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Using Fuzzy Inference System for Interference Mitigation in Cognitive Radio based Heterogeneous Wireless Sensor Network(FIS-CoRHAN)

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Abstract: Cognitive Radio based Heterogeneous Wireless Sensor Network (CoRHAN) is an innovative multi-layered infrastructure approach in wireless engineering which incorporates different communication modes over large geographical area. CoRHAN employs cooperative communication among sensor nodes and cognitive radio to ensure an optimized communication experience for users. It shares radio resources fairly and efficiently by integrating multiple networks together. Challenge in such network is the ability to instantly detect interference on the frequencies being used and quickly tune to other better frequencies for communication reliability. In this paper, we have proposed an enhanced CoRHAN using Fuzzy Inference System (FIS). FIS is applied to mitigate the fading frequencies due to co-channel interference. It helps to sort out the best frequency channel among the selected cooperative spectrum sensed channels. Prototype was developed to demonstrate the proof of concept and analyze the feasibility and practicality of using FIS-CoRHAN technique in Cognitive Radio based Heterogeneous Wireless Sensor Network. Simulation results show that our solution achieves better performance when compared to existing CoRHAN approach substantially satisfying the robustness constraints.

Keywords : Channel Sensing, Channel Switching, Cognitive Radio, Fuzzy Inference System, Heterogeneous Wireless Sensors, Interference Mitigation.

I. INTRODUCTION

Heterogeneous Wireless Sensor Networks (HWSNs) have been widely deployed for extensive range of IOT applications such as smart city etc. Low cost, simplicity and broadcast characteristics of wireless senor nodes have further accelerated the deployments of HWSNs. Heterogeneous wireless systems cooperate with each other to provide ubiquitous "always best connection" to users. Introducing a CR science into a HWSN is one way of analyzing the radio capability in a given geographical area. Cognitive Radio supports multiple protocols and air interfaces facilitating the convergence of HWSNs. Cognitive Radio based Heterogeneous Wireless Sensor Network (CoRHAN) [1] is an innovative multi-layered infrastructure approach which incorporates different communication modes in wireless engineering. It employs cooperative communication by integrating sensor nodes and cognitive radio among multiple networks and sharing radio resources fairly and efficiently to ensure an optimized communication experience for users. In CoRHAN the sensor nodes in a radio access network serve to send data to CR enabled node (acts as gateway - it collects, stores and transmits data from its neighbor sensor node to Data Acquisition System) which performs spectrum sensing and channel switching to improve the communication reliability.

Need for IOT applications have led to unrelenting growth in the usage of smart and personal wireless communications systems. With interference being the primary limiting factor - unprecedented level co-channel interference (signals transmitted from multiple networks which operate in close proximity cause interference to each other) negatively impacts coverage, reliability and performance in such systems. Major obstacles to high capacity transmission (in a power and bandwidth limited wireless communications) are random propagating channels, limited radio spectrum, fading channel and inter-symbol interference. Several recent studies have addressed burstiness and interference in wireless links. Ghasemi investigated the fundamental limits of spectrum sharing with interference constraints in fading environments [2]. Zhang et al [3]., considered an opportunistic channel sensing and access in cognitive radio networks describing the time slot when sensing is imperfect and the number of channels users can access at a time by deriving logarithmic regret performance for different scenarios. Kannan Srinivasan et al., proposed a metric to quantify link burstiness, impact on protocol performance and achievable improvements in transmission cost [4]. However, these solutions cannot react to instantaneous (dynamic) changes in the channel condition.

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Spectrum occupation can change rapidly resulting in unfavorable channel conditions; challenge is to find better channels to maintain communication.

Aim of this research work is to fully utilize the best of different wireless technologies to provide more reliable radio services effectively through optimal radio selection scheme. Primary focus lies in reducing harmful interference and providing more reliable radio services among various heterogeneous wireless systems. In order to make an intelligent wireless communication system that can learn and adapt to the environment and statistical variations (analyzing radio resources collectively), a Fuzzy Inference System (FIS) in CoRHAN is introduced. This approach brings many advantages to sharing radio resources fairly and efficiently among multiple networks through deterministic and adaptive channel allocation [14][15] process. Using fuzzy inference technique for interference mitigation over real-time sensing helps to instantly change channels when better frequencies are detected. Among the cooperative spectrum sensed channels [5]-[10] selected, FIS mitigates fading frequencies (caused due to co-channel interference), sorts and picks the best frequency channel for data communication. The FIS-CoRHAN technique proposed in this paper makes use of sophisticated interference mitigation mechanism using fuzzy inference system leveraging cognitive technology in aspects of the interference mitigated radio operation. It allows radios to increase their dwell time on a channel even in the presence of interference (that would cause traditional radios to fail) thereby improving the reliability of the network in harsh RF conditions. Nevertheless, it identifies potential impairments (like interference) and adjusts its transmitting parameters to ensure opportunistic spectrum sharing[11]-[13] communication experience for users unlike their traditional counterparts. Simulation was conducted to prove the efficacy of the proposed FIS-CoRHAN technique. Performance of the proposed system was evaluated by developing a simulation model using self written script in MATLAB. Model was used to demonstrate the proof of concept and analyze the feasibility and practicality of using FIS in Radio based Heterogeneous Wireless Sensor Area Network. Simulation result shows that our solution achieves better performance when compared to existing CoRHAN approach substantially satisfying the robustness constraints.

The remainder of the paper is organized as follows. In Section 2, we discuss the proposed FIS-CoRHAN network architecture and its current technology research towards the realization of this model. In Section 3, simulation and experimental results of the proposed model is discussed. Finally, Section 4 concludes our paper.

II. MATERIALS AND METHODS

In this system, we consider a CoRHAN architecture, where CR device is introduced within a coverage area that has a set of heterogeneous wireless sensor nodes deployed. HWSNs have sensor nodes with varied radio techniques (each radio access network consists of group of sensors that have different radio techniques) to communicate over interference mitigated channels as shown in figure 1. Radio access network in FIS-CoRHAN is categorized as

- *Primary Radio (PR or P_{radio})* - Nodes communicate through CR deployed in its group.
- *Secondary Radio (SR or S_{radio})* - Nodes communicate through CR deployed outside to its group.

