# Performance Comparison of Routing Protocols in Cognitive Radio Networks

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***Abstract***

Cognitive radio sensor networks (CRSNs) are the fifth-generation wireless sensor networks (WSNs). The growing demand of additional spectrum resources can be met by these networks. The cognitive radio technology eases the overcrowded unlicensed spectrum bands by providing an opportunity to use the unoccupied licensed spectrum bands. The lifetime of a wireless sensor network can be prolonged by clustering. Clustering involves selecting a cluster head and then rotating the cluster head periodically to distribute energy consumption among nodes in a cluster. The cluster heads collect the data from nodes in their cluster, aggregate it and send the data to the base station. There are a large number of protocols pertaining to CRSNs is available in the literature. This paper presents a comparative analysis of five routing protocols of CRSNs namely ECR (Energy and Cognitive Radio aware Routing), ERP (Energy aware event driven Routing), ESAC (Event driven Spectrum Aware Clustering), EACRP (Energy Aware Cluster based Routing Protocol) and SCR (Spectrum aware Cluster based Routing).

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## 1. Introduction

With the drift to Internet of Things (IoT) [1] there has been a tremendous increase in the number of devices in the networks causing the ISM band (Industrial, Scientific and Medical band) to be congested. While there is an underutilization of licensed bands. So, to solve this problem of spectrum shortage, cognitive radio technology came into existence. In Cognitive radio technology [2, 3] there are two types of users i.e. Primary Users also knows as PUs and secondary users also knows as SUs. The primary users are the users of spectrum who have the licensed band whereas the secondary users are the cognitive capabilities enabled users who can use the licensed band of secondary users when primary users are not using their band. That is, secondary users can detect the presence and absence of a primary user on a licensed band. And if the licensed band is unoccupied by the primary user, the secondary user can take this opportunity and start using that band. The secondary user has to continuously check the spectrum for the availability of primary user. If the primary user wishes to use its licensed band and enters the network, the secondary use has to relinquish the control of the licensed band to the primary user. In this case, the secondary users then switch to a backup (another) band for its communication. For this purpose, the secondary user's transceiver should have cognitive capabilities so that it can opportunistically use the spectrum.

Thus, a cognitive radio sensor network (CRSN) [5, 6] is a wireless sensor network consisting of cognitive capabilities enabled sensor nodes which can opportunistically access the spectrum.

There are various challenges [7] which there CRSN networks face. Apart from being spectrum aware, these networks have to deal with energy and hardware limitations of cognitive radio enabled sensor nodes commonly known as CR (Cognitive Radio) nodes. The solutions which exist for wireless sensor networks [8] cannot be applied to cognitive radio networks because WSNs do not consider CR functionalities. The existing solutions for CRSNs also do not deal with the challenges of energy and hardware. So, new methods are to be found in order to deal with these issues of energy and spectrum. There is a lot of work to be done in this area. The cognitive radio field has been receiving a great interest from the research community. The research works which existed recently are focussing on clustering [9, 11] and routing [10].

One of the most important concepts in wireless networks is that of clustering. Fig. 1 depicts the clustering scenario in wireless networks. The nodes deployed in a sensor field to detect the surroundings are grouped in clusters. This is done to maintain the topology, scalability and stability of the network. There is a lot of work done in the field of wireless sensor networks and wireless ad-hoc networks in the area of clustering. As per the literature, whole network is divided into a group of nodes called clusters. One member node out of the cluster is selected as a cluster head CH [12] and rest nodes are called member nodes. The member nodes of a cluster sense the environment and send their sensed data to the cluster head. The cluster head collects the data of all the sensor nodes of its cluster, aggregates that data and send the aggregated data to the base station. The clustering algorithms available in WSN elects the cluster head on the basis of residual energy [13] of the nodes. These algorithms cannot be applied to CRSN because CRSN are spectrum aware networks. The nodes in CRSN are clustered only if they have at least one channel in common. However due to dynamic activity of the CRSN networks this alone cannot guarantee the stability of the network.

