Improving Reliability of Safety Applications in Vehicle Ad hoc Networks through the Implementation of a Cognitive Network

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Abstract*- Researchers have suggested Vehicular Ad hoc Networks as a way to enable car to car communications and to allow for the exchange of safety and other types of information among cars. The Wireless Access in Vehicular Environments (WAVE) protocol stack is standardized by the IEEE, and it allocates spectrum for vehicular communication. In our work we prove that it does not provide sufficient spectrum for reliable exchange of safety information. To alleviate this problem, we present a system that employs cognitive network principles to increase the spectrum allocated to the control channel (CCH) by the WAVE protocols, where all safety information is transmitted. To accomplish this objective, the proposed system relies on sensed data sent by the cars to road side units that in turn forward the aggregated data to a processing unit. The processing unit infers data contention locations and generates spectrum schedules to dispatch to the passing cars. Analysis and simulation results indicate the effectiveness of the system in improving data delivery in vehicular networks and thus increasing the reliability of safety applications.

***Keywords*-VANETs, safety applications, cognitive networks, spectrum Sharing, data transmission contention.**

I. INTRODUCTION AND RELATED WORK

A Vehicular Ad Hoc Network is a distributed network that does not rely on a central administration for communication among vehicles and between vehicles and fixed road side equipment (also known as Road Side Unit, RSU). VANETs have unique characteristics in comparison to other Mobile Ad Hoc Networks (MANETs) [9], in that they have a high degree of mobility which introduces a high variation in the network topology and leads to a high rate of link changes [23]. In an effort to assign a spectrum for vehicular usage, the U.S. Federal Communication Commission (FCC), in the year 1999, allocated 75MHz of Dedicated Short Range Communications (DSRC) spectrum at 5.9 GHz to be used exclusively for vehicle-to-vehicle and infrastructure-to-vehicle communications. The DSRC spectrum is divided into 7 channels with a 10 MHz bandwidth allocated to each one. Six out of these channels are service channels (SCH) and the center one is the control channel (CCH).

The allocation of the DSRC band was followed by an effort to standardize the entire protocol stack used by vehicular communication. The IEEE 802.11p Wireless Access in Vehicular Environments (WAVE) amendment is strictly limited to the lower MAC and PHY layers [16], while the overall DSRC communication stack between the link layer and the applications is being standardized by the IEEE 1609 working group. In particular, the IEEE 1609.3 standard covers the WAVE connection setup and management [13], whereas the IEEE 1609.4 standard sits right on top of the IEEE 802.11p and enables operation of upper layers across multiple channels, without requiring knowledge of PHY parameters [12].

In the DSRC band, all common safety messages are supposed to be exchanged in the control channel, while non-safety usage in the control channel is limited to occasional advertisements of private applications that utilize a service channel, but it is insignificant to the overall channel load [14]. A synchronization procedure is used to allow WAVE devices to monitor the control channel during a common time interval called the CCH interval. Recent simulations studying the safety message access delay and packet reception rate have shown that the control channel can suffer from large data contention, implying that the 10 MHz channel allocated for safety usage may not be enough [25]. To assess the performance of safety applications over the existing 802.11p protocol, we conducted an analysis for the 10 MHz control channel mainly considering the safety message access delay and packet reception rate. Safety message access delay should be less than 200 milliseconds to allow proper driver reaction time to traffic warning signals [10]. Safety message access delay is defined as the average delay a packet experiences between the time at which the packet is generated and the time it is successfully received at the receiver, while packet reception rate is defined as the ratio of the number of packets successfully received to the total number of packets transmitted. Moreover, the system must deliver safety packets reliably especially that broadcast scenarios constitute a key part of a VANET's usage [24]. Therefore, the sender cannot expect acknowledgments, and thus he cannot tell if a packet was successfully received. Actually, according to [27], the probability of message delivery failure in a vehicular network should be less than 0.01.