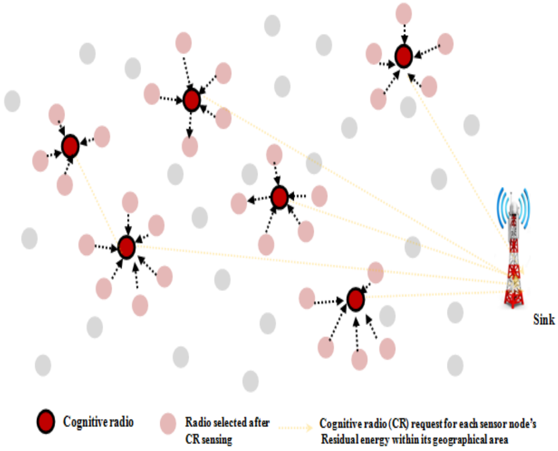

Fig. 1.System Model of FIS-CoRHAN.

Primary activity of the FIS-CoRHAN is to scan the radio capability of CR's at a given instant of time, analyze radio with maximum communication capability and switch over to those radio access network for effective data transmission. Essentially, the proposed FIS-CoRHAN employs advanced intelligence using fuzzy inference mechanism to determine, at a granular level, how much interference it can effectively withstand before reconfiguring its parameters. FIS-CoRHAN's interference mitigation capability greatly increases the capacity of offering robust, reliable and best frequency channels for use. The proposed FIS-CoRHAN system architecture includes the following main components:

Senor Node:

The sensor nodes (S_n^i) senses the environment, collects sensory information and communicates to the Cognitive Radio node.

Cognitive Radio Node:

CR node scans the environment and prioritizes the most suitable radio for particular geographical area. The role of CR node has been extended by bringing intelligence for more flexible dynamic reconfiguration and high performance communication.

Sink:

It is the back-end centralized control system. It continuously synchronizes data received from CR nodes over time to the server. The collected information represents a vital source of big data for the statistical and research activity. The proposed FIS-CoRHAN system is categorized into the following phases

- Opportunistic Channel Analysis (OCA)
- Interference Mitigated Channel Allocation using Fuzzy Inference System

Summary of notations used is FIS-CoRHAN model is referred in table 1.

Table 1 Summary of Notations used in FIS-CoRHAN

Notation	Description
N	Number of Cognitive Radio Node in the network
I	Interference Tolerance
R_S	Sensing Radius
I_f	Interference
T_{power}	Transmission Power`
N_o	Noise
E_{res}	Residual Energy
D_L	Delay
F_q	Frequency
$\mathbf{P_{radio}}$	Primary Radio
S_{radio}	Secondary Radio
T_{Slot}	Time Slot
Sp_{hole}	Spectrum Hole
$SHole_{data}$	Data regarding Spectrum Hole

A. Opportunistic Channel Analysis (OCA)

Primary operation of CR during this phase is to sense the environment within their sensing range for channel identification. Local sensing results are probed to discover set of spectrum holes at varied time slot. Operating parameters (such as transmission power (T_{power}), Noise (N_o), Frequency (F_q), Delay (D_L) and interference (I_f)) are sensed in the radio environment. CR periodically selects and modifies Radio Environment Map (REM) with its cognitive and reconfiguration capability.

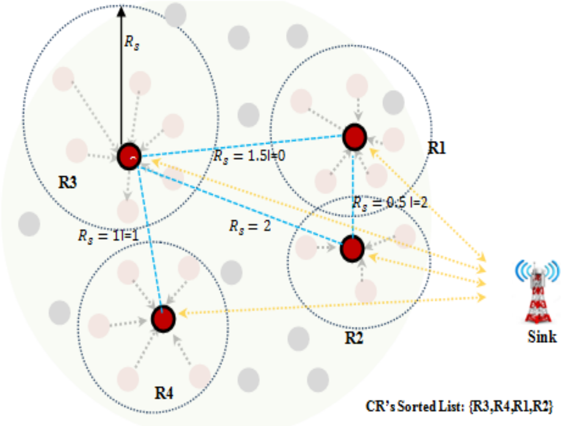

Fig. 2.Opportunistic Channel Analysis process in FIS-CoRHAN

Let us assume that FIS-CoRHAN system considered in our scenario have 'n' regions (n=4). Each region has single CR and multiple sensor nodes as shown in figure 2. Set of sensor nodes (SN) within the region communicates through P_{radio} (radio access network of CR1) or S_{radio} (radio access network of other CRs that exists outside the region of CR1). The P_{radio} or S_{radio} has access to the radio frequency statistics logged into REM. Let Region 1 as shown in figure 3 represent the communication range of Cognitive Radio 1.

Cooperative sensing technique is employed in our approach to ensure effective analysis, selection and allocation of radio channels especially under interference constrained and serious fading environment. It prevents multiple CR from accessing the same channel at same time.

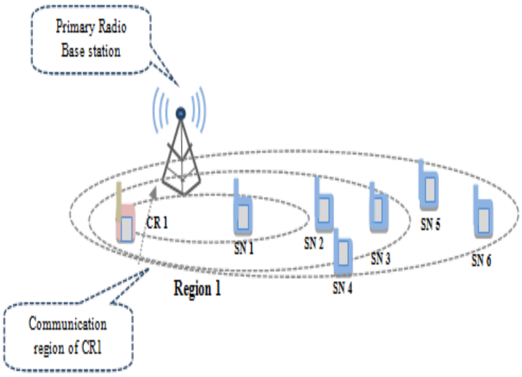

Fig. 3.Communication range of Cognitive Radio in region 1.

CR consistently monitors the P_{radio} and S_{radio} channel through sensing mechanism. Let delay intolerant data traffic from sensors in Region 1 arrives at CR1 in a distributed fashion with an arrival probability 'p' as shown in figure 4.

