QoS-based Channel and Radio Assignment Algorithm for Mesh Cognitive Radio Networks intended for HealthCare

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Abstract*— Smart homes monitoring for patient healthcare is an emerging research area. Monitoring smart homes locally at large scale requires a lot of infrastructure deployment which is not a cost effective solution. Thus the recent advancement in the cloud computing and introduction of cognitive radio's provides a new direction to the smart homes monitoring. Thus in future all the data monitoring and analysis at large scale will be on cloud using cognitive radios. Cognitive radios utilize radio spectrum opportunistically without purchasing their license. Therefore, efficient routing and quality of service based channel selection and radio assignment are most challenging issues in the deployment of this technology for remote smart homes monitoring. In this paper, we proposed a novel channel selection and radio assignment scheme for multi-radio multi-channel multi-hop mesh cognitive networks with the objectives of minimizing overall network interference and minimum interference with the primary users. Channel and radio assignment in such networks is a NP-hard problem. Therefore, integer linear programming model is presented and heuristic solution for susceptibility and capacity aware channel selection and radio assignment is proposed. Furthermore, collaborative channel utilization and local healing Scheme is also presented. Our proposed algorithms maintain highly quality of service based stable routes with the overall reduction of network interference.

Keywords- Multipath routing; Susceptibility and capacity aware channel assignment; Multi-hop mesh cognitive networks; local healing

I. INTRODUCTION

In medical applications collecting patient's related information's are crucial for taking timely treatments and providing other emergency services. In the last few years patient health care has been improved using Smart Homes Monitoring Systems (SHMS). In SHMS the patient related information's are exchanged using modern telecommunication technologies which enable the medical and emergency teams to take timely decision to save the patient's lives [1]. In the past few years, Wireless Mesh Networks (WMN's) turn into a very prominent form of networking and being used for providing many interesting services such as multicast video delivery, content sharing and sensor network backhaul [2]. Moreover, many patients' monitoring and healthcare applications are also relay on this form of networking due to amazing characteristics such as self organization, self haling and self management. WMN has a lot of advantages like large coverage area, low operation and deployment cost and improved reliability and robustness [3] this idea was first introduced by a Victor Pierobon in 1995 [4]. Figure 1 shows SHM using multi-hop mesh cognitive networks.

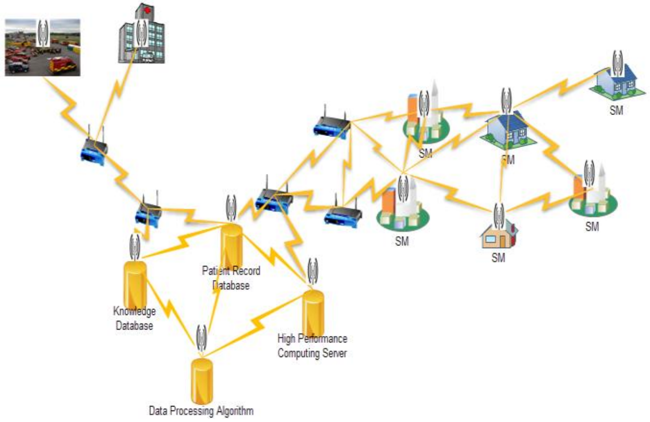

Figure 1. Multi-hop Mesh Cognitive Networking of SM's.

Cognitive Radio (CR) introduced by Joseph Mitola III in 1999 to improve the utilization of radio spectrum is evolves as future networking technology [5]. Recent measurements show that around 70% to 80% of assigned spectrum is being wasted in U.S [6]. Mesh nodes equipped with multiple cognitive radios can be viewed as a novel approach for improving the bandwidth scarcity of mesh networks by efficiently utilizing the white spaces and performing concurrent transmission [7]. Currently, cognitive radios equipped mesh networking is being considered for critical and Quality of Service (QoS) demanding health care applications, where stability of communication paths and reliability of contents delivery are major concern as well these are most critical issues in Cognitive Radio Networks (CRN's).