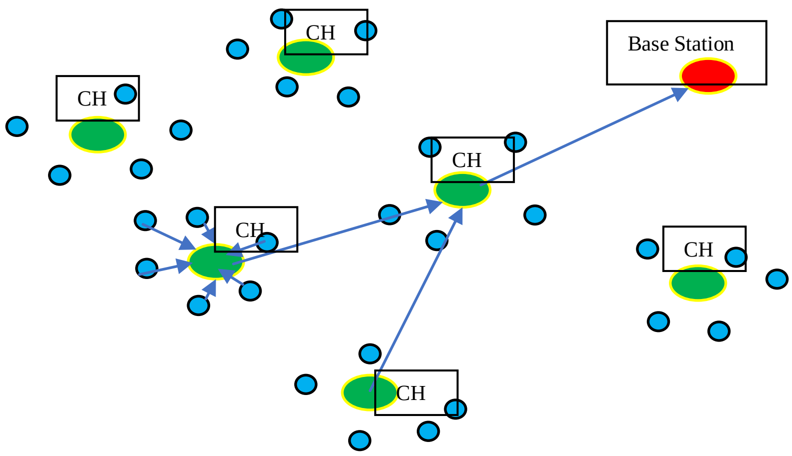


**Fig 1:** Clustering scenario in wireless networks

Routing algorithms in WSN were focussed on transmitting sensed data to the base station which involves minimum energy consumption. The main focus of routing schemes of WSN was prolonging the lifetime of the network. It operated on fixed channel allocation. Whereas, the main focus of routing schemes in CRSN is maintaining the network connectivity which is challenged by the dynamic nature of radio environment. Due to the variation of spectrum, there is frequent route re-establishment in CRSNs. Energy aware Cognitive radio Routing, ECR [14] satisfied the routing requirements of CRSN by taking advantage of both CRAHNs [4] and WSNs. ERP [15], Energy aware event driven Routing Protocol uses the concept of eligible nodes for clustering in addition to spectrum aware functionality. ESAC [16], Event driven Spectrum Aware Clustering is an event driven algorithm in the event. In [17] authors proposed EACRP, Energy Aware Cluster based Routing Protocol which was based on forming optimal number of clusters. The authors in [18] proposed a cluster based algorithm called SCR, Spectrum aware Cluster based Routing which included spectrum aware features of CRSN. SCR is based on limiting the number of nodes which participates in route formation so that the energy of the network is conserved. This paper aims at comparing the performances of these algorithms namely ECR, ESAC, ERP, EACRP and SCR.

The rest of the paper is planned as follows. Section 2 describes the five cognitive radio routing protocols studied in this paper namely, Energy aware Cognitive radio Routing protocol (ECR), Energy aware event driven Routing Protocol (ERP), Event driven Spectrum Aware Clustering (ESAC), Energy Aware Cluster based Routing Protocol (EACRP) and Spectrum aware Cluster based Routing (SCR). Section 3 gives the simulation setup of the network. Section 4 shows the comparative analysis of all these mentioned protocols and section 5 concludes the paper.

## 2. Background

In this section, a brief review of the five routing protocols considered in this study is presented.

### 2.1 ECR Protocol

ECR (Energy and Cognitive Radio aware Routing) protocol is an enhancement to AODV [19] (Adhoc on demand distance vector routing) protocol. It uses the piggybacking mechanism of DSR (Dynamic Source Routing) [20] to pass the residual energy and channel availability information of intermediate nodes. A routing table is maintained by each intermediate node in the network. ECR finds the route from source to destination considering spectrum availability of the nodes. The route discovery protocol consists of four phases: *route request, route selection, route reply and route maintenance*. Each of these phases is explained below:

*Route Request:* This is the first phase of route discovery process of ECR. It finds all the possible routes from source to destination. The request packet is broadcasted to neighbouring nodes until it reaches the destination node. The request packet is rebroadcasted at every intermediate node by checking the residual energy status and common channel availability with the previous node. The packet is rebroadcasted by the neighbouring nodes only if it satisfies the below two requirements.