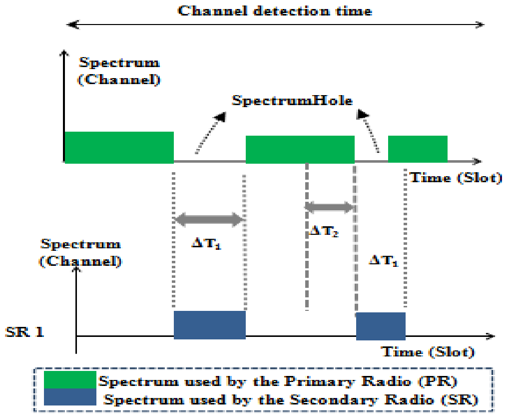

Fig. 4.Spectrum sensing and analysis for opportunistic utilization.

In such scenario, the data transmission can undergo the following:

- data transmission fails if there are no free channels available at that instant of time.
- data transmission becomes unreliable if interference constrained channels are allocated.
- data transmission is said to be lost if two of more such transmission occupies the same idle channel for transmission (collision is caused).

Effective sensing, analysis and channel estimation mechanism prevents such failure during data transmission. FIS-CoRHAN technique ensures CR to explore and find an optimal channel (belonging to P_{radio} or S_{radio}) to maximize its throughput (total amount of data that is successfully delivered per unit time). By optimizing throughput (maximize P_{radio} or S_{radio} utilization), the sum throughput (total amount of data (T_{data}) indicates the sum throughput of P_{radio} plus sum sum throughput of S_{radio}) of the overall system improves. Algorithm 1 represents the steps involved for OCA process in FIS-CoRHAN scheme.

Algorithm 1: Opportunistic Channel Analysis

```
Input: CR senses operating parameters for effective channel utilization.
1. CR periodically senses $T_{power}$, $F_q$, $N_o$, $I_f$, $D_L$ from radio environment to detect spectrum holes.
 2. /*Spectrum sensing*/
 Initialize $CR_{count} = 0$;
 $CR_{count}$ = getCRcount( ); // function that returns the num ber of cognitive radio in geo area.
for i = 1: $CR_{count}$
    if $P_{radio}$ not utilizing spectrum at $T_{slot}$ then
/*Spectrum Hole Detection*/
CR$_i$ Senses $Sp_{hole}$ in $P_{radio}$ ;
Store $SHole_{data}$; /*Store list of spectrum holes in the list and increment the counter*/
     $CR_{count}$ = $CR_{count}$ + 1;
    end
  end /*for loop*/
3. /*Channel Analysis and optimal band selection for Secondary Radio Communication. Among list of available channels, analysis is done to select the optimal channel that satisfies QoS requirement of Secondary radio $S_{radio}$ and interference threshold ($I_g$) of Primary radio $P_{radio}$*/
Initialize $hole_{count} = 0$;
 for each $Sp_{hole}$ at $T_{slot}$
      $Ch_i$ = getShole();
      /* Get spectrum hole for $S_{radio}$ communication */
       Store $hole_{data}(Ch_i)$;
      /*Store spectrum holes in the list separately*/
       $hole_{count} = hole_{count} + 1$;
end
$hole_{count}$ = get$hole_{data}$();
4. The lists of spectrum holes are identified.
5. Most suitable channel or spectrum hole for data transmission as per Algorithm 2 is selected
Output: List of spectrum holes or frequency band or channels are identified.
```

At any given point of time, availability of unused channel is analyzed using initial set of statistical information. Each channel has only two possible states; idle (OFF) or busy (ON). Let us consider P_{radio} channels will be in ON or OFF state randomly distributed. Channel when in use by P_{radio} is said to be *busy* otherwise *idle*. The duration that the P_{radio} user passage are independently exponentially distributed (the period of ON, B_n, follows an exponential distribution with mean $^1/_{\lambda B_n}$. On the other hand, the period of OFF,I_n, also follows an exponential distribution with mean $^1/_{\lambda I_n}$) as shown in figure 5.

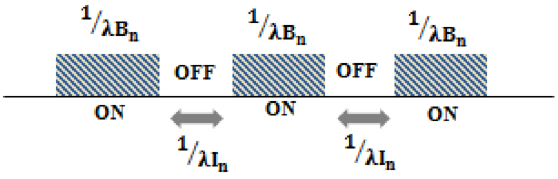

Fig. 5.ON/OFF decision on whether data transmission is present or not.

1) *Calculating Mean for Busy Channel Bn (ON)*

Let X be a continuous variable, set of values the random variable can take R= [0, N]. Let $\lambda B_n \in R$

$$E(X) = \int_0^N xfX(x)dx$$

$$= \int_0^N x(\lambda B_n \exp(-\lambda B_n)\, dx$$

Exponential distribution S [0, ∞] is defined as, $fX(x) = \int_0^\infty \lambda exp\ (-\lambda x)$ if $x \in S$; $x \notin S$, X is exponential distribution with λ. Integrating by parts,

$$= \int_0^N [-x\exp(-\lambda B_n x)] + \int_0^N \exp(-\lambda B_n)\, dx$$

$$= (0-0) + [-\frac{1}{\lambda B_n} \exp\ (-\lambda B_n x]_0^N$$

$$= 0 + (0 + \frac{1}{\lambda B_n})$$

$$E(X) = \frac{1}{\lambda B_n}$$

2) *Calculating Mean for Idle Channel In (OFF)*

Let X be a continuous variable, set of values the random variable can take R= [0, N]. Let $\lambda I_n \in R$

$$E(X) = \int_0^N xfX(x)dx$$

$$= \int_0^N x(\lambda I_n \exp(-\lambda I_n)\, dx$$

Exponential distribution S [0, ∞] is defined as, $fX(x) = \int_0^\infty \lambda exp\ (-\lambda x)$ if $x \in S$; $x \notin S$, X is exponential distribution with λ . Integrating by parts,

$$= \int_0^N [-x\exp(-\lambda I_n x)] + \int_0^N \exp(-\lambda I_n)\, dx$$

$$= (0-0) + [-\frac{1}{\lambda I_n} \exp\ (-\lambda I_n x]_0^N$$

$$= 0 + (0 + \frac{1}{\lambda I_n})$$

$$E(X) = \frac{1}{\lambda I_n}$$

Most important observation or findings from measurement reported is identifying set of frequency bands (radio channels or spectrum) not in use for significant period of time. Cognitive radio opportunistically allocates frequency bands for S_{radio} users when P_{radio} users are absent. In the case when a P_{radio} signal reappears, cognitive radios must vacate the channel being used by S_{radio} users to avoid causing interference to P_{radio} signal transmission. Fuzzy Inference system based interference mitigated channel allocation in CoRHAN allows S_{radio} users to coexist with P_{radio} signal without causing harmful interference to P_{radio} users. Detailed illustration of this phase is explained in the following section.

