CR Channel Allocation Using Fuzzy Logic in VANETs

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Received: Jan. 2015 & Published Online: Mar. Issue 2015

Abstract: Vehicular Ad-hoc Networks (VANETs) are being considered vital in order to reduce or even eliminate the loss to human life, movable and immovable property due to road accidents. The DSRC/WAVE/IEEE802.11p protocol has been proposed for vehicular network traffic but due to increasing road traffic it may not be enough to cope with network traffic, especially emergency messages, hence the use of cognitive Radio (CR) technology has been introduced. Our paper utilizes fuzzy logic for the allocation of different types of TV channels having different ON/OFF timings in hours of the day taking time, vehicle speed, message priority and CR channel sensing results as input. The simulations performed show the utilization of every type of channels in speed versus time and message priority versus time. These results can be utilized well for the allocation patterns of CR channels.

Keywords: ITS, WAVE, V2I, I2V, RSU, PU, SU

1. Introduction

Vehicular Ad-hoc Networks (VANETs) are being considered as a backbone network for the road transport. In United States it has been reported that number of fatal road accidents have never dropped below 35000 annually since 1994 [1]. The main cause of these accidents is bad decisions on the part of drivers. Hence there needs to be a robust network to provide proper guidance to the drivers and provide safety and comfort to the passengers. In 2003, Federal Communications Commission (FCC) introduced Dedicated Short Range Communications (DSRC) in the 5.9 GHz band [2], specifically for improving road transport networks. Afterwards an amendment (IEEE 802.11p) for the MAC and PHY layer was introduced to improve it further [3]. The family of the protocol stack is Wireless Access in Vehicular Environment (WAVE) and its services and interfaces are defined by the IEEE 1609 standard [4]. Various aspects of Intelligent Transportation Systems (ITSs) have been covered in the VANETs; these include Vehicle to Vehicle Communication (V2V), Vehicle to Infrastructure Communication (V2I) and Infrastructure to Vehicle Communication (I2V). V2V involves direct communication between vehicles in their communication range. V2I and I2V involves Road Side Units (RSUs) for the communication between vehicles which are not in direct communication range; and between fixed infrastructure and vehicles [5].

Due to increasing traffic on roads day by day; a huge burden has been observed on the DSRC spectrum band in the form of increased network traffic. Hence it has been proposed on different forums to add to the resources in order to minimize the delay for immediate and urgent messages from and to the vehicles. Many researchers have proposed the use of Cognitive Radio (CR) technology in order to efficiently use the under-utilized spectrum resources of various Radio Access Technologies (RATs) such as Wi-Fi, Wi-MAX, VHF/UHF TV, Infra-Red, Cellular Phone, Microwave, and Satellite. There are four major steps in CR technology; Spectrum Sensing, Spectrum Decision, Spectrum Sharing, and Spectrum Mobility [6]. Spectrum Sensing involves the adaptation by the Secondary User (SU) to the environment by efficiently detecting the unused spectrum bands (holes) without developing any harmful interference to the authorized Primary User (PU) network. Energy detection, matched filter detection and feature detection are three different techniques used in spectrum sensing. Spectrum Decision involves the decision made after detecting the holes in primary network depending on different QoS requirements of SU. There are four different Spectrum Sharing techniques; Spectrum Overlay in which SU uses the holes not being used by PU causing no interference to PU network, Spectrum Underlay in which SU uses the CR spectrum in parallel with PU with low power such that communication of SU is considered noise by the PU, Intra-Network Spectrum Sharing and Inter-Network Spectrum Sharing. Spectrum Mobility involves the steps taken in case during transmission by a SU if PU returns to occupy the spectrum; hence SU has to change its band for further transmission.

In [7], the authors have highlighted the challenges and research directions in dynamic routing emphasizing that a secondary user suffers from high interference from primary users and other secondary users. Therefore the secondary transmission must be confined to ensure sufficient operation of PUs, which thereby deteriorates the QoS provisioning. Due to channel switching and users' interference, the longer paths will be chosen for transmissions which may create a problem of larger routing graphs and end-to-end delay.

In [8], the authors have proposed a Cog-V2V framework for CR-VANETs involving cooperative spectrum sensing among the vehicles for the detection of holes in CR network. This paper also explains the procedure for the use of CR spectrum bands in future in case PU returns and occupies the spectrum band being used by any vehicle (SU). The authors have also proposed the integration method of this framework into existing IEEE 802.11p/1609.4 WAVE protocol stack. In [9], the authors propose the use of spectrum sensing database for different road segments for reducing the sensing overhead on the network resources. Authors have also studied the impact of broadcast frequency and vehicle velocity on the spectrum sensing. In [10] authors have proposed a cooperative sensing and spectrum allocation scheme based on the Hidden Markov Chain model to increase the bandwidth utilized by the SU and further reduce the transmission delay especially for emergency messages. In [11] for collaborative spectrum sensing, the authors have proposed the use of Belief Propagation technique to cover the distributed observations and to reduce the redundancy in space and time. In [12] authors have emphasized the use of CR technology in VANETs due to increasing traffic on roads and network traffic on DSRC spectrum. Specifically, there is a need to minimize the propagation delay of life critical messages. The authors have proposed a cognition cycle consisting of four phases; Observe, Analyze, Reason and Act. Many issues have been discussed like QoS requirements, Bandwidth Scarcity and Congestion and offloading lower priority flows, Resiliency, More spectrum holes on highways, sufficient space and power supply in vehicles, High mobile environment and reprogrammable vehicular telemetrics. In [13], the author has checked the performance of Vehicular Dynamic Spectrum Access (VDSA) within a TV whitespace environment. A technique for Vehicle Cooperative Communication and Vehicle Platooning has also been proposed. A test-bed implementing the VSDA for performance evaluation has also been proposed. In [14], the author has mainly focused on the spectrum sensing techniques, routing methodology, and security for cognitive radio vehicular networks. Further, the impact of changes in the network formed by vehicles on radio propagation channel has been discussed and finally its performance has been evaluated. In [15], the authors have tried to establish the bounds on the detected CR signal levels in order to avoid false alarms and misdetections. The authors have compared three detection techniques; coherent pilot detection, simple non-coherent energy detection and network layer technique based on collaborative detection. The authors have concluded that pilot detection needs small sensing time but requires perfect synchronization; energy detection needs large processing time and suffers from noise uncertainties. Hence for efficient implementation FFT may be used which offers signal processing gains for energy detection of sine wave.