These two parameters were analyzed widely in literature. In [17], access delay was found to be around 1.2 ms and in our simulations the delay was less than 1.5 ms. Packet reception rate values obtained from the literature as well as from our own performed simulations show that the packet reception rate falls well below the expected value of 0.99. In [24], the probability of reception was found to be less than 0.6 at zero distance under the Nakagami radio propagation model. Similar results were found in [17]. Our simulations produced consistent results and showed that the packet error rate is much greater than 0.01. These results suggest that the 10MHz allocated to the DSRC control channel cannot provide performance guarantees under realistic road and traffic conditions. Some researchers suggested that non-safety use of DSRC ought to be severely restricted during peak hours of traffic to insure that automotive safety is not compromised [6], although such solutions for spectrum scarcity could impact the commercial side of DSRC. Other researchers have proposed some enhancements to the existing safety applications using a repetition scheme [10][17][26]: the sender vehicle repeats the transmission of the safety message several times to increase the reliability of safety communications. It is shown in [17] that such scheme would in fact increase the probability of reception rate to above 99%, making safety communications reliable over the control channel. However; a 20 MHz bandwidth and a low message size of 200 bytes were assumed, meaning that the repetition scheme scales badly with the increase of the safety message size. In fact, it is suggested in [22] that the message size would reach 800 bytes after adding security features to it. Also, repetition incurs additional traffic on the control channel which can cause significant delays. To assess this hypothesis, we performed a simulation that adopts the same topology and parameters used in [17], but cars were distributed on four lanes, and a message size of 800 bytes was used. We implemented repetition and restricted it to a maximum of 10, which is in fact below values that reached 30 and were proposed in some schemes, like [26]. In our simulations the delay exceeded in some cases 1 second, and the average was above 200ms. This clearly violates the delay limit, and in that sense, repetition schemes also fail to provide reliable safety communications in all situations. Given the above, we propose to apply Cognitive Network principles to VANET environments to alleviate the data contention that could take place in the control channel.

A cognitive network inherits its properties from the concept of cognitive radio, which, in addition to its awareness and adaptive capabilities, can use previous knowledge relying on learning and acquired experience to adapt to a non predefined scenario [11]. The cognitive radio technology is based on the notion of utilizing open spectrum in the space, time, and frequency dimensions that until now have been unavailable [7]. The FCC Spectrum Policy Task Force recommended in its report on November 2002 to adopt cognitive radio as a method for additional spectrum access [6]. The main idea of cognitive radio is to periodically sense the radio spectrum, intelligently detect occupancy and usage in the spectrum, and finally make the decision to adjust its radio parameters to opportunistically communicate over spectrum holes of the primary system. This principle has attracted a great deal of attention from both academia and industry. Indeed, the Defense Advanced Research Projects Agency (DARPA) has initiated recently the next-generation communications (XG) program to develop the so-called opportunistic spectrum access techniques for military and emergency applications [2]. Our system implements a cognitive network to offer cars on the road additional spectrum from the TV band that is underused [5], thus rendering the exchange of safety messages between cars more reliable and actually faster.

A cognitive network would enable the coexistence of spectrum between primary and secondary users in licensed and unlicensed bands, where primary users are the licensed ones who reserved the spectrum, while the secondary users are those who are using the same spectrum on a non interfering basis. Related to this, a cognitive-network-based system is currently being developed by the IEEE 802.22 working group, which is chartered with the development of a CN-based Physical and Medium Access Control layers for use by license-exempt devices in the spectrum allocated to the Television service [4]. The 802.22 system is composed of a fixed point-to-multipoint wireless air interface in which a base station (BS) manages its own cell and all associated Consumer Premise Equipments (CPEs). The BS controls the medium access in its cell and transmits to the various CPEs. In addition to its traditional role, a BS also manages a unique feature of distributed sensing by instructing the various CPEs to perform measurement of TV channels. Based on the feedback, the BS decides what to do, like allowing transmissions on channels or stopping them.

We conclude this section by describing the notion of cognitive radio ad hoc networks (CRAHNs) proposed in [1]. A CRAHN differs from classical ad hoc networks in that it deals with a changing spectrum environment while protecting the transmission of the primary users. In order to adapt to dynamic spectrum environments, the CRAHN incorporates the following functions in the classical layering protocol: spectrum sensing, decision, sharing, and mobility. Spectrum sensing is used to identify spectrum holes, while the decision is made to select the appropriate band to use. Spectrum sharing offers the capability to coordinate between the available nodes, and finally, spectrum mobility is used in case of a handover when a primary user is detected and when the cognitive users evacuate the spectrum.

