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Deploying an Efficient Safety System for VANET

Ghassan Samara
Department of Computer Science
Faculty of Science and Information Technology, Zarqa Private University,
Zarqa, Jordan

Mohammad Rasmi
Department of Software Engineering
Faculty of Science and Information Technology, Zarqa Private University,
Zarqa, Jordan

Abstract— The rapid development of wireless communication networks in recent years has made vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications possible in mobile ad hoc networks (MANETs). It has also led to the development of a new technology called vehicular ad hoc network (VANET), which aims to achieve road safety, infotainment, and a comfortable driving experience. It can support safety systems designed to avoid road accidents in two ways: 1) periodic transmissions (beacon) from all vehicles that inform neighbors about their current status, and 2) dissemination of emergency messages to warn other vehicles to avoid the danger.

The intent of the research is to propose an efficient safety system for VANET by designing communication protocols and techniques to provide the means for successful transmission of safety-related information. Therefore, three protocols based on power control, contention, and position-based mechanisms are proposed to shape data traffic, such that messages are received with high probability and reliability where they are relevant.

First, a method Coded Repetition Neighbor Table (CRNT) is proposed in [1], which aims to increase the network awareness to enable the network vehicles to know about current network situations and detect other vehicle movements. Second, a method called Particle swarm optimization Contention Based Broadcast (PCBB) is proposed in [2] for fast and effective dissemination of emergency messages within a geographical area to distribute the emergency message. Third, a method called Particle swarm optimization Beacon Power Control (PBPC) is proposed in [3], which aims to decrease the packet collision resulting from periodic messages leading to the control of the load on the channel while ensuring a high probability of message reception within the safety distance of the sender vehicle.

Using the latest version of Matlab simulator, the merits of all the approaches, as well as of their synergies are demonstrated. Simulation results show that PBPC is capable of improving the reception rates of beacon messages and increasing the probability of reception of emergency messages over a wide range of distances between sender and receivers. PCBB enhances the delivery of the emergency information to all nodes located in a geographical area by more than 70%. Furthermore, it enables the emergency message to reach greater distances, thus benefiting the incoming vehicles receiving the important information. When PCBB is used in combination with CRNT and PBPC, the dissemination efficiency and delay are considerably improved. Finally, PBPC is capable of improving the channel performance by controlling the channel load resulting from the beacon messages, reducing packet collision by 50%.

Keywords-VANET; Safety System; PBPC; CRNT; PCBB.

I. Introduction

VANET safety applications depend on exchanging the safety information among vehicles (C2C communication) or between Vehicle to infrastructure (C2I Communication) using the control channel.

VANET safety communication can be made by two means: Periodic Safety Message (called Beacon) and Event Driven Message, both sharing only one control channel [4, 5, and 6] 2006).

Emergency Messages are messages sent by a vehicle detect a potential dangerous situation on the road; this information should be disseminated to alarm other vehicles about a probable danger that could affect the incoming vehicles. VANET is a high mobile network where the nodes are moving in speeds that may exceed 120km/h, which means that this vehicle move 33.33m/s, even if these vehicles are very far from the danger, they will reach it very soon, here milliseconds will be very important to avoid the danger [7], and hence there should be a way to deliver the safety information to large number of vehicles in efficient and fast manner, it is also worth noting that the channel conditions affects the efficiency of sending and receiving the safety messages, it also helps to make the system more reliable in safety message delivery which will insure the deployment of the safety system [8 and 9].

Research in VANET technology has evolved into two categories, namely, inter-vehicle communications and road side units (RSUs) (see Figure 1). Inter-vehicle communications represents communications between vehicles, whereas RSUs are placed on various locations, such as roads, signs, and parking areas. Inter-vehicle communications is more technically challenging because this must be supported even when vehicles are stopping and when they are moving [10]. Intra-vehicle communications represents communications occurring within a vehicle; these enable vehicle diagnostics wherein a technician can plug a tester into a port in the vehicle network in order to examine the operational state of various components of the vehicle and gather other information (e.g., fluid levels and engine performance). The current research focuses on inter-vehicle communications, especially cooperative driving. One of the major efforts dedicated to VANET was launched in 2011 where the United Nations (UN) Road Safety Collaboration has developed a global plan for the Decade of Action for Road Safety 2011–2020. The categories of activities include building road safety, improving the safety of road infrastructure, and broader transport networks; the plan also aims to develop safer vehicles and enhance the behavior of road users [11].

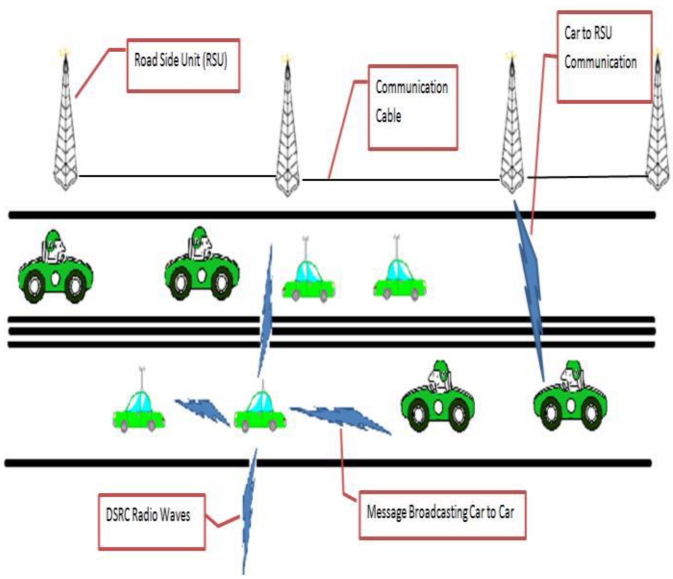

Figure 1: VANET Structure [3].

