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A Fuzzy-based Dynamic Channel Allocation Scheme in Cognitive Radio Networks

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Abstract—In traditional wireless networks, fixed allocation of spectrum is one of the main reason causing low utilization of spectrum. In order to solve this problem, a new wireless communication model has been proposed, which called Cognitive Radio Networks (CRN). CRN adopts Dynamic Spectrum Access (DSA) technology, thus it can flexibly use the spectrum which primary user temporarily unused. In cognitive radio networks, due to each secondary user (SU) has different location and surrounding spectrum environment, it may have variety of available channels. How to assign these available channels is the crucial point of system performance. However, existing methods doesn't consider the problem of multipath fading; therefore, this study proposed an improved channel allocation scheme. We consider the received signal strength to define the channel access priority of secondary users applied by fuzzy theory. Finally, the simulation results show the superior of our approach and verify the effectiveness of the proposed scheme.
Keywords: *Cognitive Radio; Fuzzy; Channel Allocation*

I. Introduction

Due to the increasing in wireless communication demand, spectrum shortage problem have been more prominent. According to Federal Communications Commission (FCC) report [1], temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%. Various types of wireless communication system in order to prevent mutual interference between each other, systems are operating on the license band which they have the exclusive right to use. However, some portion of these license bands are used sporadically, leading to underutilization of spectrum. To solve this problem, a new wireless communication model has been proposed, which called Cognitive Radio Networks (CRN) [2, 3].

CRN contains Dynamic Spectrum Access (DSA) [3, 4] technology and Cognitive Radio (CR) [5] technology. DSA provides functionality to improve the spectrum utilization efficiency. As shown in Fig. 1, when the spectrum owner doesn't need to use the spectrum temporarily, lot of unused spectrum will be generated, which is referred to as "spectrum hole". If we can detect these spectrum holes correctly and using these spectrum holes between each other flexibility, spectrum utilization will be improved. On the other hand, CR is defined as a radio that can change its transmitter parameters based on interaction with its environment. Two main characteristics of cognitive radio can be defined as follows [3, 6]:

- Cognitive capability: Cognitive capability refers to the ability of the radio technology to sense the information from its radio environment. Through this capability, the portions of the spectrum that are unused at a specific time or location can be identified. Consequently, the best spectrum and appropriate operating parameters can be selected.
- Reconfigurability: Reconfigurability enables the radio to be dynamically programmed according to the radio environment.

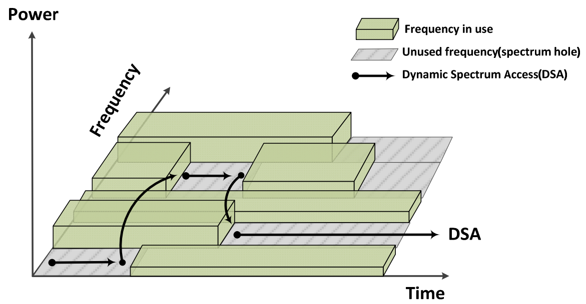

Fig. 1. Dynamic Spectrum Access (DSA)

The basic elements of the CRN can be defined as follows [5, 7]:

- Primary User (Licensed user, PU)
  - users of primary network
  - not be affected by the operations of any other unauthorized user.
- Primary Base Station(P_BS)
  - a fixed infrastructure network component which has spectrum license.
- Secondary User(Unlicensed user, SU)
  - users of secondary network
  - including spectrum sensing, spectrum decision, spectrum handoff and cognitive radio MAC/routing/transport protocols.
- Cognitive Radio Base Station (CR_BS)
  - provides connection to SUs without affecting PUs

In CRN, SU can utilize the channels which PU temporarily unused. Therefore, how to assign these channels to SUs appropriate is the key point to enhance the performance of the network [8]. In the research literature on the channel allocation scheme, Kaniezhil et al. proposed a three input 27-rule based fuzzy logic system [9].They studied the spectrum utilization efficiency, degree of mobility and distance of secondary user to the primary user. But the multipath fading problem [10] has not been considered, thus the system performance may be degraded due to the signal strength is too low or too much additional interference. As a result, we proposed an improved channel allocation scheme based on Kaniezhil's scheme, after detecting the available channels, we consider the received signal strength to define the channel access priority of secondary users applied by fuzzy inference system. Through our improvement channel allocation scheme, we expect to effectively upgrade the overall throughput of the secondary network.