II. PROPOSED SYSTEM

This paper presents a system that represents a cognitive vehicle ad hoc network to face spectrum scarcity in the control channel, in urban areas. Our approach to designing the system takes into consideration several aspects. First, our proposed system is dynamic in how it increases the spectrum allocated to VANETs in the standard. A vehicle is allocated additional spectrum on speculated need basis reflected by contention. Second, the system relies on a learning algorithm to react to non-previously encountered situations, to predict or forecast car contentions, and to identify free parts of the spectrum based on a linear prediction model and past gathered data. Moreover, our proposed system is totally distributed and decentralized, and thus it avoids a single point of failure. Finally, the infrastructure which we are proposing is assumed to possess modest processing power, which makes the future deployment of the system easier and more feasible. Since the processing is local and the processing units need not to be interconnected directly, the privacy of drivers' behaviors is basically respected as no driving patterns are being collected and no global profiles of cars and drivers are developed. One very important point in our approach is the employment of cognitive radio concepts, which essentially translates to allowing the use of the additional spectrum as a secondary user, while employing techniques to prevent interference to licensed users.

A. *Control Channel Extension Scheme*

The application of cognitive radio in VANETs is enabled by the physical layer described in IEEE 802.11p.The modulation scheme adopted for a single channel is OFDM, where the control channel is divided into 64 sub-channels (48 are data) with a variety of modulation rates and coding rates. The sub-channels are overlapped so that the inter-carrier spacing is 0.15625 MHz and it is equal to the bandwidth of a single sub-channel. Actually, this bandwidth is half that of 802.11a and it is appropriate to combat frequency selective fading and Doppler shifts. Given so, bit rates can vary within 3, 4.5, 6, 9, 12, 18, 24, and 27 Mbps. As a result, to achieve more throughput in the network, it would be desirable to be able to achieve high bitrates. However, this comes at a cost, increasing the bit rate by increasing the modulation order and decreasing the coding rate would increase the required SNR and thus increase the BER which will make the situation worse [18].

As a matter of fact, the widening of the control channel spectrum can be done by simply extending it to the band indicated by the cognitive radio mechanisms. The newly added spectrum is divided into sub-channels with the same parameters as those defined in 802.11p (inter-carrier spacing of 0.15625 MHz) while preserving the orthogonality requirement. So the number of available sub-carriers increases to suit the system's requirements. This allows the bandwidth of the subcarriers to stay constant, and the bit rate to increase but by preserving the modulation order and the coding rate. This form of an OFDM, where the implementation achieves the high data rates via collective usage of a large number of non-contiguous subcarriers, is called non-contiguous OFDM (NC-OFDM) [20]. NC-OFDM provides the necessary agile spectrum usage needed when portions of the target licensed spectrum are occupied by both primary and secondary users. When they detect a primary user, the secondary users deactivate subcarriers that can potentially interfere with him. In this regard, techniques have been proposed to implement NC-OFDM transceivers, like the one in [21] which introduces an algorithm for quick pruning of the fast Fourier transform (FFT) that represents the core component of an NC-OFDM transceiver. This, plus the fact that enabling car communication technologies are being developed makes our proposed system feasible and also attractive since it realizes a system that is more in line with the recommendations and trends for solving spectrum scarcity issues.

B. *Network Contention Metric*

A main operation of the system is to determine the areas along the road that suffer from data transmission contention. We need to define a metric that quantifies contention at each location of the road. We say that the control channel suffers from contention if the needed bitrate (actual bitrate) exceeds the offered bitrate (available bitrate). Contention Window (CW) of 802.11 might seem an appropriate contention metric. However, the DCF (Distributed Coordination Function) technique for medium access mechanism of IEEE 802.11 incurs delays that are not modeled by any sense in the contention window CW. According to DCF, whenever a station senses the medium to be busy, it pauses its backoff timer until the medium is found idle again. These delays infer contention in the medium and affect the overall performance, and thus affect the transmission of the safety information. We simulate two different scenarios, one suffering from network contention and the other not. The contention window used by each station just before its successful transmission was collected while increasing number of transmitting stations. The data actually failed to differentiate between the two scenarios as the measurements coincided, clearly yielding no clear cut determination of the contention.