Table 2 Classification- interference

Input field	Range	Fuzzy set (Membership Function)
Interference	9dB 14dB 18dB	Low Medium High

Fuzzification is the first step in the design of any fuzzy logic system. It refers to the process of mapping a crisp value of an input to membership degrees in different Fuzzy Linguistic variables.

Fuzzification is followed by fuzzy rule base creation process. Fuzzy rule base is created using logical combination of input variables with AND operator. Quality of results in a fuzzy system depends on the fuzzy rules. For example, sample fuzzy rule base using interference, transmission power and noise variable is referred below:

If (Interference is low) and (Transmission Power is low) and (Noise is low) then Decision Status is L_{low}

If (Interference is Medium) and (Transmission Power is Medium and(Noise is low) then Decision Status is $L_{moderate}$

If (Interference is high) and (Transmission Power is high) and (Noise is medium) then Decision Status is L_{high}

Decision status (D_{status}) derived using fuzzy rule set are the output variables. Effective decision making using rule base results in crisp output (L_{low} or $L_{moderate}$ or L_{high}). Crisp output of the proposed scheme is to select the most suitable radio for effective data transmission. The CR receives the radio frequency factors from the sensor nodes and involves itself in the decision making process to accommodate both P_{radio} and S_{radio} users. Considering the determining parameters such as interference (I_f), transmission power (T_{power}), noise (N_o) and varying sensing radius (R_s,), the Interference tolerance (I) limit is set. The basic idea behind FIS-CoRHAN is to set up an upper interference limit (interference tolerance (I) level) for a given frequency bands in a specific area. Any S_{radio} users utilizing this band must guarantee that their transmissions added to the existing interference must not exceed the Interference Tolerance (I) at a P_{radio}. Ie., S_{radio} users tend to reduce their T_{power} based on their location with respect to the P_{radio} users. Interference caused by S_{radio} to P_{radio} when the transmission power of the relaying users exceeds a predefined interference constraint assigned by the P_{radio} in taken into account by the proposed approach. The probability of a CR colliding with other CRs (i.e. higher interference tolerance (I=2)) increases as the sensing radius (R_S) decreases i.e., when R_s = 0.5 m. Further, the lower interference tolerance I=0 (zero tolerance) is achieved as the sensing radius is higher i.e., R_s = 1.5m. The presence of CR node with sensing radius R_s = 1 and interference tolerance I=1 introduces sufficient interference to other CR nodes which cause decrease in data gathering from the sensor nodes. Fuzzy rule set is formed using the parameters considered for decision making operation for varied ranges of sensing radius (R_s). We assume the residual energy (E_{res}) of sensor node be moderate in all cases. Also, the descriptive linguistic variables of FIS (w.r.t to varied sensing radius *R_s={1, 0.5,1.5}*) is divided into three categories*: L-low (R_s=0.5), M-medium (R_s=1) and H-high (R_s=1.5).* Table 3 displays the fuzzy rules corresponding to the parameters used for decision making process for varied sensing radius R_s=0.5m, R_s=1m and R_s=1.5m respectively.

Table 3 FIS crisp output derived for varied sensing radius using Interference, Transmission Power and Noise

R_s	I_f	T_{power}	N_o	D_{status}
R_S = 1	L	L	L	L_{low}
	L	L	M	$L_{moderate}$
	M	H	M	L_{high}
	M	L	L	L_{low}
	M	M	M	$L_{moderate}$
	H	H	M	L_{high}
R_S = 0.5	L	L	M	L_{low}
	L	M	M	$L_{moderate}$
	L	H	M	L_{high}
	M	L	L	L_{low}
	M	M	M	$L_{moderate}$
	M	H	M	L_{high}
R_S = 1.5	L	L	M	L_{low}
	L	M	M	$L_{moderate}$
	L	H	M	L_{high}
	H	M	L	L_{low}
	M	L	L	$L_{moderate}$
	H	H	M	L_{high}
	H	H	H	L_{low}

FIS's interference mitigation capability employs intelligence (level of interference CR can effectively withstand before reconfiguring its parameters) at granular level to determine the crisp output in selecting the best frequency channel for use. The performance of the system depends not only on the selection of interference tolerance level specific to region, but ideally on the FIS technique used. An accurate estimate of interference by capturing a channel's availability over time helps in achieving better reliability and lower latency through dynamic radio resources allocation. The probability of switching between radios dynamically using FIS based interference mitigation mechanism is done effectively. Thus the ability to enumerate the RF environment has benefits for insuring the interference rights of spectrum users, to the capacity to efficiently adapt to the environment dynamics and the potential to provide new opportunities to use the spectrum more intensively**.** Practically, errors such as *False Alarm* (FA) and *Miss Detection* (MD) caused due to spectrum sensing are inevitable. In case of FA, S_{radio} users detects frequency band 'ON' or 'Busy' while it is actually 'OFF' and in case of MD, S_{radio} users detects frequency band 'OFF' or 'Idle' while P_{radio} users is transmitting in it. Algorithm 2 details the steps involved in FIS's interference mitigation channel allocation mechanism.

