CHAPTER 5: COGNITIVE RADIO ENABLED IoT NETWORKS

In this chapter we have considered IoT application and tested how cognitive radio technology can be integrated in IoT for its better working. With the recent emergence and its wide spread applicability Internet of Things (IoT) is placing pressure on network resources and most importantly on availability of spectrum. Spectrum scarcity is the issue to be addressed in networking within IoT. Cognitive radio is the technology which addresses the problem of spectrum scarcity in an efficient way. Equipping the IoT devices with cognitive radio capability will lead to a new dimension called cognitive radio enabled IoT devices. To achieve ON-demand IoT solutions and interference free communications cognitive radio enabled IoT devices will become an effective platform for many applications. As there is high dynamicity in availability of spectrum it is challenging for designing an efficient routing protocol for secondary users in cognitive device networks. In this work spectrum quality and spectrum availability based on two parameters called global information about spectrum usage and instant spectrum status information is estimated. Enhanced spectrum sensing is used at each and every node for better probability of detection. For estimating spectrum quality and availability novel routing metrics are introduced. To have restriction on the number of rerouting and to increase the performance of routing, in our proposed routing metric only one retransmission is allowed. Then, two algorithms for routing are designed for evaluating the performance of routing, and it is found that the bit error rates of proposed algorithms (nodes are dynamic) have decreased a lot when compared to conventional methods (nodes are static) and throughput of proposed algorithm also improved a lot.

5.1 Introduction

In the existing wireless and cellular networks only few devices are connected viz., tablets, smart phones and laptops. But Internet of things (IoT) includes many variety of sensors like health monitoring devices, autonomous cars, home appliances, environmental sensors, smart meters and many [117], [118]. Concept of IoT enabled human to machine and machine to machine communications are discussed in [119].

There are so many application areas in IoT paradigm which includes smart manufacturing and precision agriculture. In order to develop the IoT solutions lot of work is to be done to design networking components. As the sensors in IoT possess different software, hardware and network types, refinement of networking components is required in order to work together.

As deployment of devices and mobile applications are increasing day by day the unlicensed Industrial scientific and Medicine (ISM) bands are crowded heavily. The Federal communications commission has mentioned that most of the spectrum is static allocated in certain geographical regions and hence large portions of the spectrum are underutilized [120]. To have an efficient usage of spectrum cognitive radio has been introduced [121-123]. In cognitive radio networks (CRNs) primary users and secondary users coexist to transfer their data. Secondary users are usually cognitive devices which will sense the surroundings and make an opportunistic decision on which band they have to transfer their data packets. In doing so, secondary users must not interfere with primary users. Whenever there is a hint of primary user coming back, secondary user has to switch the spectrum band to continue its data transfer.

Nowadays multi-hop cognitive device networks (CDNs) are gaining popularity [124]-[129]. In multi hop CDN, multiple IoT devices are present which are equipped with cognitive radio technology and communicate among themselves over the available spectrum bands which are opportunistically chosen from primary users in a multi hop manner [130]. In multi hop CDN the cognitive devices will perform spectrum sensing method and choose the appropriate channels which are declared idle by spectrum sensing methods and choose another channel immediately when the sensing algorithm identifies that primary user wants to use the channel. With the help of cognitive radio technology multi hop CDNs or cognitive enabled IoT devices will increase spectrum efficiency, utilization of spectrum and network lifetime [130], [131].

Amongst different research surveys in networking, routing plays an important role and hence it has got attention in research groups. In order to transfer data packets from source to destination routing plays an important role. Much of research has happened on routing techniques [132]-[135] for wireless sensor networks and existing CDNs. If these routing techniques are directly implemented in multi hop CDNs or cognitive enabled IoT devices these routing techniques will fail. Because of mobility of devices in the network, routing in multi hop CDNs becomes a challenging task [136] – [138]. First, in multi hop CDNs there won't be any common channel which could be used by all secondary users (SU) between source SU and destination SU. In the traditional and existing routing schemes the goal was to identify path which can be accessed by all the secondary users with one common available channel. On the other side there exists a path where neighboring secondary users will share a common available channel even though global common channel does not exist along the path. Second, as the availability of spectrum changes randomly for secondary users it is preferable to estimate spectrum availability from local and global views. It is known fact that rerouting is required whenever primary user comes back while secondary user is transmitting its data packets. Hence in multi hop CDNs routing performance will greatly decrease due to rerouting and spectrum hand offs. Therefore in our work it is important to select a routing path which has less number of rerouting which requires consideration of temporarily unavailable spectrum. Lastly for optimal selection of routing path, maintenance of spectrum quality (spectrum average idle time, spectrum bandwidths) is required. A selected path may have multiple bands with their own spectrum availability and quality. When the data transmission is happening, the band which is chosen will become invalid with the arrival of primary users. Instantly new band has to be chosen which might be available due to primary users exit. Hence it is required to assess the quality of available and unavailable spectrum for a good routing scheme. The above mentioned scenarios are kept in mind while designing a routing scheme in Cognitive radio enabled IoT devices.