The current research aims to achieve better safety system by deploying techniques capable of enhancing the performance of the VANET system, while ensuring successful reception of emergency and status information under all network conditions. Special attention is given to the challenges presented in scenarios where dense traffic has a high level of channel saturation, causing long latency and increasing the packet collision and channel load.

II. Research Methodology

In this research, the three proposed protocols will be deployed altogether to achieve better safety system, and to do this, these protocols will be summarized in next, see figure 2 which provides interconnected solutions for the current system problems.

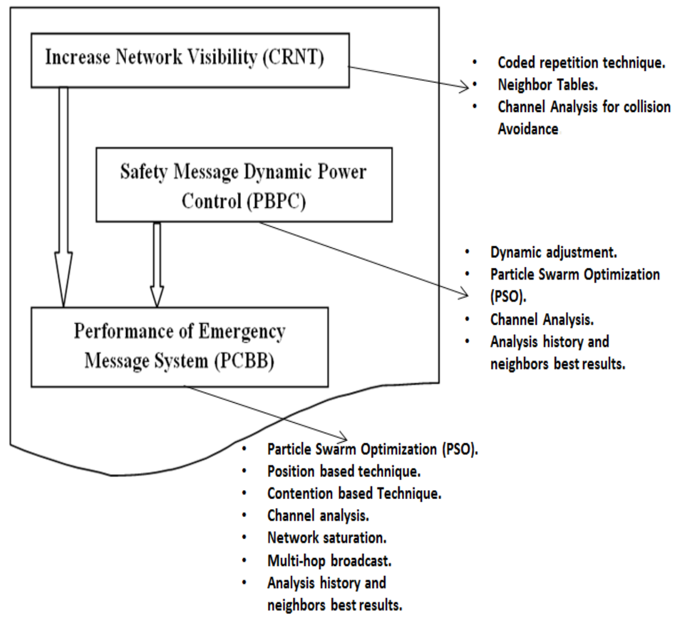

Figure 2: Proposed system methodology.

The methodology works as follows. First, the CRNT protocol gathers information about the network using coded repetition, neighbor tables, and collision avoidance. The collected data provides the network vehicles with rich information about its neighbors, including hidden or unseen vehicles.

Second, the PBPC protocol controls channel collision by channel analysis and PSO intelligent technique. PSO has three parameters: lBest, which is derived from current network analysis made by the sender vehicle; pBest, which is the analysis history made by the sender; and gBest, which is the best analysis made by all neighboring vehicles. This protocol decreases channel collision, increases channel performance, and allows the beacon and emergency messages to utilize the channel better.

Third, the PCBB protocol disseminates the emergency messages with high reliability and short delay. By deploying the PSO, it takes the gBest information from the CRNT to gain more accurate data and analysis and utilizes the collision-free channel resulting from the PBPC protocol.

1- Increasing network visibility:

The protocol starts with the analysis of channel collisions. If there are a high percentage of collisions, the protocol stops working to avoid further collisions in the channel. If collisions are low, the vehicle begins inserting its neighbors' information into its Neighbor Table, piggybacking this table onto any ready beacon and broadcasting it to its neighbors. The receiving neighbor checks if the received beacon has a Piggybacked Neighbor Table (PNT). If it does, the vehicle checks for the expiry and whether or not it has been received before. If the PNT is not expired and has not been received before, then it is extracted.

All the received PNTs are gathered to form all the information gained by the neighbors, which helps avoid any fault the vehicle may commit when analyzing neighbors' locations, and to fill in the gaps for any un-received beacons. This also helps extend the network vision for the current network. Figure 3 shows the protocol flowchart.

2- Performance of emergency message system

The extended vision and information are utilized when predicting probable danger. When a vehicle detects a source of danger, it broadcasts an emergency message to warn other vehicles about this danger. All the vehicles behind the transmitter benefit from receiving this critical information, because a distant vehicle may reach the danger zone in a few seconds if it is traveling at high speed. Single hop broadcasting is not enough as it reaches only 1,000 m according to the DSRC specification [12], and broadcasting emergency messages farther informs distant vehicles about danger before reaching it. The sender vehicle broadcasts its emergency message in single hop fashion, assigning beforehand the vehicle that is farthest away from it as the forwarder vehicle. This forwarder then takes the emergency message and rebroadcasts it to all neighboring vehicles, thus expanding the number of vehicles receiving the warning and the distance over which the warning is broadcast. It also gives the original sender's neighbors another chance to receive the warning in case they do not receive it in the first broadcast.