Algorithm 2: Interference Mitigated Channel Allocation using FIS

```
Input: Interference ($I_f$), transmission power ($T_{power}$) and noise ($N_o$)
are provided to FIS engine. CR performs FIS process to select the
most suitable channel for data communication.
1. /*Spectrum hole analysis process - Among channels sensed, an
appropriate channel at particular timeslot is
 chosen for $S_{radio\ communication}$*/
Initialize $suitable_{count} = 0$; /*Parameter adjustment-adaptation
of parameter to the radio environment*/
    if ($hole_{count}$ ~= 0)
        for each $hole_{data}$
  if (($hole_{data}$ satisfies $S_{radio}$ requirement ) then
            /* $hole_{data}$ is selected as suitable channel $Ch_i$
            for $S_{radio}$ */
      $Ch_{suitable\_list} = Ch_{suitable}$;
      /*Store  suitable channels separately and  increment
      the counter*/
      $suitable_{count} = suitable_{count} + 1$;
      end
   end
end /*for loop*/
2.  /*The list of suitable channels for $Tr_{slot}$ is updated to radio
environment. Among channels analyzed, an appropriate channel at
particular timeslot is chosen for $S_{radio}$ communication */
for each $suitable_{count}$
  $Ch^i_p = Ch_{suitable\_list}(i)$;
  /* FIS rule base for interference
mitigation in CoRHAN*/
```

```
    if ($Ch_p^i \geq T_{rate}$) && ($Ch_p^i \leq Error_{rate}$) ||
    ($Ch_p^i \leq T_{delay}$)&& ($Ch_p^i \geq T_{BW}$)then
    /* Select most $Ch_{suitable}$ for $Tr_{slot}$ */
    if ($R_S$ ==1) && ($I_f$ == Low) && ($T_{power}$ == Low) &&
    ($N_o$ == Low ) then
        $D_{status}$ = $L_{low}$;
    else if ($R_S$ ==1) && ($I_f$ == Low) && ($T_{power}$ == Low)
    && ($N_o$ == Medium ) then
        $D_{status}$ = $L_{moderate}$;
    else if ($R_S$ ==1) && ($I_f$ == High) && ($T_{power}$ == High) && ($N_o$ ==
    Medium ) then
    $D_{status}$ = $L_{high}$;
end

 /*Select Channel based on Derived Status */
    if ($D_{status}$ satisfies $S_{radio}$ requirement Level) then
       $Ch_{optimal\_channel}$ = $Ch^i_p$;
    end
   end
end /* for loop*/
```

Let us consider the cognitive radio (N) in the sensing area with interference tolerance (I) and sensing radius (R_S). CR scans the given geographical area to sense radios around it as shown in the figure 6. Assume four radio frequencies, i.e., R1, R2, R3, and R4 with different transmission range were sensed by the CR from the radio environment at a particular instant of time. Consider channel 'Ch_p' of primary network will be available for transmission and is used by P_{radio} periodically. The channel 'Ch_p' is open to S_{radio}. CR analyses the radio list {R1,R2,R3,R4} and derives list of radios with spectrum holes. Using FIS technique CR further categorizes, prioritizes and selects the most suitable radio (R1) for effective data collection. The true data collected is assumed to be equivalent to the data collected through wired medium (i.e. false negative is high rather than false positive) as shown in figure 6. Radio (R1) is selected as the most suitable radio for the given geographical area based on Fuzzification logic decision making rules within the sensed area. CR then allows S_{radio} to use the spectrum of the P_{radio} simultaneously under the constraint that the interference caused to the P_{radio} by S_{radio} does not degrade its communication.

Output: Most optimal channel selected based on FIS for data transmission for current Tr_{slot}

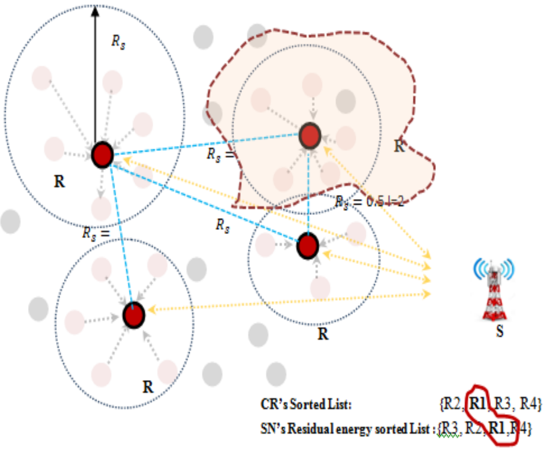

Fig. 6.Optimal radio selection process using fuzzification process.

Interference Mitigated Channel estimation and allocation using Fuzzy Inference System enables CR to intelligently detect occupancy in the different frequency bands by monitoring radio spectrum periodically and then opportunistically utilizing the spectrum bands for effective communication with minimal or no interference to the active P_{radio} users. Simplicity of FIS permits execution on devices with limited capabilities managing imprecise and uncertain information to obtain a robust system without high computational load. FIS analytics greatly increases the capacity of offering reliable channels for data communication. Flow model of FIS-CoRHAN is displayed in figure 7.