5.2 Related Works

With the introduction of accessing the spectrum dynamically researchers have started utilizing cognitive radio technology in CDNs/Cognitive radio based IoT. Good amount of research can be found in [130], [139]. By applying different metrics in routing several approaches are proposed [123], [138], [139]. Therefore routing on demand opportunistically comes under two categories:

5.2.1 Routing on Demand in CDNs

From a global point of view selection of a path from multiple paths is a prime focus in routing on demand CDNs (Adhoc On Demand Distance Vector (AODV) [140]). In AODV, path can be discovered on demand by licensed user. In [138] a routing protocol is designed which is aware of spectrum availability (SEARCH-spectrum aware routing protocol for cognitive adhoc networks) where broadcasting of route requests on each channel is done using Greedy Geographic strategy, then the secondary user at the destination choose a path which has least number of hops to the source and minimum interference with primary users. As SEARCH algorithm doesn't have ability to estimate availability of spectrum, route selection is correlated with changes in application. In [141] a shortest path algorithm with spectrum hand off scheduler and rerouting technology is proposed which can be applied on the primary users arrival. In [139] authors proposed an estimation technique of the spectrums available between any two secondary users which leads to success probability maximization in multi hop networks. It is known fact that the availability of spectrum is dynamic, due to this the rerouting will increase in [139] which causes degradation of route performance. Geographic routing protocol is proposed in [142] where secondary user will choose an optimal path which is shortest in distance to destination. This algorithm will perform well in sparse applications where there is less activity of primary users but it will behave poorly in applications where the availability of spectrum is dynamic.

5.2.2 Opportunistic Routing in CDNs

The prime idea behind routing opportunistically in CDNs is to find out the neighbors who has priority orders for every intermediate node. At the network layer each secondary user broadcasts data packets to the neighbors, whereas only one secondary user will respond and act as next relay in MAC layer. In [143] a routing protocol is proposed in which relay node priority is calculated by its spectrum position and quality such as channel reliability, channel throughput and distance to destination. A cross layer distributed opportunistic routing protocol is proposed in [144] where the selection of relay and sensing of spectrum are considered jointly for decreasing the delay in delivery rate. In [145] a routing protocol is proposed which is aware of spectrum and energy efficient to analyze the problem of optimizing spectrum usage efficiency and dynamics of spectrum. With this technique energy consumption and delivery latency are decreased. Though retransmissions are decreased by using broadcasting mechanisms in opportunistic routing methods they fall sometimes in local optimization in CDNs because availability of spectrum is not considered from global and local point of view.

5.3 System Model of Cognitive Radio Based IoT Networks

In this section we first give network model of cognitive radio based IoT networks (CDNs) and then present routing metrics followed by the problem formulation. In the previous works [146] the network model considered was multi hop CDN consisting static primary users and secondary users. In our work we are considering multi hop CDN with dynamic primary users and secondary users. At each and every secondary user node enhanced spectrum sensing [82] is adopted for greater probability of detection instead of conventional energy detector. In the proposed CDN model, transmission of data will happen in multi hop manner when the distance from source and destination is greater than the transmission range of the source. To have easier routing, we consider, for any pair of secondary users there is at least one route path is present.