The rest of this paper is organized as follows. In Section II, we discuss channel allocation operation in CRN and a brief introduction of fuzzy inference system model. In Section III, we show the proposed model of our fuzzy-based dynamic channel allocation scheme. Section V presents the simulation results, we show the superior of our approach and verify the effectiveness of the proposed scheme. Finally, we conclude this paper in Section VI.

II. Related Works

2.1 Channel Allocation Operation in CRN

In CRN, the cognitive capability of a cognitive radio enables SU to sense the surrounding spectrum environment and detect all of the available channels as well as the relevant available channel information, and then SU will deliver the available channel information to the CR_BS. After received above information, CR_BS will analysis according to the channel characteristics and user requirements. Finally, appropriate channel allocation will be achieved. This process is called cognitive cycle [5]. As shown in Fig. 2.

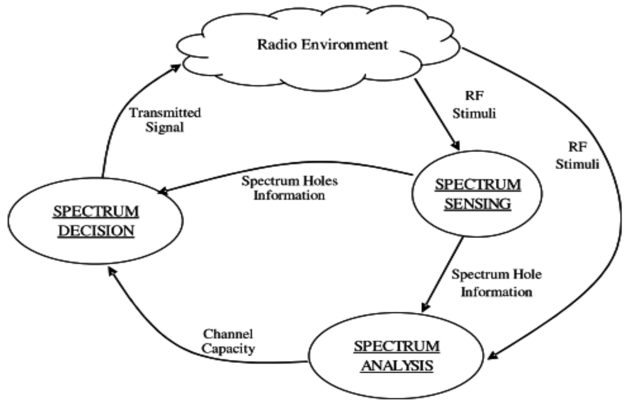

Fig. 2. Cognitive cycle

2.2 Fuzzy Inference System

In our approach, we utilize fuzzy inference system (FIS) [11] to reach an appropriate channel arrangement. Thus, here we brie y introduce FIS.

Fuzzy logic resembles human like thinking being, due to that efficient decision making operation can easily done and also it is well suited for multi-valued decision. Fig. 3 shows a complete FIS structure which consists of four main modules. When an input is applied to a FIS, it will fuzzified by the predefined membership functions (MF), and then converted crisp values to a set of fuzzy numbers. In inference engine module, fuzzy numbers are fed into the predefined rule base that presents the relations of the input and output variables with IF–THEN pattern. Consequently, the output of the inference engine is changed into a crisp value in defuzzification module that represents the actual output of the system. The definitions required for each interface are defined in fuzzy knowledge base.

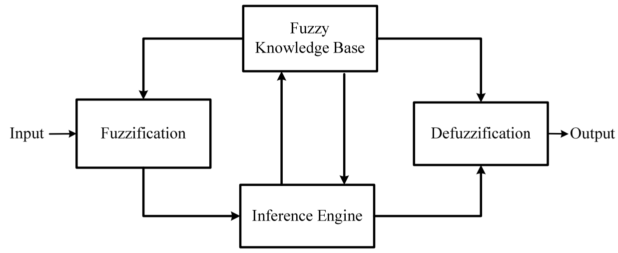

Fig. 3. Fuzzy Inference System

III. Fuzzy-based Dynamic Channel Allocation

Through the above description, we see that how to appropriately assign the available channels to the SU is an important issue in CRN. In this section, we present our approach using FIS to assign the available channels to the SUs without interfering to the PUs. Flow chart as the proposed scheme is shown in Fig. 4, two main parts can be classified: Establish available channel table and SU priority scheduling respectively.

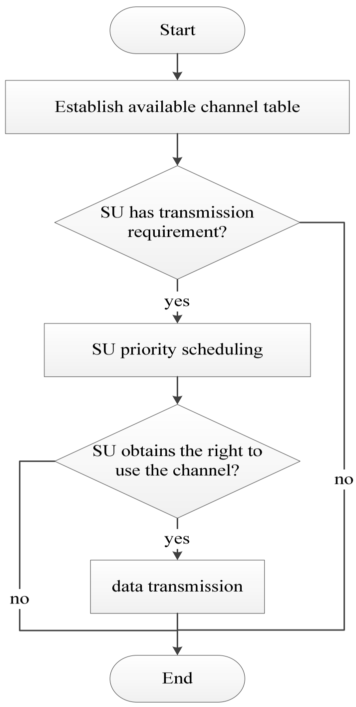

Fig. 4. Fuzzy-based dynamic channel allocation scheme

3.1 System Model

In this research, as depicted in Fig. 5, we assume secondary network is completely covered by primary network, a centralized CR_BS responsible to assign the available channels to SUs. Furthermore, SUs are randomly deployed within range of the secondary network, and it can arbitrarily move according to the requirement.