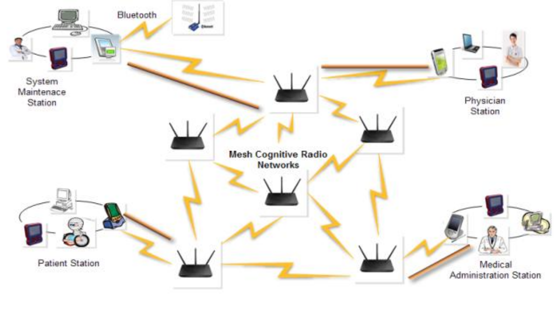

Figure 2. Use of Mesh Cognitive in HealthCare Applications.

Figure 2 shows another use of cognitive mesh networking for patient health care and medical applications. Figure 3 show the importance of channel and radio assignment for healthcare and remote monitoring applications. All such applications required routing for exchange of information therefore, connected, stable and interference free routes are being demanded. All these can be achieved by efficient channel and radio assignment.

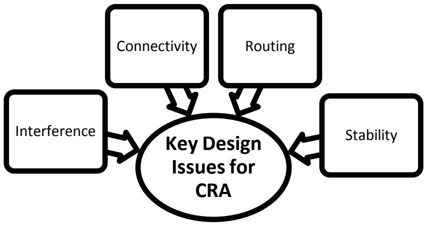

Figure 3. Significance of Channel Assignment.

To the best of our knowledge, available routing proposals for the Mesh Cognitive Radio Networks (MCRNs) select free available channels without considering their susceptibility as well as radios are being selected without proper analysis of their workload. Therefore, an efficient channel and radio assignment mechanism is still an open issue to increase the overall network performance. In this paper, we have presented a new metric that considered the best availability of channel before selection as well as we also considered the utilization of available radio's before their assignment.

The organization of the rest of the paper is as follows: In Section 2, we have presented the current state-of-the-art and our motivation. In section 3, we have presented problem statement, assumptions and system model. In section 4, we have shown derivation and calculation of our selected parameters. In section 5, we presented the Integer Linear Programming (ILP) modeling of channel and radio assignment and our proposed algorithm is presented in section 6. Conclusion and future work are discussed in section 7.

II. LITERATURE REVIEW

Multi-radio MCRN's are more powerful and flexible than Single-radio CRN. Therefore, algorithms designing for Multi-radio MCRN's are substantially more challenging than that for ordinary Single-radio CRN.

Ramachandran et al. [8] calculated interference estimation based on the packet capturing and based on that scheme they purposed channel assignment for mesh networks. Dai et al. [9] presented a channel assignment algorithm for CRN based on SINR. The channel is selected based on the SINR values and then assigned to the communicating nodes. Junior et al. in [10] presented a common control channel based distributed channel assignment algorithm for single radio cognitive networks. Kim et al. in [2] Proposed Urban-X a channel assignment for MCRN operating is ISM band. They use primary node activities and workload as important parameters in their algorithm. Wang et al. in [11] proposed a new multipath routing and spectrum access (MRSA) framework for multi-radio mesh networks assuming cognitive radio (CR) environments. The proposed framework seeks to establish multiple paths that maximize "spectrum wise" disjointedness to minimize contention and interference among links.

It is clear from the current state-of-the-art that the mostly algorithms are focusing on reducing the interferences with the primary user and other co-located users which is the primary objective of the CRN but none of them considering the reliability and stability of available channel set which is primary need of critical applications such as healthcare. Per packet channel switching degrades overall network performance as well as causes long delays in communication which is not affordable in such crucial and QoS demanding applications [12]. Our algorithm mainly focuses on reliability of available and capacity of available channels as well as we considered the workload of available radios.

III. PROBLEM STATEMENT

The channel assignment problem for Multi-hop Multi-radio Mesh Cognitive Networks (M^3CN's) is described as follows: Given a M^3CN with each mesh node equipped with multiple cognitive radios and each node has an option of selecting multiple licensed channels for its communication. The objective of our channel and radio assignment scheme is to select best channels and radios those meets the QoS demand of critical applications for each flow with minimum inter and intra flow interference as well as minimum interference with the primary users. To achieve this objective, we proposed susceptibility and capacity aware channel and radio assignment scheme.

A. Assumptions

Following are assumptions of our system:

- Common Control Channel (CCC) is available for sharing network information's.
- Each cognitive node has the capability of sensing and determining the arrivals and utilization time of licensed channels.

