



## RESEARCH ARTICLE

### SPECTRUM AWARE CLUSTER BASED ROUTING PROTOCOL (SACBRP)

**\*Ramesh Palanisamy and Mathivanan, V.**

AMET University, Chennai, TamilNadu, India

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#### ABSTRACT

Wireless networking is the recent wonder in current communication era. This provides a vast scope of infrastructure less networking arena called as cognitive radio mobile ad hoc systems shortly coined as CRAHNs. This part of doctoral research emphasize in proposing a spectrum aware cluster based routing protocol (SACBRP). SACBRP contains a node joining appliance by which making a non-clustered node to become a member in a cluster. Cluster head election is then carried out followed up with routing. Simulations are performed using NS2 network simulator. Performance metrics such as packet delivery ratio, end-to-end latency and primary user's activity (PU) are permitted out and the results depicts that the proposed SACBRP implements improved.

## INTRODUCTION

Cognitive radio (CR) is a drawing in advancement that permits cognitive clients to take a shot at the void parts of the spectrum apportioned to essential clients. CR is thoroughly considered as a promising advancement that approaches with the spectrum inadequacy issue accomplished by the present rigid spectrum-section technique. It is readied for recognizing its radio surroundings and adaptively identifying to pick transmission parameters as indicated results, which upgrades CR structure execution and avoids interrupting with Discharge. Late research exercises drove in CR have fundamentally centered on wise spectrum access and spectrum use. In any case, CR improvement will have huge effect on upper layer execution in remote systems, especially in adaptable phenomenally assigned systems (MANETs), which draw in remote contraptions to continuously, create systems without on an exceptionally fundamental level utilizing a settled base. Positively, issues in non-cognitive MANETs in light of present circumstances are still of excitement for the CR viewpoint. Notwithstanding, some unmistakable qualities of CRs acquaint new nontrivial issues with CR-MANETs. Yet a few endeavours have been done to the medium access control (Macintosh) layer issues, routing is still one of the especially fundamental systems administration issues in CR-MANETs. From a routing viewpoint, it is normal that information packs are coordinated by strategy for a persevering and strong way to deal with abstain from unending rerouting issues coming about

to dynamic rerouting may prompt show storms to the system, abuse the uncommon radio resources, and savage end-to-end system execution, for example, throughput and postponement. Separated and standard MANETs, a way in CRMANETs is especially frail since it is influenced by the portability of CUs and in addition by the hindrance to Discharge also. There are a substantial number of routing protocols proposed in established MANETs, for example, destination-sequenced distance vector routing, dynamic source routing (DSR), and ad hoc on-demand distance vector (AODV) routing. Be that as it may, it is hard to apply them straightforwardly to CR-MANETs because of the unmistakable qualities portrayed previously. On the other hand, it may not be alluring to outline another routing convention devoted to CR-MANETs because of the development and accessibility of existing routing protocols.

## LITERATURE REVIEW

In Vizziello *et al.*, 2013, a localization algorithm was developed to calculate PUs position and a novel location based CR (LCR) routing protocol was proposed. LCR routing protocol acts in two steps: intra-cluster and inter-cluster. In Ghive *et al.*, 2014 RESS was proposed which helps to maintain the inter and intra cluster connectivity so that robustness can be strengthened between the nodes. In Shirke, N *et al.*, 2014, Energy Efficient Cluster based Routing protocol was proposed, which works in distributed manner in mobile CR adhoc network. The objective was to provide efficient energy level to network nodes; so that it can relief the problem

\*Corresponding author: Ramesh Palanisamy,  
AMET University, Chennai, TamilNadu, India.

of energy consumption that arises due to packet generation and formation of cluster. In Dutta, N *et al.*, 2014 a novel clustering approach for cognitive nodes in CRN based Ad Hoc Networks (CRAHNs) was proposed namely Signal to Interference plus Noise Ratio (SINR). It was produced by Primary Users (PUs) on collocated Cognitive Users (CUs) along with Expected Transmission Time (ETT) among CUs is taken into account in order to form the clusters. Mansoor, N *et al.*, 2013 proposed a time slotted based broadcasting protocol for the clustered architecture. For effective routing and load balancing, it divides Ad-hoc architecture into clusters. Kok-Lim Alvin Yau *et al.*, 2014 reviewed clustering algorithms, and they were characterized by clustering objectives, metrics and the number of hops in each cluster. It also present complexity analysis, performance enhancements achieved by the clustering algorithms, as well as open issues, in order to establish a foundation for further research and to spark new research interests in this area. Athina Bourdena *et al.*, 2014 proposed a resource intensive traffic-aware scheme, incorporated into an energy-efficient routing protocol that enables energy conservation and efficient data flow coordination, among secondary communicating nodes with heterogeneous spectrum availability in distributed cognitive radio networks. Majid Ashouri *et al.*, 2015 designed a prediction-based approach, named PDC, to mainly contribute in data-aware clustering. It exploited both spatial and temporal correlations to form highly stable clusters of nodes sensing similar values.