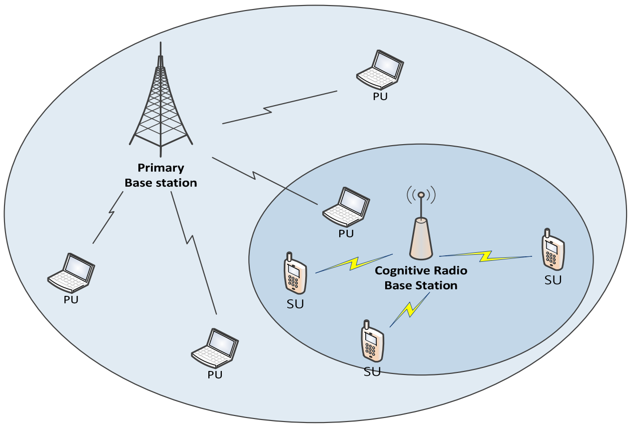

Fig. 5. System model

On the other hand, as depicted in Fig. 6, time is cut to the same size as many time slots, each slot can be divided into three stages:

- Sensing: SU checking whether the channel is available or not, and then transmit the channel status to CR_BS in order to establish the available channel table.
- Contention: Via the FIS, CR_BS calculate the priority to the SU who has the transmission requirement. After that the channel will be assigned to the SU who has the highest priority.
- Transmission: SU who obtain the right to use the channel will be able to transmit.

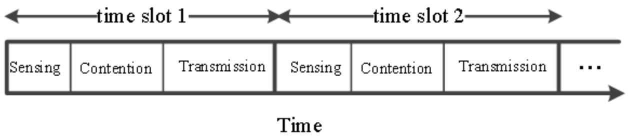

Fig. 6. Time slots illustration

3.2 Establish Available Channel Table

For the proper sense of the available channel, in this paper, we adopt energy detection [12], which the most common way of spectrum sensing because of its low computational and implementation complexities. The main idea is to detect the signal power and make accumulated to all these signal power, then we can get a cumulative power value T(y). The metric can be written as

$$T(y) = \frac{1}{N}\sum_{n=1}^{N}|y(n)|^2 \quad (1)$$

After that the cumulative power value T(y) compared with a predefined threshold ε

$$\theta = \begin{cases} H_0, if \ T(y) < \varepsilon \\ H_1, if \ T(y) > \varepsilon \end{cases} \quad (2)$$

If $T(y) < \varepsilon$, SU will determine there is no PU signal on the channel, the channel is available(H_0). On the other hand, if $T(y) > \varepsilon$, SU determine PU is transmitting at this moment, thus the channel is not available(H_1).

However, in the available channel sensing process, hidden terminal problem [12] are likely to be encounter, this causes an inaccurate sensing result. Therefore, after each SU making a binary decision to determine whether the channel is available through energy detection, the result will transmit to the CR_BS. According to the binary decision, CR_BS make a fusion decision [13] based on the fusion rule. Finally, we can determine whether the channel is actually available or not through the fusion decision. The basic fusion rule can be written as

$$Z = \sum_{i=1}^{K} D_i \begin{cases} < n, & H_0 \\ \geq n, & H_1 \end{cases} \quad (3)$$

When there are K SUs, at least n SUs regarded as PU is transmitting, so will the decision determine the channel is unavailable (H_1), and vice versa.

Table I Available channel table

SU_ID \ CH No.	ch1	ch2	ch3	….
#1	H_0	H_1	H_1	….
#2	H_0	H_1	H_0	….
#3	H_0	H_1	H_0	….
#4	H_0	H_1	H_1	….
#5	H_1	H_0	H_1	….
…	…	…	…	….

By way of fusion decision, CR_BS will be able to establish the available channel table which recorded all available channels of SUs. The paradigm of available channel table is shown in Table I.