Meanwhile, if the preselected forwarder does not receive the emergency message, another forwarder must be chosen to overcome the preselected forwarder rebroadcasting failure. To resolve this use, two protocols are proposed: the Contention Based Broadcasting Protocol (CBB) and the Particle Swarm Optimization Contention Based Broadcasting Protocol (PCBB). The CBB protocol divides the network into a fixed number of segments and assigns the rebroadcast job to vehicles inside the last non-empty segment. The number of vehicles inside this segment must exceed a predefined threshold. The PCBB is an enhanced version of the CBB and depends on the swarm intelligence technique in selecting the forwarders in the last non-empty segment.

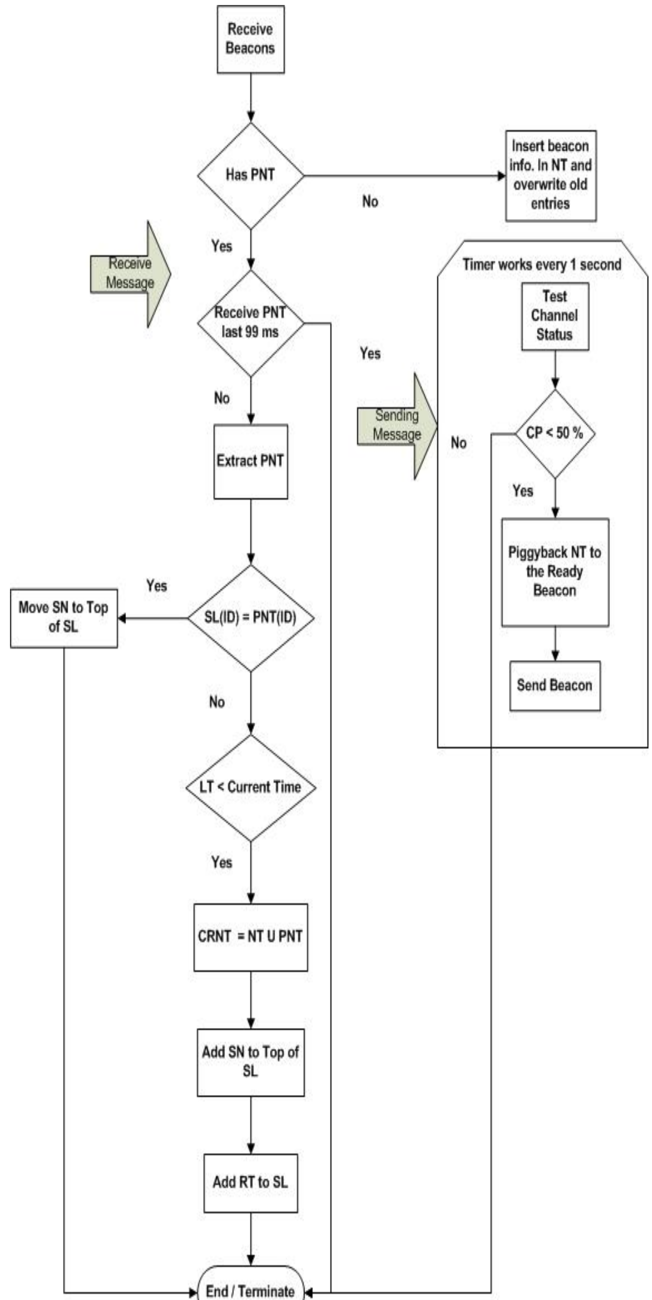

Figure 3. CRNT protocol flowchart.

Sometimes the sender's analysis for the network is wrong or incomplete, in which case the sender can obtain the neighbors' channel readings by utilizing CRNT information. The analysis uses the PSO intelligent algorithm by forming an input parameter for the PSO algorithm called the Global Best (gBest). Other parameters (i.e., Local Best–lBest and Personal Best–pBest) are obtained from the sender vehicle analysis. The fitness function to obtain lBest and gBest depends on the neighboring vehicles' areas of concentration and progress from the original sender, where the possibility of receiving the signal is higher if the message is sent for many vehicles than if it has been sent for a single vehicle. The protocol then selects areas with a high concentration of vehicles with higher progress, giving the message a chance to reach higher distances. Vehicles selected for the rebroadcast in CBB and PCBB contends in the mean of time and wait for a contention period, whereas vehicles that have high progress from the original sender have to wait shorter times than the vehicles near the sender. When a vehicle receives the emergency message, it checks the message and tests whether or not the receiver is the preselected forwarder. Then, either it rebroadcasts the message without waiting for the contention period or it tests if it is located in the last non-empty segment, which computes the contention period; finally, it chooses a random back-off time depending on the contention period. When the back-off time ends, it checks if another vehicle has made the rebroadcast. If the message has not been rebroadcast, the vehicle then rebroadcasts the message. The CBB and PCBB enable the message to be received by a higher number of vehicles compared with the normal system. Furthermore, PCBB uses an intelligent technique in selecting the forwarders depending on the best results obtained by the sender and neighbor vehicles, thus avoiding error sender channel analysis. Figure 4 shows the protocol flowchart.

3- Safety Message Dynamic Power Control

In order to send emergency messages with short delay and high reliability, availability, efficiency and performance, channel performance and collisions must be controlled. The transmission power at which beacon messages are sent can affect channel performance. For example, if each vehicle in a network sends 10 messages/second, such activities may cause continuous problems for the channel if the transmission power for these beacons are not controlled wisely.

