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An Efficient Spectrum Sensing Mechanism for CR-VANETs

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ABSTRACT

VANET (Vehicular Adhoc Network), used for inter-vehicular communication nowadays is not sufficient due to increase in traffic day by day.Hence use of CR (Cognitive Radio) is being considered for vehicular communication. In this paper we propose an efficient spectrum sensing mechanism for sensing and sharing the CR spectrum by mobile vehicles, which combines best of Stand-alone sensing and Cooperative sensing techniques. The proposed mechanism not only improves the probability of correct detection but also diminishes the probability of misdetection.
KEYWORDS: Spectrum Sensing, RSU, DSRC, WAVE, PU, SU.

1. INTRODUCTION

VANET a special form of MANET (Mobile Adhoc Network) is designed for high mobility conditions of nodes. Due to increase of vehicular traffic resources provided for the vehicular communication are becoming insufficient. Especially the emergency messages enough communication resources in order to avoid accidents. Provision of communication means by CR technology is beneficial for vehicular communication for which accurate spectrum sensing and coordination techniques are needed. Many techniques for sensing and coordination have been proposed and we in this paper propose a technique that improves the sensing and coordination results.

Unlike MANET, most VANET nodes (Vehicles) are equipped with large batteries and due to availability of a charging mechanism within the vehicle; the power problem is almost negligible [1][26][27]. VANETs are specially designed for moving vehicles include many applications classified as public safety, traffic management, freight/cargo transport, transit, traveler information/support etc. The primary goal of the public safety application is to reduce or even eliminate accidents which result in fewer injuries and fatalities, lowering the direct or indirect financial costs, and reducing traffic congestion. Examples are forward obstacle detection and avoidance, lane departure warning, turn accident warning, intersection accident warning, low bridge warning, roll over warning, work zone warning, stopped vehicle warning and railway crossing warning. The goal of traffic management is to improve the flow of traffic in order to facilitate the passengers and drivers and reduce travel time. Application examples are smart traffic signals, variable message signs, and rapid response to incidents, enhanced public transit, emergency vehicle warning, central traffic management and electronic toll collection. Enhanced transit systems include traffic signal priority, bus only lane enforcement, bus turn light priority, automated fare collection and reporting, automated passenger counting, route optimization and schedule tracking, rider information, on demand transit services, security systems, fleet operations and maintenance, parking, and many other on-board systems. Freight and cargo systems include vehicle registration/ inspection and credentials, route guidance and tracking, vehicle monitoring and maintenance systems, cargo monitoring and tracking, and fleet operations. Traveler information and support includes pre-trip planning, route and fare information, access to news, weather reports and internet, navigation aids, traffic information on routes, access to personal information during the trip, restaurant and fuelling station information, and vehicle repair center information. Other entertainment services include audio, video, and email services [2][30].

The IEEE has standardized 802.11p/WAVE (Wireless Access in Vehicular Environment) for vehicle to vehicle communication(V-V) and vehicle to infrastructure communication (V-I). This process has been initiated with DSRC (Dedicated Short Range Communication) spectrum allocation. The USA Federal Communication Commission (FCC), in the year 1999, allocated 75 MHz, 5.9 GHz band DSRC especially for the V-V and V-I communication as shown in figure. 1.As shown in the figure, DSRC is divided into seven 10 MHz channels. Channel 178 is control channel (CCH) and is especially reserved for public safety messages. Channel 172 is High Availability Low Latency (HALL) channel and is reserved for critical safety V-V applications. Channel 184 is reserved for High power public safety applications. The other four channels are service channels (SCH) used either for safety or non-safety applications [3]. Channels 174 and 176 or 180 and 182 can be combined to get two 20 MHz channels. The range of the DSRC standard is around 300 meters to a maximum of 1000 meters. Its data rate is from 6 to 27 Mbps. It is a half-duplex communication standard.

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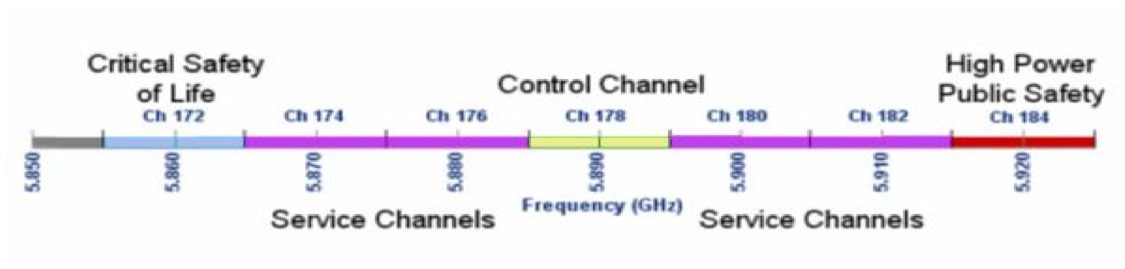

Fig. 1: DSRC 75 MHz Spectrum

IEEE 802.11p/WAVE is not a single standard, but it is a group of standards which comprises of P1609.1 (Resource Manager), P1609.2 (Security Services), P1609.3 (Networking Services), 1609.4 (Multi-channel Operations), and 802.11p (MAC Layer)[4][29].The European Union (EU) is also getting close to allocating 30 MHz in 5 GHz band, especially for the vehicular communication [3].

A lot of wireless technologies are in practice around the globe today, like Wi-Fi, Wi-Max, Cellular Telephone Technologies (e.g GSM, CDMA, LTE), TV bands, and IR remotes. It can be found by scanning that some of the frequency bands are over utilized, while others are under-utilized which costs a lot to the authorities. CR is an excellent way of dealing with the spectrum under-utilization problem. It can be observed by means of scanning that some of the slots of wireless spectrum are occupied by the primary (Licensed) users, while some slots are empty. Empty slots can be made available to secondary (un-licensed) users which are un-serviced due to congestion in their own spectrum. Empty slots are referred to as holes [5][31]. There are three transmission modes of CR, which are interweave, spectrum overlay and spectrum underlay. Comparison of these modes is discussed in [23].

