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Maximizing Minimum Transmission Rate in Spectrum Sharing by Implementing Multi-Relay in Cognitive Radio Networks

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ABSTRACT

Cognitive Radio Networks(CRN) is a type of wireless transmission in which automatically detects available channels in wireless spectrum, then accordingly changes its transmission and reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. In cognitive radio, the main challenge after detecting the available spectrum is to access or share the spectrum among the secondary users within the network. The function of spectrum sharing is to distribute the spectrum among the secondary users to access the available channel. The existing techniques used in sharing the spectrum among the unlicensed users is wireless mesh node network and cross layer design (CLD). The mesh nodes are utilized to determine the available spectrum resources. However, this topology is very difficult to maintain and overall network cost is too high. The proposed method utilizes relays for sharing the spectrum and to maximize the minimum transmission rate to the secondary users. It is achieved by getting spectrum sensing information from primary base station when the secondary users get crowded in the network. In order to avoid congestion and delay in sharing spectrum among SUs, relays are implemented for easy access of spectrum. Simulations are carried out for heavy, medium and low traffic condition with implementing different relays in the CR network. From the simulation results, it is observed that implementing more relays with heavy traffic condition provides fair sum-rate in the CR network although multiple relays in low traffic condition produce average sum-rate which is similar to the sumrate produced by SBS without implementing relays. Hence multiple relays in CR network provide fair sum-rate when CR network is in high traffic condition. Further, the proposed MR technique increases the max-min rate of the DT by 8% and 12% when the relay node is 8 and 10 respectively. Simulation results for sum-rate in different traffic condition with different relays are illustrated in detail in this paper.

INTRODUCTION

Cognitive Radio is a promising technology that offers an efficient way to improve utilization of available channel resources by prescribing the coexistence of licensed and un-licensed radio nodes on the same bandwidth. By using this technique, the performance of wireless network can be improved and satisfies the demands of future wireless applications. It has a wider area includes spectrum sensing, spectrum sharing, spectrum mobility and spectrum management. In spectrum sharing, partial relay selection was lately proposed in (Song, L., 2011) and it implemented with pratical ad-hoc and sensor networks. In this method, relays are placed close to each other so that long-term routing process is required for relay selection. Thus, more number of relays are utilized to implement this process and hence overall cost is high. To reduce the cost of relay and to obtain high performance, dual-hop fixed-gain relaying scenarios is proposed in (Costa, D.B. and S. Assia, 2009). The

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dual-hop cooperative networks with partial relay selection in spectrum-sharing systems uses only two relays and the required instantaneous feedback from a large number of relays is not necessary.

In Cognitive Radio Networks, Wireless mesh network (WMN) is utilized for sharing spectrum resources more efficiently. Hence, it has better network capacity drastically. In multi-hop path, available spectrum bands may be different at each node because spectrum occupancy is location dependent. Hence, several routing and spectrum allocation algorithm has been investigated in the literature. In (Wang, Q. and H. Zheng, 2006), Dynamic Source Routing (DSR) for path selection and it selects the route with maximum throughput and schedules a collision-free channel for this route. The work in (Shih, C.-F., *et al*., 2011) introduces the robustness of the route for path selection in multi-hop cognitive radio networks. The route robustness approach in (Shih, C.-F., *et al*., 2011) guaranteed only a basic level of robustness for a set of routes. The Routing and Spectrum Allocation algorithm (ROSA) is proposed in (Ding, L., 2009) focused only on maximal throughput and the robustness of the routes is not guaranteed. The target of (Hou, Y.T., *et al*., 2007) was developed a novel sequential fixing algorithm to the cross-layer optimization problem. But delay will be more in sequential fixing algorithm. A centralized and a distributed protocol for spectrum allocation is proposed in (Yuan, Y., *et al*., 2009). Frequent reallocation of time spectrum blocks takes place in (Yuan, Y., *et al*., 2009), which is inefficient due to consume more time. In (Amr A. El-Sherif and Amr Mohamed, 2014), the cross-layer joint design of routing and resource allocation protocols in cognitive radio based WMNs is discussed. In our system model, we consider a CR network which is implemented with different relays in different traffic conditions.

