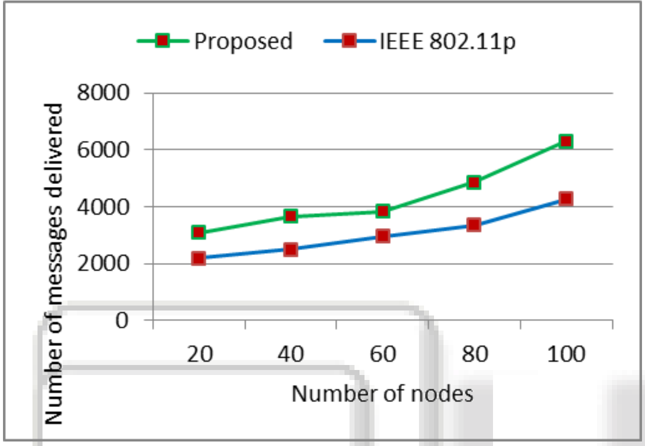


Fig. 10: Comparison between numbers of message delivered vs. no of nodes

In figure 16 shows the comparisons between numbers of safety message switching delay versus no of vehicle nodes. We had seen that when we increase the no of nodes the safety message switching delay also increases.

In figure 17 comparisons between numbers of channel allocation versus no of nodes. When the no of nodes is become large the channel allocation is not possible for all users.

Figure 18 shows the comparisons between numbers of non safety message switching delay versus no of nodes. We have seen that the difference between the safety messages switching delay is less than difference between non-safety message switching delays.

Figure 19 shows the no of message delivered versus no of vehicle nodes. As the no of vehicle nodes increase the message delivered are also increases.

As a result, in networks with high misbehavior probabilities, we should increase the transmission range so that we can increase the probability of receiving safety messages in a timely and accurate manner. In this case, a greater number of nodes are able to receive a true event report directly, regardless of misbehaviors. It is clear that the imposition of this policy can eventually increase reliability. However, we must note that increasing R to a greater value than the proposed value can have two negative effects. First, it increases λ, which, according to the presented analysis in Section 3.2, may increase the decision-making delay to such an extent that the trust management system will lose its efficiency. Second, the channel collision rate and the dropped packet rate may increase when choosing high values for R.

VII. CONCLUSION

Reliability and trust are considered as the two of the main requirements for intelligent vehicular networks. Managing trust elaborately, along with holding the decision-making delay below its desired value, plays a considerable role in increasing reliability. To this end, a method was presented in this article based on deriving the probability of event occurrence using a Markov chain to maintain the safety message transmission delay below its acceptable value. Furthermore, as cognitive radio technology is considered an innovative solution to spectrum scarcity in vehicular networks, the proposed trust management system was applied to a CR-VANET to improve the reliability of such networks. Simulation results show that by keeping the coverage of transmission below the range derived by analysis, the delay elapsed in safety message delivery would be at its acceptable level. Moreover, the accuracy of critical message delivery was measured in terms of the percentage of malicious nodes, showing that the proposed algorithm may reach 100% accuracy when the probability of having malicious communicating vehicles is low.

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