Many signal detection techniques can be used for spectrum sensing in order to improve the probability of detection. Some techniques are energy detection, matched filter detection, cyclostationary detection, and wavelet detection. Every technique has its own pros and corns [6][28]. Spectrum sensing is a very important aspect of cognitive radio networks as the important decision of using a licensed spectrum is to be taken based on the results obtained by spectrum sensing. Hence spectrum sensing must be carried out accurately and in a timely manner so that reuse of the licensed spectrum by the secondary users can be achieved with minimum or even negligible interference to the licensed primary users [7][32].

Due to the increase in the number of vehicles, it has been observed that DSRC may not be able to cope with the large number of messages to be communicated in VANETs. Hence it is evident that vehicles may have to utilize holes in other licensed spectrums, especially for safety critical messages. Considering the critical safety applications of VANETs, accuracy in spectrum sensing is important. A lot of research work is being carried out on use of cognitive radio in VANETs. Some have proposed stand-alone sensing schemes[8][9], and some have proposed cooperative spectrum sensing [6][28]. Typical architecture of VANETs including Cognitive Radios is shown in figure 2 [25].

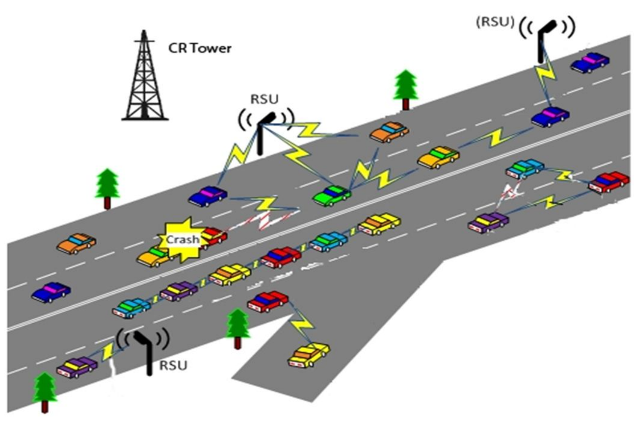

Fig. 2: Typical Structure of CR_VANET

Rest of the paper is organized as follows: Section 2 explains related work, Section 3 includes proposed system model, Section 4 includes the Spectrum sensing and coordination framework, section 5 provides simulations and results, and Section 6 concludes the paper.

2. RELATEDWORK

A lot of research work is being carried out on the use of cognitive radio in VANETs due to high priority information being exchanged between vehicles and between vehicle and RSUs. Since any wrong message or any delayed message may cause threat to the life of passengers, it is important to pass the safety critical messages in a timely manner. In IEEE 802.11p/WAVE, higher load is on the control channel (CCH) so it is proposed in [10] to create a structure comprising vehicles, RSUs, and Local Acquisition and Processing Units (LAPUs) for the use of cognitive radios in TV bands. It is a centralized architecture controlled by RSUs and LAPUs as decision centers are these units. RSUs are responsible for assigning the holes to the vehicles in their range on the basis of detecting the load on CCH channel gathered from the member vehicles. In [11] it is proposed that each vehicle be assigned specific channel to sense and use in TV spectrum band and each vehicle senses and uses the spectrum independently and information gathered be exchanged between vehicles for future decisions on the use of spectrum.. This scheme lacks coordination and may suffer from the problem of using of a particular hole by more than one vehicle. In [12] it is proposed that vehicles may utilize unlicensed Wi-Fi channels in urban areas and ISM bands (2.4 GHz or 5 GHz) by periodically sensing, using the spectrum holes and sharing the information between each other for future usage. Another solution is proposed in [13] which is based on belief propagation. Every vehicle broadcasts a message to its neighbors containing the information about the presence of primary user signals in its range. Receiving vehicles decides on the basis of belief messages received from its neighbors and its own observations; which PU channels to use for communication. This scheme suffers from slow processing due to dependence on all of its neighbor data. In [16] it is proposed that each secondary user senses the PU spectrum and uses if the hole is detected. It also shares the information on DSRC channels with its neighbors. In [17] authors have proposed a three state model; one describing the empty slot (hole), other specifying the presence of primary user, and third specifying the occupancy of channel by any secondary user. This scheme also insists on individual spectrum sensing by the secondary users with no collaboration. The proposals in [11], [12], [13], [16], and [17] are decentralized and may suffer from interference and collisions.

In [14] it is proposed to group the vehicles in clusters with one cluster head. Every cluster member performs the sensing of the PU spectrum and sends the results to cluster head which assigns the holes to requesting nodes based on the information received from whole of the cluster. This scheme is more centralized and decision is only taken by the cluster head for the channel allocation. This decision may not suit to all cluster members as holes detected by others may not be available to every cluster member due to various factors like shadowing or distance etc. This scheme may also suffer from delay as the holes detected may be occupied till the decision is received from the cluster head. In [15] it is proposed to divide the wideband spectrum of CR network in small sub-bands and assign each small narrow band to a group of nodes (vehicles) to scan and use the spectrum. Secondary users sense the spectrum and send the results to a Cognitive Base Station (CBS) which detects the transmitted values using MAP (Maximum a Posteriori) detector and then fuse the results to find the occupancy of the channel. This scheme may save the time of scanning as several groups are sensing different narrow bands at a time but lacks the correct decision making policy as no factor is considered in assigning the narrow band to a group of vehicles. A particular narrow band may suit one group of vehicles but may not suit another group.

In [18] authors have proposed a cooperative framework for spectrum sensing. Each vehicle senses the PU spectrum individually and shares the information with neighbors. Each sample of information collected from a user is assigned a weight, and then weight is adjusted and normalized. Afterwards, a decision is made for the availability of a hole and the decision is forwarded to all neighbors. This paper does not propose the method of utilizing of hole after it is found. In [19] energy detection techniques have been discussed. This paper does not mention any cooperative mechanism that which vehicles will sense the spectrum and who will decide or how will be decided the availability of hole and how will be decided the allocation of a hole to any secondary user. In [20] multi radio technologies (Multi-RAT) have been discussed and it has been proposed that every vehicle will sense or use any technology according to the required class of service. For example it proposes the usage of Wi-MAX for video conferencing and to use Wi-Fi for free data exchange. No cooperative sensing mechanism or channel allocation mechanism has been proposed.

In [21], a two user model has been discussed with one acts as a relay sending the information regarding presence or absence of PU in the spectrum to other user. Two cooperative schemes have been discussed. In the first scheme both users detect the PU and first one to detect tells the other about the presence or absence of a PU signal through a central controller. In the second scheme, users follow Amplify and Forward (AF) protocol to reduce the detection time. Since VANET is a multiuser scheme, and each user may have different ideas and findings related to presence or absence of PU signals, so this proposed scheme is not suitable for a VANET structure.