In [16], we have proposed an efficient cooperative cum stand-alone spectrum sensing mechanism based on three coordinators headed by main coordinator, one forward and one

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-3/MAGNT.111)

backward coordinator. The coordinators sense the spectrum based on the energy detection technique and based on two out of three decisions decide the availability of the hole. The main coordinator upon request from cluster member vehicles sends a list of available holes. Vehicles re-sense the holes provided by the Main coordinator, and use the spectrum after reconfirmation. Simulation results show reduction in false alarms and elimination of misdetections. In [17] we have modified our work presented in [16] by Employing Hata Model for large scale fading, Rayleigh Fading Model for small scale fading and modified Gibbs Mobility Model for the vehicle movement. Results show a considerable improvement in the metrics. In [18] we have proposed to Update, Preserve, and utilize the history of availability of spectrum resources in spatio-time-frequency slots. Data of each slot is updated upon new sensing results. Database is kept and updated by RSUs upon receiving results from Main Coordinators for different clusters. For utilization vehicles collect the database through coordinators from the RSU and re-sense the spectrum holes before using. History keeping needs storage capacity but can quickly provide the availability of spectrum resources list for the particular slots of the vehicle's concern. As many CR resources especially TV and Radio channels have specific on/off timings so results using history show an improved trend in allocation, lowering rejection ratios, and eliminating forceful vacation of holes by PU.

Fuzzy Logic (FL) provides a simpler method to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Real world problems are not discrete (0 or 1). Just like sound may be very low, low, medium, high, very high, and exceptionally high. FL converts real world problems into membership functions describing graphically the variable states. Based on those states decisions are made by if-then rules including all possible events and decision is taken based on those rules. Due to several unique features FL is considered a good choice for many control problems. FL is robust and hence doesn't need noise free and precise inputs. Output is a smooth function even in the case of variations in inputs or a wide range of inputs. FL can be modified easily as it depends on user defined rules. Any number of inputs can be processed by FL and generating any number of outputs. But to avoid complexity FL should be broken up into small processes. Nonlinear systems can easily be modeled by a FL system [19].

In [20], the authors have proposed a new evolutionary approach based on a hybrid fuzzy-particle swarm optimization (PSO) hybrid algorithm to solve the problem of the distribution networks reconfiguration.

In [21], the authors have designed a Fuzzy-Logic based spectrum allocation algorithm, by which the RSUs check actual CCH contention conditions, and extend dynamically the CCH bandwidth in the case of network congestion, by utilizing the detected vacant frequencies by the sensing module. In [22], the authors have used distance, velocity, signal strength, spectrum efficiency as input variables to fuzzy logic. Mamdani type fuzzy rule base system has been used. Based on the fuzzy if-then rules decision is taken for the availability of the spectrum. In [23], the Spectrum Utilization Efficiency, Degree of Mobility and Distance of Secondary user to the PU are used as input variables. A fuzzy logic rule base is used to avoid the collision among various contenders for spectrum access. According to authors SU with higher possibility can access the spectrum with guarantee.

In this paper, the spectrum sensing logic is based on [18]. We collect the database for various TV channels based on historic usage and use it as input to the FL processor. Other inputs used in this paper are vehicle velocity, message priority and hours of the day. Outputs show the spectrum availability and allocation for different type of TV channels. Since Immediate and Urgent messages are high priority messages, these types of messages are given more spectrum resources and options to jump in case if spectrum mobility is needed. We could not find the work carried out in this paper performed by any researcher previously. So our simulation results are not compared with any previous work.

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-3/MAGNT.111)

Our paper is organized as follows: Section 2 explains the overall system model; section 3 provides simulation and results; and section 4 concludes the paper.

2. System Model

We have modeled our problem solving system with fuzzy logic. Our fuzzy logic system is multi-input multi-output (MIMO). The main purpose of the system is the selection of the channels from TV channels available on Cognitive Radio (CR) network based on different input scenarios. The block diagram of our system is given in figure 1 below.

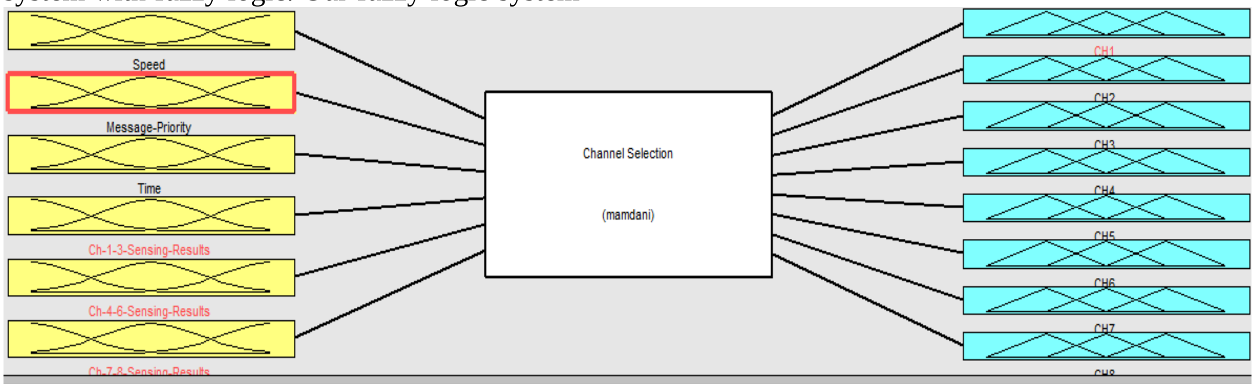

Figure 1: Overall Fuzzy Logic System

a. Inputs and Membership Functions

Our system is a six input eight output system. The first input is the speed of the vehicle. The set of linguistic values for speeds are very slow, slow, medium, fast, and very fast. Vehicles moving specifically on highways have a speed from zero to 150 km/h. Speed plays an important role in channel assignment. As vehicles move in clusters and sensing is based on control by the coordinators of the cluster [16] [17], so the vehicles moving with very fast or very slow speed leave the cluster early whereas vehicles moving with medium speed stay in the cluster for a longer duration. Thus, vehicles moving with very fast or very slow speed shall be allocated those channels which are available for a shorter duration of time and the vehicles moving with medium speed shall be allocated the channels which are available for a longer duration of time. The speed of the vehicles is assumed to follow the truncated Gaussian distribution [24]. The membership function of speed is given in figure 2.