The proposed PBPC Protocol offers a dynamic mechanism, by which to control the channel load and increase its performance. The protocol starts by testing the channel collision status, which it does by computing the success percentage of each beacon received from a neighbor vehicle, taking into account the power used and the distance between the sender and the receiver. The success percentage gives an indication of collisions caused by the transmitted beacons' power usage. This percentage forms the fitness function (lBest) for the PSO algorithm, whereas gBest is the best result obtained by neighboring vehicles located in the same area. gBest is obtained from the neighbor's beacons and helps avoid mistakes occurring in the sender's analysis. Thus, the proposed protocol decreases channel load and enhances its performance.

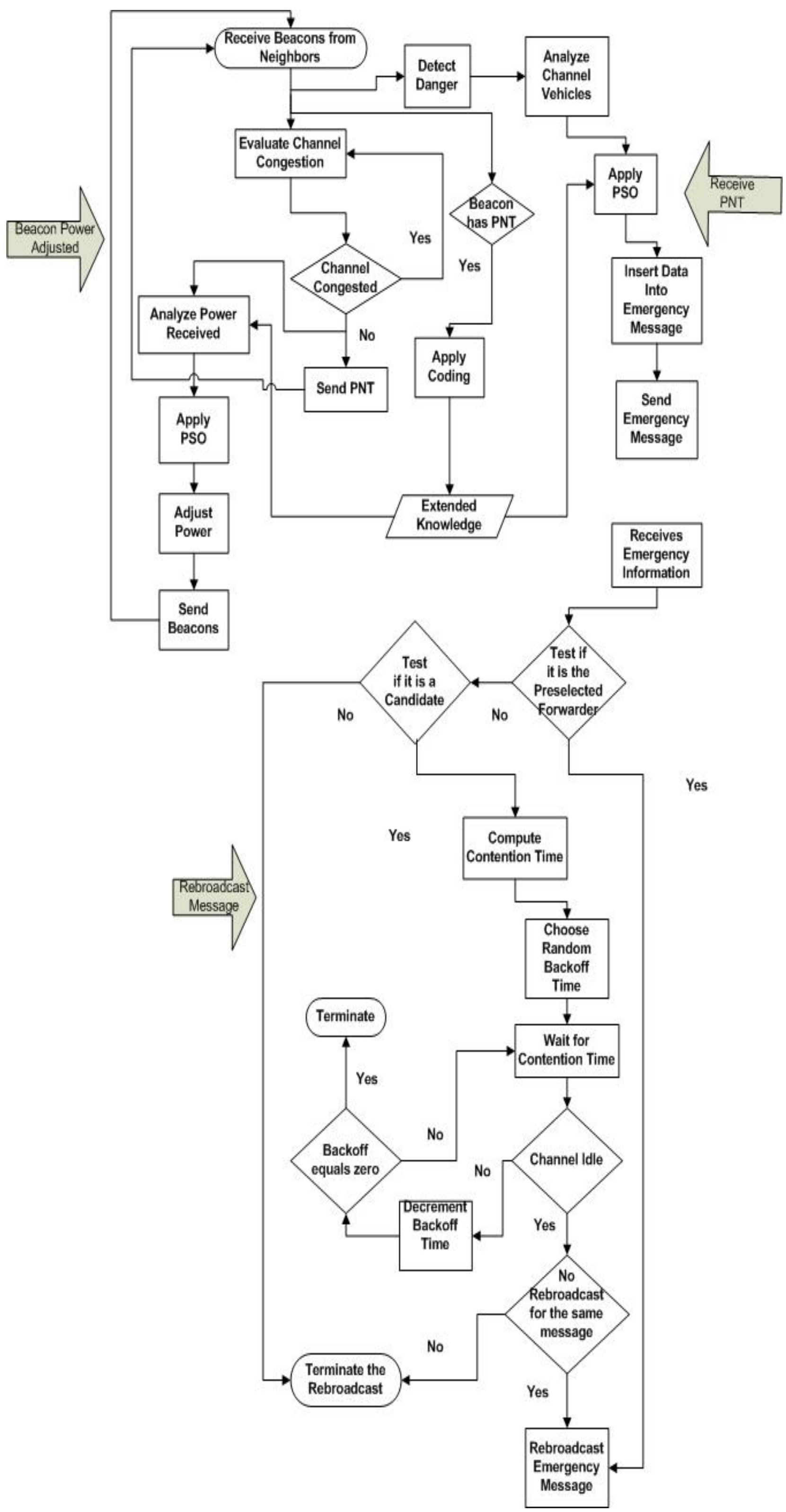

Figure 4. PCBB protocol flowchart.