In [7] combination of standalone and cooperative spectrum sensing mechanism has been proposed. It combines the best of both approaches. In this approach, the spectrum is divided into several non-overlapping channels with a channel spacing of 6,7, and 8 MHz and the secondary network has a common channel for the exchange of control information over DSRC (5.9 GHz) band. A coordinating node (vehicle) periodically senses the spectrum and sends a group of channels (holes) to the requesting nodes (vehicles). The requesting node on receipt of holes, rescans the obtained holes and after reconfirmation uses the hole as per class of demand. This approach has its merits and demerits. The merit is that rescanning of holes by requesting nodes confirms the availability of channel at that time. The demerit is that every channel in a wideband cognitive radio spectrum may not be a hole for every vehicle due to its dynamic nature and geographical location.

We in this paper propose a unique cognitive radio spectrum sensing mechanism based on more than one coordinating nodes in a cluster (moving cell) in the absence of an RSU and with one Main coordinating node deciding on the basis of results from all coordinators; that which requesting node to be assigned which group of channels based on GPS coordinates. Our approach considers the location of requesting node into account in order to allocate the channels. Requesting nodes may then rescan the granted holes and after confirmation of detection of a hole and class of service required every node may decide better for the use of empty slots in the spectrum.

3. PROPOSED SYSTEM MODEL

In order to model the proposed system, we need to study the channels availability on CR spectrum, sensing technique used and its mathematical model, pattern of CR spectrum usage requests and their mathematical model, and vehicle mobility patterns and model. This section describes all these techniques and highlights the assumptions used.

3.1. Network Model

Each vehicle shall be equipped with a CR-Radio capable of sensing and utilizing the available resources (holes) in the spectrum, a GPS system to track its position and navigate its path to the intended destination, in addition to the equipment utilizing DSRC IEEE 802.11p resources for preferred normal communication among the vehicles and between vehicles and RSUs at 5.9 GHz band. In case DSRC resources fall short of the requirements, vehicles can use CR-spectrum for their communication.

In USA TV bands use 7-1002 MHz spectrum with VHF low band using 5.9-88 MHz, VHF high band using 175-216 MHz, and UHF using 470-890 MHz with the channel bandwidth of 6 MHz CATV uses 7-48 and 55-1002 MHz with 4.5 MHz channel bandwidth. Hence if vehicle uses CR-spectrum, it may divide the spectrum intok non overlapping channels $\{C|C_i$, i=1, 2, 3, ------, k}, not necessarily equally spaced (in order to utilize the available spectrum resources of various technologies.) centered at $\{f_c^i\}_{i=1}^k$. Secondary network of vehicles use channel 172 (High Availability Low Latency Channel) on 5.9 GHz band DSRC spectrum, in order to communicate information and management messages for the use of CR spectrum among vehicles and between vehicles and RSUs. This channel is referred to as C_H.

3.2. Spectrum Sensing Model

CR network has primary users, which are licensed and must not to face any interference from secondary users. Hence spectrum sensing shall be carried out in such a way to avoid any interference to primary users' communication. Every wireless technology has its own pilot carriers for its different channels. Let f_*^i indicate the pilot frequency of primary user networks (i indicates the number of channel and * indicate the technology used; such as v for VHF, U for UHF, and t for CATV). Parallel sensing is used for VHF, UHF, and CATV channels to reduce the time of sensing the channels. The energy detection technique is used to effectively identify the presence and absence of primary user signals. Binary hypothesis test can be applied where H_1 is used for presence and H_0 is used for the absence of primary user signals. As proposed in[22] and [7] using these two hypothesis conditions, the band pass signal observed by a secondary user for the channel C_i can be represented as

$$r_i(t) = \begin{cases} Re\left\{[h_c S_{LP}(t) + n_{LP}(t)]e^{j2\pi f_*^i t}\right\}, H_1 \\ Re\left\{n_{LP}(t)e^{j2\pi f_*^i t}\right\}, \qquad H_0 \end{cases} \quad (1)$$

Where real part of the complex waveform is represented by Re{.}, i=1,2,3,---,M, f_*^i is the carrier frequency of primary channel (* indicates v for VHF, U for UHF, and t for CATV), if we use the secondary user pilot carrier frequency for the detection of secondary user signal occupying the primary network we use f_s^i, $S_{LP}(t)$ is the equivalent low pass representation of the detected primary or secondary user signal. Additive white Gaussian noise with zero mean is represented by $n_{LP}(t)$. Using the energy detection technique and bandpass filter, the energy of detected signal $r_i(t)$ for the period $0 \le t \le T$ can be represented as

$$e_i = \cong \frac{2}{N_0}\int_T \; r_i{}^2(t)dt \quad (2)$$

$e_i$is a random variable and it has chi-square distribution. Its probability density function can be expressed as [22] and [7]

$$f(e_i) = \begin{cases} \frac{1}{2^{k/2}\gamma(k/2)} e_i^{(k/2)-1} e^{-e_i/2}, & H_0 \\ \frac{1}{2} e^{-\left(e_i/2+\omega\right)} \left(\frac{e_i}{2\omega}\right)^{k/4-0.5} I_{(k/2)-1}\left(\sqrt{2\omega e_i}\right), & H_1 \end{cases} \quad (3)$$

Here γ is the Gamma function, I is the modified Bessel function, ω is the instantaneous signal to noise ratio (SNR), and k is the degree of freedom.

Situations may arise due to fading if the detected signals have low SNR confusing it with the noise. In this case caused by misdetection meaning signal is present but it may be considered as absent. In this case interference may be caused by the secondary users with the communication of the primary user. There may also be a case of false alarm meaning the signal is absent but is considered present. But this case causes no harm as far as interference is considered. User requests are considered random to the main coordinator. Main coordinator furnishes the requests on the first come first serve basis.