3.3 SU Priority Scheduling

In the above-mentioned discuss, CR_BS can verified the available channels. The following study presents how we assign these available channels to the suitable SU by FIS, also known as SU priority scheduling. The flow chart is shown in Fig. 7, blocks with the dashed border mean as the FIS. After calculation by FIS, all available channels corresponding to the SU would generate a priority factor, and then the channel would be assigned to the SU who has the biggest priority factor. The details are described below.

When SU needs to transmit, it will send out a transmission requirement to the CR_BS, and four parameters which competition for the desired channel will be send at the same time. The four parameters are shown as follows:

✓ **Spectrum utilization Efficiency**: Ratio of the required spectrum by the SU to the total available spectrum [9]

$$\eta_s = \frac{BW_s}{BW_a} \times 100\% \quad (4)$$

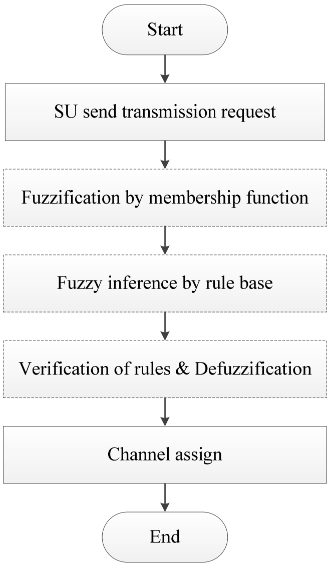

Fig. 7. Flow chart for SU priority scheduling

- ✓ **Mobility**: The SU mobility would leads to the Doppler shift [9], reduce its ability to detect the PU signal. Doppler shift can be written as

$$f_d = \frac{v}{\lambda}\cos\theta = \frac{v f_c}{c}\cos\theta \quad (5)$$

- ✓ **Distance**: The closer between SU and PU, the possibility of interference to PU greater. We use Received Signal Strength Indication (RSSI) [14] to calculated the distance between SU and PU

$$\mathrm{RSSI}(d) = P_T - P_L(d_0) - 10\alpha\log_{10}\frac{d}{d_0} + X_\sigma \quad (6)$$

- ✓ **Signal Strength**: We use Signal-to-noise ratio (SNR) to reflect the actual use of the channel conditions, the metric can be written as

$$SNR_s = \frac{P_s}{N_0} \quad (7)$$

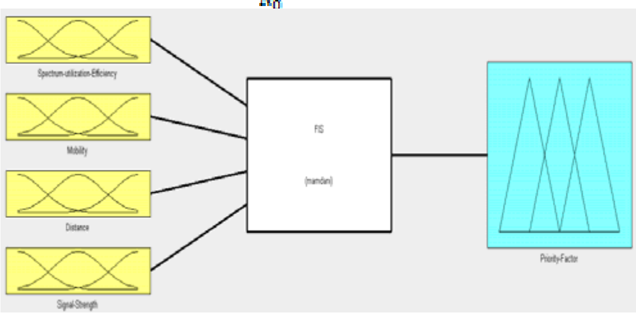

Fig. 8. Model of the proposed FIS

We consider a 4-input 1-output FLS, as shown in Fig. 8. As previously mentioned in Section 2.2, to begin with, we needs to converted crisp values to a set of fuzzy numbers. Therefore, membership functions of the 4 inputs and 1 output have been defined.

Membership functions of the 4 inputs are described respectively in Fig. 9 to Fig. 12, and the linguistic variables are kept to be {Low, Medium, High}. On the other hand, as shown in Fig. 13, the output priority factor is divided into five levels {Very Low, Low, Medium, High, Very High}.