### Spectrum Aware Cluster Based Routing Protocol (SACBRP)

Every secondary user (SUs) is in non-clustered state at the beginning stage. Cluster arrangement makes legitimate gatherings (or clusters) comprises of cluster heads and part nodes. At first, each SU-scans each of the accessible channels for a brief timeframe duration  $T_{w,scan}$  during which a node may get clustering message CH data from its neighbouring nodes (e.g., clustered and non-clustered nodes), and keep up its neighbour table.

#### Node joining

Node joining is the procedure of partner a non-clustered node with a cluster. SACBRP satisfies the accessibility of a sure number of regular diverts in a cluster upon node joining with a specific end goal to expand solidness. A SU  $i$  scans the rundown of accessible diverts in a consecutive way, and every channel is examined for  $T_{w,scan}$  span. After examining all the available channels in the list  $listchannel_i$ , if a SU gets CH data, it stores the sender of CH data and the individual data in its neighbour table. To some extent II of Calculation 1(a), there are two circumstances in which a SU decides to join a cluster head. Initial, a SU has gotten clustering message CH information from a solitary cluster head (i.e.,  $N_{CHinfo.nodestate=CH=1}$ ), thus this cluster head is picked. Second, a SU has gotten more than one clustering message CH info from different cluster heads (i.e.,  $N_{CHinfo.nodestate=CH=1}$ ), then it positions the expert channels of the cluster heads taking into account channel limit metric  $\varphi_k^t$ . The cluster heads are positioned such that a cluster head  $j$  has the most elevated rank (i.e.,  $\gamma_{CH,j=1}^t$ ) if its expert channel  $k$  has the most astounding channel limit among the channel limits of expert channels of other neighbouring cluster heads (i.e.,  $\varphi_k^t > \varphi_{i \in M}^t \subset CH_{m \in NB_i}$ ). Also, other cluster heads are positioned as second, third et

cetera. At long last, the node chooses a cluster head  $j$  with the most elevated rank (i.e.,  $\gamma_{CH,j=1}^t$ ). Next, in both circumstances, a SU  $i$  sends a cluster joining solicitation ( $JREQ_{i,j}$ ) to the chose cluster head  $j$ , and sits tight for its reaction inside of a period duration  $T_{w,res}$ . On the off chance that a SU  $i$  gets an acknowledgment reaction ( $JACCI_{i,j}$ ) from cluster head  $j$ , it turns into the part node  $MN_{i,j}$  of the particular cluster  $j$  (i.e.,  $nodestate_i \leftarrow MN_{i,j}$ ); generally, the next cluster head with the most astounding rank utilizing its expert channel is picked. Next, we concentrate on the condition in which a cluster head  $CH_j$  receives  $JREQ_{i,j}$  message from a non-clustered node  $i$ . The cluster head  $CH_j$  just acknowledge a sending so as to join in solicitation back cluster joining acknowledgment ( $JACCI_{i,j}$ ) message if the quantity of basic channels  $n_c$  in its cluster  $c$   $C_j$  fulfils the limit for the base number of basic directs in a cluster (i.e.,  $n_{c,C_j} \geq h_{c,min}$ ) upon node joining with a specific end goal to amplify cluster security. Else, it decays the sending so as to join solicitation back cluster joining decrease ( $JDEC_{i,j}$ ) message to the SU  $i$ .

#### Cluster head election

SACBRP utilizes a clustering metric that chooses a node with the most elevated number of accessible channels as cluster head amid cluster head decision so as to stay away from successive re-choosing. A cluster head likewise procedures cluster joining solicitation from non-clustered nodes. In SACBRP, a cluster head must en-beyond any doubt that its cluster satisfies the prerequisite on the base number of regular channels upon any new node joining with a specific end goal to expand cluster solidness. A SU  $i$  may not get clustering message CHinfo from any cluster head if there is absence of cluster head in its neighborhood, thus it stays in non-clustered state. It begins to shape a cluster with non-clustered SU neighbor nodes  $N_{N_{i \in NB_i}}$ .