3.3. Vehicle Mobility Model

Mobility model used for the vehicle mobility is mainly Gipps model [24] with a slight modification that if the distance between the current vehicle and the leading vehicle is less than safe distance, then the current vehicle shall overtake the leading vehicle. Other parameters follow the Gipps model as given below.

$$v_{safe}(t) = v_l(t) + \frac{g(t) - v_l(t)\tau}{\frac{\overline{v}}{b(\overline{v})} + \tau} \quad (4)$$

$$v_{des}(t) = \min\left[v_{max}, v + a, v_{safe}(t)\right] \quad (5)$$

$$v(t) = \max[0, rand[v_{des}(t) - \epsilon a, v_{des}(t)]] \quad (6)$$

In equations (4), (5), and (6) above $v_l(t)$ is the speed of leading vehicle at time t, $g(t)$ is the gap of leading vehicle at time t, $\overline{v}$ is the average speed, $b(\overline{v})$ is the deceleration function, τ is the driver's reaction time (usually 1 second), v_{max} is the maximum allowable speed of the vehicle, a is the acceleration, $v_{des}(t)$ is the desired speed, ϵ is the human error factor between 0 and 1, and $v(t)$ is the final speed at time t.

4. SPECTRUMSENSING AND COORDINATION FRAMEWORK

Different ideas have been proposed for the sensing of the CR spectrum. Some are standalone, whose sensing results are faster but they cause unnecessary interference to the primary user signals and also among secondary users using CR spectrum. Some approaches are cooperation based which create a master/slave relationship among coordinating node or RSU and secondary users; also sensing results may not be accurate. Further scalability and intractability problems are also noticed in these types of approaches. One approach proposed in [7] claim to combine best of both approaches but the results sensed by a coordinator may not be accurate in high mobility VANET environment. Our proposed coordinating sensing idea has more than one localized coordinating node and sensing results are based on a majority decision, which causes more accuracy, scalability, intractability, and reduces the interference.

In the proposed coordination sensing framework, a main coordinator N_M coordinates the sensing activities and forwards the sensing results to the requesting secondary users based on its sensing results and the results received from N_F, forward edge coordinator, and N_B, backward edge coordinator. Sensing results received by N_M from N_F and N_B are finalized using best two out of three decisions. For example if a channel sensed is considered available (hole) by two or more coordinators, it is stored as a hole in the database. Requesting secondary users after receiving a group of channels (holes) from N_M re-sense the channels, but for a slightly longer time compared to coordinators, confirming these as holes, and then pick a channel suitable for the class of service requested. Secondary users receive information based on three differently located coordinators which can be considered more accurate thereby causing negligible interference to primary user networks.

The proposed sensing coordination framework works as follows. The main coordinator $N_M$andthe two edge coordinators N_F and $N_B$sense periodically the CR spectrum channelsC_i. $N_F$andN_B send the sensed results to N_M periodically on C_H channel of DSRC spectrum. Sensing is performed using the energy detection technique based on hypothesis as given in (1). N_M, after receiving the sensed results makes a decision based on majority for declaring a channel as occupied or empty (hole) and stores the calculated results in the database. Upon arrival of request $X \in R_k$ (received from a secondary user N_j on channel C_H of a particular class of service,the main coordinator N_M sends the sensed results of that class of service to N_j. The requesting secondary user N_j(after receiving the results), re-senses the received channels, picks a channel and sends an ACK (acknowledgement) message mentioning the number of channel picked for use. $N_M$afterreceiving an ACK, deletes the channel picked by the N_j from its available channels database. If the requesting secondary user after re-sensing the channels finds the channels occupied, it sends a NACK (Non-acknowledgement) message to the N_M, after receipt of which N_M sends the freshly sensed results to N_j.

4.1. Coordinators Selection Phase

Coordinators selection is performed dynamically whenever a secondary user wants to access the CR spectrum. In case of RSU based system, a RSU will act as the coordinator for its coverage range hence RSUs shall be installed in such a way to fully utilize the CR resources. In case when RSUs are not available, separate set of coordinators shall be selected for the both sides of highways. This will ensure that the groups will remain intact for a longer period of time on highways.

When a secondary user N_j wants to use the CR network for transmission; it firstly checks if there is any main coordinator available in its vicinity. It confirms this confirming if it is periodically receiving messages from anyN_M. If no main coordinator is available, the requesting node itself starts behaving as main coordinator N_M. After being selected asN_M, it sends message on C_H channel to all nodes (vehicles) in its coverage range to send the GPS coordinates and current speed. When every node replies with the GPS coordinates and speed, N_M selects farthest node in front with the speed equal or less than (within 5%) the speed of N_M, as the front edge coordinator N_F; and farthest node in back with the speed equal to or greater than (with in 5%) the speed of N_M, as the backward edge coordinator N_B. N_M collects the GPS coordinates and speed of the cluster (moving cell) nodes periodically and reassign the duty of N_F and N_B to the nodes matching the criteria as discussed above as due to difference in speed coordinating nodes may be at different locations than expected.

4.2. Spectrum Sensing Phase

CR-spectrum sensing responsibility is on the coordinators N_M, $N_F$andN_B. Each coordinator will sense the channels $\{C_i\}_{i=1}^{k}$ in parallel, periodically, and in a proactive manner. Each coordinator will sense the channels independently of each other. Each coordinator shall be able to detect the presence or absence of the primary or secondary user signals while remaining efficient to reduce the likelihood of interference. At each iteration of energy detection on channels $\{C_i\}_{i=1}^{k}$, the N_F and N_B will send the results on C_H channel to N_M and which will compile the results in terms of likelihood of channel availability $\{p_i(t)\}_{i=1}^{k}$ according to the following rule.

"The channel C_i will be declared available if and only if at least two of the coordinators will decide the availability of the channel on the basis of hypothesis H_0 (signal absence) or H_1 (signal presence)".

The probability of detecting the user (primary or secondary) is defined as:

$$p_d = p[atleast\ two\ of\ the\ coordinators\ will\ decide\ that\ the\ user\ is\ present|H_1]$$

$$= p\begin{bmatrix} N_M\ and\ N_F\ will\ decide\ present|H_1\ or \\ N_F\ and\ N_B\ will\ decide\ present|H_1\ or \\ N_B\ and\ N_M\ will\ decide\ present|H_1 or \\ N_M\ and\ N_F\ \ and\ N_B\ will\ decide\ present|H_1 \end{bmatrix} \tag{7}$$

In order to obtainp_d, we need to express H_1 or H_0 as been evaluated atN_M,N_F and N_B also we need to derive joint pdf as expressed later in this section. It is important that during the sensing phase all the coordinators shall be synchronized. i.e they all shall sense the channel C_i at the same time.