B. Network Model

We are considering that our MCRN is operating under the heterogeneous licensed channels where each node is equipped with multiple cognitive radios. We modeled our network using undirected graph $G = (V, E)$where $V = \{v_1, v_2, \dots . v_n\}$ is set of cognitive nodes and $E = \{e_1, e_2 \dots e_n\}$is set of vertices. $I = \{i_1, i_2, \dots . i_n\}$ is a set of global available channels and each node have a subset of this global set. $Pr = \{Pr_1, Pr_2, \dots . Pr_n\}$ is a global set of primary nodes operating on licensed channels and any subset of this set is operating in any particular vicinity. Each mesh node is equipped with R radios $R = \{R_1, R_2, \dots . R_k\}$ is set of available cognitive radios.

IV. PARAMETERS DERIVATION AND CALCULATION

Our channel and radio assignment algorithm is mainly based on two important parameters known as susceptibility and capacity. These two parameters show characteristics of communication channels in term of reliability of available channels and amount/speed of data delivery over the channels.

A. *Susceptibility*

Means that how much a channel changes due to the cause of some force or some parameter changing's. In CRN primary user is one of the parameter that's causes the change in licensed channel availability. As we are concentrating on rate of change of channel due to primary user arrivals therefore we will select a channel with less susceptibility value for successful transmission over a stable path to maximize the network performance.

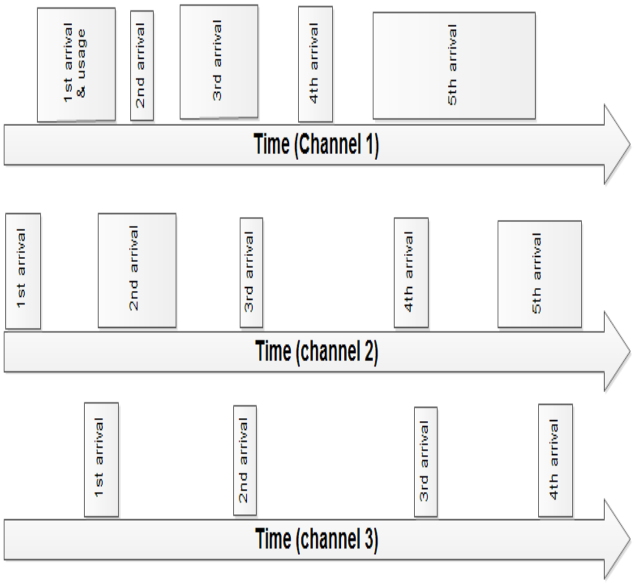

Figure 4. Primary user activity.

In the above Fig 4 **A_1**, **A_2**, **A_3**.... **A_n** are the arrivals of primary user on any licensed channel. We are considering a scenario in which no of primary user arrivals as well as utilization time during each arrival is random. First we calculate the total utilization of any licensed channel by its primary user. This calculation is based on following values:

1- Total scanning time of a channel
2- Total number of arrivals
3- Total utilization time during each arrival.

$$CU = \frac{A_1+A_2+A_3+\ldots\ldots+A_n}{total\ scanning\ time\ of\ a\ channel} \times 100 \qquad (1)$$

Where CU is average Channel Utilization. Above equation (1) gives us the total utilization of a channel, our objective is to find the susceptibility on the basics of channel utilization. Then we will tag each channel based on its susceptibility value and select a most reliable and durable channel from the poll of available channels.

$$Channel\ Susceptibility = \frac{TF\ time\ of\ a\ channel \times 100}{(TU\ time\ of\ channel \times TNA) + TF\ time\ of\ channel} \quad (2)$$

Where ***TF*** is Total Free, ***TU*** is Total Usage and ***TNA*** is Total Number of Arrivals.

B. *Example Calculations*

$\frac{70*100}{30*10+70} = 18.91$ when 10 No. of arrivals, and free space 70%

$\frac{50*100}{50*15+50} = 6.25$ when 15 No. of arrivals and free space 50%

$\frac{80*100}{20*4+80} = 50$ when 4 No. of arrivals and free space 80%

So, each node maintains a pool of free available channels with susceptibility tag. Thus pool of free available channel looks like as follows:

TABLE 1. SUSCEPTIBILITY POOL.

