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Reduction of Ping-Pong Effect In Cognitive Radio Spectrum Handoffs Using Fuzzy Logic Based Inference

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***Abstract*—The evolution in wireless communication and networking has increased the demand for the availability of extra spectrum bands. The spectrum is a scarce resource and requires to be utilized in an efficient way. Research in this domain has envisaged that the problem of spectrum scarcity can be addressed by Cognitive Radio. Cognitive Radio Networks are comprised of multiple technologies and networks which permits the dynamic use of spectrum. Spectrum Handoffs, is thus a major necessity of Cognitive Radio Network and if not properly executed, might cause ping-pong effect. The Ping-pong effect is caused due to the motion of mobile users between boundaries of adjacent cells thus, initiating unnecessary Spectrum Handoffs. In this paper, a Fuzzy Logic based system is proposed that is capable of making efficient decisions about the execution of Spectrum Handoffs thus, and reduces the chances of the ping-pong effect.**

Keywords-Cognitive Radio; Cognitive Radio Network; Spectrum Handoffs; Ping-pong effect; Fuzzy Logic; WLAN; UMTS.

I. INTRODUCTION

With the progressing wireless technology, the better utilization of spectrum, better ways of spectrum allocation and more efficient network coordination, is required. Furthermore, there are many issues that need to be addressed e.g. interference that limits the spectrum capacity and its scalability. It has been found that 90% of the time the radio spectrum, remains unused [1]. The available frequency bands are mostly congested with traffic, also it is illegal to access licensed bands and therefore, this whole scenario creates the problem of spectrum scarcity, which is believed to exaggerate in future [2]. Cognitive Radio Network has been gaining attention in recent years as it is thought to be a method that is potentially able to solve the issue of spectrum scarcity [3]. The concept of Cognitive Radio revolves around the idea of sharing of spectrum between licensed and unlicensed users. Cognitive Radio is a radio that is capable of changing parameters of its transmitter in accordance to its surroundings [4]. Licensed user or Primary user (PU), is a licensed user who has the priority to use the spectrum, Cognitive user or Secondary user (SU), accesses the network opportunistically in the absence of licensed user, it is thus important for the SU to be intelligent enough to sense the availability of spectrum bands [2]. Spectrum sensing involves sensing the surrounding RF frequencies which are not currently in use of PU. The spectrum decision helps the SU to select one of the spectrum holes for its opportunistic transmission either by help of the network or by its own. After selection of spectrum hole, the next step is to execute Spectrum Handoffs [5]. The spectrum handoffs, is the process whereby a SU switches its operating frequency because of the many reasons including channel occupation by the PU, sudden arrival of PU, quality of service degradation, interference to the transmission of PU etc. The process of Spectrum Handoffs should be carried out with minimum delay [6][7].

The purpose of Spectrum Handoffs is to use the unutilized scarce spectrum resource. The Spectrum Handoffs occur between the underlying technologies available in a particular region. The channel or band switching for Spectrum Handoffs, if not properly executed, might lead to some unwanted problems like the ping-pong effect. The Ping-pong effect happens when a mobile station (MS) performs handoffs frequently and rapidly between base stations (BS) when the signal strength from the previous BS is sufficient [8].

For the purpose of resource management and due to unpredictable nature of wireless communication, some intelligent technique is required that can facilitate in deciding about carrying out of Spectrum Handoffs. One such technique is the Fuzzy logic. Fuzzy logic helps in modeling problems where traditional mathematical methods cannot be applied effectively or where the information about the problem is not complete. Fuzzy Logic is well suited for problems which are multidimensional and this technique is suitable for dynamic and distributed environments as well. The fuzzy sets and inference rules in Fuzzy Logic are

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human understandable to ascertain satisfactory solution of a problem [7][9].