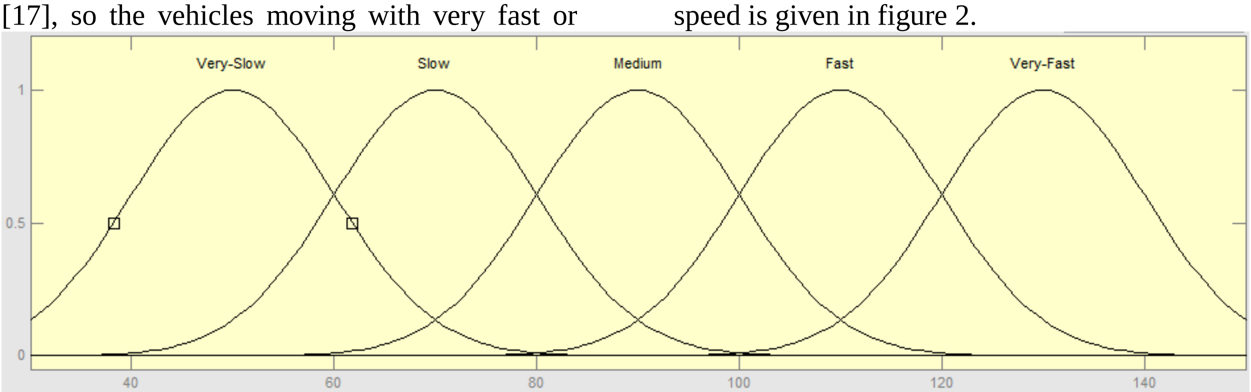

Figure 2: Membership Function of speed

The second input linguistic variable is message priority. The set of linguistic values for message priority are Immediate, urgent, normal and ordinary. Immediate messages include emergency messages like accident information, congestion information, bridge broken, train crossing, and safety messages like inter-vehicle distance, speed, intersection collision avoidance, and location information. Urgent messages include traveler's information like signal status, road signs, school ahead, hospital ahead, service area ahead and location based services like toll

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-3/MAGNT.111)

collection, and online payments. GPS and probe messages fall in the category of normal messages. While net-surfing and emails fall in the category of ordinary messages [25]. Message category plays an important role in the channel allocation mechanism. Higher priority messages need to have stable and longer duration channels, whereas lower priority messages can have channels with lower stability or duration. The membership function in trapezoid shape is shown in figure 3 below.

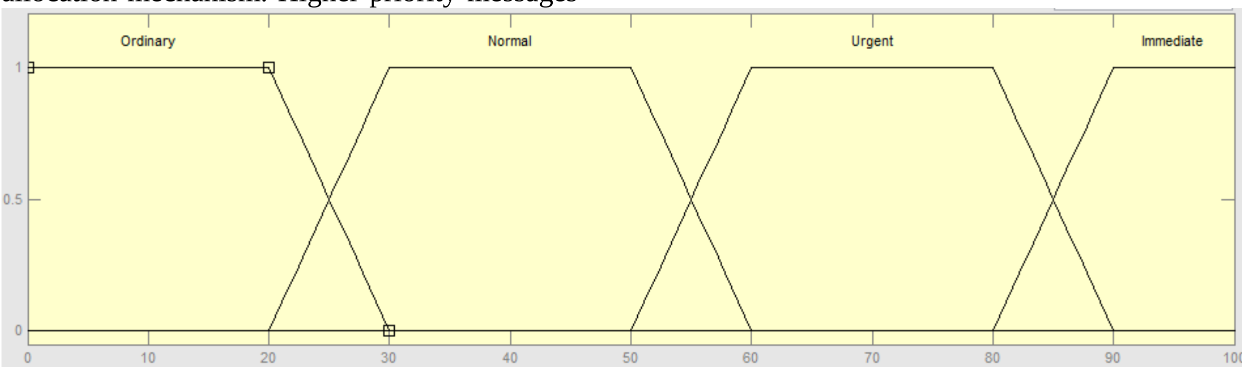

Figure 3: Membership Function of Message Priority

The third input linguistic variable is time in hours of the day. Linguistic values for the time are mid-night, morning, noon, after-noon, evening and night. Different TV channels have different on/off timings. Some channels are on late night, some during evening and some during mid-day. So time is an important factor for the determination of channel allocation of TV channels. The membership function in trapezoid shape of time is shown in figure 4.