At N_M, the received bandpass waveform on $C_i$as per equation (1) is given by:

$$r_{N_M}^{i}(t) = \begin{cases} Re\left\{\left[h_{N_M}S_{LP}(t) + n_{N_M}(t)\right]e^{j2\pi f_*^i t}\right\}, H_1 \\ Re\left\{n_{N_M}(t)e^{j2\pi f_*^i t}\right\}, \qquad H_0 \end{cases} \tag{8}$$

AtN_F, the received bandpass waveform on C_i as per equation (1) is given by:

$$r_{N_F}^{i}(t) = \begin{cases} Re\left\{\left[h_{N_F}S_{LP}(t) + n_{N_F}(t)\right]e^{j2\pi f_*^i t}\right\}, H_1 \\ Re\left\{n_{N_F}(t)e^{j2\pi f_*^i t}\right\}, \qquad H_0 \end{cases} \tag{9}$$

AtN_B, the received bandpass waveform on C_i as per equation (1) is given by:

$$r_{N_B}^{i}(t) = \begin{cases} Re\left\{\left[h_{N_B}S_{LP}(t) + n_{N_B}(t)\right]e^{j2\pi f_*^i t}\right\}, H_1 \\ Re\left\{n_{N_B}(t)e^{j2\pi f_*^i t}\right\}, \qquad H_0 \end{cases} \tag{10}$$

As per equation (2) the output of energy detection at each coordinator is given by equations (11), (12), and (13). In this step it is assumed that mean of noise component is zero and variance is$\frac{N_0}{2}$.

$$e_{N_M}^{i} = \cong \frac{2}{N_0}\int_T \ {r_{N_M}^{i}}^2(t)dt \tag{11}$$

$$e_{N_F}^{i} = \cong \frac{2}{N_0}\int_T \ {r_{N_F}^{i}}^2(t)dt \tag{12}$$

$$e_{N_B}^{i} = \cong \frac{2}{N_0}\int_T \ {r_{N_B}^{i}}^2(t)dt \tag{13}$$

The pdf of individual$r_{N_M}^{i}(t)$,$r_{N_M}^{i}(t)$ and $r_{N_M}^{i}(t)$ is given by equation (14), (15), and (16) respectively.

$$f\left(e_{N_M}^i\right)=\begin{cases}\frac{1}{2^{k/2}\gamma\left(k/2\right)}e_{N_M}^{i\ \ (k/2)-1}e^{-e_{N_M}^i/2}, & H_0\\ \frac{1}{2}e^{-\left(e_{N_M}^i/2+\omega\right)}\left(\frac{e_{N_M}^i}{2\omega}\right)^{k/4-0.5}I_{\left(k/2\right)-1}\left(\sqrt{2\omega e_{N_M}^i}\right), & H_1\end{cases} \quad (14)$$

$$f\left(e_{N_F}^i\right)=\begin{cases}\frac{1}{2^{k/2}\gamma\left(k/2\right)}e_{N_F}^{i\ \ (k/2)-1}e^{-e_{N_F}^i/2}, & H_0\\ \frac{1}{2}e^{-\left(e_{N_F}^i/2+\omega\right)}\left(\frac{e_{N_F}^i}{2\omega}\right)^{k/4-0.5}I_{\left(k/2\right)-1}\left(\sqrt{2\omega e_{N_F}^i}\right), & H_1\end{cases} \quad (15)$$

$$f\left(e_{N_B}^i\right)=\begin{cases}\frac{1}{2^{k/2}\gamma\left(k/2\right)}e_{N_B}^{i\ \ (k/2)-1}e^{-e_{N_B}^i/2}, & H_0\\ \frac{1}{2}e^{-\left(e_{N_B}^i/2+\omega\right)}\left(\frac{e_{N_B}^i}{2\omega}\right)^{k/4-0.5}I_{\left(k/2\right)-1}\left(\sqrt{2\omega e_{N_B}^i}\right), & H_1\end{cases} \quad (16)$$

Since all the coordinators perform the energy detection independently, hence the joint pdf and third order pdf are given by equations (17) to (20).

$$f\left(e_{N_M}^i,e_{N_F}^i\right)=f\left(e_{N_M}^i\right)f\left(e_{N_F}^i\right) \quad (17)$$

$$f\left(e_{N_F}^i,e_{N_B}^i\right)=f\left(e_{N_F}^i\right)f\left(e_{N_B}^i\right) \quad (18)$$

$$f\left(e_{N_B}^i,e_{N_M}^i\right)=f\left(e_{N_B}^i\right)f\left(e_{N_M}^i\right) \quad (19)$$

$$f\left(e_{N_M}^i,e_{N_F}^i,e_{N_B}^i\right)=f\left(e_{N_M}^i\right)f\left(e_{N_F}^i\right)f\left(e_{N_B}^i\right) \quad (20)$$

Therefore probability of detection at N_M can be evaluated as:

$$\begin{aligned}p_{d|N_0}=\ & p\left[e_{N_M}^i>\gamma,e_{N_F}^i>\gamma|H_1,N_0\right]+\\ & p\left[e_{N_F}^i>\gamma,e_{N_B}^i>\gamma|H_1,N_0\right]+\\ & p\left[e_{N_B}^i>\gamma,e_{N_M}^i>\gamma|H_1,N_0\right]-\\ & 2p\left[e_{N_M}^i>\gamma,e_{N_F}^i>\gamma,e_{N_B}^i>\gamma|H_1,N_0\right]\end{aligned} \quad (21)$$

$$\begin{aligned}p_{d|N_0}=\ & \iint_{\gamma}^{\infty} f\left(e_{N_M}^i,e_{N_F}^i\right)|H_1 de_{N_M}^i de_{N_F}^i+\\ & \iint_{\gamma}^{\infty} f\left(e_{N_F}^i,e_{N_B}^i\right)|H_1 de_{N_F}^i de_{N_B}^i+\\ & \iint_{\gamma}^{\infty} f\left(e_{N_B}^i,e_{N_M}^i\right)|H_1 de_{N_B}^i de_{N_M}^i-\\ & 2\iint_{\gamma}^{\infty} f\left(e_{N_M}^i,e_{N_F}^i,e_{N_B}^i\right)|H_1 de_{N_M}^i de_{N_F}^i de_{N_B}^i\end{aligned} \quad (22)$$