1) The residual energy of the intermediate node: If the residual energy of the intermediate nodes is below a certain threshold level, then the node drops the request packet and does not take part in route discovery process. This is done to save the energy of the node and to distribute the network node evenly.
2) Common channels with the previous node: If there is no common channel between the intermediate node and the previous node then the request packet is dropped.

*Route Selection:* The second phase is the route selection. All the route request packets are collected at the destination and the best route is selected based on residual energy ratio of the route, common channel, number of hops and availability of the licensed channel. The route having the largest residual energy ratio, a greater number of common channels between the intermediate nodes, minimum number of hops and having licensed channel is the best route which is selected.

*Route Reply:* In the third phase after the best route is selected, the route reply is unicasted back to the source node through the selected route. On receiving route reply message, the intermediate nodes will update its routing table.

*Route Maintenance:* The fourth phase is route maintenance. For this purpose, the repair mechanism of AODV protocol is followed. If there is an interruption of link because of PU arrival or intermediate node's failure, then the intermediate node sends a request message to destination to provide a local alternate route which can avoid the failed node. If alternative route is found then the original route can be continued. Else, the intermediate node will inform the source and destination about the breakage of the route through route error message. And a new route discovery process is started.

### 2.2 ERP Protocol

ERP is an energy aware event driven routing protocol for cognitive radio sensor networks. Upon detection of an event, ERP determines eligible nodes for clustering. After determining eligible nodes, cluster head selection process starts based on the residual energy values, available channels, neighbours and distance to the sink. Cluster heads starts the cluster formation process and forms the cluster by selecting most stable data channel for corresponding clusters. After the clusters are formed event detecting nodes start sending their data to the sink. There are appropriate primary and secondary gateway nodes for sending data packets to the sinks. The various phases of ERP are explained below:

*Determining eligible nodes:* When an event is detected those nodes become eligible for cluster formation which meets these two requirements 1) The nodes which are closer to the sink and 2) The nodes whose residual energy is greater than the minimum threshold energy.

*Forming of Clusters:* An assembly of neighbouring nodes sharing common channels form clusters. Each eligible node then calculates its weight based on number of neighbouring nodes and number of channels available with the node. The eligible node having a greater number of neighbouring nodes and channels i.e highest weight is selected as the cluster head. The cluster head then forms the cluster and selects a common data channel for the cluster. The channel which has lowest PU appearance probability and highest idle time is selected as the common channel for the cluster. The cluster head also selects a backup channel for the cluster. During transmission if a PU appears on its common channel, then the cluster head switches to this back up channel so, that the transmission is carried out without interruption.

*Gateway node selection:* ECR transmits the data packets from source to destination by inter cluster communication making use of gateway nodes. The node having the higher residual energy, lower probability of PU appearance and higher PU idle time is selected as the gateway node.

*Routing:* By forming spectrum aware clusters, ERP generates a passage between event detecting source nodes and destination sink for routing the data packets.

### 2.3 ESAC Protocol

ESAC is an event driven clustering protocol which is based on forming temporal clusters for each event in the cognitive radio sensor networks. When an event is detected, eligible nodes for clustering are determined. It takes into account the local position of nodes between event and sink. Among these eligible nodes cluster heads are selected based on node degree, available channels and distance to the sink. Clusters are not available after the end of the event as clusters are formed between event and sink. This avoids unnecessary cluster formation and helps in saving energy. The two phases of ESAC are explained below:

*Determining nodes eligible to form clusters:* ESAC is triggered by the event. Whenever an event takes place then only the clusters are formed. The nodes which detect the event are directly eligible for clustering. They further send eligibility_for_clustering request message to their one hop neighbours. This one hop neighbour nodes join the cluster if they are closer to the sink than the eligibility_for_clustering request message sending nodes.

Clustering: Only the nodes which are eligible for clustering take part in cluster formation. In clustering phase, first the cluster head is elected and then the cluster is formed. The cluster heads are elected such that they can reach the maximum number of two hop neighbours through their one hop member nodes. This constraint helps in avoiding isolated clusters. Spectrum awareness is added while forming clusters. The nodes in clusters have similar vacant bands. The cluster head is the node which has higher eligible node degree, higher number of channels and which has lesser distance towards the sink node. The cluster head then forms the cluster.