Paper Organization:

The rest of the paper is organized as follows. System model and algorithm is discussed in Section II. Section III discuss about simulation results and conclusion is illustrated in Section IV.

System Model And Algorithm:

A. System Model:

In this work, we study the minimum transmission rate in of SUs in a CRN. In direct transmission(DT), source s_i transmits data to its destination in both time slots and the corresponding mutual information(I_{io}) in which γ_{sidi} is signal-to-noise ratio at d_i , h_{sidi} is effect of path loss, σ_{di}^2 is variance of noise at d_i and P_{si} is transmit signal power.

$$I_{io} = \log_2(\gamma_{sidi})$$

where $$\gamma_{sidi} = \frac{P_{si}|h_{sidi}|^2}{(\sigma_{di}^2)}$$

In channel allocation (RC), the relay assignment variable uij is represented as follows

$$u_{ij} = \begin{cases} 1 & \text{if relay } r_j \text{ is assigned to pair } (s_i, d_i) \\ 0 & \text{Otherwise} \end{cases}$$

$$\sum_{j=0}^{m} u_{ij} = 1, \ \forall i, 1 \leq i \leq n$$

To model the channel allocation, binary variables for source and relays are represented by

$$v_{ik} = \begin{cases} 1 & \text{if channel } b_k \text{ is allocated to pair } (s_i,d_i) \\ 0 & \text{Otherwise} \end{cases}$$

$$w_{jk} = \begin{cases} 1 & \text{if channel } b_k \text{ is allocated to relay } r_j \\ 0 & \text{Otherwise} \end{cases}$$

Moreover, a common channel should be allocated to the nodes in the same unicast session using direct transmission. Such a network configuration for DT can be represented by

$$u_{ij} + v_{ik} - 1 \leq w_{jk} \leq v_{ik} - u_{ij} + 1$$
$$\forall\, i, j, k, 1 \leq i \leq n, 1 \leq j \leq m, 1 \leq k \leq l$$

The transmission rate of source-destination pair on channel b_k with the help of relay r_j can be calculated as

$$C(s_i, b_k, r_j) \leq \frac{W_k I_{ij}}{|S(b_k)|}$$

Where $S(b_k)$ denotes the set of pairs allocated with same channel b_k.

In channel allocation with network coding(RCNC), the transmission rate s_i with the help of relay r_j on channel b_k can be calculated by

$$C^{NC}(s_i, r_j, b_k) \leq \frac{W_k I_{ij}^{NC} |S(r_j)|}{|S(b_k)|(|S(r_j)|+1)},$$

Where $S(r_j)$ denotes the set of pairs assigned a common relay node r_j. The mutual information I_{ij}^{NC} can be calculated by

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$$I_{ij}^{NC} = \log_2\left(1+\gamma_{s_i} d_i + \frac{\gamma_{s_i r_j}\gamma_{r_j} d_i}{\frac{\delta_{d_i}^2}{\sigma_{d_i}^2}\sum_{k=1}^{n} u_{kj} + \gamma_{r_j} d_i + \frac{\delta_{d_i}^2}{\sigma_d^2}\sum_{k=1}^{n}(u_{k_j}\gamma_{s_k} r_j)}\right)$$

$$\delta_{d_i}^2 = \sigma_{d_i}^2 + (\sum_{k=1}^{n} u_{kj}+1)(\alpha_{y_j} h_{r_j} d_i)^2 + \sum_{k\in[1,n]}^{k\neq i}\left[u_{kj}\sigma_{d_i}^2\left(\frac{\alpha_{r_j} h_{s_k r_j} h_{r_j d_i}}{h_{s_k d_i}}\right)^2\right]$$

Where α_{rj} is the amplification factor at relay r_j.