In the literature, some metrics are defined to be used for measuring load at the control channel. The interferer number is defined in [26] and the communication density in [15]. These metrics lack the needed practicality to be implemented in a real system. Some variables used in these metrics are hard to be estimated in real time by individual cars, such as vehicular density and interference range. Therefore, in order to determine contention at a given location, we propose a network contention metric $C_r(t)$ that represents the contention level in region r at time t. If this metric is above a certain threshold C_{th}, then it is assumed that this region r suffers from network contention.

We made the contention metric at time t rely on $C_r(t\text{-}1)$ and on the newly sensed contention $\widehat{C_r}$ so as to account for changes in the contention level and to make the system robust to fallacious data. For a given location r, the contention is related to the average number of safety packets transmitted and their average sizes, and the channel capacity in this region as reflected by the achievable bitrate according to the adaptive modulation scheme employed in IEEE 802.11. Thus, if the system accounts for near history reflected in $C_r(t\text{-}1)$ while always considering the current sensed results of contention reflected by the cars, the new $C_r(t)$ should model actual contention accurately.

The contention at region r and time t is calculated in Equation (1) using a linear prediction model similar to the approach employed to calculate the Round-Trip Time (RTT) in the TCP protocol [19]:

$$C_r(t) = \gamma C_r(t-1) + (1-\gamma)\widehat{C_r} \qquad (1)$$

where γ reflects the weight given to history, and $(1-\gamma)$ denotes the weight of the sensed contention.

The sensed metric $\widehat{C_r}$ depends on the evaluation of data relayed from n cars. $\widehat{C_r}$ is a linear combination of two factors, the first being the product of the access delay D of safety packets, and the channel's offered bitrate B divided by the average payload size S, while the second factor being the average number of untransmitted safety packets U per total attempted transmissions. With higher contention, D increases due to the 802.11 carrier sensing mechanism, where each node pauses its backoff timer during the MAC backoff process whenever it senses a busy channel. Those incurred delays that are actually affected by the channel available bitrate B, provide a partial contention indication. The payload size S is used to get the average delay per byte, and finally, the number of untransmitted packets U also increases with contention since the control channel interval is limited to 50 ms and the collision avoidance mechanism imposes that certain packets will never be able to get transmitted if contention persists. The result is a unitless sensed contention metric that is calculated as follows:

$$\widehat{C_r}(t) = \alpha \frac{D_r \times B_r}{S_r} + \beta U_r \qquad (2)$$

The symbols D_r, B_r, S_r and U_r are the parameters D, B, S and U respectively at region r. The experimental method to compute α and β is shown in section *III.B* below.

III. System Architecture

The proposed system is composed of several entities that enable its operations. The major ones are the vehicle, the road side unit (RSU), and a local processing unit referred to as the local acquisition and processing unit (LAPU).

A. Entities Description and Layout

The system topology is depicted in Figure 1. In the following we state the capabilities each component implements. The first component, the vehicle, is assumed to include an on-board computing unit (OBU) that implements the WAVE standard family previously described and whose radio is software defined. It also comprises an on-board GPS, a navigator with its associated maps, a spectrum sensing unit for secondary usage of specific spectrum through cognitive radio, an on-board central computer with I/O interfaces. In fact, all those assumptions are reasonable and most of the features are already deployed in present commercial cars.

The second component, namely the RSU, refers to the definition indicated in the WAVE standard. It has the ability to communicate simultaneously with multiple OBUs, and it is assumed to have a software-defined radio and memory capabilities for caching relevant information presented later.

The third component is the Local Acquisition and Processing Unit (LAPU) which is a computer with modest processing capabilities and a regular size associated database. While no entity from the ones presented so far is cognitive by itself, the system as a whole is cognitive since learning, adaptation, and reaction will be taking place at different locations and through various entities. The specific spectrum that the cars use as secondary users is the TV spectrum since it is clearly underutilized. Each RSU is connected to all of its next hop RSUs (along the road directions which could be 1 or 2 ways) through the same LAPU. On the other hand, each LAPU is independent by itself and is not connected to other LAPUs.