### 2.4 EACRP Protocol

EACRP is an energy aware cluster-based routing protocol which studies both energy and spectrum challenges for cognitive radio sensor networks. The major challenge with the existing clustering schemes is that they suffer from high frequency of re-clustering due to PU activities and therefore are energy inefficient. EACRP generates optimal number of clusters by self-organizing distributed clustering. EACRP forms clusters which have more number of common channels to reduce the outcome of PU activities. For intra cluster communication it uses the concept of cooperative sensing in selecting data channels. For inter cluster communication it makes use of gateway nodes. The gateway nodes are selected such that they have more energy, closer to sink node and more number of common channels with the neighbouring nodes. To achieve longer network lifetime, a cluster head rotation mechanism is employed that selects the cluster head based on nodes' residual energy values, neighbours, distance to the sink and available channels. When an event occurs, EACRP routes the data through a stable path from source node to the sink node.

### 2.5 SCR Protocol

SCR is a spectrum aware cluster-based routing protocol used in cognitive radio sensor networks. SCR handles the issue of energy consumption and dynamic spectrum access efficiently. SCR clusters channels along with the nodes SCR uses carrier sense multiple access (CSMA) for inter cluster routing and time division multiple access (TDMA) for intra cluster routing. It is a cross layer design of routing. SCR begins with finding the spectrum rank of the nodes. Spectrum rank is the opportunity of the node to transmit on a given channel. The nodes which have higher spectrum rank or greater number of idle channels forms the clusters. The node having the highest spectrum energy rank is elected as the cluster head. The route established is started by the cluster head after the clusters are formed. Data is routed in transmission rounds. Maximum length random access period and variable length TDMA frame constitute the transmission round. Selecting and scheduling of channels is an important characteristic of cluster head. Scheduling of channels is done by the cluster head over a TDMA frame. The time slots in TDMA frame are allocated in a round robin fashion. Each node which requires to transmit its data gets a time slot assigned by the cluster head. Nodes operate in TDMA mode only during transmission and reception. Otherwise, they switch to CSMA mode and operate in common control channel.

There is proactive routing in SCR. The only nodes which establish the route with the sink are the cluster heads. Thus, the overhead in routing is less as compared to when all the nodes are involved in route set up phase. If the number of gateway nodes in SCR is higher then there are greater chances of TDMA and CSMA running in concurrent mode and hence the delay in routing is less. The existing clustering schemes are summarized in table 1 regarding their objectives, mechanism, clustering, methods used in CH Selection, any special node available and performance enhancements.

**Table 1:** Comparison of the existing clustering schemes

| **Clustering Scheme** | **Objectives** | **Mechanism** | **Clustering** | **CH Selection** | **Special Node** | **Performance Enhancement** |
|---|---|---|---|---|---|---|
| **ECR** | Adds cognitive radio features to AODV | ECR is an enhancement to conventional algorithm AODV. It performs node-channel assignment by taking energy into consideration | No Clustering in ECR | No clustering in ECR | NA | Network lifetime, packet delivery ratio (at the cost of scalability, communication complexity) |
| **ERP** | Energy aware event driven routing | ERP forms clusters only after occurrence of an event, between event detecting nodes and the sink. | Spectrum availabilities, Residual Energy levels, Eligible Nodes | Based on Residual Energy, available channels, neighbours, distance to the sink | Gateway Node | Network Lifetime, Energy consumption, packet delivery ratio, throughput, stable routing path |

| | | | | | | |
|---|---|---|---|---|---|---|
| **ESAC** | Event Driven Clustering | ESAC forms temporal cluster for each event, determines eligible nodes based on local position of nodes between event and sink. | Spectrum availabilities, Eligible nodes, Optimal clustering | Based on Node degree, available channels and distance to the sink | NA | Energy Consumption (with a cost of delay) |
| **EACRP** | Cooperative sensing and Self-organized distributed clustering | EACRP forms optimal number of clusters and routes the data through gateway nodes on stable paths. | Spectrum availabilities, Residual Energy | Residual Energy, available channels, neighbours, distance to the sink | Gateway Node | Longer network lifetime |
| **SCR** | Routing | SCR employs hybrid medium access. TDMA (time division multiple access) for intra cluster transmission and CSMA (Carrier sense multiple access) for inter cluster routing. | Spectrum Measurements, Residual Energy | Based on Spectrum Energy Rank | NA | Mean Packet Delay Energy Consumption |