There are two circumstances. In the first place, there is absence of non-clustered SU neighbor nodes of SU  $i$   $N_{N_{i \in NB_i}}$ , and so SU  $i$  frames a cluster itself and turns into a cluster head (i.e.,  $nodeState_i = CH_i$ ). Second, there is no less than a solitary non-clustered SU neighbor node (i.e.,  $N_{(NN_{i \in NB_i}(i))} > 1$ ), and so SU  $i$  turns into a cluster head in the event that it has the most noteworthy clustering metric, particularly the most noteworthy number of accessible channels ( $N_{listchannels_i} \geq N_{listchannels_{j \in NN_{i \in NB_i}}}$ ), among its non-clustered SU neighbor nodes. In this way, the new cluster head positions its accessible channels utilizing the channel  $N_{listchannels_i}$  limit metric  $\varphi_k^t$  and chooses an expert channel with the most astounding rank  $\gamma_{chan,k}^t = 1$ , and a reinforcement channel with the second most astounding rank  $\gamma_{chan,k}^t = 2$ ; and accordingly broadcasts this data utilizing clustering message CHinfo. Notwithstanding, if a SU  $i$  doesn't have the most elevated clustering metric among its non-clustered SU neighbour nodes, it sets a clock to  $T_{w,CHE}$  allow non-clustered SU neighbour nodes with the most astounding clustering metric among the individual neighbourhood to wind up cluster head and joins the cluster with the most noteworthy rank. Note that, if a SU does not get any clustering message CHinfo from any cluster head upon the lapse of the timer  $T_{w,CHE}$ , it begins another round of procedure for non-clustered node.

## Routing in SACBRP

This segment presents directing plan of SACBRP which keeps running on a clustered system. The cluster-construct steering plan is based with respect to a RL-based directing model known as Q-directing, which was proposed by Boyan and Littman, 1994. Q-steering is propelled by a RL methodology known as Q-learning (R.S.Sutton and Barto, 1998). The primary goal of the directing plan is to give stable courses higher OFF-state probabilities of diverts along the courses with a specific end goal to decrease SUs' transmission intrusion because of the re-appearance of Discharge's exercises, especially the quantity of channel switches and the event of re-steering. This leads to upgraded SUs' system execution thus it is relied upon to add to the change of SUs' vitality proficiency. Our methodology is not the same as the traditional Q-directing methodology which depends on end-to-end delay (Boyan and Littman, 1994), as our methodology depends on OFF-state likelihood of the bottleneck channel of a course. To the best of our insight, the utilization of RL to cluster based directing in CRNs is novel in its methodology. In SACBRP, the Q-directing model is implanted in each SU in light of the fact that it stands an equivalent chance to serve as a cluster head. The steering choice (i.e., SU next-hop neighbour node choice) is made by the cluster head of a SU source node and the middle of the road cluster heads in view of channel determination performed by clustering. The essential representations in the RL model are for a specialized state and activity. State  $S^t$  represents the choice making elements, which influence the prize (or system execution), saw by a specialists from the working environment. Activity speaks to an operators  $i$ 's activity, which may change or influence the state (or working environment) and compensate (or arrange execution), thus the specialists figures out how to take ideal activities at the greater part of the times. Reward  $\gamma_i^{t+1}(s^{t+1})$  represents the positive or negative impacts got at time  $t + 1$  of an operators' activity on its working surroundings taken at time  $t$ . At choice age  $t$ , a specialists  $i$  watches its working surroundings to focus its present state  $s^t$ . Taking into account the state  $s^t$ , the specialists picks an activity  $a_i^t$ . Next, at choice age  $t + 1$ , the states  $s^t$  changes  $s^{t+1}$  to as an activity's outcome  $a_i^t$ , and the operators  $i$  gets reward  $r_i^t(s^{t+1})$ .