B. Network Model:

Consider a system model having two networks consists of M primary users and N Secondary Users. The primary users are represented by PU_1, PU_2, PU_3….. PU_M and secondary users are represented by SU_1, SU_2, SU_3 ….SU_N. Each network has its own primary base station (PBS) and secondary base station in which SBS has the information about the channel, which is idle within its network.

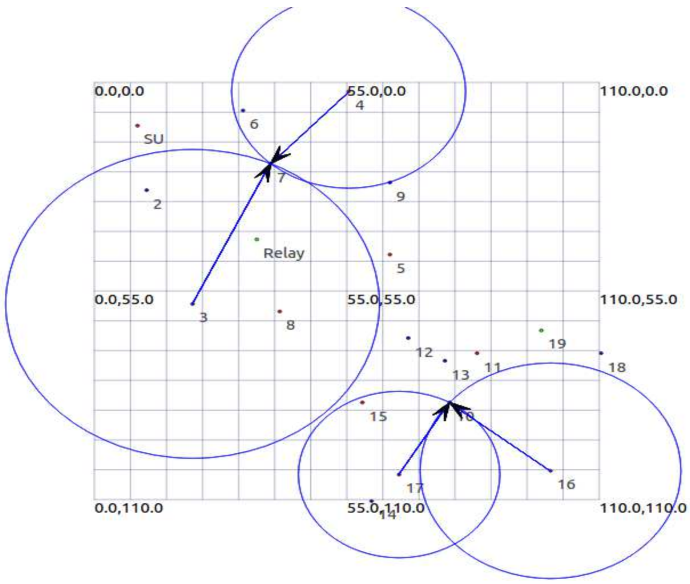

Fig. 1: Representation of CR Networks with transmission of Request from SU to SBS

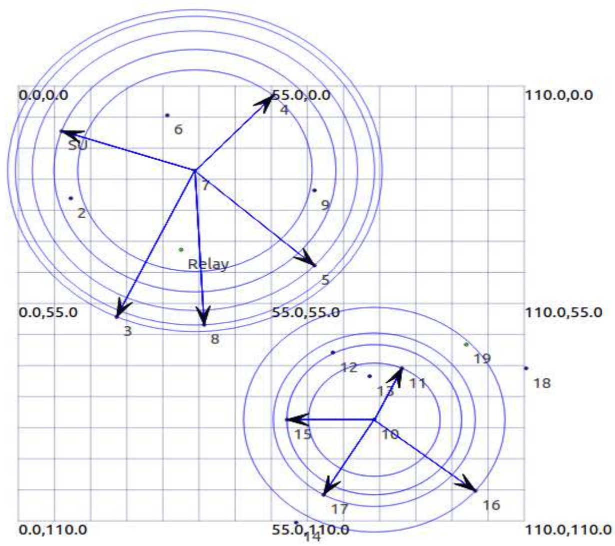

Fig. 2: Representation of CR Networks in which SBS acknowledge the SUs

In case of sensing the idle channel, SBS send request to the PBS to know about idle channel of the licensed user which in turn PBS acknowledges SBS with channel state information (CSI). The SUs request the neighboring SBS to access the unused licensed spectrum which is depicted in Fig.1. On receiving the channel state information, SBS access and distribute the channel to requesting CRs on request which is represented in Fig.2. Meantime, some of the SUs moved from the coverage area of SBS_1 to SBS_2 and in turn requesting SBS_2 for accessing unused licensed spectrum. If more number of SUs needs to utilize the spectrum of licensed user at certain time, then congestion occurs in the network. Due to congestion, there is difficulty in sharing the spectrum to all SUs by SBS_2 which is depicted in Fig.3. In this proposed method, relay will help SBS when more number of secondary users occupied in the network. Suppose the network is under heavy traffic, the SBS request the relay and it transmit information about the idle channel. The relay implemented in the network will acknowledge the SBS to share the spectrum among the secondary users based on channel condition.