## 3. Simulation Setup

The simulations are done on MATLAB. 150 C-R enabled sensor nodes are uniformly distributed in an area of 150 × 150 $m^{2.}$ The number of PUs taken are 20. From a pool of channels, a licensed channel is randomly selected. The unoccupied licensed channels are opportunistically used by SUs. Sink node is placed at (50, 50) location. The performance evaluation considers only licensed channels. The simulations are run for 1000s.

**Table 2:** Parameters used in Simulation

| **Setup Parameters** | **Value Taken** |
|---|---|
| Area | 150 m × 150 m |
| Location of sink | (50, 50) |
| Number of CR nodes | 150 |
| Number of PU nodes | 20 |
| Bandwidth of channel | 1024 Kbps |
| Size of packet | 512 B |
| Packet rate | 10-20 packets per sec |
| No. of events | 2-20 |

| | |
|---|---|
| Initial energy of node | 1000 Joule |
| Type of traffic | CBR |
| Transmission range of SU node | 100 m |
| Transmission range of PU node | 200 m |
| Number of events | 2-20 |
| Simulation time | 1000 s |

## 4. Results & Analysis

The performance of the studied protocols is discussed in terms of number of performance metrics like average end-to-end packet delay, average node energy consumption, packet delivery ratio. The existing protocols ECR, EACRP, ESAC, ERP and SCR are compared on these performance parameters. The simulations are done in MATLAB. For this purpose, we position the sensor nodes in an area of 150 × 150 m sq. m. randomly. The transmission range of Primary users and secondary users are set to 100 m and 200 m respectively. The number of channels taken for communication is 10. The parameters used during simulations are presented in table 2.

**Average end-to-end packet delay:** The average end-to-end packet delay is the time taken by a packet to travel from source node to sink node. We evaluate the end-to-end delay under different number of PU density, SU density and number of clusters. Fig. 2 shows the end-to-end delay of nodes by taking 150 SU nodes and 10 channels and varying the number of PUs. It can be noticed from the figure that all schemes have less average end-to-end delay when PU density is low. As we increase the number of PUs the average end-to-end delay increases. This is because as the number of PUs are high, there is less probability of SUs transmissions. ECR has the highest average end-to-end delay because in ECR the channel selection is done randomly due to which the route discovery rate is high. EACRP has lowest end-to-end delay because in this algorithm the data communication is from event node to sink node through optimal clusters and also it selects the data channels and gateway nodes which are highly stable.

Fig. 3 shows average end-to-end delay under different SU density. The number of SUs are varied from 20 to 200 whereas the number of PUs and channels are fixed to 10. It is again noticed from the figure that EACRP has the lowest end-to-end delay and ECR has the highest end-to-end delay.

Fig. 4 shows average end-to-end under different number of clusters. Here the number of PUs and number of channels are fixed to 10 and number of SUs to 150. And number of clusters are varied from 5 to 30. Since there is no clustering in ECR algorithm, it is a non-clustering algorithm so ECR is not considered in comparative analysis of end-to-end delay by varying number of clusters. It is noticed from the figure that as the number of clusters are increased the average end-to-end delay increases. EACRP has lowest end to end delay. This is because of the optimal number of clusters formed in EACRP. ESAC has the highest end to end delay. This is because of the delay caused in determining the eligible nodes to form clusters.