$$\begin{aligned}p_{d|N_0}=\ & \int_{\gamma}^{\infty} f\left(e_{N_M}^i\right)|H_1 de_{N_M}^i\int_{\gamma}^{\infty} f\left(e_{N_F}^i\right)|H_1 de_{N_F}^i+\\ & \int_{\gamma}^{\infty} f\left(e_{N_F}^i\right)|H_1 de_{N_F}^i\int_{\gamma}^{\infty} f\left(e_{N_B}^i\right)|H_1 de_{N_B}^i+\\ & \int_{\gamma}^{\infty} f\left(e_{N_B}^i\right)|H_1 de_{N_B}^i\int_{\gamma}^{\infty} f\left(e_{N_M}^i|H_1\right) de_{N_M}^i-\\ & 2\int_{\gamma}^{\infty} f\left(e_{N_M}^i\right)|H_1 de_{N_M}^i\int_{\gamma}^{\infty} f\left(e_{N_F}^i\right)|H_1 de_{N_F}^i\int_{\gamma}^{\infty} f\left(e_{N_B}^i\right)|H_1 de_{N_B}^i\end{aligned} \quad (23)$$

The detection threshold can be obtained from [7, eq. (6)]. Average detection probability can be obtained by averaging out of $p_{d|N_0}$ over SNR of different signals on CR spectrum as given by (24) below.

$$p_d = \frac{1}{\overline{\omega}_*}\int_0^{\infty} p_{d|N_0} e^{-\omega_*/\overline{\omega}_*} d\omega_* \quad (24)$$

Where ω_* is the instantaneous SNR of different (VHF, UHF, CATV) signals on CR spectrum and $\overline{\omega}_*$ is the average SNR.

Upon arrival of the requests from the vehicles, main coordinator N_M send the list of detected holes to the requesting vehicles on first come first serve basis. Requesting vehicle upon receipt of list of holes re-senses the received holes multiple times to re-confirm the availability of the channels and picks the first available channels for the transmission. It sends the channel acquiring message to the N_M so that it may delete the channel from the list of available channels. Re-sensing by the requesting vehicle reduces the chances of misdetection and hence avoids interference with the primary user signals.

5. COORDINATORSSELECTION AND SENSING ALGORITHMS

Coordinators selection algorithm is given below:

$if\, N_j$ detects no N_M then
$N_j = N_M$
(Front Coordinator selection)
$N_1 = N_F$
for i = 2 to p (p front nodes)
$N_M -> if\ Distance\ (N_i\ to\ N_M) > Distance(N_F\ to\ N_M)\ then$
$N_i = N_F$
end
(Back coordinator selection)
$N_1 = N_B$
for i = 2 to q (q back nodes)
$N_M -> if\ Distance\ (N_i\ to\ N_M) > Distance(N_B\ to\ N_M)\ then$
$N_i = N_B$
end

Algorithm for sensing of the spectrum by three coordinators and compiling the results is given below:

$N_M,\ N_F, N_B\ sense\ the\ spectrum\ (C_i\ channels)$
$N_M -> store\ channels\ state\ in\ array\ A_M$
$N_F -> store\ channels\ state\ in\ array\ A_F$
$N_F -> send\ A_F\ to\ N_M$
$N_B -> store\ channels\ state\ in\ array\ A_B$
$N_B -> send\ A_B\ to\ N_M$
$for\ i = 1\ to\ M$
$if\ (A_M.state(C_i) = idle\ and\ A_F.state(C_i) = idle)\ or$
$(A_F.state(C_i) = idle\ and\ A_B.state(C_i) = idle)\ or$
$(A_B.state(C_i) = idle\ and\ A_M.state(C_i) = idle)$
$A_{final}.state(C_i) = idle$
$else$
$A_{final}.state(C_i) = busy$

end

Flow charts of every activity are given below in figure 3, 4, 5, 6.