In this paper, a Fuzzy Logic based decision-making system is proposed for the reduction of ping-pong effect in Cognitive Radio Networks. The system is designed to reduce Spectrum Handoffs and as a result pong-pong effect can be reduced. The major cause of ping-pong effect is mobility of the user between the adjacent cells, therefore, in this paper a situation is considered where a SU is mobile. Thus, an important parameter of velocity of SU is considered in the proposed system.

II. Related Work

Recent studies show that most of the licensed radio band spectrum is under-utilized in both time and space domains at a certain location, this under-utilization of spectrum creates "white spaces" in time-frequency grid [10][3]. Due to the limitations in currently followed static licensing scheme of spectrum access, "spectrum holes" or "spectrum opportunities" arise. Spectrum holes are defined as the frequency bands, which at a certain time and location, if not used by the licensed user (PU), can be used by the unlicensed user (SU) [11].

Mitola [12] gave the concept of Cognitive Radio Network as a network that is aware and adaptive of its environment, capable to learn and take decisions. This network employs machine learning mechanism, representation of knowledge, and automated reasoning for forming, conducting and terminating communication with existing radio networks. Cognitive radio networks can be made adjustable to varying parameters according to its environment [13]. Cognitive radio permits the unlicensed user (SU) to access the unused portion of the spectrum, temporarily, when not used by the Primary user (PU) [14][15].

There are four basic spectrum management functionalities of Cognitive Radio Networks. First is Spectrum sensing i.e. determination of the best available channels or bands and making sure that the PU isn't using the band at the moment. Second is Spectrum Management i.e. selection of best available channel. Third is Spectrum Sharing i.e. sharing the spectrum and coordination with users trying to access the channel and fourth is Spectrum mobility i.e. vacating the channel as soon as the activity of PU is detected. In terms of spectrum mobility, channel engaged by the SU, should be vacated for PU [16][17].

In Cognitive Radio Networks, an important part of spectrum management framework is of Spectrum Handoffs. Spectrum Handoff is a procedure through which the transition of bands for the SUs is made to keep the process communication ongoing [18]. The process of Spectrum Handoffs in Cognitive Radio Network is more complex as it requires more accuracy because the networks are heterogenous and therefore, coverage areas of different networks are also heterogenous. Fuzzy logic theory is suitable to be applied and used to take decisions for carrying out Spectrum Handoffs in uncertain environment like that of Cognitive Radio Networks. Such a fuzzy logic based inference system for reduction of Spectrum Handoffs is proposed in [19]. The proposed approach makes effective Spectrum Handoffs decisions, in view of a scenario that SU is causing significant interference to PU. The proposed system is composed of two sets of Fuzzy Logic based control system. First system controls the power of SU to reduce the interference caused to PU by SU. The second Fuzzy Logic based control system, decide about the execution of Spectrum Handoffs. The deciding parameters of the system includes Signal strength of PU measured by SU, distance between PU and SU, and Interference caused by SU to PU.

In [20] a Fuzzy Logic based system is proposed, which is composed of two sets of Fuzzy Logic based control systems. The first system, here too controls the power of SU and second system decides about execution of Spectrum Handoffs. The parameters on which the decision is based are data rate of SU, Hold-time of the channel i.e. the period in which the PU is not using the channel and power of SU. The power of SU is modified and monitored, according to the proximity of PU, so to control interference to PU.

Another similar system is proposed in [21] which is based on Fuzzy Logic. Here again two sets of systems are proposed, the first one controls the power of SU and second one decides about the execution of Spectrum Handoffs based on inputs which are transmission power of SU, bit rate of SU and signal strength of PU received at SU. Furthermore, a single cell scenario is considered along with random walk model, in which the user moves randomly in any random direction.

Different studies in this area, so far, have not considered the state of motion of SU i.e. SU might be stationary or it might be moving. In both the scenarios SU might go through spectrum shift, thus forcing SU to change its operating frequency multiple times and thus initiating a Spectrum Handoffs, which when happens frequently might lead to the Ping-pong effect.