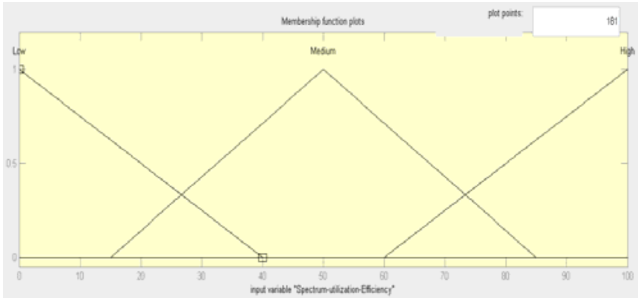

Fig. 9. Membership function of Spectrum utilization Efficiency

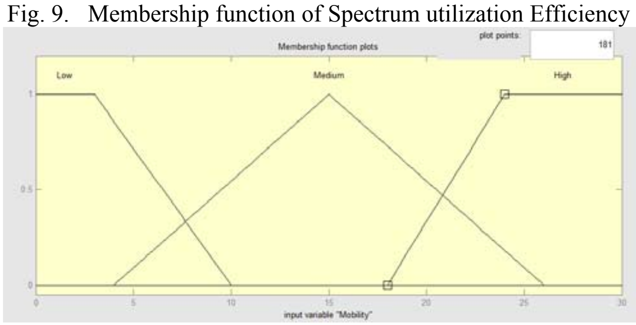

Fig. 10. Membership function of Mobility

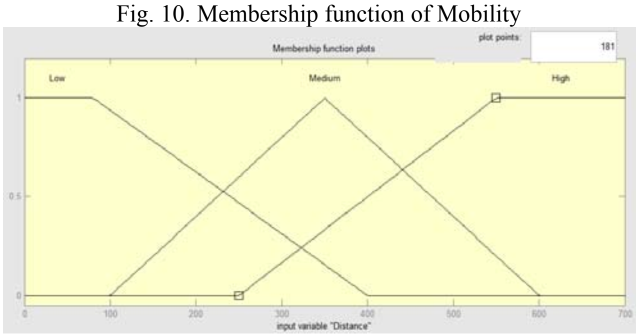

Fig. 11. Membership function of Distance

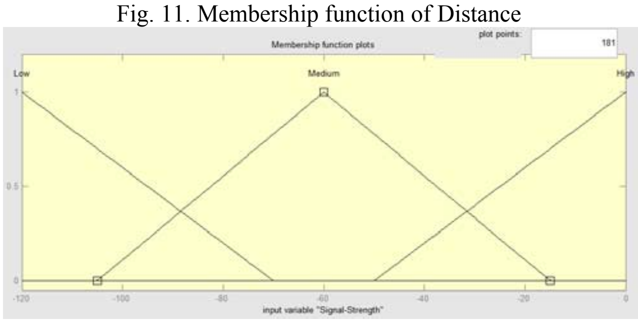

Fig. 12. Membership function of Signal Strength

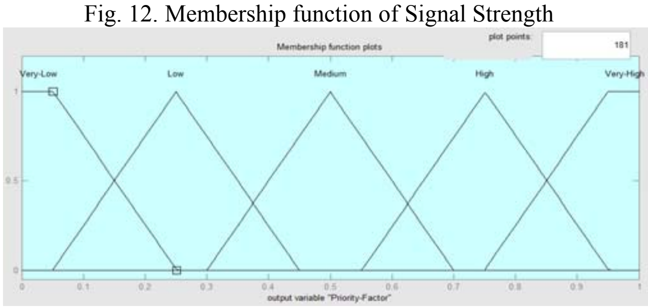

Fig. 13. Membership function of Priority factor

Next, based on the knowledge on the linguistic variables, we need to construct the rule base for the FIS. The rule base is consist of $3^4 = 81$ fuzzy rules in IF-THEN format such as

“**IF** Spectrum utilization Efficiency is Low AND Mobility is High AND Distance is Medium AND Signal Strength is High **THEN** Priority is______.”

Table II demonstrates the complete rules contained in the rule base. Furthermore, the fuzzy inference engine computes the output set C^l_{avg} corresponding to each rule, the metric can be written as

$$C^l_{avg} = \frac{\sum_{i=1}^{l} w_i^l C^i}{\sum_{i=1}^{l} w_i^l} \quad (8)$$

in which w_i^l is the number of choosing linguistic label i for the consequence of rule l and C^i is the centroid of the ith consequence set.