Available Channels	Susceptibility Value
C_1	18.91
C_2	6.25
C_3	50

C. *Channel capacity*

Channel capacity is one of the primary criteria for QoS demanding applications where channel over the selected path ensures this demand [13]. CRN's are heterogeneous in term of channels availability as well as in term of bandwidths. Therefore we are interested to select a channel which is better both in term of susceptibility as well as capacity to fulfill the requirement of applications. The effective capacity of any channel is calculated as follows:

$$\boldsymbol{C^{i}_{v_i\, v_j} = W_i log_2\left(1 + \frac{P_w}{N_0 W_i} \times d^{-\tau}_{v_i,v_j}\right)} \qquad (3)$$

$\boldsymbol{C^{i}_{v_i\, v_j}}$ is capacity of channel i between two $nodes\ v_i and\ v_j$, $\boldsymbol{W_i}$ is bandwidth of channel i N_o is power spectral density of noise and $\boldsymbol{d^{-\tau}_{v_i,v_j}}$ is distance between node $\boldsymbol{v_i}$ and $\boldsymbol{v_j}$ with Transmission power $\boldsymbol{P_w}$ and $\boldsymbol{\tau}$ is path fading parameter. Using equation (3) each node calculates the effective capacity on all available channels and further channels are tagged with their effective capacity values. Thus, after associating capacity value against each available channel, our table looks as follows:

TABLE 2. SUSCEPTIBILITY AND CAPACITY.

Available Channels	Susceptibility Value	Capacity (Mbps)
C_1	18.91	2
C_2	6.25	11
C_3	50	5.5

D. *Radio Usage information*

We are considering Mesh Cognitive Nodes (MCN's) equipped with multiple radios. As each node is working as router therefore, it's being used for passing many other flows/traffic other than its own traffic. Selecting if radio on any MCN node count a lot as per packet switching of radio causes overall network performance degradation as well causes long delays. Thus for efficient radio utilization and to improve overall network performance each node must add its radio usage information's with the susceptibility and capacity table and use this information for assigning radio for any new flow. Furthermore, operating multiple radios over the same channel cause intra radios interference. Thus our table approach will help to avoid this intra radio interference. After adding radio usage information the table looks like as follows:

TABLE 3. RADIO INFORMATION TABLE (RIT).

Available Radios	Status	Tuned on Channel	Used among No. of Flows
R_1	Idle		0
R_2	Busy	C_1	2
R_3	Idle		0
R_4	Busy	C_3	3

We merge all necessary information's into a single table called Channel Susceptibility Capacity and Radio Information Table (CR^{2}IT). We will use this CR^{2}IT table in our SCACRA algorithm. Thus after adding inheriting some use full information from RIT table, CR^{2}IT looks like as follows:

TABLE 4. CHANNEL SUSCEPTIBILITY CAPACITY RADIO INFORMATION TABLE.

Channel	Susceptibility	Capacity	Radio Usage	Used among No. of Flows
C_1	18.91	2	R_2	2
C_2	6.25	11		0
C_3	50	5.5	R_4	3
C_4	8.91	20		0
C_5	40.12	55		0
C_6	12.40	11		0

V. ILP FORMULATION

In this section, we formulate the Integer Linear Programming (ILP) modeling of radio and channel selection problem. Presented ILP model will help to obtain the optimal results of our said problem. Consider an undirected graph $G = (V, E)$ where $V = \{v_1, v_2, \dots . v_n\}$ is set of cognitive radio node and $E = \{e_1, e_2 \dots e_n\}$ is set of vertices $I = \{i_1, i_2, \dots . i_n\}$ is set of global licensed channels and each cognitive node have subset of this global channel set. C_i is capacity of each channel i. $F_{e_j} is$ flow demand passing on link e_j where e_j is link between two cognitive nodes v_i, v_j operating on channel i. $I' = \{I'_1, I'_2, \dots I'_n\}$ is set of interfering cognitive nodes on channel i. each cognitive node is equipped with multiple radios $R = \{R_1, R_2, \dots . R_k\}$ is set of available radios. $Pr = \{Pr_1, Pr_2, \dots . Pr_n\}$ is set of primary nodes operating in the vicinity of CMN.