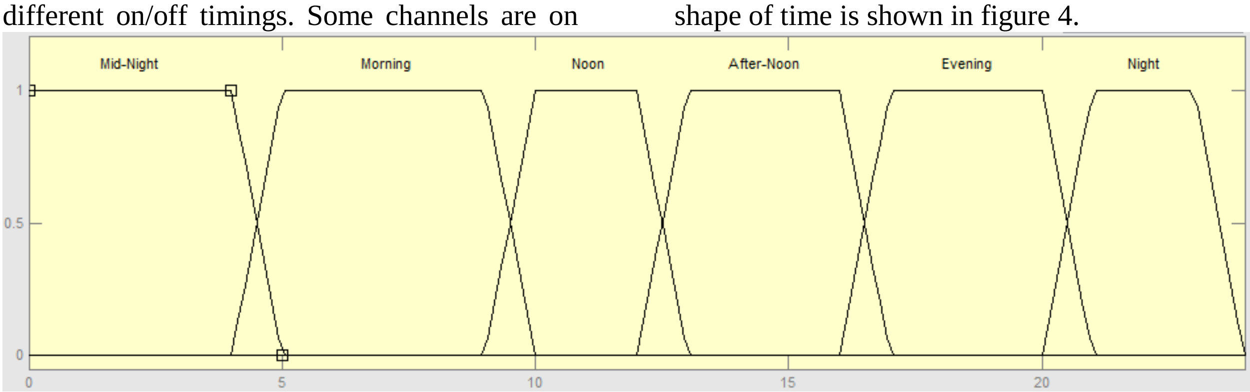

Figure 4: Membership Function of Time

Channel sensing is crucial in the channel allocation scheme. We use the spectrum sensing results obtained by using techniques proposed in our previous work [16] [17] [18]. In this paper we have used the sensing result based on the categorization of the different types of TV channels as discussed in next paragraph. We have combined the sensing results of channels 1 to 3 in one input variable, 4 to 6 in another input variable and 7 to 8 in another input variable.

b. Outputs

Output variables are eight different types of channels. We have categorized these channels as; channel-1 is entertainment channel, channel-2 is news channel, channel-3 is infotainment channel, channel-4 is kids channel, channel-5 is informative channel, channel-6 is educational channel, channel-7 is food channel and channel-8 is midnight programs channel. These different categorized channels have different on/off timings. We have formed the membership function for the availability (off timing) of each type of channel as shown in figures 5 to 12.

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-3/MAGNT.111)