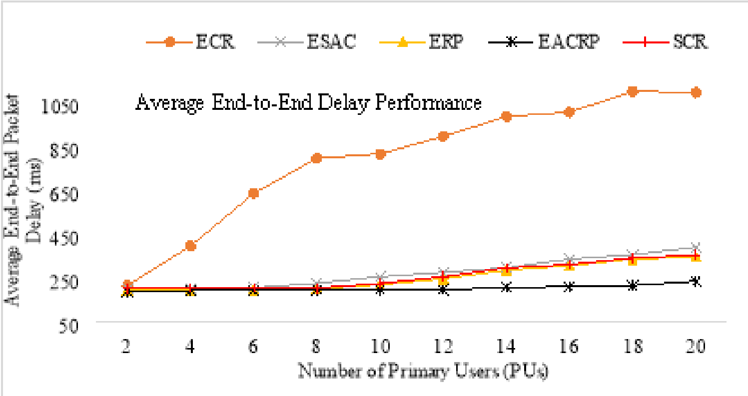


**Fig 2:** Average end-to-end delay with different PU density

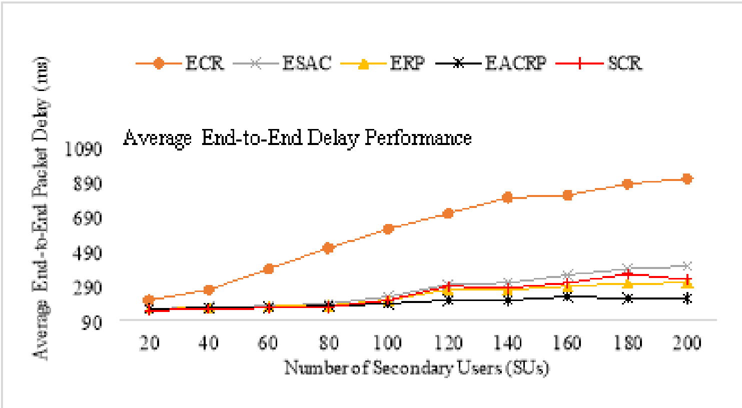


**Fig 3:** Average end-to-end delay with different SU density

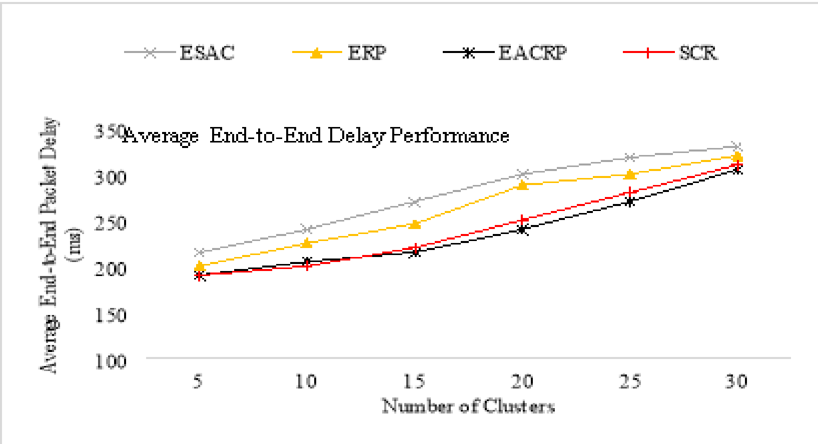


**Fig 4:** Average end-to-end delay with different cluster density

**Average node energy consumption:** For measuring the average node energy consumption the performance of different schemes is compared by varying number of PUs, number of SUs and number of clusters. The average node energy consumption is shown in Fig. 5, 6 & 7 under different PU density, SU density and different number of clusters respectively.

In Fig. 5, the number of PUs are varied from 2 to 20, SUs are set to 150, number of channels are kept to 10 and the impact of average node energy consumption is studied. It is observed that when the number of PUs are less, then number of clusters formed by SUs is less, and under low number of clusters the distance between cluster head and nodes is high and hence it causes high average energy node consumption. Whereas, when the number of PU density increases large number of different clusters are formed which in turn again causes high energy consumption. Minimum energy consumption is achieved with optimal number of clusters. The highest average node energy consumption is that of ECR. This is because ECR is a non-clustered approach so it does not form clusters and involves all the nodes in the communication. Hence it consumes more energy. It can be deduced that as the number of PUs increases, the average node energy consumption also increases.