To overcome this shortcoming in the existing work, in this paper, we propose a Fuzzy Logic based inference system that considers one important factor i.e. velocity of SU. Velocity plays a vital role in causing the ping-pong effect as due to it multiple Spectrum Handoffs might occur, therefore the system proposed reduces the Spectrum Handoffs and in turn reduces the chances of Spectrum Handoffs.

III. FUZZY -BASED SPECTRUM HANDOFF SYSTEM

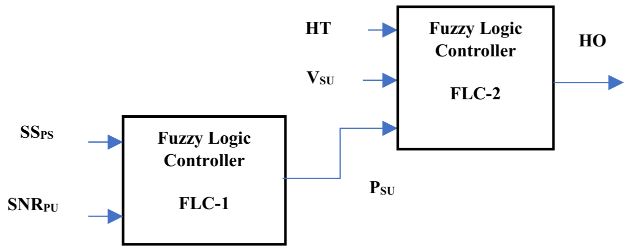


Fig. 1. Block diagram of the system proposed

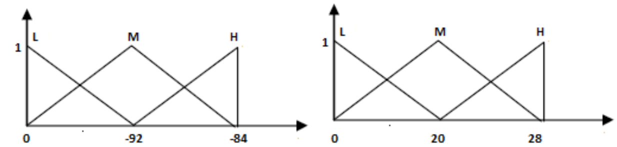
Fig. 1 shows the block diagram of the proposed system. In the proposed system, Cognitive Radio Network is considered which is assumed to be composed of two networks, i.e. UMTS and WLAN, furthermore, SUs are assumed to have the ability to sense the presence of PUs nearby. The proposed system consists of two sets of Fuzzy Logic Controllers i.e. FLC-1 and FLC-2 respectively. The first system i.e. FLC-1 is designed to control the power of SU, so that interference to PU can be controlled and kept to its minimum. The second system i.e. FLC-2 is designed to take decision in order to execute Spectrum Handoffs. Inputs to FLC-2 are Channel Hold-time (HT), Velocity of SU (V_{SU}) and power of SU (P_{SU}). The occurrence of Spectrum Handoffs in an environment, where conditions and situations of the network are ambiguous and unknown, the range of transmitting power of SU is kept between that of WLAN and UMTS i.e. 30dBm and 43dBm respectively [22]. The method of defuzzification used is centroid.

A. *Fuzzy Logic Controller-1:*

The first fuzzy logic controller 1 (FLC-1) is designed to control the power of SU (P_{SU}) according to the provided inputs. The term set for FLC-1 is defined as the function of T(x) and T(y), where "x" is the linguistic variable for inputs and "y" is the linguistic variable for output. For FLC-1 term set is shown in (1).

$$T(x) = T(y) = T(SS_{PS}) = T(SNR_{PU}) = T(P_{SU}) = \{Low, Medium, High\} \quad (1)$$

The inputs to FLC-1 is SS_{PS} i.e. the Signal strength of PU as measured by SU and SNR_{PU} i.e. Signal to Noise ratio of PU. Fig. 2 shows the "membership functions" of the inputs of FLC-1. Fig. 2(a) shows the membership function of SS_{PU}. It is defined on three linguistic variables i.e. L, M, H. the range of the membership function is chosen to be from 0dBm to -84dBm, which is an acceptable range of signal strength for communication. Fig. 2(b) shows the membership function of signal to noise ratio of PU (SNR_{PU}).



(a) (b)

Fig. 2. Membership functions for SS_{PS} and SNR_{PU}

B. *Fuzzy Logic Controller-2*

The Second Fuzzy Logic Controller (FLC-2) is designed to take decision about execution of the Spectrum Handoffs (HO_{prob}), based on HT i.e. Channel Hold-Time, which is the duration in which the PU is not utilizing the channel, V_{SU} i.e. velocity of the SU and P_{SU} (output of FLC-1), The fuzzy rule base for FLC-2 are shown in Table-1.