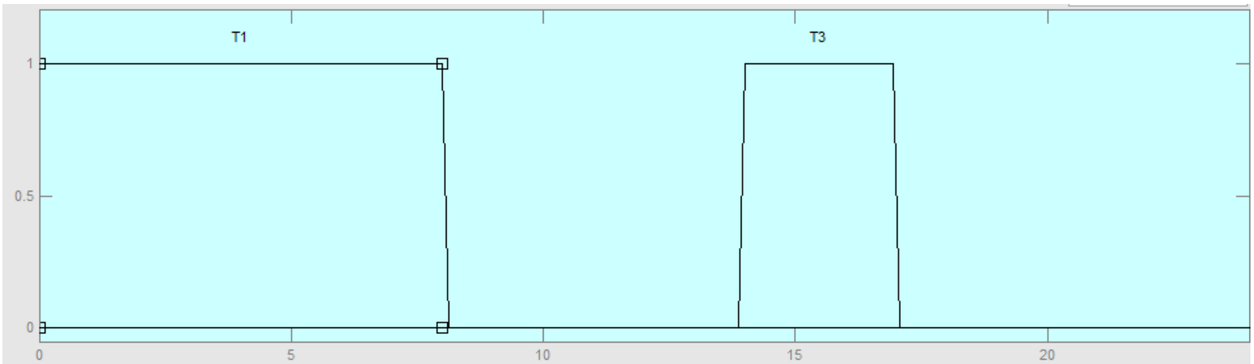

Figure 5: Availability of Channel-1

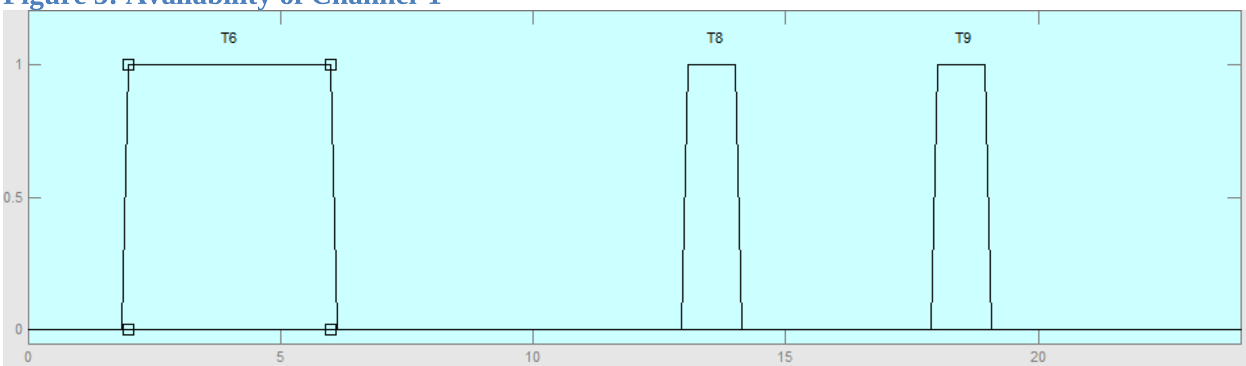

Figure 6: Availability of Channel-2

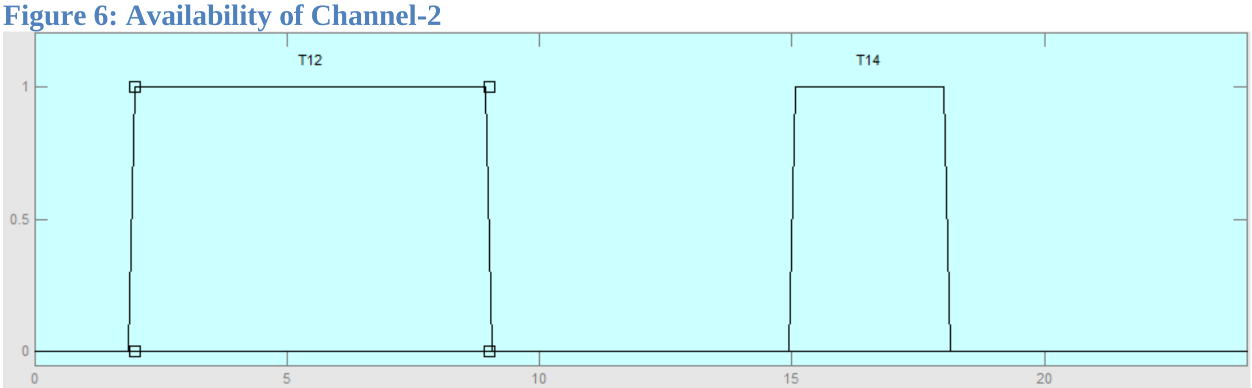

Figure 7: Availability of Channel-3

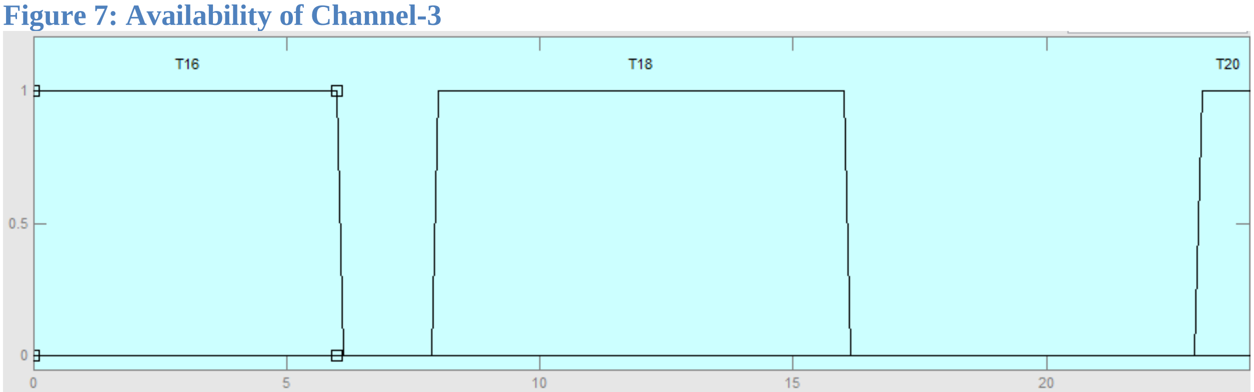

Figure 8: Availability of Channel-4

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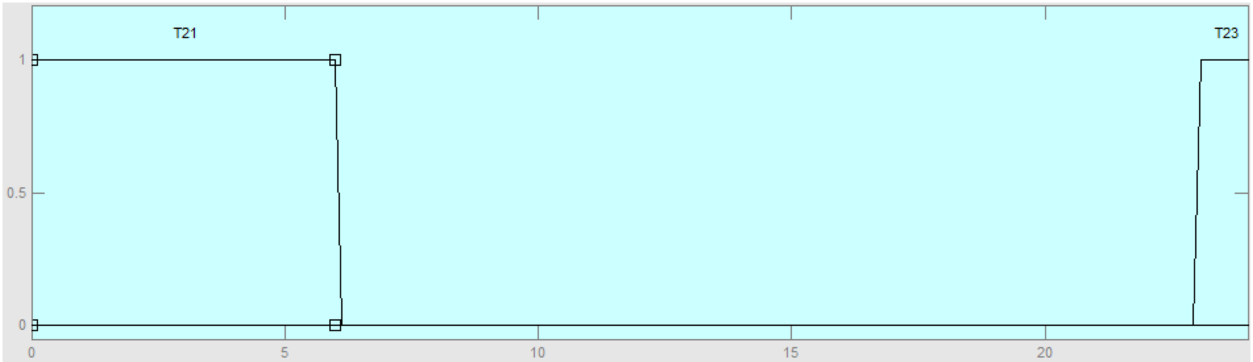