In SACBRP, the state  $s^t$  represents the SU destination node and the action  $a_i^t$  represents SU  $i$ 's next-hop neighbour node that transfers parcels toward SU destination nodes  $s^t$ . At time  $t$ , a cluster head  $i$  assesses the Q-esteem  $Q_i^t(s^t, a_i^t)$  for each and every SU neighbour node  $a_i^t$ , which demonstrates the OFF-state likelihood of the bottleneck channel along a course and redesigns its steering table of Q-qualities. The bottleneck channel is the channel of a connection having the minimum OFF-state likelihood for the next time opening along a course. Utilizing the OFF-state likelihood of channels serves to diminish the dynamicity's impacts of divert accessibility in CRNs by selecting stable courses that have directs with higher OFF-state likelihood keeping in mind the end goal to amplify the use of white spaces. It demonstrates a SU neighbour node of the SU source node  $i$ , while every line demonstrates a destination nodes  $s^t$ . Every cell speaks to the Q-estimation of a next-hop neighbor node at  $i$  chose by SU source node  $i$  to achieve the SU destination nodes  $s^t$ . A cluster head figures Q-esteem for each SU neighbour node, while SU middle of the road node computes the OFF-state likelihood of the jug neck channel from itself toward the destination node  $s^t$  and advances

this likelihood to an upstream node in RREP message. A cluster head  $i$  makes course choice by selecting a SU next-hop neighbour node  $a_i^t = j$  as follows:

$$Q_i^t(s^t, a_i^t) \leftarrow ((1-\alpha) \times Q_i^t(s_i^t, j) + [\alpha \times \min(\gamma_i^{t+1}(j), \max_{k \in a_j^t} Q_i^t(s^t, k))])$$

where  $0 \leq \alpha \leq 1$  addresses the learning rate,  $\gamma_i^{t+1}(j)$  is the OFF-state probability of the working channel between SU  $i$  and SU neighbor center point  $j$ ,  $Q_i^t(s^t, k)$  is the OFF-state probability of the bottleneck channel along a course from SU center point  $k \in a_j^t$  (i.e., a SU next-hop neighbor node of SU  $j$ ) to SU destination nodes  $t$ , and  $\min(\gamma_i^{t+1}(j), \max_{k \in a_j^t} Q_i^t(s^t, k))$  is the OFF-state probability of one of the bottleneck channels among  $(\gamma_i^{t+1}(j)$  and  $\max_{k \in a_j^t} Q_i^t(s^t, k)$ . This infers that either the connection connecting SU  $i$  and SU  $j$ , or one of the connections in the course settled between SU  $j$  and SU destination center  $s^t$  is the bottleneck join. Using this model, SUs get some answers concerning the courses on the fly. Due to assorted levels of Release's activities, the courses may have particular OFF-state probabilities of channels. Along these lines, the picked course will have higher OFF-state probabilities of channels which will make the way steady when contrasted with other available way.

SACBRP is expected for ad hoc CRN which is depicted by the dynamicity of channel openness as a result of unmistakable levels of Release's activities. The trading of RREQ and RREP messages is a profitable way to deal with discovers dynamic paths in SACBRP. In SACBRP, RREQ message is used to find a path from a SU source center point to a SU destination center point if the SU source center is not aware of any path or the present path toward the SU destination center point is slipped by. RREP message is used to light up the SU path center point around a course toward a SU destination center point and the OFF-state probability of the bottleneck channel along the path. Since a SU part center sends its information to its gathering head, which serves as a condition of methodology for each and every part center in its pack, we consider a SU gathering head as the path center point. Accept, a gathering head  $i$  doesn't know a course to destination center point  $s^t = l$  (i.e.,  $route_{i,l} = \emptyset$ ), so it triggers course revelation. It makes a RREQ message and consolidates its own particular center ID in course record  $RREQ_{RREC,i,l} = l$ . By then, it surges the RREQ message by broadcasting on its master channel right when a path center point  $GN_{i,j,l}$  gets the RREQ message from its gathering head  $CH_i$  it advance. In Algorithm 1, when a SU transitional cluster-head  $m$  gets a RREQ message, it reuses the RREQ message by adding its own individual node ID to the list of route record (i.e.,  $RREQ_{RREC,i,l} \leftarrow RREQ_{RREC,i,l} \cup m$ ). In this manner, it rebroadcasts the message on its master channel in the event that it is not the SU destination hub  $l$ , which may be sent by door hubs to neighbouring, bunches. At the point when a RREQ message is gotten by a SU destination hub  $l$ , it produces a RREP message utilizing the route found as a part of the RREQ message. When a SU moderate hub  $m$  gets a RREP message from its next-hop neighbour node  $n$ , it ascertains the OFF-state likelihood of the bottleneck channel from itself to SU destination nodes  $s^t = l$  through its next-hop neighbour node  $n$  (i.e.,  $Q_m^t(l, n)$  embeds it into the RREP message and advances to the downstream hub in the rundown of route record  $RREQ_{RREC,i,l}$ . The RREP message takes after

the opposite route that the RREQ message navigates with the goal that it achieves.