Table I: Rule base for FLC-2

	Inputs			Output
Rules	**HT**	**P_{SU}**	**V_{SU}**	**HO_{Prob}**
1.	L	L	L	M
2.	L	L	M	H
3.	L	L	H	VH
4.	L	M	L	M
5.	L	M	M	H
6.	L	M	H	H
7.	L	H	L	H
8.	L	H	M	H
9.	L	H	H	VH
10.	M	L	L	M
11.	M	L	M	M
12.	M	L	H	H
13.	M	M	L	L
14.	M	M	M	L
15.	M	M	H	H
16.	M	H	L	VL
17.	M	H	M	L
18.	M	H	H	M
19.	H	L	L	M
20.	H	L	M	H
21.	H	L	H	VH
22.	H	M	L	VL
23.	H	M	M	L
24.	H	M	H	M
25.	H	H	L	VL
26.	H	H	M	L
27.	H	H	H	M

The term sets for FLC-2 is defined as the function of T(x) and T(y) respectively, where "x" represents inputs and "y" represents output. Term sets for FLC-2 is shown in (2) and (3).

$$T(x) = T(HT) = T(P_{SU}) = T(V_{SU}) = \{\text{Low, Medium, High}\} \quad (2)$$

$$T(y) = T(HO_{Prob}) = \{\text{Very low, Low, Medium, High, Very high}\} \quad (3)$$

Fig. 3 shows the membership functions for the inputs of FLC-2.

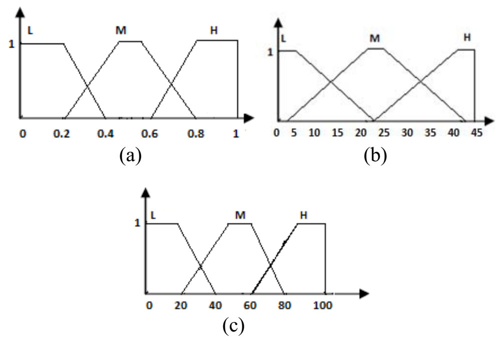


Fig. 3. Membership function of HT, P_{SU} and V_{SU}

Fig. 3(a) shows membership function of probability of Channel Holdtime (HT). Fig. 3(b) shows the membership function of P_{SU} . Fig. 3(c) shows the membership function of "V_{SU}" i.e. velocity of SU. The velocity of SU is set upto 100Km/h as this covers the maximum allowed range of speed in highly populated urban areas, which is upto 50Km/h, on arterial roads, which is upto 80Km/h and on highways i.e. upto 100Km/h to 120Km/h. Mostly, in populated areas cell sizes are small and especially in Cognitive Radio environment the sizes of cell are also hetrogenous therefore, chances of Spectrum Handoffs and ping-pong effect are more.

The decision of carrying out Spectrum Handoffs is based on the states of given inputs. For example, in Rule No. 1, the states of HT, P_{SU} and V_{SU} are "L". Here, HT is low which means that the chances of appearance of PU is high and therefore, the probability of Spectrum Handoffs occurrence is medium. Similarly, in Rule No. 9 HT is "L", P_{SU} and V_{SU} are both "H", chances of PU appearance are therefore high, so HO_{prob} is "VH". In Rule No. 27 all the inputs are "H" therefore, HO_{prob} is "M" thus, at high velocity the chances of ping-pong effect are high therefore, Spectrum Handoffs need to be monitored and intelligent decision would help in reducing unnecessary Spectrum Handoffs.

IV. Results And Discussion

In order to evaluate the system proposed, simulations are done using the Fuzzy logic tool in MATLAB. Fig. 4 shows probabilty of Spectrum Handoffs with respect to P_{SU} and V_{SU}. Figure shows probability of Spectrum Handoffs with respect to P_{SU} and V_{SU}. Figure shows that probability of Spectrum Handoffs remains very low even for high values of P_{SU}. The figure again shows that HO_{prob}>0.5 when the value of V_{SU} is maximum, this means that probability of Spectrum Handoffs is high only when the value of P_{SU} is low and that of V_{SU} is high.