Figure 9: Availability of Channel-5

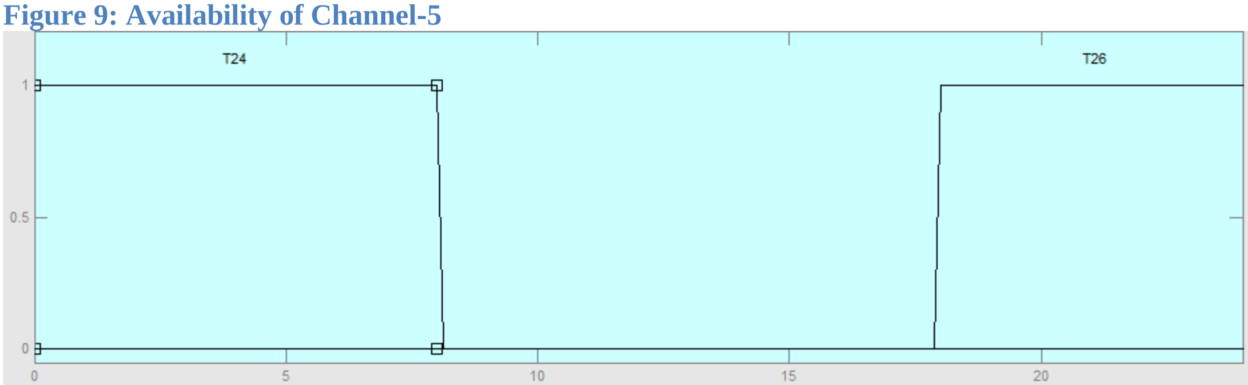

Figure 10: Availability of Channel-6

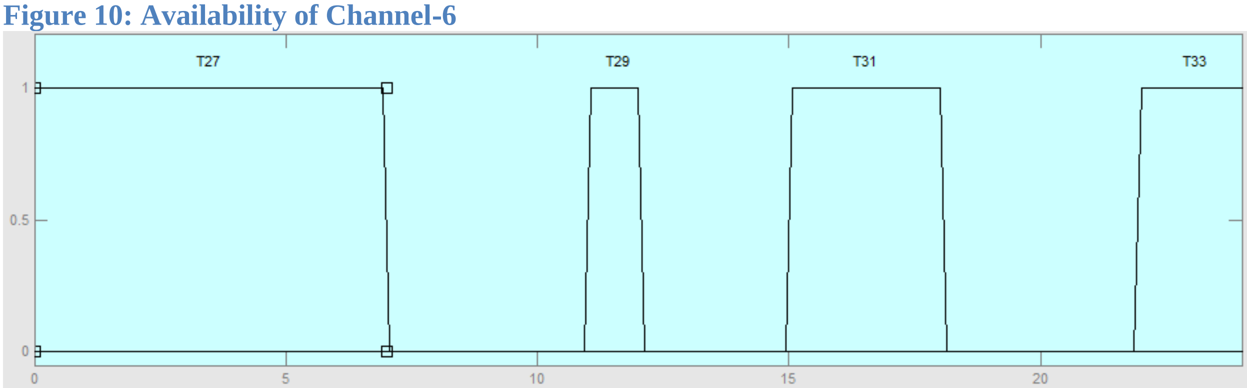

Figure 11: Availability of Channel-7

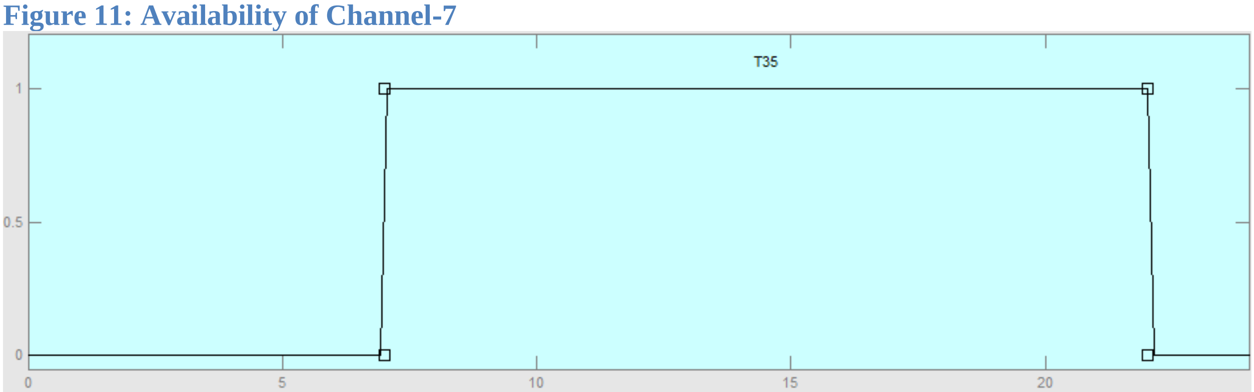

Figure 12: Availability of Channel-8

We have taken on/off timings of above categorized channels as arbitrary as different countries have different timings for TV channels. Anyone willing to use this technique has to alter the timings according to their own available timing slots.

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-3/MAGNT.111)

c. Fuzzy IF-THEN Rules

By using vehicle speed, message priority, hours of the day and channel sensing results we can model the fuzzy IF-THEN rules based the criteria discussed in above paragraphs. Our system presented in this paper has been modeled using 320 rules. Some rules are given below for better understanding.

- If (Speed is Very-Fast) and (Message-Priority is Normal) and (Time is Noon) then (CH1 is not T1)(CH2 is not T8)(CH3 is not T12)(CH4 is T18)(CH5 is not T21)(CH6 is not T24)(CH7 is not T29)
- If (Speed is Very-Slow) and (Message-Priority is Immediate) and (Time is Noon) then (CH1 is not T1)(CH2 is not T6)(CH3 is not T12)(CH5 is not T21)(CH6 is not T24)(CH8 is T35)
- If (Speed is Fast) and (Message-Priority is Ordinary) and (Time is Evening) and (Ch-1-3-Sensing-Results is not T9) and (Ch-4-6-Sensing-Results is T26) then (CH1 is not T3)(CH2 is not T9)(CH3 is not T14)(CH4 is not T18)(CH5 is not T23)(CH6 is T26)(CH7 is not T31)(CH8 is not T35)
- If (Speed is Slow) and (Message-Priority is Normal) and (Time is Evening) and (Ch-4-6-Sensing-Results is T26) then (CH1 is not T3)(CH3 is not T14)(CH4 is not T20)(CH5 is not T23)(CH6 is T26)(CH7 is not T31)(CH8 is not T35)
- If (Speed is Medium) and (Message-Priority is Immediate) and (Time is Night) and (Ch-7-8-Sensing-Results is T35) then (CH1 is not T3)(CH2 is not T9)(CH3 is not T14)(CH4 is not T20)(CH5 is not T23)(CH7 is not T33)(CH8 is T35)

A widely used implication in fuzzy systems and controls is Mamdani Implications. The argument in the favor of Mamdani Implications is that it considers fuzzy IF-THEN rules as local. For global implications other type of implications are available.

3. Simulation and Results

Simulations have been carried out using MATLAB version R2012a, Fuzzy Logic Toolbox. Mamdani Implications have been used to model the Channel Selection Fuzzy model. Input, output linguistic variables used and membership functions modeled are described in detail in System Model section above. Three hundred and twenty IF-THEN rules have been used to model the system. Results have been obtained checking the utility of the proposed system by looking at the utility of the channels in speed-time domain and in message priority-time domain. Figures 13 to 20 show the utility of channel-1 to 8 in speed-time domain and Figures 21 to 28 show the utility of the same channels in message priority-time domain.