A. *Decision variables*

$$I_{i,v_j}^{Pr} = \begin{cases} \mathbf{1}\ if\ node\ v_j select\ channel\ i\ and\ no\ primary \\ \quad user\ pr\ operating\ on\ it\ in\ its\ vicinity \\ \mathbf{0} \qquad\qquad otherwise \end{cases}$$

$$R_{e_j}^{r_k} = \begin{cases} \mathbf{1}\ \ if\ radio\ r_k\ is\ assigned\ to\ link\ e_j\ on\ i \\ \\ \mathbf{0} \qquad\qquad otherwise \end{cases}$$

$$X_{e_j}^{i,r_k} = \begin{cases} \mathbf{1}\ \ if\ channel\ i\ is\ assigned\ to\ link\ e_j\ on\ r_k \\ \\ \mathbf{0} \qquad\qquad otherwise \end{cases}$$

B. *Objective Function*

$$Max\ \ Z = \sum_{i=1}^{n} . \sum_{e_j \in E}^{1} \sum_{R_k \in E} (F_{e_j} * X_{e_j}^{i,r_k}) * I_{i,v_j}^{Pr} \qquad (4)$$

Subject to the following Constraints:

C. *Channel availibility Constraint*

$$\sum_{\forall pr_l \in P_r} X_{pr_l}^{i,r_p} = 0 \qquad (5)$$

Channel is free only when no primary node operating on it.

D. *Inter and Intra node Interference Constraint*

$$X_{e_j}^{i,r_k} + \sum_{\forall e_k \in I'} X_{e_k}^{i,r_k} \leq 1 \qquad (6)$$

At most one mesh cognitive node can operate on free channel from all interfering nodes.

E. Intra flow/radio Interference Constraint

$$X_{e_j}^{i,r_k} + \sum_{\forall r_l \in R} X_{e_k}^{i,r_l} \leq 1 \qquad (7)$$

At any mesh cognitive node at most one radio can operate on any channel at a time.

F. Radio Interfaces Constraint

$$\sum_{\forall r_l \in R} X_{v_i}^{i,r_l} \leq \mathrm{R}_{\mathrm{v_i}} \qquad (8)$$

$$\forall\ \mathrm{v_i} \in V$$

$$where\ \mathrm{R}_{\mathrm{v_i}} \text{ are available radios on node } \mathrm{v_i}$$

Any cognitive node cannot use more than the available interfaces.

G. Channel Constraint

$$\sum_{\forall v_i \in V} X_{v_i}^{i,r_l} \leq \mathrm{I}_{\mathrm{v_i}} \qquad (9)$$

$$\forall\ \mathrm{v_i} \in V\ \&$$
$$\forall\ \mathrm{R}_{\mathrm{v_i}} \in R$$

$$where\ \mathrm{I}_{\mathrm{v_i}} \text{ are available radios on node } \mathrm{v_i}$$

Any mesh cognitive node cannot use more than the available channels or vice vera a channel cannot be assigned if it is not available.

H. Channel Capacity Constraint

$$\mathrm{F}_{\mathrm{e_j}} * \mathrm{X}_{\mathrm{e_j}}^{\mathrm{i,r_k}} \leq \mathrm{C_i} \qquad (10)$$

$$\forall\ \mathrm{v_i} \in V\ \&\ \forall\ \mathrm{i} \in I$$

Mesh cognitive node cannot transmit traffic/flow demand more than the available capacity of the channel.

I. Flow preservation Constraint

$$\sum_{\forall \mathrm{v_i} \epsilon \mathrm{V}} \mathrm{F}_{\mathrm{v_i,v_j}} * \mathrm{X}_{\mathrm{v_i,v_j}}^{\mathrm{i,r_k}} = \mathrm{F}_{\mathrm{v_j,v_k}} * \mathrm{X}_{\mathrm{v_j,v_k}}^{\mathrm{i,r_k}} \qquad (11)$$

$$\forall\ \mathrm{v_i} \in V\ except\ source\ and\ destination\ nodes$$

Each mesh cognitive node must pass the amount of traffic it receives.

J. End to End Flow preservation Constraint

$$\mathrm{F}_{\mathrm{S_i}} * \mathrm{X}_{\mathrm{e_j}}^{\mathrm{i,r_k}} = \mathrm{F}_{\mathrm{D_i}} * \mathrm{X}_{\mathrm{e_j}}^{\mathrm{i,r_k}} \qquad (12)$$
$$\forall\ \mathrm{F}\ \&\ \forall\ S_i\ and\ D_i$$

$S_i\ and\ D_i$ are source and destination nodes respectively

Amount of data at destination mesh node must be equal the amount of data send by source node.