**Algorithm 1** RREQ propagation and RREP processing at SU node  $m$ .

```

/* Part I: RREQ propagation */
If receive RREQ and  $m \in RREQ_{RREQ,i,l}$  then
 $RREQ_{RREQ,i,l} = RREQ_{RREQ,i,l} \cup m$ ;
If  $m = l$  then
/*  $l$  is the destination node */
Create RREP;
Send RREP using the reverse path in  $RREQ_{RREQ,i,l}$ ;
Else
Rebroadcast RREQ;
end if
/* Part II: RREP handling */
else if receive RREP from  $n$  then
if  $m = i$  then
/*  $i$  is the source node */
Update  $Q_i^t(l, n)$ ;
Else
Calculate likelihood of bottleneck channel  $Q_m^t(l, n)$ ;
Insert Q-esteem in RREP;
Forward RREP;
end if
end if
    
```

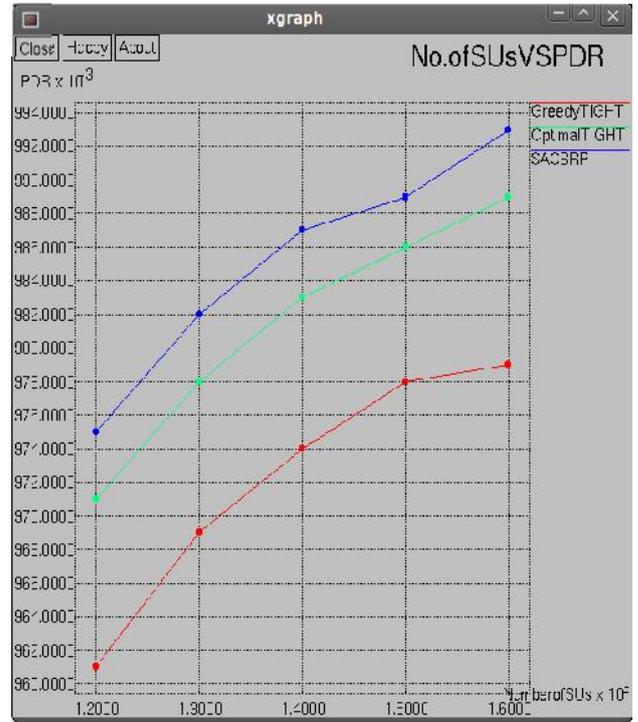
**Performance evaluation**

In this section, we evaluate SACBRP using simulations. There are no publicly available implementations of existing CRMANET or CRAHN routing protocols [G.Cheng *et al.*, 2007, A.Sampath *et al.*, 2008, G.M.Zhu *et al.*, 2008, K.Chowdhury and I.Akyildiz.,2011, A.Cacciapuoti *et al.*, 2012]. Also, many key implementation details are not clear enough for us to truthfully realize the functionalities they provide. The simulation code was written in C++. Initially, we tried the NS2 simulator and found that SACBRP has similar packet delivery ratio (PDR) to that of TIGHT in small-scale CRAHN. In terms of end-to-end latency, SACBRP only slightly outperforms TIGHT due to the small network scale. Since NS2 is known to have a poor performance in simulating large-scale CRAHN, we opted for C++ simulations to see the performance of SACBRP in large-scale networks. The fidelity of C++ simulations for SACBRP and TIGHT is still very high. Specifically, the routing of every packet in both SACBRP and TIGHT depends on the spontaneous network topology only. Therefore, we can simply evaluate the performance of SACBRP and TIGHT under node random walk mobility by sending packets over a number of randomly generated network topologies. We chose to compare TIGHT with GPSR which sends packets over the secondary channel only. The default simulation settings are as follows: We simulate an area of  $4,000 \times 3,000 m^2$  with 6 PUs and 1,334 SUs. The transmission range of PUs and SUs is 250 m. We run the simulation 8,000 times, and the PUs and SUs are uniformly distributed at random with a different random seed in each simulation run. We fix 30 pairs of source and destination PUs with random relative locations in each simulation run. SACBRP is used only when the source and destination SUs are both outside of any PU region; otherwise, TIGHT is used to send packets over the secondary channel only. Each source SU sends one packet of 512 bytes to its destination SU in each simulation run. Therefore, totally 8,000 packets are sent between each source destination SU pair, and each data point