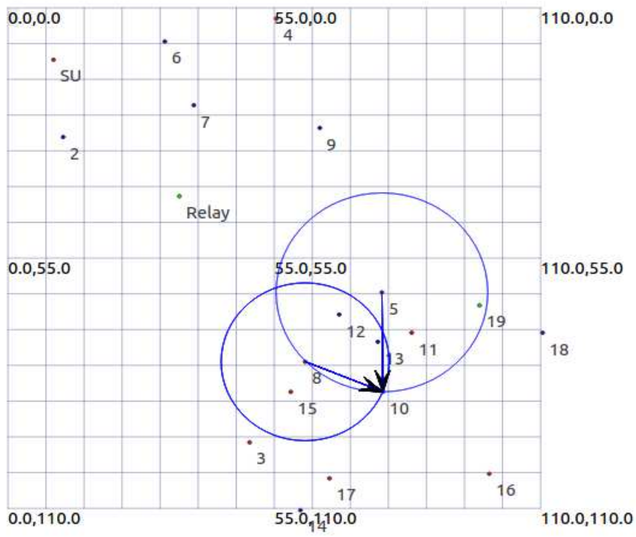

Fig. 3: Representation of CR Networks when SBS_2 crowded with more SUs

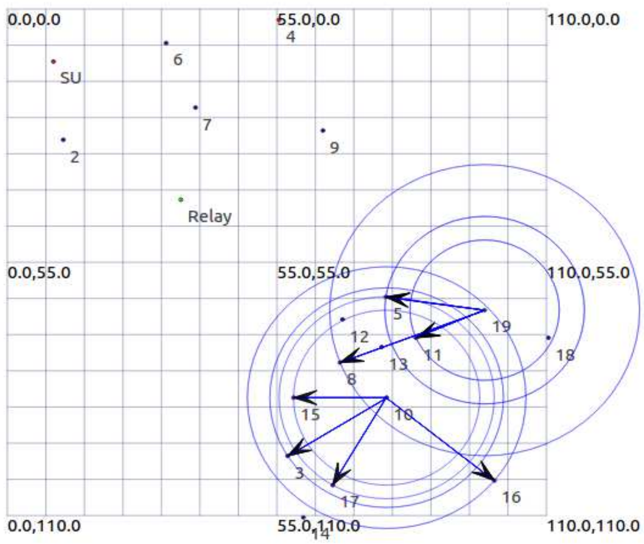

Fig. 4: Representation of sharing the spectrum with Relay

The main challenge is sharing the spectrum to the unlicensed users while they are in mobility. The relay and SBS together shares the spectrum of licensed user to the unlicensed users near by it. Hence, the relay will reduce the congestion in the network and delay of accessing the channel will be minimized and the relay acknowledges SBS on receiving channel state information. With channel state information, relays enables sharing of sensed idle channel with the help of channel state information from SBS_2 and it distribute to nearby SUs which in turn reduces the delay in accessing the channel and improves the sum-rate. Fig.4 represents the sharing of idle spectrum by SBS_2 with the help of relay implemented in CR networks.

C.Performance Metrics:

Consider a network having R relays, end users u_1 and u_2, s_1 and s_2 are the information system of u_1 and u_2. The j[th] relay are used to exchange the information symbol between two users. The noises from the two end users are represented as ω_1 and ω_2 respectively. The j[th] relay forwards the superposition of the signal and it is received by

$$\tilde{y}_{u1} = \sqrt{P}\sum_{j\in R}\alpha_j \left| f_j g_j \right| s_2 + \sum_{j\in R}\alpha_j f_j \tilde{v}_j + \omega_1 ,$$

$$\tilde{y}_{u2} = \sqrt{P}\sum_{j\in R}\alpha_j \left| f_j g_j \right| s_1 + \sum_{j\in R}\alpha_j f_j \tilde{v}_j + \omega_2$$