K. Non Negativity Constraint

$$I_{i,v_j}^{Pr} \geq 0, R_{e_j}^{r_k} \geq 0\ and\ X_{e_j}^{i,r_k} \geq 0 \qquad (13)$$

VI. PROPOSED ALGORITHM

In this section, we presented our proposed heuristic algorithm that select best options of channels and radios along a selected path. We are assuming best paths are selected based on any criteria like minimum hop count etc.$Path = \{v_1, v_2, \dots . v_3\}$ is a set of selected intermediate mesh cognitive nodes. Before presenting radio and channel selection algorithm we first present collaborative channel utilization and Local healing algorithm for mesh cognitive nodes.

A. Collaborative Channel Utilization and Local Healing Scheme (CCULHS) for Mesh Cognitive Nodes

1. All nodes share their CR^{2}IT information's on Common Control Channel (CCC) with its 1-Hop neighbors periodically or triggered this event when there are some updates in its local CR^{2}IT.
2. Each node update its table after receiving CR^{2}IT information's from its 1-Hop neighbors and mark those channel unavailable which are already being used by its 1-Hop neighbor.
3. Each node mark the channel unavailable as primary user is detected on the channel and unicast the new table information with its communicating nodes over CCC.
4. Each effected node selects some other suitable channel locally based on CR^{2}IT information.
5. Transmeter node tune its Tx on newly selected channel and inform the receiving node about this newly selected channel on CCC.
6. Receving node also tune its Rx and Tx radios accordingly and update its CR^{2}IT.

C is a set of common channels for path that are used by neither primary node nor any 1-hop MCN. But channels can be already tuned on some other radio on the same MCN. In the following algorithm, we discussed major cases of channel and radios selection and assignment and further sub cases will be considered in the detail while implementing the algorithm. If radio is not idle then tuning already our new channel cause more delay therefore we are giving priority to the channel which is already tuned and we are considering fair scheduling in our algorithm.

B. Susceptibility and Capacity Aware Channel and Radio Assignment (SCACRA) Algorithm

```
While (Path! =Null) {
   For each (channel available on all nodes)
      Compute C on path
      While ([vi,vj] ϵ Path) {
         Case 1: both radios and channels are idle {
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```
6.          If (Rvi = idle && Rvj = idle) {
7.      //Selecting best channel for pair of radios
8.              Compute free channel with less
                Susceptibility and high Bandwidth
9.            OR
10.             Compute free channel with less
                Susceptibility and good Bandwidth
11.           OR
12.             Compute free channel with average
                Susceptibility and High Bandwidth
13.           OR
14.             Compute free channel with average
                Susceptibility and Average Bandwidth
15.           } end if
16.         } end Case1:
17.       Case 2: One radio and one channel is idle {
18.             If ((Rvi = idle && Rvj ≠ idle) || (Rvi
                    ≠ idle   && Rvj =idle)) {
19.                 Repeat step 11 to 17
20.           OR
21.             Compute used channel with less usage
                Ratio, less Susceptibility and good
                Bandwidth and select that already
                Tuned radio as no idle radio
22.           OR
23.             Compute used channel with average
                Usage ratio, average Susceptibility and
                average bandwidth and select that already
                tuned radio as non idle radio
24.           } end if
25.         } end Case2:
26.       Case 3: Both radio and channels are not idle{
27.         If (Rvi ≠ idle && Rvj ≠ idle) {
28.             Repeat step 11 to 17
29.             OR
30.                 Compute used channels and radios with
                    less usage ratio, less- Susceptibility and
                    good bandwidth and select these
                    channels and radios
31.               OR
32.                 Compute used channels and radios with
                    average usage ratio, average
                    Susceptibility average good bandwidth
                    and select these channels and radios
33.           } end if
34.         } end Case2:
35.       } End While
36.     } End For
37.   } end while
```

VII. CONCLUSION AND FUTURE WORK

We proposed a novel susceptibility and capacity aware channel and radio assignment algorithms for MCRN's indented for QoS based traffics like multimedia traffic for healthcare. Susceptibility plays a vital role in reliable channel assignment while capacity ensures the QoS need of, QoS demanding applications. In our future work, we will study the detail analysis of our proposed algorithm with optimal solution which can be obtained from our presented ILP and with some other available algorithms.

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