In a CDN only one channel can be accessed by each primary user from an orthogonal channel set C= {C1, C2, …..Cn}. A common control channel exists from which controlling messages of secondary users are exchanged. With the addition of common channel, every secondary user equipped with half duplex CR [147] can access and switch to any primary user channels which are available. In a CDN, the secondary users find out the frequency channels that are not utilized by primary users with the help of spectrum sensing. Every secondary user makes a choice of possible control channel after sensing spectrum holes. The possible control channel is selected based on a quality metric which is interference-power constraint [148] imposed by primary users. The interference constraint is less with a higher channel quality such that the channel is available for more time for cognitive user transmission. Each secondary users prefer frequency channels with better quality as the control channel. As mentioned before secondary user has to vacate the channel and search for one more available channel whenever primary user comes back and claims for the channel. For easy routing on a given channel secondary users are assumed to transfer data with fixed transmission power. An ON-OFF model is proposed in the reference [149], where a renewal process is introduced to formulate the activities of primary users. In ON-OFF model channel accessing follows a poisson process, where ON period is represented as T^k_{ON} with λ_k rate and T^k_{OFF} is represented for OFF period with μ_k rate. Hence T^k_{ON} and T^k_{OFF} are used to represent primary users availability and non-availability to access channel k.

5.4 Routing Metrics

In this section routing metrics are discussed from statistical point of view only, where no current spectrum available information is not considered, and then we introduced proposed routing metrics by considering global statistical data and current spectrum availability (instant information).

5.4.1 When Instant Information is not Considered

With the help of alternating renewal process method limiting probability can be obtained. Where at any given time a primary user i cannot access a channel k. We represent it as $P^k_{OFF,i}$ which can be given as

$$P^k_{off,i} = \frac{\mu_{i,k}}{\mu_{i,k} + \lambda_{i,k}} \quad (5.1)$$

Where $\lambda_{i,k}$ and $\mu_{i,k}$ denotes the rate of PU i using k and PU i not using k respectively. The meaning of limiting probability is inferring that a given PU i does not utilize channel k at any time with probability $P^k_{off,i}$ even if we do not obtain the actual spectrum usage information about PU i on channel k. similarly, $P^k_{on,i}$ is denoted to infer the probability a given PU being in active state over a given channel.

With the help of shannon capacity theorem the transmission rate which is achievable through channel k from secondary user i to its neighboring secondary user is given as follows

$$V_k = B + \log_2(1 + \frac{P^k_{i,j}}{BN_0}) \tag{5.2}$$

Where $P^k_{i,j}$, N_0, V_k and B represent power received by secondary user j, thermal noise, transmission rate and channel bandwidth respectively. Usually $P^k_{i,j}$ is inversely proportional to distance between SU i and SU j and directly proportional to transmission power of SU i. As it is assumed that each secondary user has fixed transmission power, the rate of transmission is sensitive to distance between two secondary users. SU will take minimum S/V_k to transmit data over channel k, where S is the size of data and V_k represents achievable data transmission rate over channel k.

As it is known fact that secondary users has to empty the channel upon the arrival of primary user, and hence total transmission delay will increase. Therefore successful transmission probability is dependent on both spectrum availability time and required transmission time. From [139] the delivery success probability of secondary user i to its peer secondary user j can be given as

$$P_{suc}^{k}(i,j) = P(T_k \geq s / v_k) \quad = e^{-s/(v_k, \mu_k)} \tag{5.3}$$

Where V_k is the amount of transmission through channel k, μ_k is the rate of channel k which is unavailable and S is given as packet size.

It is clearly observed that the above metric considers statistical information about spectrum but not including the instant information about usage of spectrum, like if the channels are utilized by primary users or not. Existing routing metrics (e.g. [139]) will consider maximum probability of successful transmission but not considering the potential channels. As we all know that due to dynamicity of primary users arrival, retransmitting and rerouting will happen when the primary user comes back. It is known fact that retransmitting and rerouting will decrease the routing performance and increase the transmission delay. So in the proposed routing metric by considering above mentioned cases minimization of retransmitting and rerouting is done. Hence it will be better to consider spectrum usage which is calculated instantly and global information about spectrum in multi hop CDNs. Now we are going to propose our routing metrics based on the above discussed factors.

5.4.2 Proposed Routing Metrics

In a multi hop CDN secondary user will select a channel for transmitting its data packets from the set of available channels. When there is any interruption in the last data transmission, secondary user can always retransmit data packets on other channel if transmission delay is not considered. Therefore with the increased number of retransmissions, data transmission will succeed finally. Even in the case of one channel availability between two secondary users, transmission can be completed by secondary user waiting till channels next availability. But this will fail in real time applications because of time-to-live (TTL) limitation for any packet will be abandoned when TTL is equal to zero. That is why it is important to consider retransmission in routing in a multi hop CDN.