Table II Rule table

Rule No.	Spectrum Efficiency	Mobility	Distance	Signal Strength	Priority
R1	Low	Low	Low	Low	Low
R2	Low	Low	Low	Medium	Low
R3	Low	Low	Low	High	Medium
R4	Low	Low	Medium	Low	Low
R5	Low	Low	Medium	Medium	Medium
R6	Low	Low	Medium	High	High
R7	Low	Low	High	Low	Medium
R8	Low	Low	High	Medium	High
R9	Low	Low	High	High	High
R10	Low	Medium	Low	Low	Very Low
R11	Low	Medium	Low	Medium	Low
R12	Low	Medium	Low	High	Low
R13	Low	Medium	Medium	Low	Low
R14	Low	Medium	Medium	Medium	Low
R15	Low	Medium	Medium	High	Medium
R16	Low	Medium	High	Low	Low
R17	Low	Medium	High	Medium	Medium
R18	Low	Medium	High	High	High
R19	Low	High	Low	Low	Very Low
R20	Low	High	Low	Medium	Very Low
R21	Low	High	Low	High	Low
R22	Low	High	Medium	Low	Very Low
R23	Low	High	Medium	Medium	Low
R24	Low	High	Medium	High	Low
R25	Low	High	High	Low	Low
R26	Low	High	High	Medium	Low
R27	Low	High	High	High	Medium
R28	Medium	Low	Low	Low	Low
R29	Medium	Low	Low	Medium	Medium
R30	Medium	Low	Low	High	High
R31	Medium	Low	Medium	Low	Medium
R32	Medium	Low	Medium	Medium	High
R33	Medium	Low	Medium	High	High
R34	Medium	Low	High	Low	High
R35	Medium	Low	High	Medium	High
R36	Medium	Low	High	High	Very High
R37	Medium	Medium	Low	Low	Low
R38	Medium	Medium	Low	Medium	Low
R39	Medium	Medium	Low	High	Medium
R40	Medium	Medium	Medium	Low	Low
R41	Medium	Medium	Medium	Medium	Medium
R42	Medium	Medium	Medium	High	High
R43	Medium	Medium	High	Low	Medium
R44	Medium	Medium	High	Medium	High
R45	Medium	Medium	High	High	High
R46	Medium	High	Low	Low	Very Low
R47	Medium	High	Low	Medium	Low
R48	Medium	High	Low	High	Low
R49	Medium	High	Medium	Low	Low
R50	Medium	High	Medium	Medium	Low
R51	Medium	High	Medium	High	Medium
R52	Medium	High	High	Low	Low
R53	Medium	High	High	Medium	Medium
R54	Medium	High	High	High	High
R55	High	Low	Low	Low	Medium
R56	High	Low	Low	Medium	High
R57	High	Low	Low	High	High
R58	High	Low	Medium	Low	High
R59	High	Low	Medium	Medium	High
R60	High	Low	Medium	High	Very High
R61	High	Low	High	Low	High
R62	High	Low	High	Medium	Very High
R63	High	Low	High	High	Very High
R64	High	Medium	Low	Low	Low
R65	High	Medium	Low	Medium	Medium
R66	High	Medium	Low	High	High
R67	High	Medium	Medium	Low	Medium
R68	High	Medium	Medium	Medium	High
R69	High	Medium	Medium	High	High
R70	High	Medium	High	Low	High
R71	High	Medium	High	Medium	High
R72	High	Medium	High	High	Very High
R73	High	High	Low	Low	Low
R74	High	High	Low	Medium	Low
R75	High	High	Low	High	Medium
R76	High	High	Medium	Low	Low
R77	High	High	Medium	Medium	Medium
R78	High	High	Medium	High	High
R79	High	High	High	Low	Medium
R80	High	High	High	Medium	High
R81	High	High	High	High	High

Finally, in the final step of the FIS, we defuzzified the fuzzy sets to a crisp value by Center of Gravity [15]. For the four input (x_1, x_2, x_3, x_4), the output $y(x_1, x_2, x_3, x_4)$ of the designed FIS is computed as

$$y(x_1, x_2, x_3, x_4) = \frac{\sum_{l=1}^{81} \mu_{F_1^l}(x_1)\mu_{F_2^l}(x_2)\mu_{F_3^l}(x_3)\mu_{F_4^l}(x_4) C^l_{avg}}{\sum_{l=1}^{81} \mu_{F_1^l}(x_1)\mu_{F_2^l}(x_2)\mu_{F_3^l}(x_3)\mu_{F_4^l}(x_4)} \quad (9)$$

SUs contended for the right to use the channel according to the Priority factor which generated by FIS. In other words, SU with higher priority factor would have higher opportunity to obtain the right to use the channel. For example, as shown in Table III, we can see that there are four SUs to compete with channel 1, but according to the priority factor, channel 1 will assigned to SU2 which has the highest priority factor 0.893. The rest may be deduced by analogy, channel 2 assigned to SU5, channel 3 assigned to SU3.