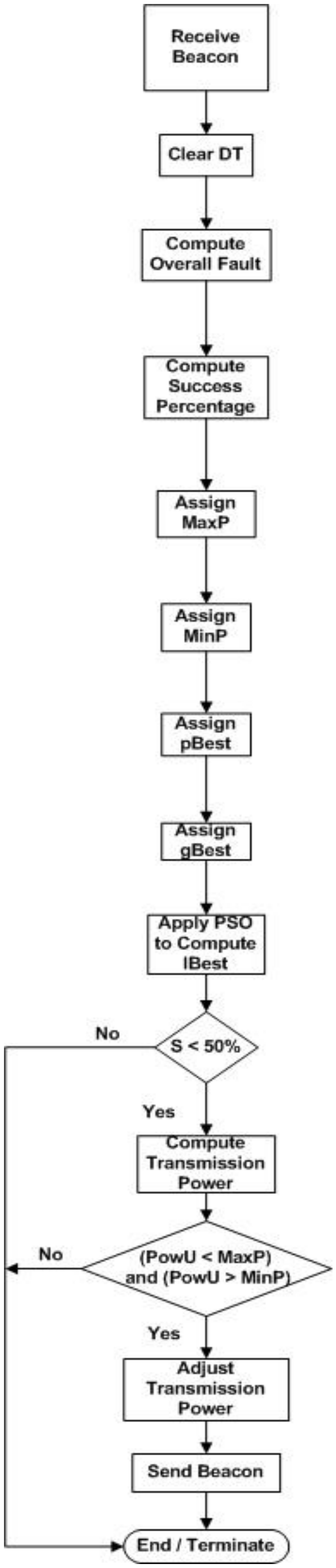

Figure 5. PBPC Protocol Flowchart.

It is worth noting that all the protocols presented in this research are designed to work in highways, where there are no speed limits and no RSUs are attached. Applying the system becomes more challenging when working in urban areas, in which speed limits are low and RSUs can distribute emergency information easily. Figure 5 represents the protocols' flowchart.

Figure 6 presents the system general flowchart, and shows how the CRNT (top middle), the PBPC (top left), and the PCBB (top right) protocols interconnect to shape the overall system. CRNT provides information about the network, which is utilized by PCBB for accurate analysis of the system; meanwhile, PBPC dynamically controls channel collisions, resulting in improved CRNT and PCBB performance.

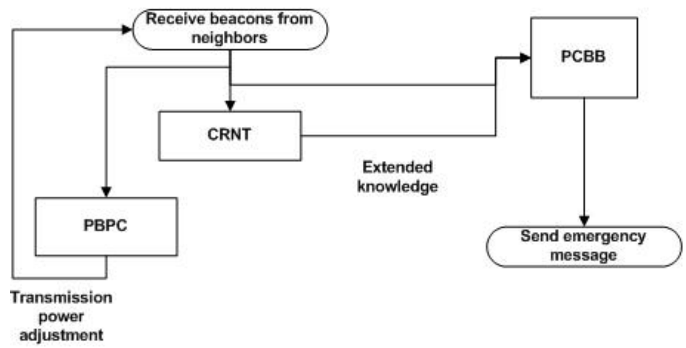

Figure 6: Proposed system general Flowchart.

III. EVALUATION AND RESULTS

This section presents the experiment involving the proposed protocols and their results. First, the evaluation criteria for the current research work are presented. This is followed by an overall analysis of the system results. Finally, a mathematical analysis of the results is performed to prove the correctness of the proposed work.

A) Evaluation Metrics

The evaluation criteria in this work concentrate on the Quality of Service (QoS) parameters, which include

1. High system performance.
2. Short Delay.
3. Low Collision.

These parameters are also utilized to evaluate the performance of the system:

– Probability of successful beacon message reception: This refers to the probability that a transmitted beacon message can be successfully received by the receiving node at a specific distance from the transmitter. This metric represents the reception ratio of one-hop messages without rebroadcasting schemes: messages are not retransmitted to improve reliability.

– Probability of emergency message reception: This refers to the probability that the emergency information generated by a specific vehicle is received by another node located at a high distance from the information originator. Furthermore, the number of message receivers should be as high as possible. This metric utilizes the rebroadcast technique (i.e., multi-hop broadcasting), and is achieved by applying the equations mentioned in [2].

– Information reception delay: This is the span between the time that a vehicle generates a message and the time at which this message is received by the corresponding application at another vehicle located at a specific distance from the originator.

– Channel collision: This is a channel measurement giving an indication of channel load or collision, and is computed by measuring the number of sent and received beacon during a specific time. This is achieved by applying the equations mentioned in [3].

B) Simulation Methodology

1- Simulation Software

For the purposes of evaluating the proposed protocols, three different experimental setups were used as detailed in the next Sections. The performance was tested using the Matlab® commercial software which provides a very a suitable environment for VANET simulation.

The simulation presented in this research performed on Dell® PC, Intel® Core™ 2 Quad CPU, Q8400 @ 2.66GHz, RAM is 4 GB.

2- Simulation scenarios and assumptions

The simulation conducted in this research implemented in highway scenario, three lanes, as highways normally having vehicles moving in high speeds exceeding 120 k/h which is suitable for the current study, the road length is 2000 m, as the DSRC specification for the emergency message is 1000 m, and the proposed protocols enables the message to reach 2000 m. The number of vehicles is 200 and the simulation time is ten seconds.

It is worth noting that the implemented scenarios in this research are the same scenarios implemented in [13] for the EMDV and DFPAV protocols. Complete simulation setup and parameters are presented in table 1.

TABLE 1: SIMULATION CONFIGURATION PARAMETERS.