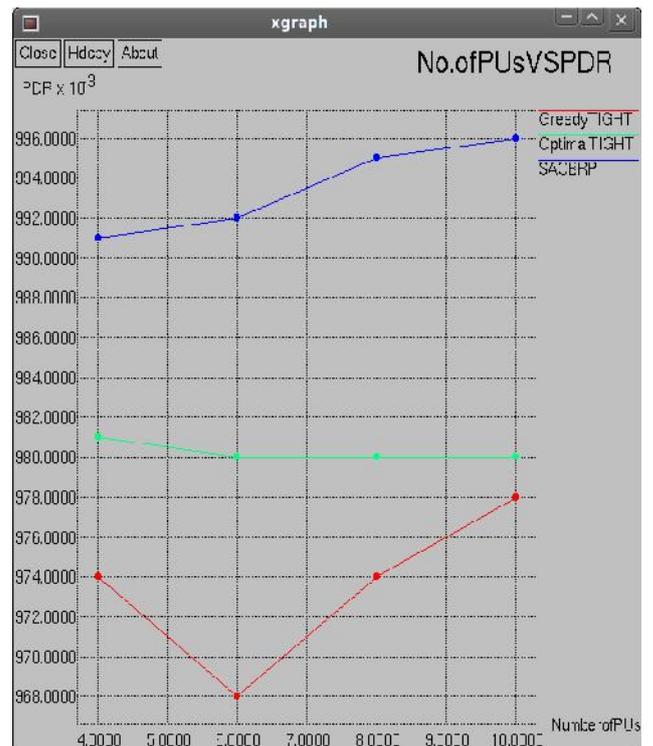
in subsequent figures represents the average for 240 thousand packets (unless stated otherwise).

**RESULTS AND DISCUSSION**

Figure 5.1 shows the performance evaluation of the proposed SACBRP protocol in terms of number of secondary users versus packet delivery ratio. It is evident that the proposed SACBRP attains better packet delivery ratio. The numerical results are also presented in Table 1.



**Figure 1.** Impact of different numbers of SU's on packet delivery ratio



**Figure 2.** Impact of different numbers of PUs on packet delivery ratio

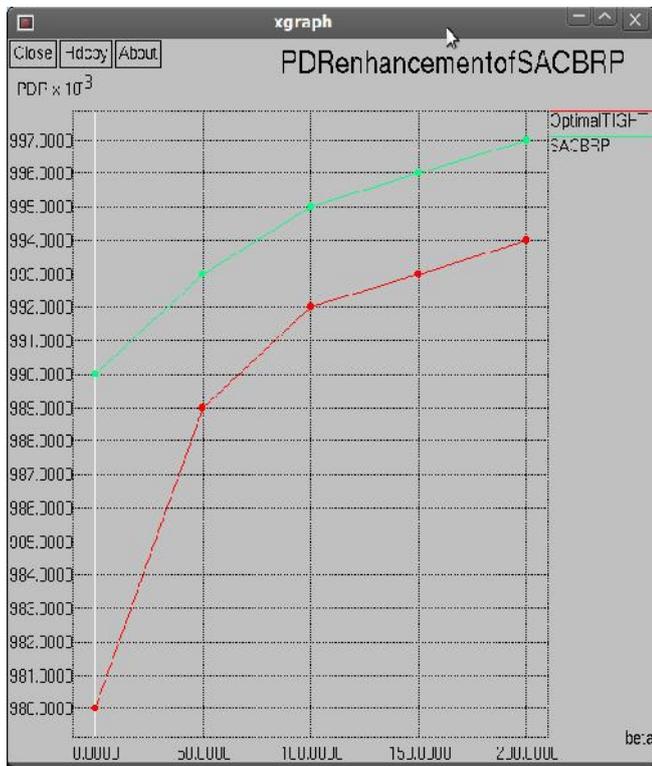
**Table 1. Impact of different numbers of SU's on packet delivery ratio**

No of SU's	Greedy TIGHT	Optimal TIGHT	SACBRP
1200	0.961	0.971	0.975
1300	0.969	0.978	0.982
1400	0.974	0.983	0.987
1500	0.978	0.986	0.989
1600	0.979	0.989	0.993

**Table 2. Impact of different numbers of PUs on packet delivery ratio**

No of PU's	Greedy TIGHT	Optimal TIGHT	SACBRP
4	0.974	0.981	0.991
6	0.968	0.980	0.992
8	0.974	0.980	0.995
10	0.978	0.980	0.996

Figure 2. Projects the performance evaluation of the proposed SACBRP protocol in terms of number of primary users versus packet delivery ratio. It is apparent that the proposed SACBRP attains better packet delivery ratio. The numerical results are also presented in Table 2.