If a condition is considered that number of transmission is 1. On any two neighboring secondary users the transmission probability over all the available channels is given as 1-(1-p1) (1-p2)…… (1-pn). Where n stands for current available channels and $P_k = P^k_{suc}$ (i, j) is represented as delivery success probability from channel k. It is fact that with the increase in number of available channels delivery success probability also will increase. But the formula mentioned above is not accurate because the channel availability will change dynamically when transmission of data is happening.

As retransmission is restricted to 1 the delivery success probability from secondary user i to neighboring secondary user j on all channels is given as

$$P_{suc}(i,j) = P_0 + (1-P_0).\sum_{k=1}^{n-1}(V_k.\prod_{m=1}^{k-1}(1-V_m)P_k) \qquad (5.4)$$

Where n indicates channels among secondary users i and j, $P_0 = P^{k'}_{suc}(i, j)$ is the major success probability and V_k represents probability of remaining channel k available if the first transmission is failed. In our work secondary user will access channel which has major delivery success probability to enhance the probability of transmission.

If secondary user fails at the first time for transmitting data on channel k, channel availability will come under two cases: unavailable and available. By keeping in mind about the two states of k channel V_k is given as

$$V_k = \max(e^{-s/(2v_k\mu_k)}, \frac{\mu_k}{\mu_k + \lambda_k}) \tag{5.5}$$

Where $e^{-s/(2.V_k \mu_k)}$ indicates, on the failure transmission what is the probability that channel k still remains accessible, and $\mu_k/\mu_k+\lambda_k$ indicates probability of channel k remains accessible.

With the constraint of retransmission initial routing metric is presented which represents delivery success probability for a path P.

$$TSP_p = \min_{(i,j)\in P} P_{suc}(i,j) \tag{5.6}$$

Where (i, j) represents secondary user i and its neighbor secondary user j in path P.

If the packet is transferred in two attempts successfully then transmission delay from secondary user i to secondary user j using all the channels, $T_{(i,j)}$ [146] is given as

$$T_{i,j} = \frac{S}{V_0}.P_0 + (1-P_0).\sum_{k=1}^{n-1}((\frac{S}{2V_0}+\frac{S}{V_k}).V_k.\prod_{m=1}^{k-1}(1-V_m).P_k) \tag{5.7}$$

Where s/v_0 is given as average time over a channel with high transmission probability. Therefore value $s/2v_0$ is average time when the first transmission fails. Second, new routing metric in a path which estimates total average transmission delay in a path can also be obtained.

Transmission time delay over path P when a packet is transferred in two attempts, TTD_P is given as

$$TTD_p = \sum_{(i,j)\in p} T_{i,j} \tag{5.8}$$

Where TTD_P is the summation of transmission delays over all neighboring secondary users in the path *P*. Therefore both instant availability of spectrum and statistical availability of spectrum have been considered in the above routing metrics.

5.5 Problem Formulation

As per the discussions about two routing metrics, routing problem in CDNs can be viewed as the goal to optimize the routing metrics [146].

1) Under the condition that only one retransmission is allowed with delivery success probability metric can be resolved as follows:

$$\max_p TSP_p \tag{5.9}$$

2) Under the condition that only one transmission allowed with transmission delay metric can be resolved as follows:

$$\min_p TTD_p \tag{5.10}$$

5.6 Proposed Routing Algorithm

By considering both instant availability of spectrum information and statistical information about usage of spectrum, two new algorithms are proposed by including enhanced spectrum sensing at each and every node and mobility of secondary users when compared with [146]. One is success transmission probability (maximization) and average delay in transmission (minimization) based on the routing metrics discussed above.

5.6.1 Success Transmission Probability (Maximization)

In this routing algorithm the aim is to find the best route with respect to maximizing the delivery success by considering only retransmission. The source secondary user will broadcast the route request message (RREQ) through common control channel. The success probability of each secondary user can be obtained by (5.6) is added along the path in RREQ message. Destination will select one route from number of RREQ messages by calculating the optimal path which has good success probability in delivering the data packets, along the path which is been chosen with the help of route reply message.

It is observed that the first method determines only the best path over which success probability is maximum in delivering data packets and will not determine actual channels in that particular path. As the spectrum resources are dynamically available each relay node can choose the channel with maximum success probability in delivering data packets from the channels which are all available. If there is a case that there are no available channels rerouting is done by relay secondary user.