Parameter	**Value**	**Description**
Radio propagation model	Nakagami-m, m = 3	Model m=3 is fixed as recommended in [26]
IEEE 802.11p data rate	6Mbps	Fixed value
PLCP header length	8 µs	Fixed value
Symbol duration	8 µs	Fixed value
Noise floor	-99dBm	Fixed value
SNR	10 - 40 dB	Adjustable to add noise to the signal
CW Min	15 µs	Fixed value
CW Max	1023 µs	Fixed value
Slot time	16 µs	Fixed value
SIFS time	32 µs	Fixed value
DIFS time	64 µs	Fixed value
Message size	512 bytes	Fixed value
Beacon Message Rate	10 Message / s	Fixed value
Number of Vehicles	200	Fixed value
Road Length	2 KM	Fixed value
Car Speed	20km – 120km	Fixed value
Simulation Time	10 s	Fixed value
Road Type	Highway	Fixed value
Number of lanes	3 lanes	Fixed value
Neighbor entry size	15 Bytes	Fixed value

3- Results

In this section, the overall system performance is examined by deploying the three protocols (CRNT, PCBB, and PBPC) together. The results are compared with those of the EMDV protocol after deploying the DFPAV protocol. The experiments concentrated on the probability of emergency message reception, emergency message delay, and the collision produced by the system, as shown in Figures 7, 8 and 9, respectively.

As can be seen, EMDV gives better performance when it is implemented along with the DFPAV. This is because the DFPAV controls channel collision, allowing EMDV to be broadcasted in a channel with better performance. The proposed PCBB protocol gives better performance when it is implemented with PBPC and the CRNT, because PBPC dynamically controls the collision in the channel, allowing PCBB to better utilize the collision-free, high-performance channel. CRNT also provides the PCBB with more information, helping the sender vehicle make more accurate analyses and better decisions. Deploying the three proposed protocols altogether creates a full functioning safety system, with high and efficient performance.

Figure 7 shows the performance of the PCBB protocol when it is deployed with the PBPC protocol. The simulation results show that the system achieves stability when deploying the three protocols together, and achieves better performance in terms of propagating emergency safety information. Furthermore, the PCBB scores the best results and performance when the PBPC is on.

Performance comparison can be done between PCBB with PBPC turned on, and EMDV with DFPAV turned on. PBPC alone scored fewer collisions than the DFPAV, as reflected on the PCBB when the PBPC is utilized with it; PBPC also gave the PCBB another reason to score better performance over the EMDV. Furthermore, PCBB with PBPC turned off (i.e., no channel collision control protocol is implemented) gives better performance than the EMDV with DFPAV turned off. This makes the proposed system more robust in terms of emergency message dissemination, which is consistent with this research' objective. EMDV with DFPAV turned on gives better performance than the PCBB with PBPC turned off. This is because DFPAV controls the channel load and allows EMDV to disseminate safety information in better channel conditions.

The NS can send the information up to 1000 m, which is the DSRC communication range, but this distance is not enough in a high mobile network such as the VANET [14].

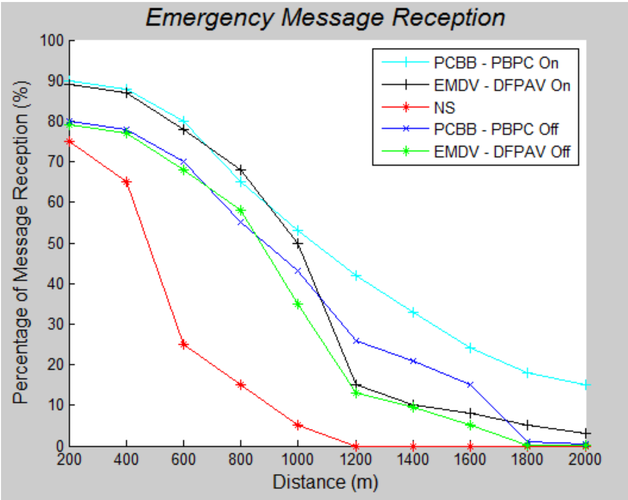

Figure 7: Overall system emergency message reception

Figure 8 shows the comparison of emergency message delays between EMDV with DFPAV turned on and off and PCBB with PBPC turned on and off. As can be seen, system performance gives shorter delay when the power control protocol is on for both the EMDV and PCBB protocols. PCBB – PBPC scores shorter delay than EMDV – DFPAV, because the PBPC scores fewer collisions than the DFPAV. Hence, the channel performs better and the messages are received with shorter delays. The NS takes longer, as no collision or power control technique is adopted; hence, channel load and performance are not controlled at all. There is also no score for NS after 1000 m, because the message is broadcast in single-hop and does not reach farther distances.

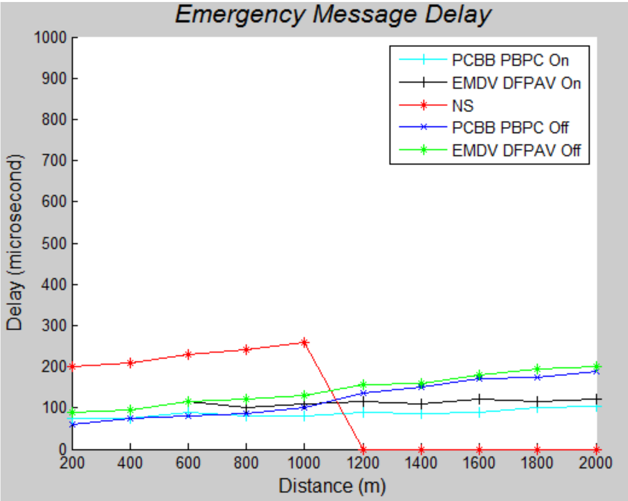

Figure 8: Overall system emergency message delay

Figure 9, meanwhile, compares channel collision performance between PCBB with PBPC (the power control for collision avoidance) turned on and off and EMDV with DFPAV turned on and off. As can be seen, PCBB results in fewer collisions than EMDV when both power control protocols are on, with the percentage reaching 80% to 20% in some cases. PBPC scores fewer collisions, because it analyzes the collision status in the channel before deciding the power value for the beacon transmission, decreasing channel collision.