Where f_j and g_j be the fading coefficient of j[th] relay from u_1 and j[th] relay from u_2 and v_j and $\tilde{v}_j$ be the noises which have the same distribution.

$$\gamma_{u1}, R = \frac{P\left(\sum_{j\in R}\alpha_j \left| f_j g_j \right|\right)^2}{1+\sum_{j\in R}\alpha_j^2 \left| g_j \right|^2},$$

$$\gamma_{u2}, R = \frac{P\left(\sum_{j\in R}\alpha_j \left| f_j g_j \right|\right)^2}{1+\sum_{j\in R}\alpha_j^2 \left| g_j \right|^2},$$

For each users, power budget of the network is considered as P. When relay R is chosen, u_1 and u_2 in the network receives SNR_s as given by above equations. Let us assume Q_j be the power budget for j[th] relay. To control the relay power, power coefficient α_j is utilized in the system as follows

$$\alpha_j = \sqrt{\frac{Q_j}{1+P\left| f_j \right|^2 + P\left| g_j \right|^2}}$$

Assume that all channels in the networks are independent and identically distributed. The information can be communicated at highest rate is defined average sum-rate and it is represented as C. The average sum-rate for relay network can be defined as follows

$$C = \frac{1}{2}\mathrm{E}\left[\log_2\left(1+\gamma_{u1}, R\right)\right] + \frac{1}{2}\mathrm{E}\left[\log_2\left(1+\gamma_{u2}, R\right)\right]$$

For relay network, the average power efficiency is defined as follows:

$$\eta \overset{\Delta}{=} \mathrm{E}\left[\frac{\min\{\gamma_{u1}, R, \gamma_{u2}, R\}}{2P+\sum_{j\in R}Q_j}\right]$$

The above equation is represented as the average worse end-to-end SNR per unit power. In the network, two end user u_1 and u_2 get SNRs in j[th] relay based on single relay selection which is calculated as follows

$$\gamma_{u1,\{j\}} = \frac{PQ_j\left| f_j g_j \right|^2}{1+\left(P+Q_j\right)\left| f_j \right|^2 + P\left| g_j \right|^2},$$

$$\gamma_{u2,\{j\}} = \frac{PQ_j\left| f_j g_j \right|^2}{1+\left(P+Q_j\right)\left| f_j \right|^2 + P\left| g_j \right|^2},$$

D.Spectrum sharing algorithm:

In this scenario, we considered ‘M’ number of primary users PU_i, where i={1,2,3,……,M} and ‘N’ number of secondary users SU_j, where j={1,2,3,………,N}. Let PBS_i, where i={1,2} be the primary base station, SBS_j, where j={1,2} be the secondary base station and R_k, where k={1,2} be the Relay in the CR network.

The proposed sharing algorithm is explained as follows:

Step 1: Initialization of ‘N’ SUs by SBS_j and initialization of ‘M’ PUs by PBS_i.

Step 2: The SBS_j receives channel state information from PBS_i. The SU_j requests SBS_j to access the idle channel.

Step 3: If the network is not congested, SBS_j access channel to SUs.

Step 4: If the network gets crowded, then SBS_j send request to R_k with channel availability status.

Step 5: The R_k acknowledges SBS_j and R_k share the spectrum to SU_j.

Step 6: If the channel is available for all SU_j, R_k shares the spectrum.

Step 7: If the channel is not available for all SU_j, then R_k send requests to the nearest relay to access channel.

The flowchart of spectrum sharing algorithm is shown in Fig.7 and it is explained as follows. Initially SBS gets channel availability status from PBS in the CR network. Suppose, if any SBS crowded with more SUs, SBS send request to relay with channel status and in turn relay acknowledges SBS for sharing of spectrum. If the channel available for all the requested SUs, relay will access the licensed spectrum to particular users. Alternatively, for channel unavailability request must be sent another relay for accessing channel.