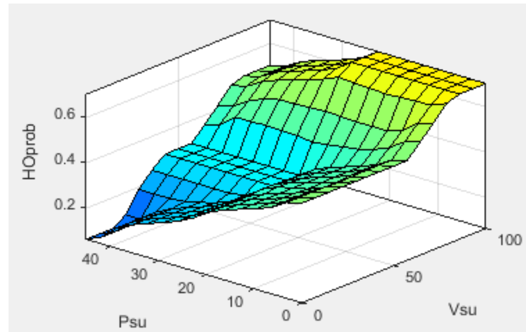


Fig. 4. HO_{prob} with respect to P_{SU} and V_{SU}.

Fig. 5 shows the probabilty of Spectrum Handoffs with respect to HT and V_{SU}. It can be seen from the figure that as probability of Spectrum Handoffs decreases and velocity of SU (V_{SU}) increases, the propbabilty of Spectrum Handoffs also increases but that increase in HO_{prob} depends on the status of Channel hold-time thus, HO_{prob} is controlled by HT therefore, chances of ping-pong effect at high velocity becomes less.

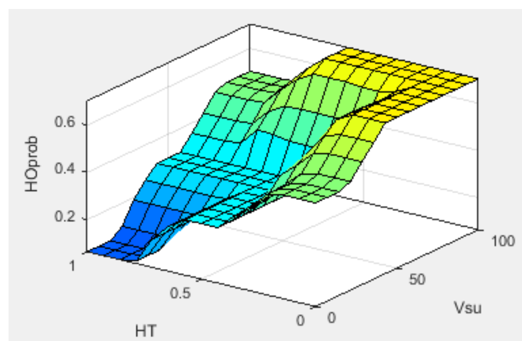


Fig. 5. HO_{prob} with respect to HT and V_{SU}

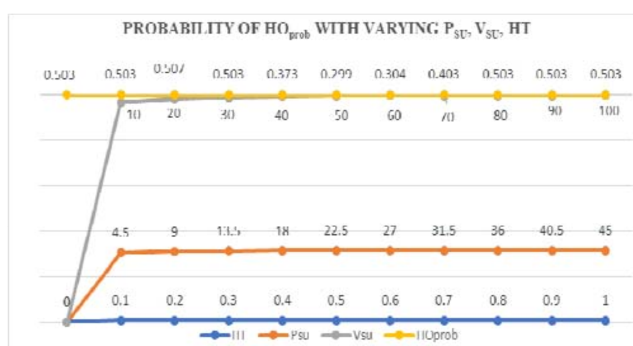


Fig. 6. HO_{prob} with respect to varying HT, P_{SU} and V_{SU}

Fig. 6 shows the effectiveness of the system proposed. It shows the effect of varying conditions of inputs i.e. HT, V_{SU} and P_{SU} on output i.e. $HO_{prob.}$ It can be seen from the figure that as the value of inputs increase, the probability of Spectrum Handoffs (HO_{prob}) also increases but even when the values of all the inputs are maximum the value of HO_{prob} does not exceed 0.503. Thus, it can be concluded that the proposed system is reducing the probability of Spectrum Handoffs and is therefore capable of reducing the ping-pong effect in Spectrum Handoffs.

V. Conclusion And Future Work

In this paper, a fuzzy logic based system is presented that reduced Spectrum Handoffs and thereby reduces the occurrence of ping-pong effect. The reduction of ping-pong effect is possible if the efficient decision is taken to execute Spectrum Handoffs. The simulation results show that proposed system intelligently reduces Spectrum Handoffs. Also, fuzzy logic, being computationally less complex, can be used in ambiguous environment of Cognitive Radio Network. Spectrum Handoffs, in Cognitive Radio Network is a vast topic that needs to be addressed in every context. Consequently, such mechanisms and procedures that make Spectrum Handoffs more efficient, need to be devised. Since not much of research has been done in consideration of reduction of ping-pong effect and other related issues in Cognitive Radio Network, therefore this area is open for more research.

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