When the PCBB and DFPAV are off, this means collisions resulting from the beacon are not controlled, and in this case, both protocols perform the broadcast and the rebroadcast, so the resulting collision is almost the same. The NS results wherein no collision control protocol is deployed, shows collisions due to beacon and emergency messages growing over time.

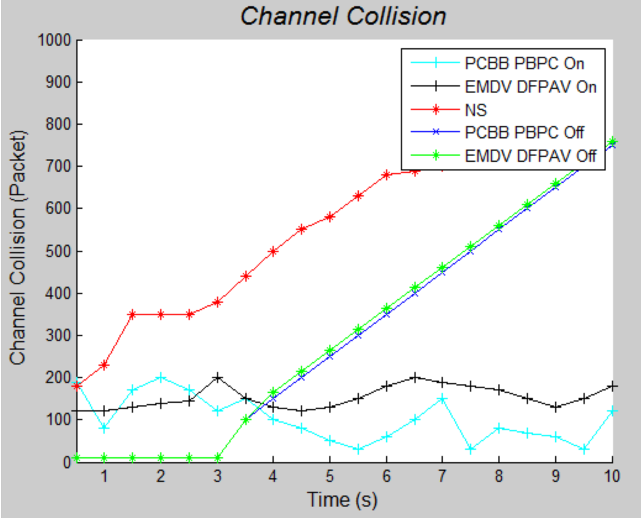

Figure 9: Overall system channel collision

The comparative studies presented in Figures 7, 8, and 9 are presented in Table 2 as the overall quantitative system results when deploying the three protocols presented in this research (i.e., CRNT, PBPC, and PCBB). This study focuses on the performance of emergency message reception, the collision produced, and the delay when the PBPC is on and off.

From table 5.2 the effect of deploying the PBPC along with the PCBB is clearly seen, for instance, when the progress from the sender is 1500 m, the percentage of the emergency reception reaches 32% when the PBPC turned on and 21% when it is turned off, this means that PBPC gave the PCBB better performance and less delay as the delay scores 85 µs which is shorter than the delay when the PBPC is off. Furthermore, when this results is compared with the EMDV results and NS, the proposed system scores superiority over them, where the EMDV scores 10% of emergency message reception with longer delay reached 115 µs. also, NS results score long delay reaches 260 µs and 5% for the message reception on the progress 1000 m, as the normal system is the VANET system without deploying any protocols to enhance it. So the maximum progress for the emergency message is 1000 m.

4- Mathematical analysis

In this section, a mathematical analysis for the performance of the PCBB against EMDV is performed, two groups of simulations for the original and modified models were conducted and the results were analyzed. For each group, several distances were considered, up to 2000m; and for each distance, 100 simulations were conducted to determine the means ($\bar{x}^{original}$ for the original model and $\bar{x}^{modified}$ for the modified model) and the standard deviations ($S^{original}$ for the original model and $S^{modified}$ for the modified model) of time of spreading the message according to the following equations:

Standard deviation

$$S = \sqrt{\frac{\sum x^2}{n} - \bar{x}^2} \qquad (1)$$

Mean

$$\bar{x} = \frac{\sum x}{n} \qquad (2)$$

a. Matmatical Analysis Discussion

In Figure 10, two curves for the comparison of models are obtained. Each curve (error bar) shows the means and the standard deviations. Table 6.5 shows the relevant measurement for the considered distances:

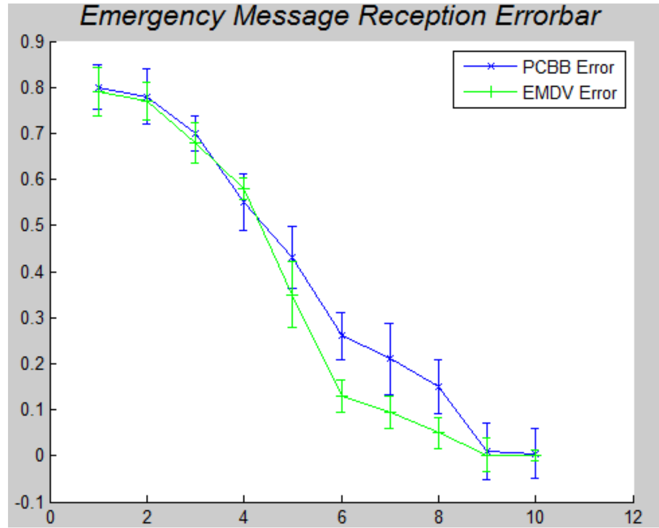

Figure 10: Emergency message reception Errorbar.

Error bars show the confidence intervals of data or the deviation along a curve, which represents the error percentage for each protocol.