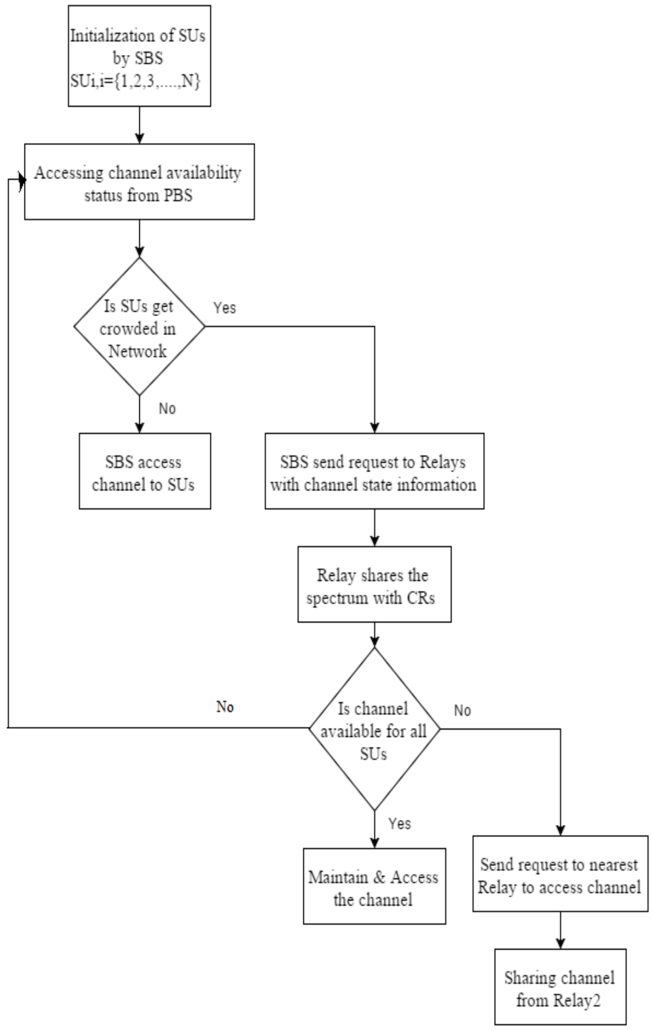

Fig. 7: Flowchart of proposed algorithm

Simulation results:

In this model, relays are implemented in cognitive radio network to achieve fair sum-rate over spectrum sharing among secondary users and to maximize the minimum transmission rate among multiple relays. Here, three conditions are illustrated such as heavy, medium and low traffic conditions. The performance metrics of cognitive radio networks by implementing multiple relays with different traffic conditions are discussed. The sum-rate curve for heavy traffic condition is shows in Fig.8 which implies that multiple relay implemented in the network improves the sumrate. The sumrate curve for medium and low traffic condition is illustrated in Fig.9 and Fig.10 respectively.