a. Utility Speed Vs Time

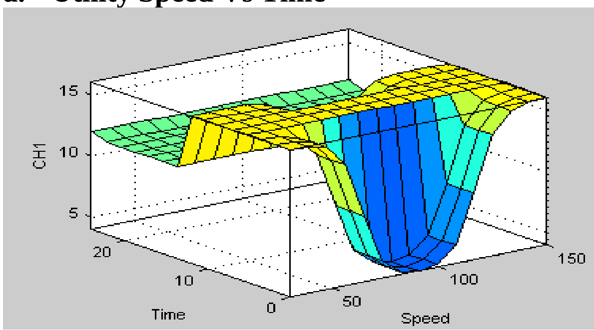

Figure 13: Speed Vs Time for Channel 1

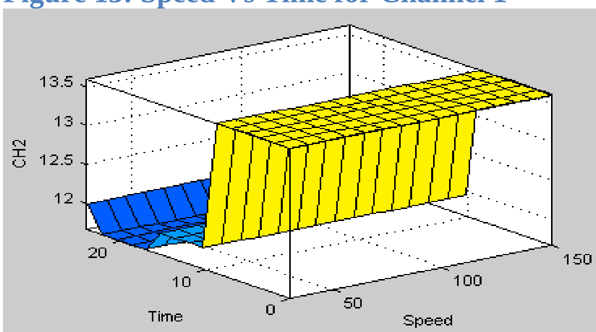

Figure 14: Speed Vs Time for Channel 2

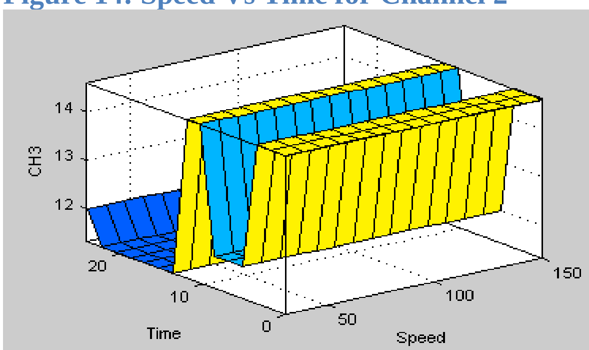

Figure 15: Speed Vs Time for Channel 3

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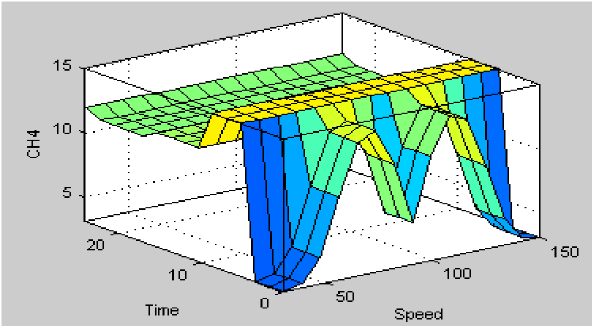

Figure 16: Speed Vs Time for Channel 4

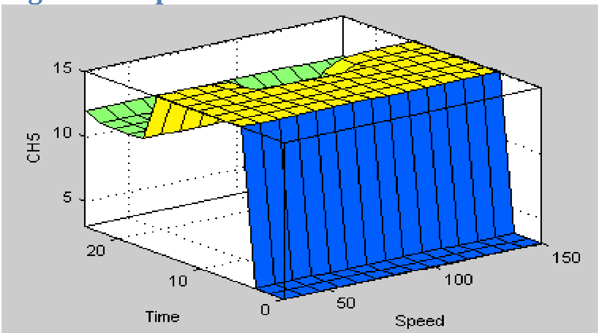

Figure 17: Speed Vs Time for Channel 5

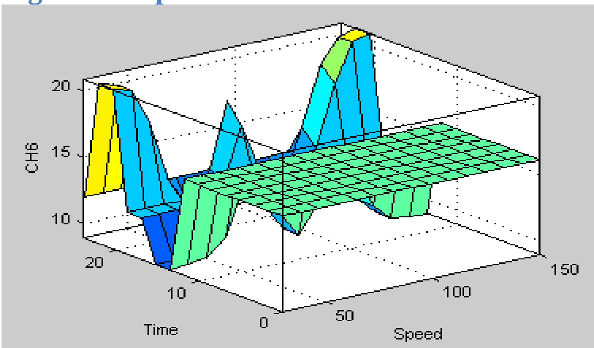

Figure 18: Speed Vs Time for Channel 6

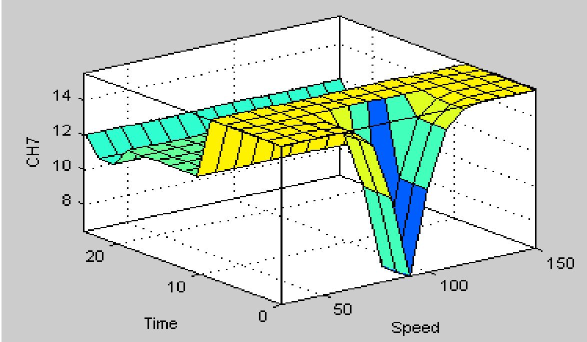

Figure 19: Speed Vs Time for Channel 7

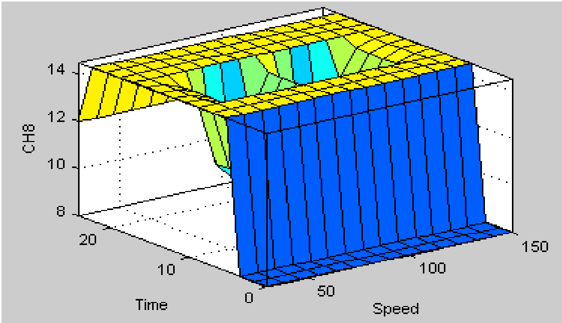

Figure 20: Speed Vs Time for Channel 8

From the above figures it is evident that channel-1 is well utilized for very fast and very slow speeds. Utility of channel-2 is better in early hours of the day. Channel-3 is best utilized for all the speeds during its availability timings. Channel-4 is better for slow and fast speeds in the early hours of the day. Channel-5 is better for all speeds during morning hours. Channel-6 is better for very slow and very fast speeds in night hours. Channel-7 is better in early hours for very slow, slow, fast and very fast speeds. Channel-8 is better during available hours for very slow, very fast and medium speeds but its utility for slow and fast speeds drops during noon and after-noon hours.