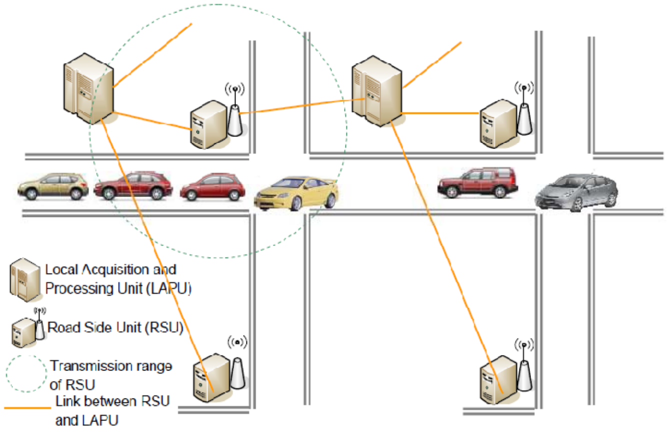

Figure 1: Proposed System topology.

In the proposed system, vehicles are regarded as consumers as they are supposed to finally benefit from the expanded spectrum in order to enhance the dissemination of safety related data. They also act as information gatherers to feed the decision-making process with timely and necessary information. By this, they perform a dual role in the cognitive radio paradigm: on one hand, they are the secondary users in the expanded spectrum, and on the other hand they are responsible for the sensing step that constitutes the first stage towards cognition.

A.1 Car Operation

Every 20 meters, a car initiates the process of "information gathering". The 20m distance is a reasonable assumption of the distance unit step of the system. It is mainly used to quantize the continuous road into points where each point represents a 20m length region r of the road. The process of information gathering for a specific region r works as follows: Every time the car enters the control channel interval i, it temporally stores the data present in Table 1.

Table 1: Car gathered data at interval *i*

$td_{r,i,j}$	access delay time of each successfully transmitted safety packet *j*
$tx_{r,i}$	number of sent safety packets at the end of CCH
$s_{r,i,k}$	payload size of all observed safety packets (sent and received)
$a_{r,i}$	number of attempted but not transmitted safety packets
$b_{r,i,j}$	available bitrate at region *r* for each safety packet *j*
$pl_{r,v,h}$	power level measured for TV channel *v* at SCH interval *h*

Also, when the car enters the service channel interval h, it takes measurements of the power levels of b TV channels, where each channel is defined to be 6 MHz. It is worthy to note that the car must cease the information gathering process at the end of either a CCH or SCH interval if it exceeds the 20m while in the middle of one of the two intervals.

At the end of the process of "information gathering", the car has to perform a "data aggregation" step as to minimize the size of data sent to the RSU. It has basically to create a record that summarizes collected data for the last 20 meters. In this step the car averages the different information gathered during the preceding N control channel intervals and M service channel intervals. The car c computes:

1. The total number of transmitted packets: $TX_r^c = \sum_{i=1}^{N} tx_{r,i}$
2. The total number of non-transmitted packets: $A_r^c = \sum_{i=1}^{N} a_{r,i}$
3. The average number of non-transmitted packets per attempted: $U_r^c = \frac{A_r^c}{TX_r^c + A_r^c}$
4. The access delay: $D_r^c = \frac{\sum_{i=1}^{N} \sum_{j=1}^{tx_{r,i}} td_{r,j,i}}{TX_r^c}$
5. The average payload of sent and received packets: $S_r^c = \frac{\sum_{i=1}^{N} \sum_{k=1}^{tx_{r,i}} s_{r,k,i}}{TX_r^c}$
6. The average bitrate at r: $B_r^c = \frac{\sum_{i=1}^{N} \sum_{j=1}^{tx_{r,i}} b_{r,j,i}}{TX_r^c}$
7. The total number of sensed power measurements: $P_r^c = M$
8. The average power for each sensed TV channel v at r: $PL_{r,v}^c = \frac{\sum_{h=1}^{M} pl_{r,v,h}}{P_r^c}$

In every 20m, the car goes through multiple CCH intervals. In fact, a car moving with an average speed of 60 Km/h will alternate between a CCH interval and SCH interval at least 12 times. The car is storing 1 record every 20m, thus the averaged data of TX_r^c, A_r^c, U_r^c, D_r^c, S_r^c, B_r^c and P_r^c processed by 1 car during 6 CCH intervals all falls in the same region r and gives redundancy to the results and reduces errors.