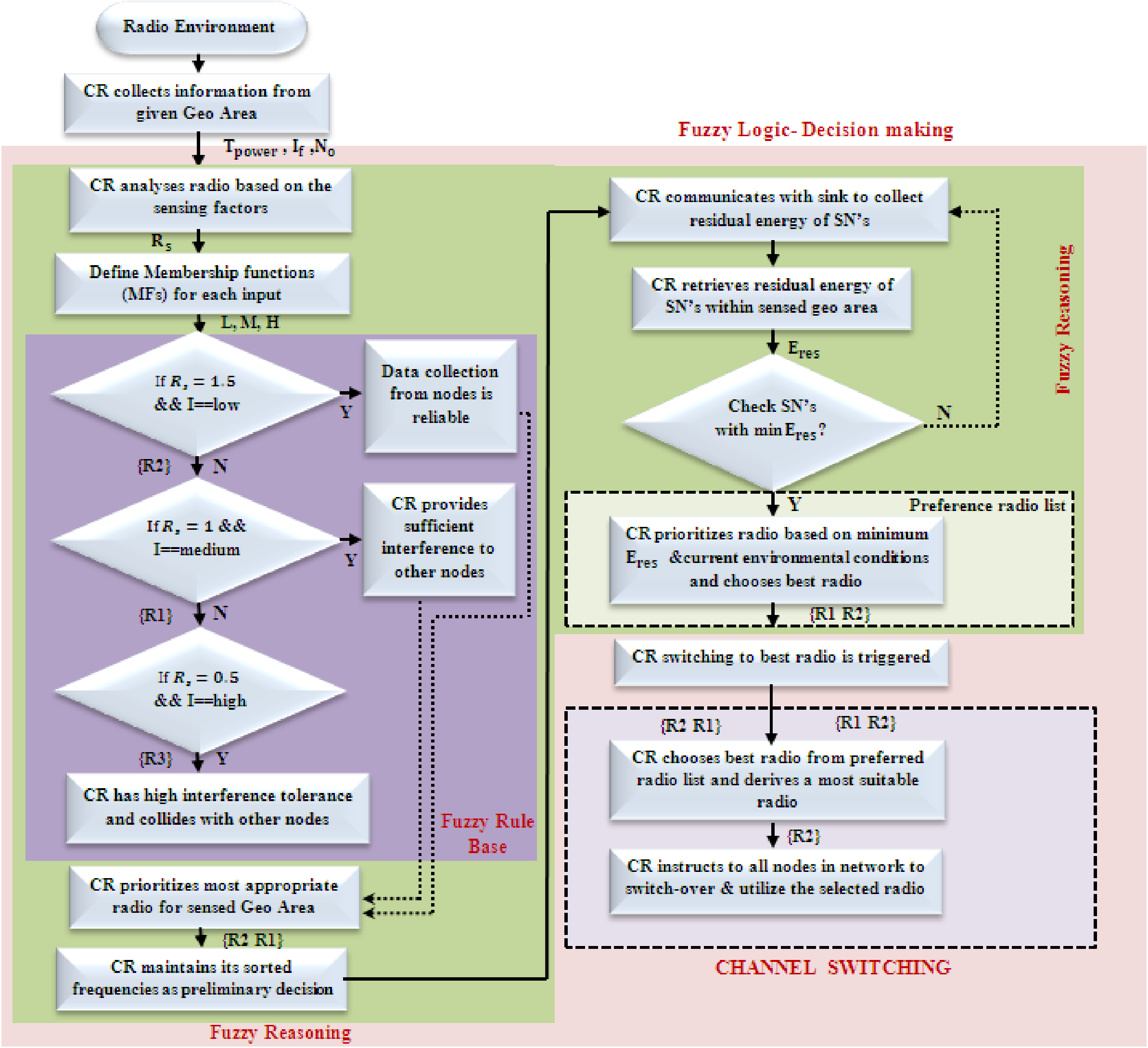

Fig. 7.Flow Model of FIS-CoHRAN Mechanism

III. SIMULATION AND EXPERIMENTAL ANALYSIS

The proposed FIS-CoRHAN scheme's performance is evaluated using a simulation model developed in MATLAB. Simulated network model consists of heterogeneous wireless sensor nodes, CR enabled node and a sink.

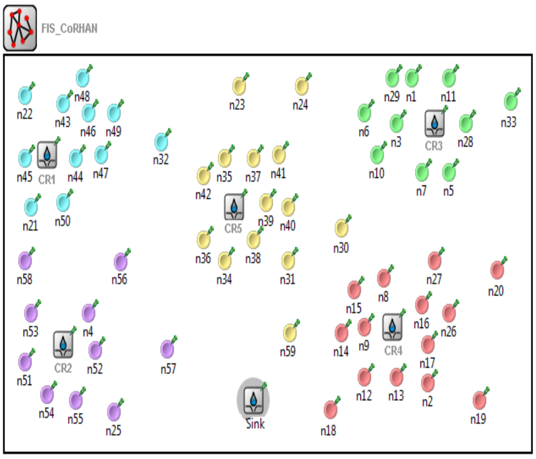

Fig. 8.Simulated network model of FIS-CoRHAN

Our experiment considers a heterogeneous Wireless Sensor Network 10 km X 10 km area, were nodes (varying from 100 to 500) are densely (500 nodes) and sparsely (100 nodes) deployed as shown in figure 8. Sensor nodes (5% to 10% of nodes) within a particular area form as groups with a single CR device deployed per group for effective communication. Nodes in each group communicate to its CR device, which further transmits data to sink. At varied time slot during simulation, nodes are randomly chosen to act as source (node that generates message and transmits to sink).

The performance of the proposed system is analyzed to identify the effectiveness of frequency utilization among primary and secondary radio's in a CR enabled FIS-CoRHAN environment. The statistical performance of the proposed system is compared with CoRHAN and conventional system to observe the stability. The following metrics was used to evaluate the performance,

Sensing Time: Time consumed by Cognitive Radio device to sense and select an optimal radio network for reliable data communication.

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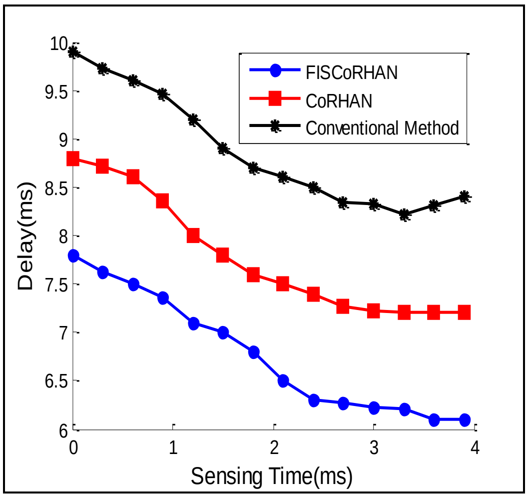

Fig. 9. Delay Vs Sensing Time

From the results as shown in figure 9, it is observed that for the proposed FIS-CoRHAN approach, the time taken by CR device to learn and adapt to the environment in its earlier stage is high compared to the later stage like other methods. Initially during sensing phase, availability of statistical information for decision making is less and increases on time. As time elapses, delay degrades and becomes stable. The CR device's sensing capability for opportunistic channel analysis using FIS technique helps to mitigate the fading frequencies and sort out the best frequency channel among the selected cooperative spectrum sensed channels for stable and effective decision making compared to CoRHAN and existing methods.

Computational Time: Time taken by Cognitive Radio to analyze and select a reliable radio resource among multiple radio resources in HWSNs. Appropriateness in instantly changing channels when better frequencies are detected through effective interference mitigation approach helps FIS-CoRHAN to achieve low computational time compared to other schemes as shown in figure 10.