5.6.2 Average Delay in Transmission (Minimization)

In this routing algorithm the path is chosen by applying second routing metric. The selection of route is same as the above method where secondary user source will first broadcast the RREQ message through common control channel. The additional inclusion in this method is during broadcasting, information about spectrum regarding transmission delay by using (5.7) is included in the RREQ message along the path. After collection of all the RREQ messages the destination will select one route path which has less average transmission delay. The destination then construct a route reply message and reply along the path chosen.

5.6.3 Pu's Reclaim, Node Mobility and Failure

Reclaim of licensed channels by primary users and SUs mobility leads to breaking of established routes. A node which moves out of range of its neighbors due to dynamic nature and PU reclaim will be detected, e.g. by link layer. In our work, affected nodes will start a limited route discovery starting from the affected node if it is second time interruption. We can reduce the disruption paths due to route breakage before the path is completely broken with the help of mobility models by estimating movement of the node. It should be noted that disrupted routes will expire by themselves and hence no action is required to remove them.

5.6.4 Updation of Route

With the primary user coming back there will be interruption in the data transmission which leads to rerouting and retransmission. Hence in this work, we consider that the next node which relays the information will remain same. For instance, two secondary users i and j are communicating over channel k will get interrupted on the arrival of primary user. If this interruption is happening second time for secondary user i during transmission, secondary user i will reroute using method 1 or method 2. If the interruption is first time for secondary user i during transmission, secondary user i will attempt for retransmission.

Algorithm 1: (Success Transmission probability (Maximization))

Input: Parameters in multi-hop CDN, destination SU D, source SU S.

Output: Route path with the largest delivery probability of success

1) Source SU S constructs RREQ messages m

2) Source SU S broadcasts m through CCC channel to the neighbouring Sus.

3) for all each SUx which receives m do

    if SUx is the destination SU D then

        SUx obtains TSPp from equation (5.6)

Else

        SUx obtains PSUC(i,j) by equation (5.3)

        SUx forwards m over CCC channel

    end if

end for

SU D waits for a predefined time upon receiving the first replica of message m

SU D determines the best route path which has the largest TSPp by using equation (5.9)

SU D sends an acknowledgement back to S along the chosen path

Algorithm 2: (Average delay in transmission (Minimization))

Input : Parameters in multi-hop CDN, destination SU D , source SU S

Output: Path with the minimum expected transmission delay source SU S constructs RREQ messages m

1) Source SU S broadcasts m through CCC channel

2) for all each SU x which receives m do

    if SU x is the destination SU D then

        SU x obtains TTDp by equation (5.8)

    else

        SU x obtains Tij by equation (5.7)

        SU x forwards m on over CCC channel

    end if

end for

SU D waits for a predefined time upon receiving the first replica of message m

SU D determines the best route path which has the minimum TTDp by using equation (5.10)

SU D sends an acknowledgement back to S along the chosen path

5.7 Results and Discussion

A Cognitive radio based IoT environment is created and simulated using MATLAB software for the evaluation of routing performance by using our proposed routing algorithm. The comparison results are between static deployment, static deployment with local and global spectrum information [146] and proposed dynamic deployment with local and global spectrum information. The network topology is adopted from our previous work (Chapter 3) [148] where mobile relays were either pedestrian based relays, vehicular based relays or a combination of both. The simulations are run by 100 times by varying the number of nodes in the network and the confidence level is 95% which can be observed in [148 fig 2-fig 4]. Considering the dynamic nature of these mobile relays, the focus was on capturing the effect of these mobile relays on the route sustenance and connection sustenance of an established connection. During setup phase by applying our proposed metrics (delivery success probability and transmission delay metric) the route is established between source and destination. Once the route is established it so happens that licensed user can come back or as the nodes are mobile the intended cognitive user relay may move out of coverage area. In [148] authors are going to get a reliable and feasible Cognitive User relays. In [148 fig 2-fig 6] by varying SNR's , considering path loss exponent and by varying the distance of mobile relay Cognitive users, from the base Station, the above mentioned parameters success rate is presented. The results in [148 fig2-fig6] show that, by including the mobile relays beyond the coverage of network the route sustenance time and connection sustenance time improves substantially and also helps in extending the service area, network lifetime and performance of the network. With the help of this tested network [148], and by the inclusion of proposed routing metrics bit error rates are calculated. BER and throughput are the parameters which are used to define the quality of service of the system. As secondary users don't have any licensed spectrum, they have to sense and capture the spectrum which are not used by primary users. Whenever primary user comes back Secondary user has to leave the band and search for another band which is free, without causing interference to primary user. In these scenarios the BER will be more and throughput of the system also will be less when compared to Primary user. The aim of this work is to decrease the error rates and improve the throughput of secondary network. Figures 5.1,5.2.5.3 and 5.4 shows the improvements. With the help of enhanced spectrum sensing, availability of local and global spectrum information will help the secondary networks overall performance. In the proposed work the parameters are checked at various SNR's and an improvement is observed in the throughput for the proposed algorithm.