In Fig. 6, the number of SUs are varied from 20 to 200 while keeping PUs and channels fixed to 10. ECR has the highest average node energy consumption because all the nodes participate in routing in this approach. Whereas, EACRP and ERP have less average node energy consumption because in ERP clusters are formed only when event occurs and in EACRP optimal number of cluster formation brings energy efficiency.

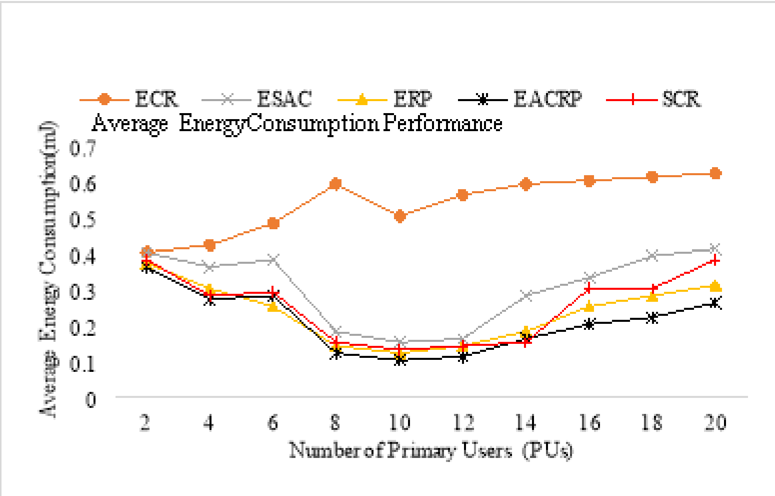


**Fig 5:** Average energy consumption under different PU density

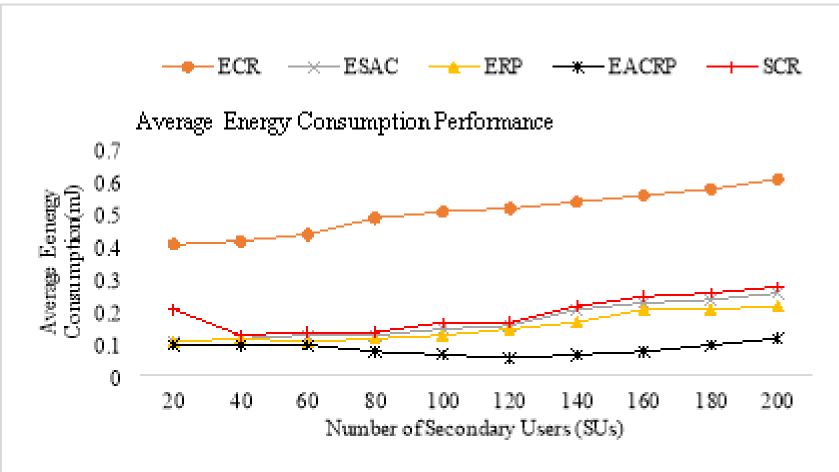


**Fig 6:** Average energy consumption under different SU density

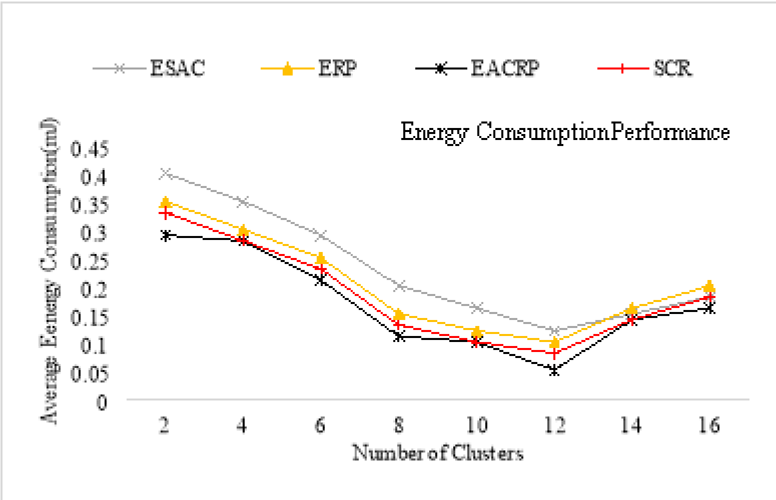


**Fig 7:** Average energy consumption under different cluster density

In Fig.7, for studying the impact of average node energy consumption by varying number of clusters we have assumed that the transmission range of sensor nodes is 100m, primary users deployed in the network in a uniform manner are 10 and number of CR nodes taken are 150. The clusters are varied from 2 to 16. It is observed that minimum energy is consumed when the number of clusters are between 12 and 13. It is seen that in all the approaches, when the number of clusters is 12, the approaches have minimum node energy consumption due to the reason that under this setup optimal number of clusters is 12. It is seen that the average node energy consumption is high for clusters 2-8. This is because when the number of clusters are less, the cluster size is large and the distance between the cluster head and the nodes is large resulting in high energy consumption for intra cluster communication. Also, as the number of clusters increases the average node energy consumption increases as seen from the figure in case of varying clusters from 14 to 16.

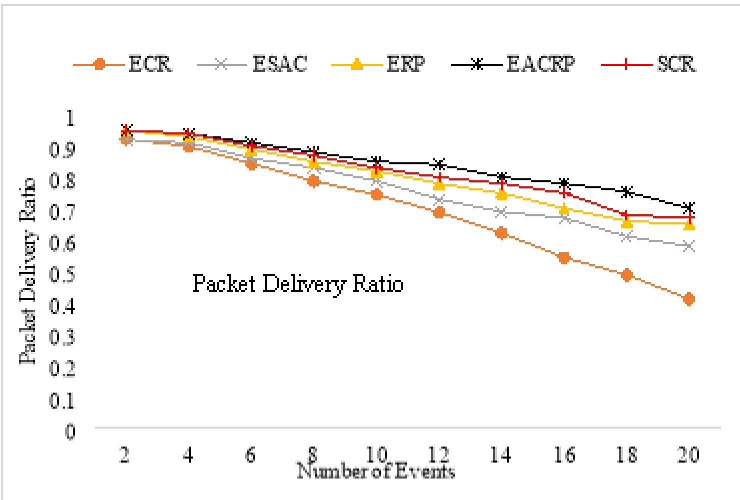