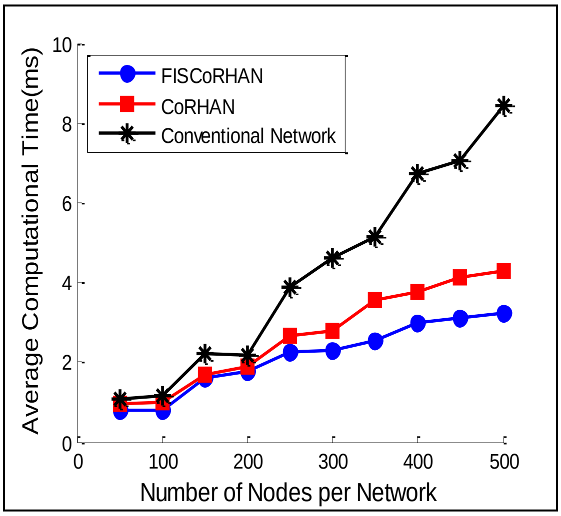

Fig. 10. Computational time Vs Nodes.

As the number of nodes increases, deep spectrum analytics using FIS infers parameters to predict optimum channels with minimum variance from idle channel list and assign them dynamically in an adaptive environment for secondary radio resource utilization. Computational time of FIS-CoRHAN approach is observed to be 5% to 7% and 15 % to 21% faster compared to CoRHAN and conventional approach. Thus the opportunistic sensing and channel analysis mechanism of FIS technique makes it better than existing schemes as shown in figure 10.

Average Probability of Error: Noise, Interference, distortion and fading at receiver end is taken into consideration to judge the quality of the signal. The performance of FIS-CoRHAN was analyzed across varied channel conditions and interference noise ratio (SINR) ranging between -15 dB to +15 dB. Data transmission rate for experimental analysis was considered to be 1Mbps with 40 bits per frame (F) and 32 bits per frame as information bits.

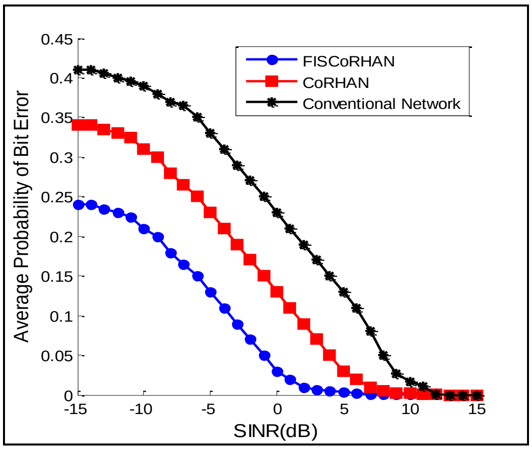

Fig. 11. Average Probability of error in FIS-CoRHAN, CoRHAN and Conventional Network.

The Average probability of error for varied SINR(dB) values is shown in figure 11. From the results, it is observed that bit error rate degrades when SINR increases. Average probability of error for FIS-CoRHAN is low compared to the other approaches. Proposed approach reaches higher SINR value earlier indicating that the signal strength is stronger in relation to the interference and noise levels, allowing higher data rates (offering better throughput) and fewer retransmissions. While the other schemes results in lower SINR comparatively resulting in secondary radio access resources to operate at lower data rates, decreasing the throughput. The result shows that with improvement in channel condition, the average bit error rate decreases i.e., in all the cases, the average probability of error decreases monotonically with SINR.

Channel Utilization: Goodput refers to the total amount of data successfully delivered to the sink per unit time. The channel utilization of P_{radio} and S_{radio} users were analyzed to identify the sum goodput of these users in FIS-CoRHAN setup. We assume the traffic arrival probability be at a rate of ρ=0.5 (bps/Hz) by both P_{radio} and S_{radio} users. As considered in system model let N=4 be the number of P_{radio} users. Goodput for different values of interference tolerance (I =0 and I=2) and sensing radius (R_s=0.5, R_s=1, R_s=2) were captured as shown in figure 12(a) and 12(b).

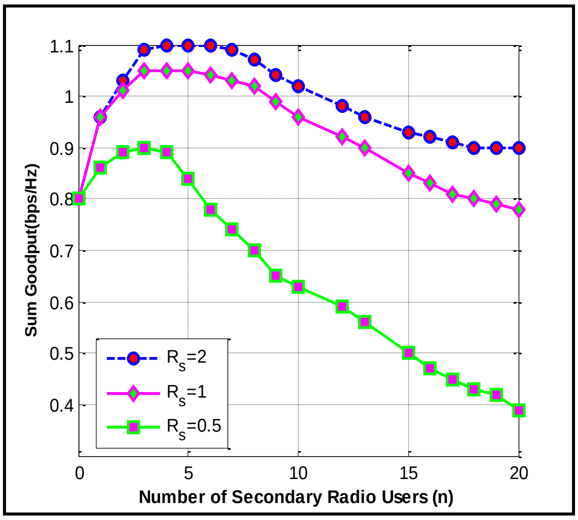

Fig. 12. (a). Sum Goodput V$_s$ N$_o$. of secondary radio users for varying R^S and I=0.

From the results in figure 12(a), it is observed that with increasing number of S$_{radio}$ users when sensing radius decreases (R_s =0.5) under a zero interference tolerance (I=0), even a small amount of interference causes S$_{radio}$ users to collide with P$_{radio}$ users. The goodput – amount of data successfully delivered to the sink is high when sensing radius increases (ie., when R_s =2).