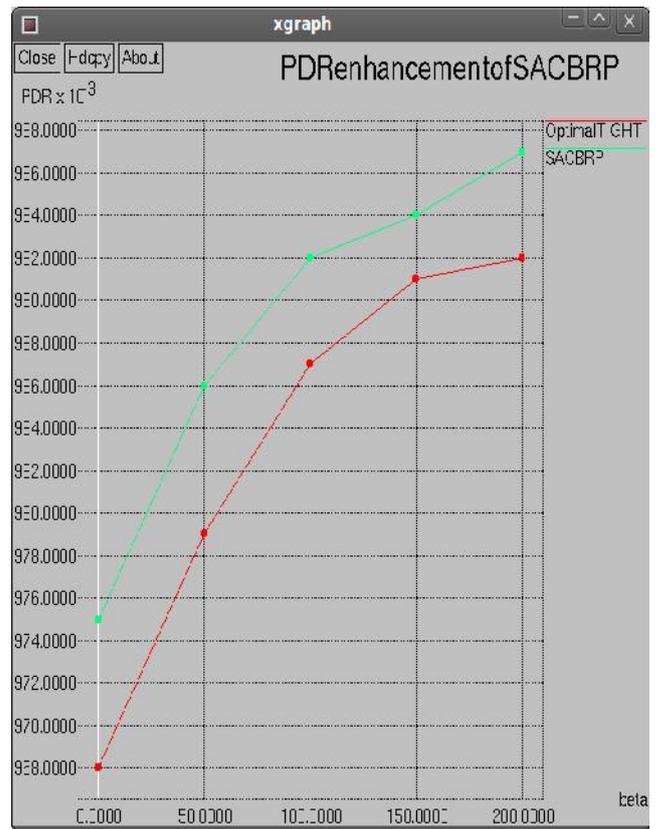
**Figure 3. PDR enhancement of TIGHT in overall channel**

Figure 3. Emphasizes the performance evaluation of the proposed SACBRP protocol in terms of packet delivery ratio in overall channel. It is palpable that the proposed SACBRP attains better packet delivery ratio. The numerical results are also presented in Table 3.

**Table 3. PDR enhancement of TIGHT in overall channel**

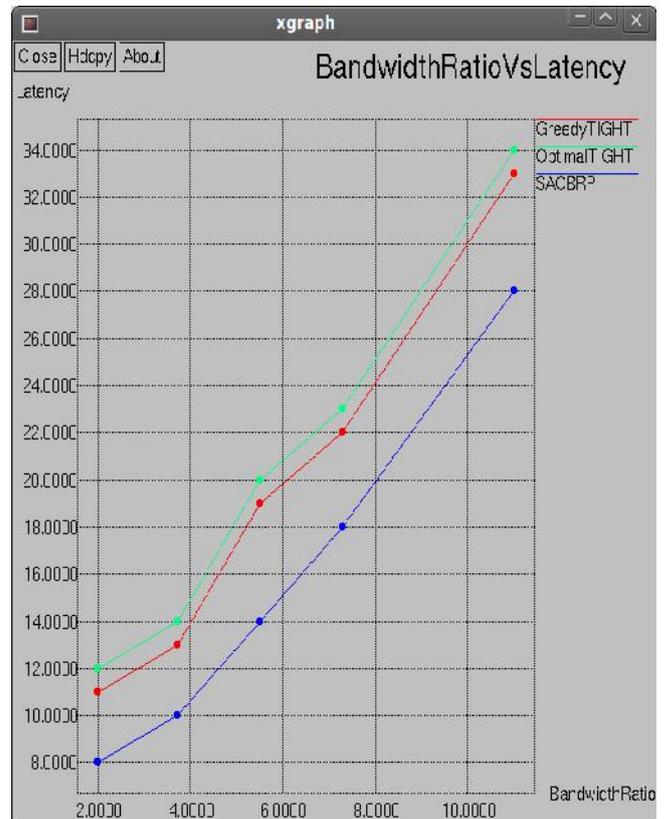
$\beta$	Optimal TIGHT	SACBRP
0	0.980	0.990
50	0.989	0.993
100	0.992	0.995
150	0.993	0.996
200	0.994	0.997

(Where  $\beta$  is a system parameter no larger than R(radius))



**Figure 4. PDR enhancement of TIGHT in primary channel**

Figure 4. Envisions the performance evaluation of the proposed EZBRP protocol in terms of packet delivery ratio in primary channel. It is overt that the proposed SACBRP attains better packet delivery ratio. The numerical results are also presented in Table 5.4.