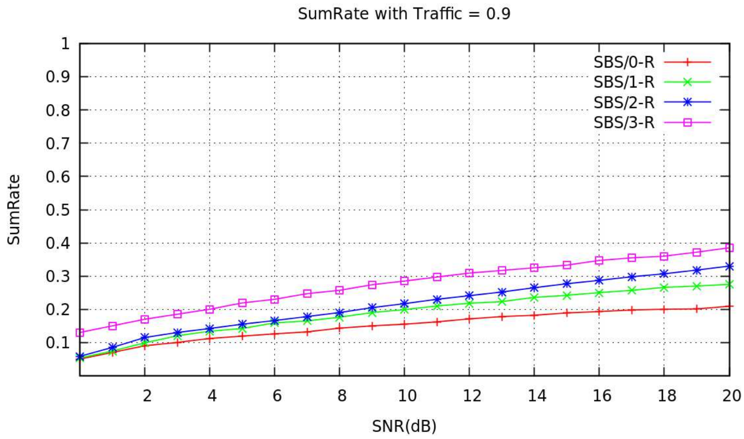

Fig. 8: Sum-rate of CR network with heavy traffic

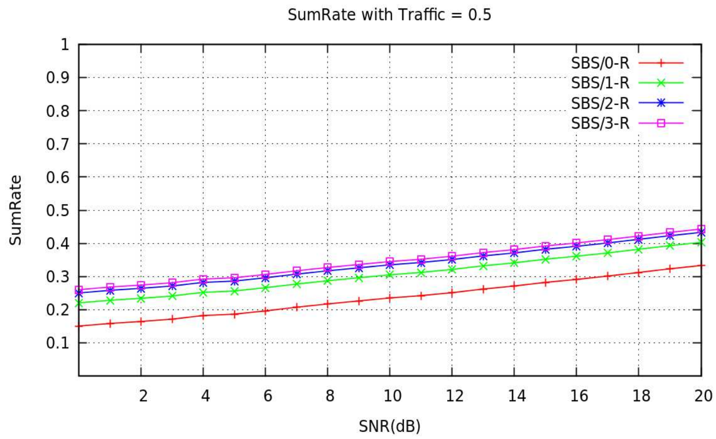

Fig. 9: Sum-rate of CR network with medium traffic

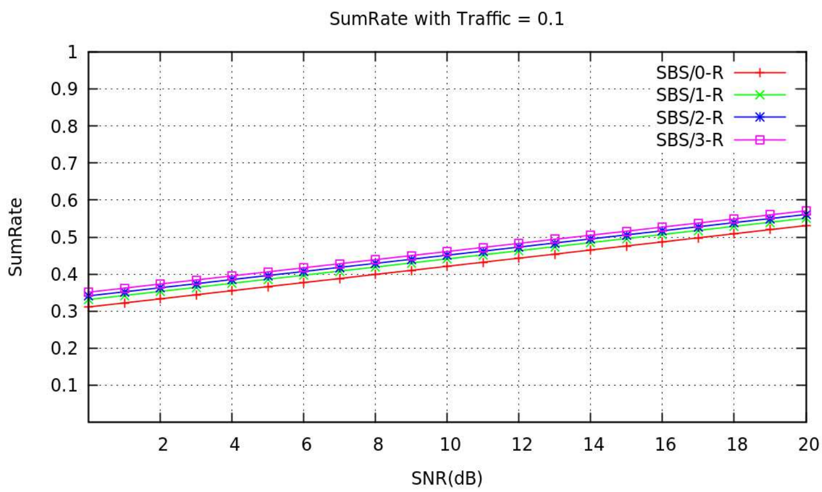

Fig. 10: Sum-rate of CR network with low traffic

From the simulation results, it is clear that for all traffic conditions, implementing more relays in networks will result in fair sum-rate although implementing relays in the network will add load to the network. The performance metric of relays is fair when more secondary users get crowded with particular SBS unless the performance metric is under achievable. Hence, implementing relays in the CR network results in good sum-rate when more SUs are crowded in the network; otherwise it produces the average sum-rate similar to the rate produced by SBS implemented in the network without relays.

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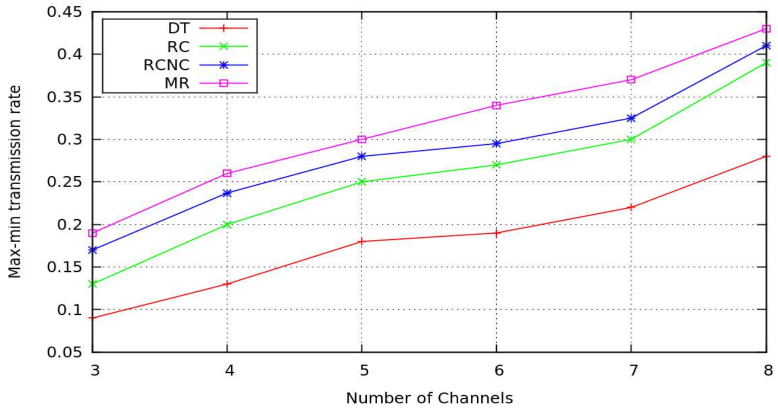