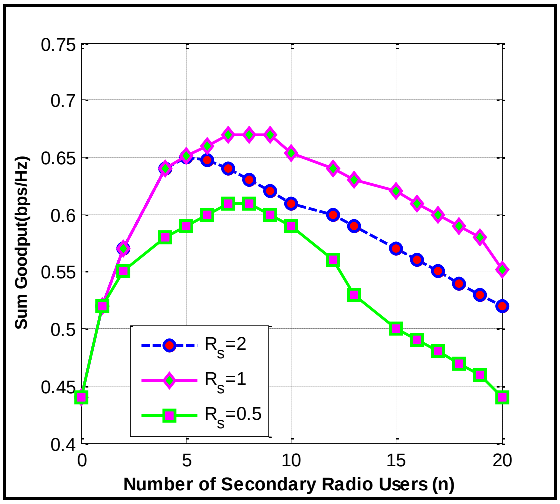

Fig. 12. (b). Sum Goodput Vs No. of secondary radio users for varying RS and I=2

It is also observed that optimal amount of goodput is achieved when S$_{radio}$ users are less (between 3 to 5) as referred in figure 12(b). Most of the primary users are detected even with a moderate sensing radius ($R_s > 1$). Each S$_{radio}$ user accounts to sufficient interference to the P$_{radio}$ user resulting in a decrease in goodput. Though the goodput is low when sensing radius is small (R_s =0.5) but its observed that he sum goodput difference between the $R_s = 1$ and R$_{s\,=}$ 2 is not very large. Figure 12(b) indicates results observed for increase in S$_{radio}$ users while I=2 (radio interference environment) and varying R_s. From the results its observed that sum goodput is low in interference constrained environment compared to I=0. Successful data delivery is higher when S$_{radio}$ users are between 6 to 8. Optimal sensing radius in an interference contrained environment is found to R$_s$=1 that achieves higher goodput compared to zero interference toleralnce setup where the optimal R_s =2. Higher goodput ranging between 0.65 bps/Hz to 0.7 bps/Hz is achieved provinding opprotunities for more S$_{radio}$ users for channel utilization. This indicates that even in the presence of interference, using the FIS mechanism, S$_{radio}$ users make use of the P$_{radio}$ links to transmit more violently to achieve better goodput. The effectiveness of FIS-CoRHAN approach improves channel utilization accommodating more S$_{radio}$ users to achieve higher goodput both in zero interference tolerance and interference constrained environment. The combination of OCA and Interference Mitigated Channel Allocation using Fuzzy Inference System increases successful data transmission in a FIS-CoRHAN network.

IV. CONCLUSION

By introducing Fuzzy Inference based analytics in CoRHAN network, we have shown that reliability and timeliness in data transmission is improved. Employing combined effort of opportunistic channel analysis and interference mitigated channel allocation approach helps not only in resolving prediction errors caused due to interference but also adapt to the environment dynamics providing new opportunities to use the spectrum more intensively by both P$_{radio}$ and S$_{radio}$ users. The absence of machine learning technique in our earlier work (CoRHAN) had a rude assumption of having less neighborhood interference channels. Fuzzy based interference mitigation technique has proven to be more accurate in helping decision based channel switching compared to table driven conventional interference mitigation methodologies. How so we have proven that FIS based computing is faster and supirior thus consuming less energy in CoRHAN. Our future works would involve introducing noisy channel environment and considering semi mobility of certain metwork nodes like smart collectors etc.

REFERENCES

1. T. Shanthi and V. Krishnamurthi, “Minimal Spanning Tree Technique for Efficient Spectrum Sensing and Optimal Radio Selection Scheme in Cognitive Radio based Wireless Sensor Heterogeneous Area Network (CoRHAN)”, International Journal of Applied Engineering Research, , Volume 10, Number 16 (2015) pp 37055-37063
2. Ghasemi and Sousa, “Fundamental limits of spectrum-sharing in fading environments”, IEEE Trans. Wireless Commun., 2007, vol. 6, no. 2, pp. 649–658.
3. Zhang, Q., J. Jia, and J. Zhang, “Cooperative relay to improve diversity in cognitive radio networks”, IEEE Communication. Magazine, 2009, vol. 47, no. 2, pp. 111– 117.
4. Kannan Srinivasan, Maria A. Kazandjieva, Saatvik Agarwal, and Philip Levis, “The beta-factor: measuring wireless link burstiness”. In Proc. of the 6th Conference on Embedded Networked Sensor Systems (SenSys), pages 29–42, Raleigh, NC, USA, November 2008.
5. S. Ahmed, M. S. Hossain, M. Abdullah, and M. A. Hossain, “Cooperative spectrum sensing over Rayleigh fading channel in cognitive radio”, International Journal of Electronics and Computer Science Engineering 2012, 2583-2592.
6. J. W. Lee, “Cooperative spectrum sensing scheme over imperfect feedback channels”, IEEE Commun. Let., June 2013, pp. 1192–1195.
7. P. Kaligineedi and V. K. Bhargava, “Sensor allocation and quantization schemes for multi-band cognitive radio cooperative sensing system”, IEEE Transactions on Wireless Communuications, 2011, 284-293.
8. H. Sun, A. Nallanathan, J. Jiang, D. Laureson, C. Wang, and H. Poor, “A novel wideband spectrum sensing system for distributed cognitive radio networks”, Proc. IEEE Globecom’11, Houston, TX, USA, pp.1-6, Dec. 2011.

9. LIU Xin, ZHONG Wei-zhi, YE Liang, LI Qing-zhong, “Joint optimal sensing time and number of cooperative users in OR-rule cooperative spectrum sensing”, International Conference on Wireless Communications & Signal Processing. Hangzhou, China: IEEE, 2014.
10. R. Fan and H. Jiang, “Optimal Multi-Channel Cooperative Sensing in Cognitive Radio Networks”, IEEE Transactions on Wireless Commununications, 2010, 1128-1138.
11. X. Zhang and H. Su, “Opportunistic spectrum sharing schemes for CDMA-based uplink MAC in cognitive radio networks”, IEEE J. Sel. Areas Commun., April 2011 vol. 29, no. 4, pp. 716-730.
12. H. Sun, A. Nallanathan, C. Wang and Y. Chen, “Wideband spectrum sensing for cognitive radio networks: a survey”, IEEE Wireless Communications, 2013, 20(2).
13. S. Maleki, S. P. Chepuri, and G. Leus, “Optimization of hard fusion based spectrum sensing for energy-constrained cognitive radio networks”, Physical Communication, Dec. 2013, vol. 9, pp. 193–198.
14. Loukas Lazos, Sisi Liu, and Marwan Krunz, Spectrum Opportunity-Based Control Channel Assignment in Cognitive Radio Networks, Dept. of Electrical and Computer Engineering, University of Arizona Email: {llazos, sisimm, krunz}@ece.arizona.edu.
15. L. T. Tan and L. B. Le, Channel assignment with access contention resolution for cognitive radio networks, IEEE Transactions Vehicular Technology, July 2012, 2808–2823.

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