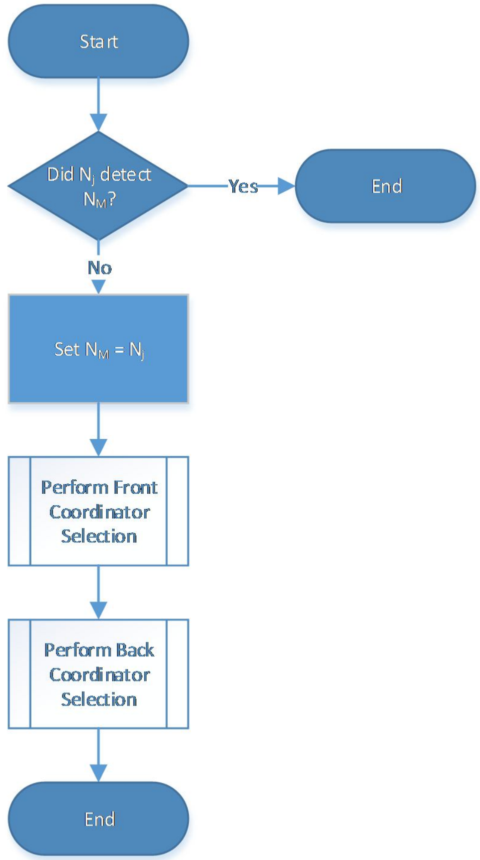

Figure 3: Coordinators Selection

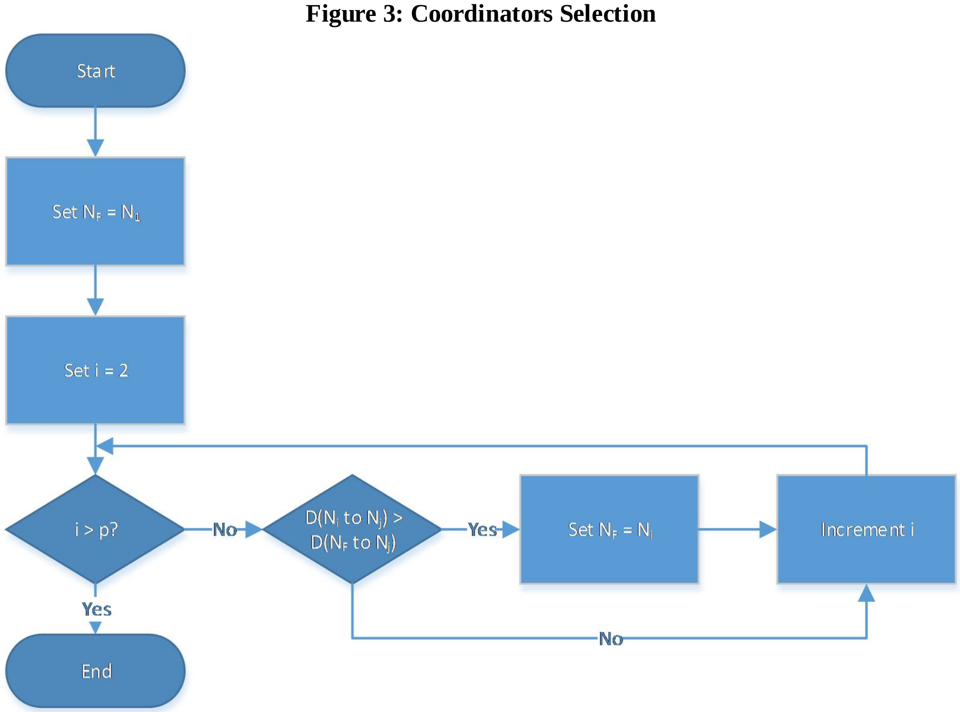

Figure 4: Front Coordinator Selection

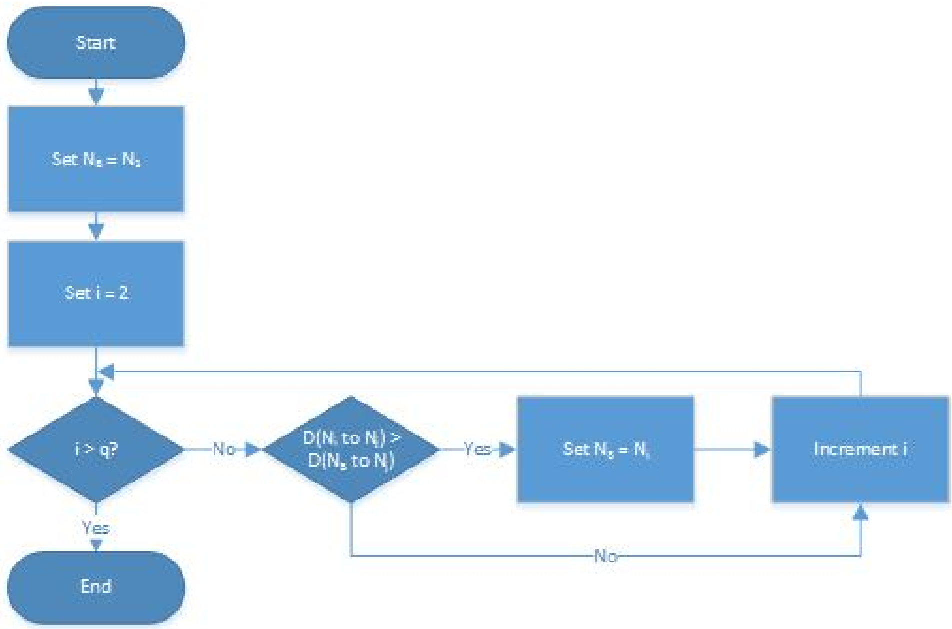

Figure 5: Back Coordinator Selection

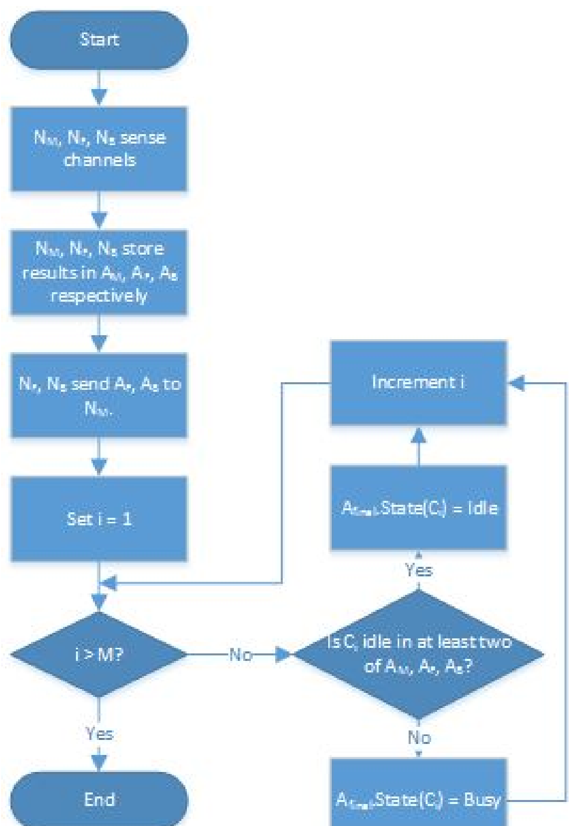

Figure 6: Spectrum Sensing

6. SIMULATIONSAND RESULTS

Simulations have been built using Microsoft C# 5.0. Simulations have been carried out by varying number of channels, number of vehicles and by changing vehicle speed. Different scenarios have been developed for standalone sensing case, cooperative sensing case, and our proposed spectrum sensing case. A 2 km piece of highway is considered for the simulation, cognitive radio towers are placed at a perpendicular distance of 91 km from the highway and transmission power taken is 100 kW. Channels are varied from 10 to 100, number of vehicles from 10 to 100, and speed from 40 to 110 km/h. Inter vehicle communication range is 240 m and sensing range is 400 m, deceleration factor is 2.12 and maximum acceleration fraction is 0.01, Noise power density considered is 0.5×10^{-6} □/□^{2} and power density threshold is1.5×10^{-6} □/□^{2}, sensing interval taken is 20 ms, vehicle communication interval is 20 to 30 ms and vehicle silent time is taken as 0.4 to 0.5 s.