A.2 RSU Operation

The RSU maintains proactively-updated tables, one for each next hop RSU, provided from a predefined LAPU that contain a header indicating the next hop RSU and the following fields: estimated contention locations along the path till this next hop RSU, and the corresponding additional spectrum allocated. The RSU acts as a middleware between the OBUs and the LAPUs. The RSU collects information saved by the vehicle when it is in its transmission range and relays this data to the corresponding LAPU. Upon the receipt of the next hop RSU information from the car, the RSU provides the car with the needed data from the corresponding stored table: the additional spectrum at the estimated data contention locations along its path. However, if the car was unable to predict or does not want to share its next hop RSU, it will put a special character in the next hop field of the message sent to the RSU. In such a situation, the RSU will send it all the next hop RSU tables. Thus the car will have all its possible paths covered with the corresponding contention locations and available spectrum. The RSU is also responsible for assigning a set of TV channels for each passing car making it responsible for checking their power levels (thus their potential availability) in a manner that guarantees that the whole TV band spectrum is sensed in a continuous. The flow of information among the entities of the system is depicted in the diagram of Figure 2.

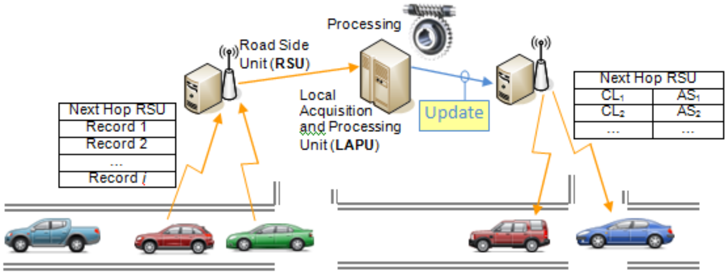

Figure 2: Proposed system overall interaction.

A.3 LAPU Operation

The LAPU is the main processing and storage unit of the system. It is responsible for the generation of the tables maintained at its connected RSUs. The LAPU tries to accurately estimate the data contention locations along the path between each pair of its connected RSUs, and then tries to find all the available white channels in the TV spectrum band where the control channel could be extended at those specific contention locations.

The LAPU, after receiving input data from the RSU for n cars providing measurements for r, calculates the final values of:

1. The access delay for r: $D_r = \frac{\sum_{c=1}^{n} TX_r^c \times D_r^c}{\sum_{c=1}^{n} TX_r^c}$
2. The average number of non-transmitted packets: $U_r = \frac{\sum_{c=1}^{n} U_r^c \times (A_r^c + TX_r^c)}{\sum_{c=1}^{n} (A_r^c + TX_r^c)}$
3. The average number of payload sizes: $S_r = \frac{\sum_{c=1}^{n} S_r^c \times TX_r^c}{\sum_{c=1}^{n} TX_r^c}$

The LAPU is now able to calculate the measured contention metric $\widehat{C_r}$ (Equation 2) and incorporate it into the linear prediction model of $C_r(t)$ (defined in Equation 1).

For each car c, the LAPU updates the corresponding TV channel power value that c sensed according to the following:

$$PL_{r,v}(t) = \delta PL_{r,v}(t-1) + (1-\delta) PL_{r,v}^c \qquad (3)$$

It is important to note here that for the TV transmission, the use of the different channels is static and all the white channels are stored in a database, as specified by the FCC released in November 2008 [8]. While this learning can automatically determine those static white channels, it will also be beneficial when dealing with other secondary users trying to cognitively use the TV spectrum.

The value of γ and δ should be chosen in order to guarantee a quick convergence of the system while keeping it robust against wrong data. Moreover, γ should be smaller than δ since each $\widehat{C_r}$ is generated by measures from n cars while $PL_{r,v,t}$ is generated only from one car. A typical value of γ could be 0.5 with equal weight to the history and to the aggregated sensed data. The parameter δ could be assigned a value of 0.15 to stress on the history component.