b. Utility Message Priority Vs Time

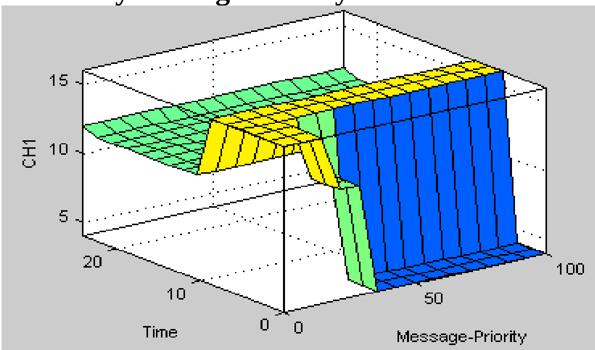

Figure 21: Message Priority Vs Time for Channel 1

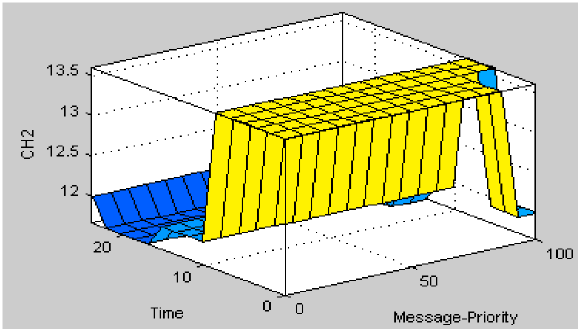

Figure 22: Message Priority Vs Time for Channel 2

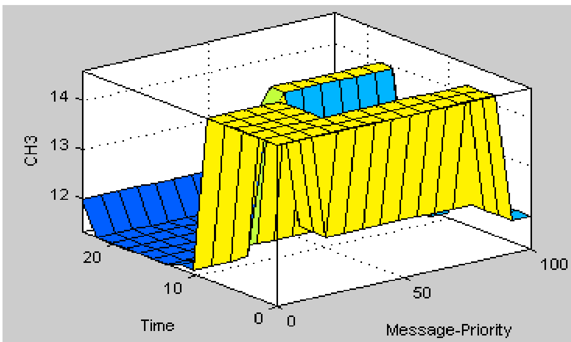

Figure 23: Message Priority Vs Time for Channel 3

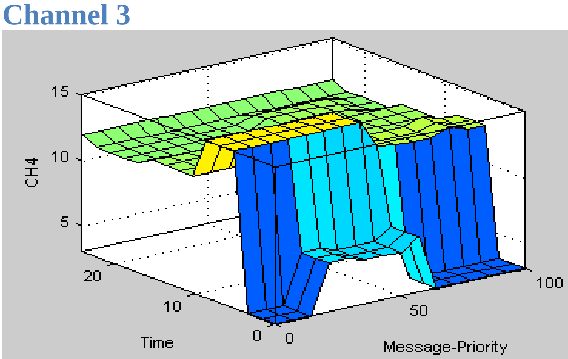

Figure 24:Message Priority Vs Time for Channel 4

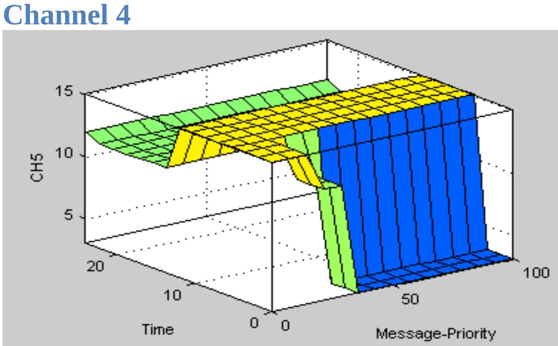

Figure 25: Message Priority Vs Time for Channel 5

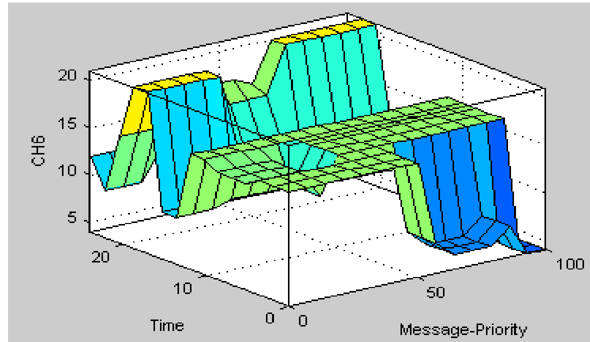

Figure 26: Message Priority Vs Time for Channel 6

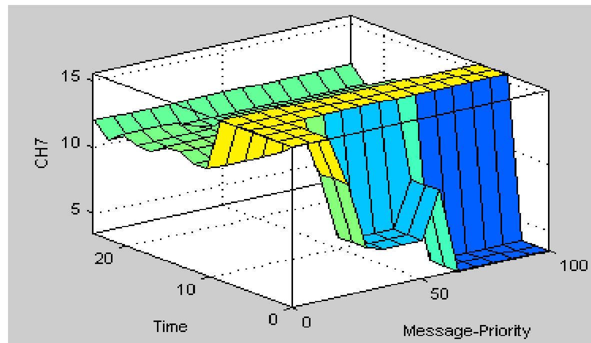

Figure 27: Message Priority Vs Time for Channel 7

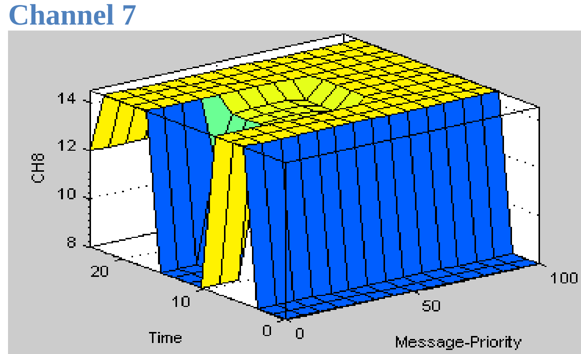

Figure 28: Message Priority Vs Time for Channel 8

From the above figures it is clear that channel-1 is well utilized during morning hours for all priority messages. Channel-2 is better during first half of the day for all priorities except immediate. Channel-3 is better in early hours for all priorities and in late hours for immediate and urgent messages. Channel-4 is better for lower priority messages and channel-5 for all priorities during morning hours. Channel-6 is better for higher priority messages during late hours. Channel-7 is better during morning hours for all sort of messages and channel-8

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-3/MAGNT.111)

very well utilized especially for immediate and urgent messages.

4. Conclusion and Future Work

The proposed model provides a clear picture while allocation of CR channels to the moving vehicles depending upon speed, message priority, hours of the day, and sensing results. Considering the utility of channels, priority in allocation can be achieved easily. There may be more than one channels of one category available at a time with same instants availability or different. This model can be utilized well for all sorts of channels depending on sensing results. We are working to add channel bandwidth, fading and distance segments as further input variables to enhance the capability of the proposed system.

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