6.1. Probability of Correct detection

Correctness of the detection technique to identify the presence or absence of primary user signal is an important factor in determining the validity of the algorithm and robustness of the equipment being used. We have plotted the probability of correct detection versus number of channels, number of vehicles and vehicle velocity as shown in figure 7, figure 8, and figure 9 respectively. Figure 7 shows that as we increase the number of channels on the primary user network, the probability of correct detection of CR network in the case of standalone and cooperative sensing methods but in the case of our proposed scheme it remains constant and almost equal to one. Figure 8 shows that if we increase the number of vehicles probability of correct detection improves with standalone sensing and it decreases with cooperative sensing whereas with our proposed sheme it remains constant at almost one. Figure 9 shows that if we increase the vehicle velocity probability of correct detection with standalone and cooperative sensing techniques is low as compared to our proposed scheme. From these three graphs it is evident that our proposed sensing technique outclasses the standalone sensing and cooperative sensing techniques.

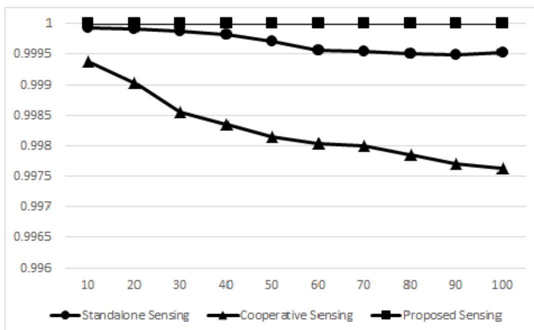

Figure 7: Probability of Correct Detection versus No. of Channels

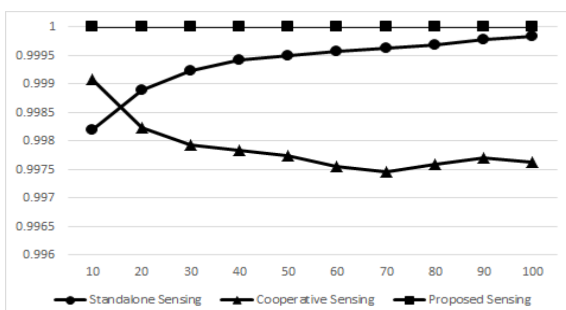

Figure 8: Probability of Correct Detection versus No. of Vehicles

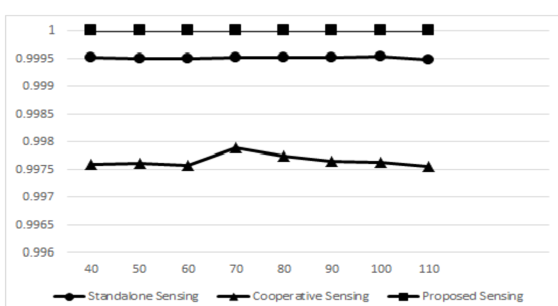

Figure 9: Probability of Correct Detection versus Vehicle Velocity

6.2. Probability of Misdetection

If any vehicle wrongly identifies the presence of primary user as absence, it can start using that channel and cause interference with the primary user signals. Hence algorithms and techniques shall correctly detect the presence of primary user so that secondary user may not harm the primary user network. Graphs given in figure 10, figure 11, and figure 12 show the probability of misdetection versus number of channels, number of vehicles, and vehicle velocity. These graphs show that misdetection caused by our proposed technique remains at zero. Some misdetection is observed in the case of standalone and cooperative sensing techniques which may cause interference with the primary user network by the unlicensed secondary users hence misdetection must be eliminated completely. These graphs show that our proposed scheme have completely eliminated the misdetection and hence does not interfere with the primary user network.

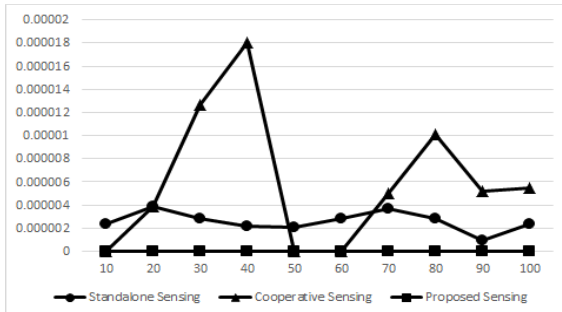

Figure 10: Probability of Misdetection versus No. of Channels

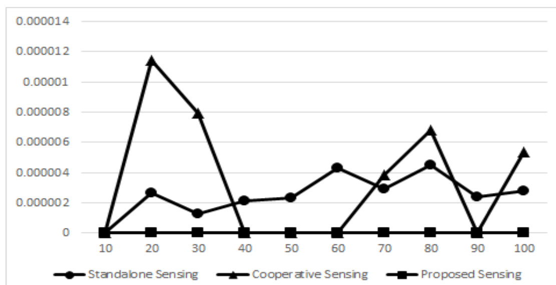

Figure 11: Probability of Misdetection versus No. of Vehicles

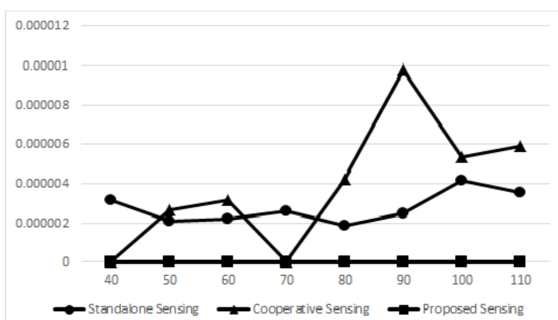

Figure 12: Probability of Misdetection versus Vehicle Velocity

7. CONCLUSION

As discussed in 'Related Work' section many different techniques have been proposed for spectrum sensing of cognitive radio networks. Since primary users are licensed users and are authorized to utilize that network hence their communication shall not be disturbed in any case by the unlicensed secondary users. So the technique and algorithm used shall correctly identify the presence or absence of primary user and it shall force the secondary users to leave the primary network channel in case primary user comes back again. As shown by the simulation results our technique has a better probability of correct detection as compared to standalone and cooperative sensing techniques further our technique has eliminated misdetection resulting in zero interference being caused with the primary user signals. Since vehicular communication is needed to be error free and quick so our technique provides the opportunity to utilize CR networks in case the resources on the DSRC spectrum are overburdened.

8. FUTURE PROSPECTS

Day by day traffic in urban areas as well as on highways is increasing leaving researchers to think about providing sufficient resources to cope with the increasing V-V and V-I communication. Our technique may help to distribute the burden of increased communication and avoid unwanted incidents. Our future work includes allocation, sharing and management of CR spectrum specially for V-V and V-I keeping the sensing technique used in this paper.

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