Table III Available channel table (update by Priority factor)

SU_ID \ CH No.	ch1	ch2	ch3	....
#1	0.312	0	0	....
#2	0.893	0	0.498	....
#3	0.736	0	0.577	....
#4	0.588	0	0	....
#5	0	0.481	0	....
...	...	...	...	....

IV. Simulation Results

In this section, to validate our approach, we have modeled the system using Fuzzy logic toolbox in Matlab2012b. In our work, we choosing the best available channel for channel assigned with the highest priority factor. Our simulation compared with Kaniezhil's scheme and random channel assignment. Normally, according to the designed rule base in Table II, SU with higher spectrum utilization Efficiency, lower mobility, higher distance to PU and higher signal strength will have higher priority factor. 5 PU and 20 SU randomly distributed in a 500*500m^2 square area. CR_BS located at the center point. To generate utility performance measures, we assume [9]:

- Maximum transmission power for each channel: 100mW
- Time slot: 100ms
- Spectrum utilization Efficiency between 0~100%
- Mobility between 0~30m/s
- Distance to PU between 0~700m
- Signal Strength between -120~0dB

In Fig. 14, the horizontal axis is SNR and vertical axis is average SU throughput, since the higher the SNR, the higher the signal quality. Therefore, when SNR increase, the average SU throughput also increased, and we can seem that the proposed scheme always better than Kaniezhil's scheme.

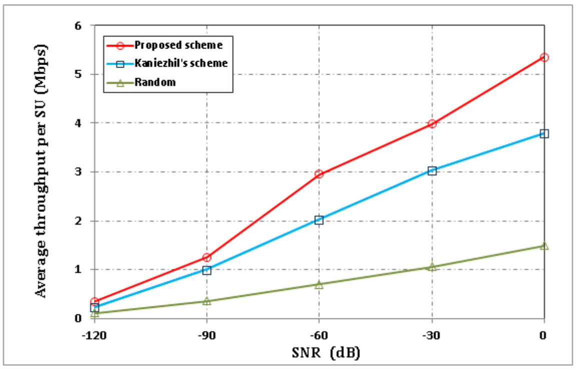

Fig. 14. Analysis of average throughput per SU

In Fig. 15, we compared the total throughput of secondary network in varying conditions of available channel rate, since in the high available channel rate scene, SU would have more available channel to use, so the total throughput of secondary network will be increased. At the same time, it is obvious that the proposed scheme have the better performance than Kaniezhil's scheme, and much better than the random assignment.

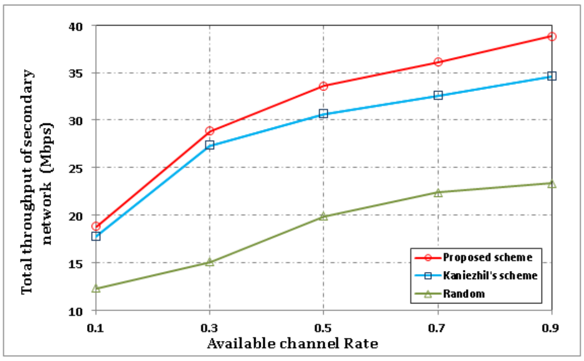

Fig. 15. Analysis of total throughput of secondary network

As a result, we verified the SU received signal strength should be taken into consideration in channel allocation scheme, and also show the effectiveness of the proposed scheme.

V. Conclusions

In CRN, how to assign available channels to SUs appropriate is the crucial point to enhance the performance of the network. In this paper, we proposed a fuzzy-based dynamic channel allocation scheme. To begin with, the available channel detection has been discussed, after that we define the channel access priority of secondary users applied by fuzzy theory. Finally, the simulation results show the superior of our approach.

In the future, due to the formulating of membership function and rule base has no universal theorem, we plan to develop a more objective membership function and rule base through systematic manner. On the other hand, we adopted the energy detection to find out the available channels. Although it is quick and simple, but the sensing result is not reliable when signal strength is too low. Therefore, if we can adopt other better sensing methods, the network performance might be more progressive.

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