B. Determining the weight values

This section describes the experimental procedure used to derive the values of α and β used throughout the system. The experimental procedure includes of the simulation of the IEEE 802.11p draft standard. To decide over the model's values of α and β, multiple scenarios of network contention were developed. As mentioned before, the bit rate in 802.11p over the 10 MHZ control channel varies between 3 Mbps and 27 Mbps with the nominal bit rate considered to be 6Mbps. When considering a control channel interval of 50 ms and a bit rate of 6Mbps, the channel capacity in the control channel interval becomes: $\frac{6Mbps \times 50ms}{8} = 37500 bytes$

This is considered to be the threshold case; any input to the network that is more than 37500 bytes during 50 ms will lead to network contention. Considering 100 cars in each other transmission range, the network contention threshold will be achieved when each car broadcasts a message of 187 bytes at 3Mbps. Similarly, two more scenarios were considered, a scenario of 200 cars each broadcasting a message of 187 bytes at 6 Mbps, and another one of 100 cars each broadcasting a message of 750 bytes at 12Mbps. The simulation was based on the network simulation software NS2, which includes support for the IEEE 802.11p Dedicated Short Range Communication (DSRC) standard, and therefore, provides realistic and accurate simulation of the proposed system [3].

For each scenario, the transmission range was set to 0.586 mW (250 m), and separation between two cars was set to 5 m. Furthermore, the cars were assumed to be in a traffic jam, so that they are stationary, and were distributed equally on four lanes. Each car broadcasts once per control channel interval a message to the cars in its transmission range, where the size of the message was determined by the simulated scenario. Furthermore, each car began broadcasting randomly within the control channel interval. The simulation was repeated 100 times for each scenario.

For all the simulations, the values of the access delay divided by the payload and multiplied by the offered bitrate in the channel were plotted against the average number of untransmitted packets per attempted number of transmitted packets. In this respect, the dependent variable is in effect the channel capacity divided by the throughput, which is the inverse of the effective channel utilization. Next, a linear regression was performed to derive the threshold using the combined data from all three scenarios. The results are illustrated in Figure 3.

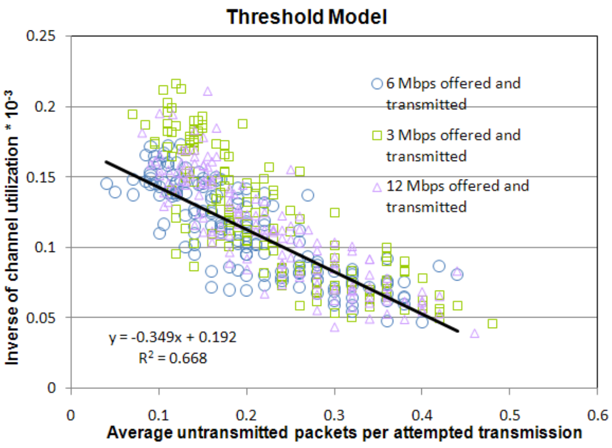

Figure 3: Linear Regression of the threshold scenario.

The graph in Figure 3 shows a linear trend with correlation equal to 0.81. By linear regression and after normalizing C_{th} to 100, we found α to be 520 and β to be 182.

C. Overall Interaction

In this section, the components of the system earlier described will be put together to form the complete picture. A car will be assigned a set of TV channels. Every 20m, the car will store a record containing the power levels of these channels, the location coordinates, the contention metrics and a timestamp as described in the previous sections. When a car and an RSU become in the transmission range of each others, an exchange of information will occur. The car will provide the RSU with its next hop RSU along its path with all the records stored since the last RSU. The RSU on the other hand will check the next hop RSU sent by the car and will accordingly forward to the car the corresponding table proactively maintained in its memory. The car will now possess the table indicating the predicted data contention locations along its path till the next hop RSU with the associated additional spectrum at these locations. The car will then extend the control channel to this additional spectrum at these locations and will use it regularly. It should be kept in mind that the car cannot directly transmit on this additional spectrum. In fact, it should perform first a fast sensing to guarantee that the additional spectrum is indeed free at the moment of transmission. But on the other hand the car should not worry about other cars not receiving the message, since all cars possess the same table and should be listening to the same extended control channel at the specified locations.