**Fig 8:** Packet Delivery Ratio

**Packet Delivery Ratio:** Packet delivery ratio is defined as the ratio of total number of packets received by the sink to the total number of packets sent in the network. The network has a better capability of transmitting data if the value of packet delivery ratio is high. Lower the rate of appearance of PU, lower will be the breakage of routes and hence there is decrease in packet drops and increase in packet delivery ratio. As seen from Fig. 8, as the number of events in the network increase, the packet delivery ratio decreases. This is because when a greater number of PUs are active there is a decline in the connectivity among the nodes. Greater the number of events, greater will be the transmissions, collisions and interferences and hence lower will be the packet delivery ratio. EACRP approach has the highest packet delivery ratio because this protocol chooses very stable gateway nodes. ECR has the lowest packet delivery ratio. The PDR (packet deliver ratio) of ESAC is higher than ECR because this approach do not consider PU activities during the allocation of channels. ERP and SCR has higher packet delivery ratio than ESAC because there is less probability of route failure in ERP and SCR than ESAC.

## 5. Conclusion

As compared to wireless sensor networks, routing in cognitive radio networks imposes unique challenges. This is because of the spectrum aware feature in these networks. This paper presented a brief description of five routing protocols of cognitive radio networks. The performance of these protocols is studied under same set of assumptions. The performance is compared in terms of average end-to-end packet delay, average node energy consumption and packet delivery ratio. There are a number of factors which affect the performance of these routing protocols. These performance parameters are studied by varying number of primary users, number of secondary users and number of clusters. This study motivates to design energy efficient spectrum aware routing protocols that address the unique challenges of cognitive radio networks. We plan to investigate this in our future work.

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