Fig. 11: The max-min transmission rate versus number of channels

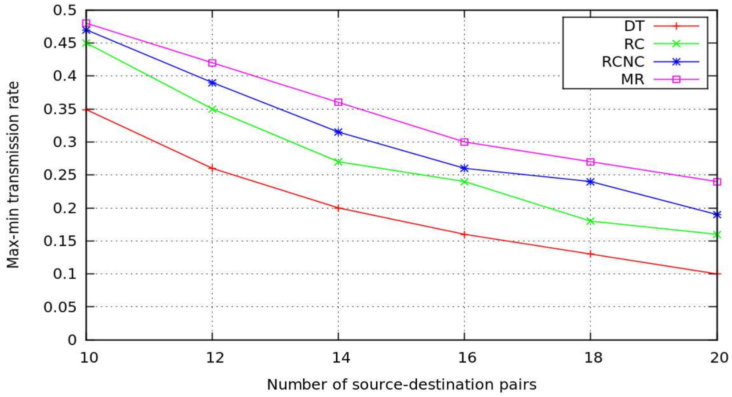

Fig. 12: The max-min transmission rate versus number of source destination pairs

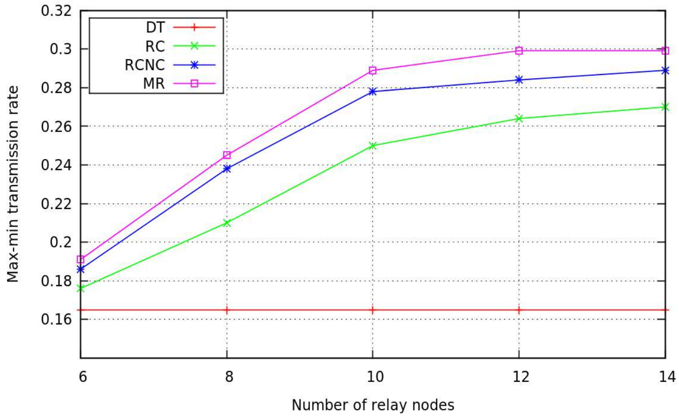

Fig. 13: The max-min transmission rate versus number of relay nodes

As shown in Fig.11, the proposed multi-relay(MR) always outperform the other techniques and their performance gap increases as the number of channel increases. The max-min rate decreases as the source-destination pair increases for all techniques. The performance of MR is absolutely higher than other techniques with more source destination pairs. Finally, the performance with different relay nodes is evaluated. As shown in Fig.13, the proposed MR technique increases the max-min rate of the DT by 8% and 12% when the relay node is 8 and 10 respectively. This gain comes from the help of relay nodes.

Conclusion:

In this paper, we analyze the problem of implementing relays in cognitive radio networks for fair sum rate and to maximize the minimum transmission rate. During congestion, relay will help the secondary users to share the spectrum among the secondary users so that delay will be reduced. Simulation results reveals that the sum-rate with heavy traffic having maximum variation with implementing multiple relays as increase in SNR values. Comparing with the results of heavy traffic and low traffic condition, the sum-rate curve have minimal variation compared with high and medium traffic condition which implies that multiple relays produces fair sum-rate when SUs are crowded in CR network. Otherwise, it produces average sum-rate which is similar to the sum-rate produced by SBS without implementing relays. From the simulation results, the proposed MR technique increases the max-min rate of the DT by 8% and 12% when the relay node is 8 and 10 respectively. Hence, implementing relays in the network shares the idle spectrum with fair sum-rate when the network gets crowded and also provides max-min transmission rate.

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