**Figure 5. End-to-end latency**

**Table 4. PDR enhancement of TIGHT in primary channel**

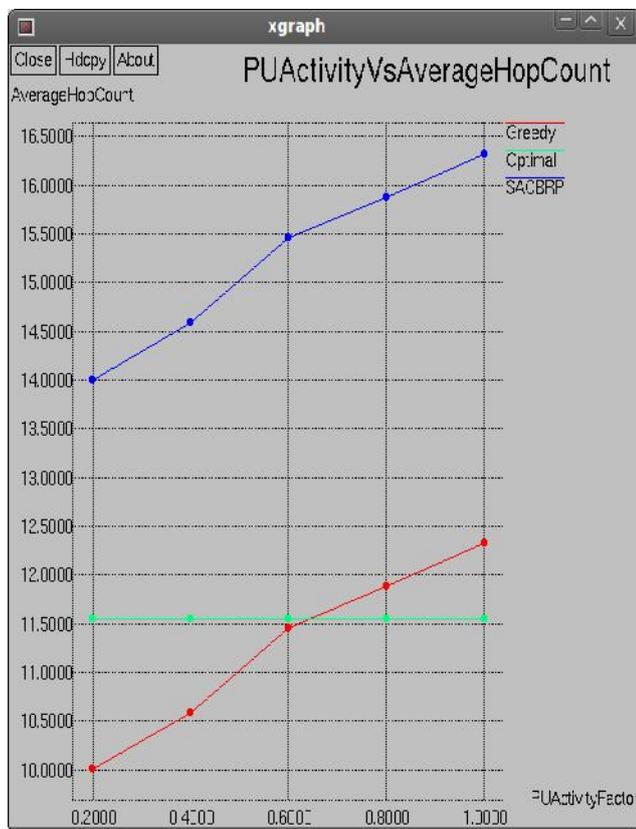
$\frac{R}{r}$	Optimal TIGHT	SACBRP
0	0.968	0.975
50	0.979	0.986
100	0.987	0.992
150	0.991	0.994
200	0.992	0.997

(Where  $r$  is a system parameter no larger than R(radius))

Figure 5. Shows the performance evaluation of the proposed SACBRP protocol in terms of end-to-end delay. It is flagrant that the proposed SACBRP attains lesser end-to-end delay. The numerical results are also presented in Table 5.5.

**Table 5. End-to-end latency**

Bandwidth Ratio	Optimal TIGHT	Greedy TIGHT	SACBRP
2	12	11	8
3.7	14	13	10
5.5	20	19	14
7.3	23	22	18
11	34	33	28



**Figure 6. PU activity**

Figure 5.6 portrays the performance evaluation of the proposed SACBRP protocol in terms of average number of hops. It is palpable that the proposed SACBRP attains better average number of hop count. The numerical results are also presented in Table 5.6.

**Table 6. PU activity**

PU Activity Factor	Greedy TIGHT	Optimal TIGHT	SACBRP
0.2	10.00215	11.54323	14.00201
0.4	10.58962	11.54321	14.58942
0.6	11.45621	11.54320	15.45609
0.8	11.87965	11.54316	15.87943
1.0	12.32145	11.54314	16.32126

**Conclusion**

This research work is the second phase of the doctoral research work. The proposed protocol is named as spectrum aware cluster based routing protocol (SACBRP) which is hybridized in nature. SACBRP has a node joining mechanism by which making a non-clustered node to become a member in a cluster. Cluster head election is then carried out followed up with routing. An adaptive route request and route reply algorithm is proposed. Simulations are performed using NS2 network simulator. Performance metrics such as packet delivery ratio, end-to-end latency and primary user’s activity are carried out and the results depicts that the proposed SACBRP outperforms well in cognitive radio mobile ad hoc scenario.

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