TABLE 2: PROBABILITY OF EMERGENCY MESSAGE RECEPTION AND THE DELAY FOR THE OVERALL SYSTEM PERFORMANCE

Message progress	100 m		500 m		1000 m		1500 m		2000 m	
PBPC	On	Off	On	Off	On	Off	On	Off	On	Off
PCBB Probability of message reception (%)	90	80	80	70	53	41	32	21	15	5
PCBB Delay (µs)	75	80	90	90	80	100	85	150	105	190
DFPAV	On	Off	On	Off	On	Off	On	Off	On	Off
EMDV Probability of message reception (%)	89	79	78	68	50	35	10	9.5	3	1
EMDV Delay (µs)	88	88	115	115	115	130	115	160	120	200
NS Probability of message reception (%)		75		25		5				
NS Delay (µs)		200		230		260				

According to these two curves in Figure 10, the PCBB scores better percentage of emergency message reception, less error, and hence, better performance.

A statistical test to prove the validity of the results is also made (Appendix B).

TABLE 3: MEANS AND THE STANDARD DEVIATIONS SCORED FROM THE EXPERIMENT

$\bar{X}$ EMDV	S	μ PCBB	σ
0.909349064	0.05178882	0.888799634	0.048826527
0.842821512	0.041095276	0.904453419	0.060171932
0.77116042	0.044515048	0.805546659	0.037246164
0.673854211	0.022259418	0.657944187	0.061188071
0.536119058	0.072654596	0.559615624	0.067619816
0.163726761	0.03568756	0.403039278	0.050768241
0.180115191	0.034426739	0.335472452	0.077796376
0.082544902	0.033271996	0.218715127	0.059306108
0.055369584	0.035758885	0.123168628	0.061459699
0.01778629	0.012536066	0.079583087	0.052943599

For each distance, the null hypothesis is made. The parameter, `H_0, which assumes that the EMDV achieves better (or similar) performance than proposed modified model is calculated as:

H_0 : $\mu_{EMDV} >= \mu_{PCBB}$ Hypothesis A.1

Accordingly, the alternative hypothesis is as follows

H_1 : $\mu_{EMDV} < \mu_{PCBB}$ Hypothesis A.2

The statistically significant level is set to 0.01 to give us more accurate results.

For each distance, the Z – Scores for the mean of the corresponding sample $\bar{x}^{modified}$ is calculated as follows:

$$z = \frac{\bar{x}^{modified} - \bar{x}^{original}}{\sigma^{original}} \qquad (5.3)$$

After applying the equations 5.1, 5.2 and 5.3, the result is taken and inserted in [15] which gives the result 1.979618.

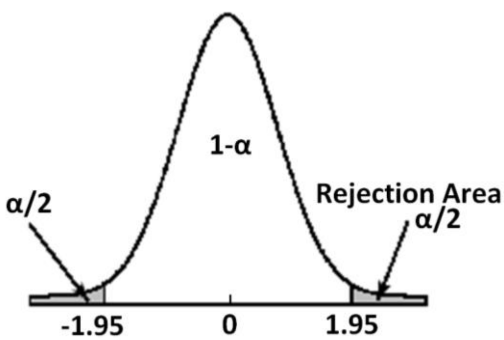

Figure 11: Acceptance and rejection area

From Figure 11, it can be seen that the previous result resides in the rejection area, indicating that the null hypothesis (H0) is rejected, and H1 is accepted.

The error bar for the delay is also tested, with results shown in Figure 12, proving that the PCBB results in shorter delays than EMDV.

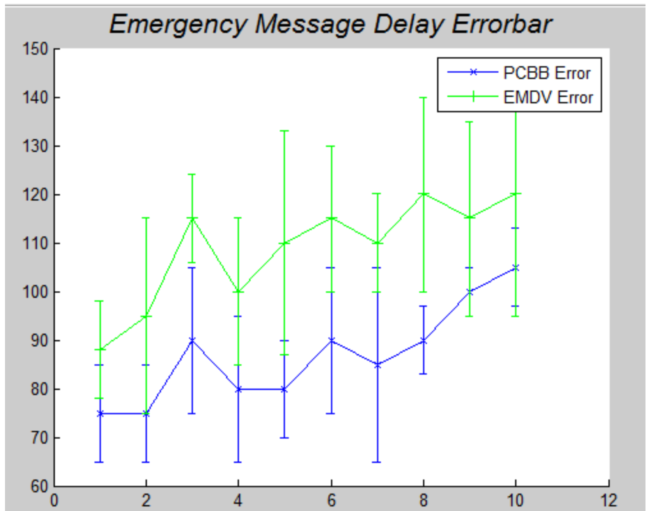

Figure 12: Emergency message delay Errorbar

IV. CONCLUSION

This research presents a design for an efficient and reliable safety system for VANET by deploying protocols and system design guidelines to overcome existing challenges to improve road safety by achieving specific objectives: 1) ensuring road safety and providing vehicles with extended information about current network vehicles using coded repetition technique: 2) achieving fast and efficient emergency message transmission and delivery by utilizing the most efficient and newest intelligent technique (PSO), which allows more accurate analysis and performance; and 3) improving collision avoidance by conducting a dynamic technique for adjusting beacon transmission power and analyzing the channel utilizing the PSO intelligent technique, which has yet to be used in the VANET system for power control.

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