Meanwhile, the RSU relays the information received from the car to the LAPU. The LAPU generates its estimates about the contention locations and the free spectrum. The LAPU does not directly update the tables stored at the RSUs; in fact, it waits till the change exceeds a portion p of the road size between 2 direct neighboring RSUs in order to trigger an update of the tables stored at those RSUs. When a table update is received by an RSU, a transition step should take place between the old and the new tables. The RSU after receiving the new table will make sure to send the old and the new tables to a set C of transition cars passing by it. In addition, those cars will be requested to only send on the regular non-extended control channel, and to listen to the extended control channel as specified in both the old and the new tables. After this set of transition cars, the new table could then be sent regularly to all passing cars which will resume regular operation sending on and listening to the extended control channel.

IV. MODEL VERIFICATION

To assess the reliability of the data contention model suggested before, we performed simulation on a network that needs 8 Mbps actual bitrate while the offered bitrate is 6Mbps. The simulation parameters were kept the same as in section *III.B*, and the simulation was repeated 100 times.

Figure 4 shows the results of the first verification experiment. The contention metrics clearly surpass the threshold indicating that the model is fairly accurate and does capture the contention effect of the channel.

The second performed experiment was about assessing the performance and possible improvements introduced by the scheme suggested in this paper. The same threshold scenario was implemented but more bandwidth was introduced: two TV channels were added, which effectively doubled the bandwidth and consequently the bit rate. Again, the simulation was repeated 100 times to get average results. The graph in Figure 5 shows that the newly plotted contention metrics (green triangles) fall below the data contention threshold which indicates also a validation of the model and major improvement that can reach 100%.

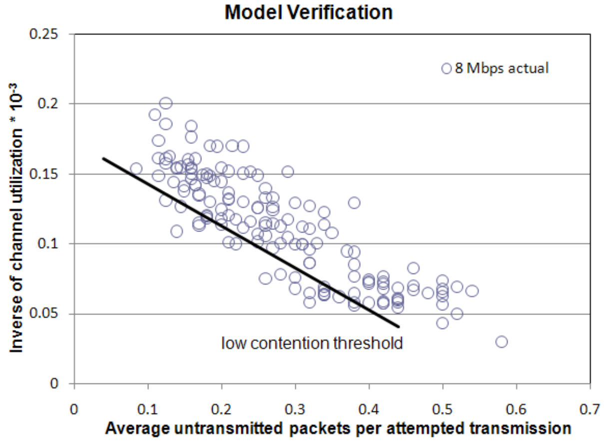

Figure 4: Congested scenario relative to the threshold.

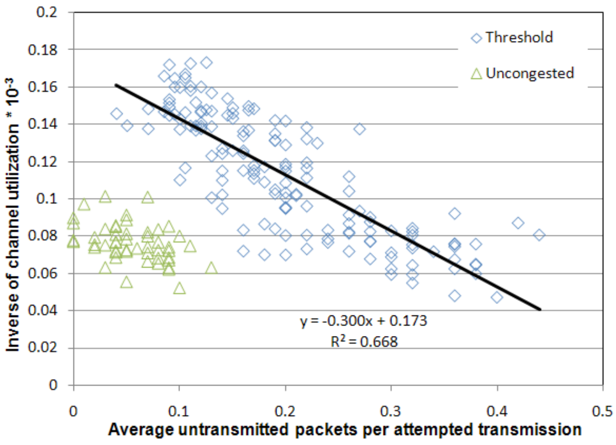

Figure 5: Uncongested scenario relative to the threshold.

V. CONCLUSION

In this paper, we introduced a new practical metric to measure contention in VANETs. More importantly, we have introduced a new system that makes use of cognitive network principles to extend the spectrum allocated for control channel in the DSRC. The system is capable of measuring contention on the roads using the contention metric that includes parameters which can realistically be measured. If contention is detected, new channels from the TV spectrum are assigned to the cars in accordance with the severity of the inferred contention. Spectrum sensing is performed by the cars which allows the system to discover white channels that can be allocated during contention scenarios. The performed simulations using NS2 clearly demonstrate the effectiveness of the system in relieving contention and thus allowing for a greater number of cars to communicate safety information, which may prove critical in areas that normally experience heavy traffic.

Future work can be focused on introducing improvements to the system: the contention metric can be further developed by incorporating in it additional variables and introducing multiple contention thresholds reflecting a more precise description of the road status, and thus enabling a more accurate assignment of white channels. One idea is to employ neural networks in the learning algorithm at the LAPU. In addition, more simulations can be performed to get more adaptable values for γ and δ.

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