It is clearly evident from the results presented below that, with the inclusion of enhanced spectrum sensing [82] at each and every node has decreased the Bit error rate (BER) and increased signal to noise ratio (SNR) and throughput. As the route between source and destination is in a multi hop fashion, the BER between two neighboring nodes at the end of a link is denoted as BER_{link}, which depends on SNR ratio at the receiving node. It is observed from the considered network communication scenario with random topology, a multi-hop route from a source to destination has n_h links of lengths $r^{(i)}_{link}$, i=1,….,n_h. $BER^{(i)}_{link}$ is the BER calculated at the end of the i-th link (the SNR at the receiving node of this link depends on the link length) assuming that (i) at each intermediate node there is regeneration; and that (ii) In successive links uncorrelated errors accumulate, it is possible to show that the BER at the end of the n_h-th link of the multi-hop route, denoted by $BER^{(n_h)}$, can be expressed as [150]

$$BER\left(n_h\right) = 1 - \prod_{i=1}^{n_h}[1 - BER_{link}(i)] \tag{5.11}$$

Gauss-Markov Model is considered as mobility model of nodes with temporal dependency. In the simulation region we have considered 40 secondary users and 10 primary users. The average spectrum usage period of primary users varies from 0.5ms to 25ms, the bandwidth of each channel is assumed to be B=0.5MHz and the data packet size is 2KB. It is also assumed that, if it is not stated the detection probability is 90% and for better Quality of service the minimum data requirement is 0.3bps/Hz.

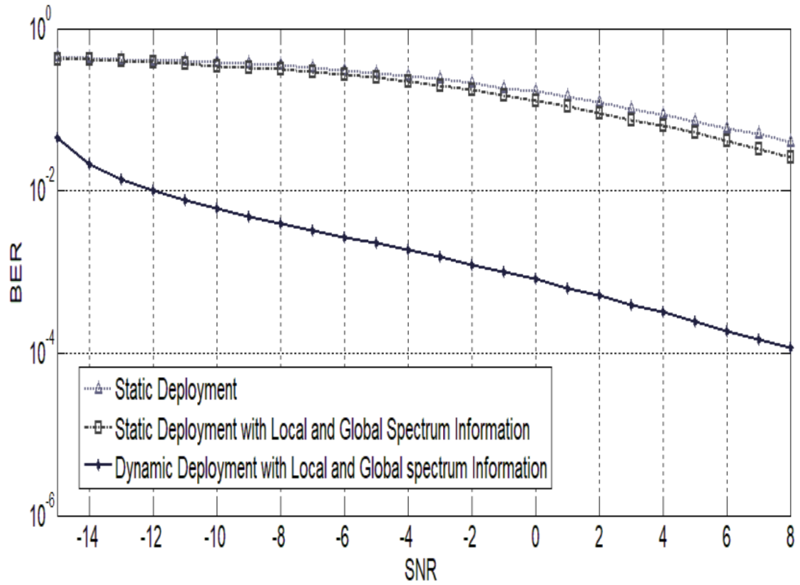

Figure 5-1 BER vs. SNR of varying deployments with Local and Global Spectrum information

From Figure 5.1 it is clearly observed that the BER of dynamic deployment with local and global spectrum information has decreased when compared with static deployment and static deployment with local and global spectrum information. This is due to usage of enhanced spectrum sensing in the proposed algorithm at each and every node. Hence false alarms and missed detections are decreased and have impact on BERs. It is also observed that at low Signal to Noise Ratios (SNR) our proposed algorithm is performing well.

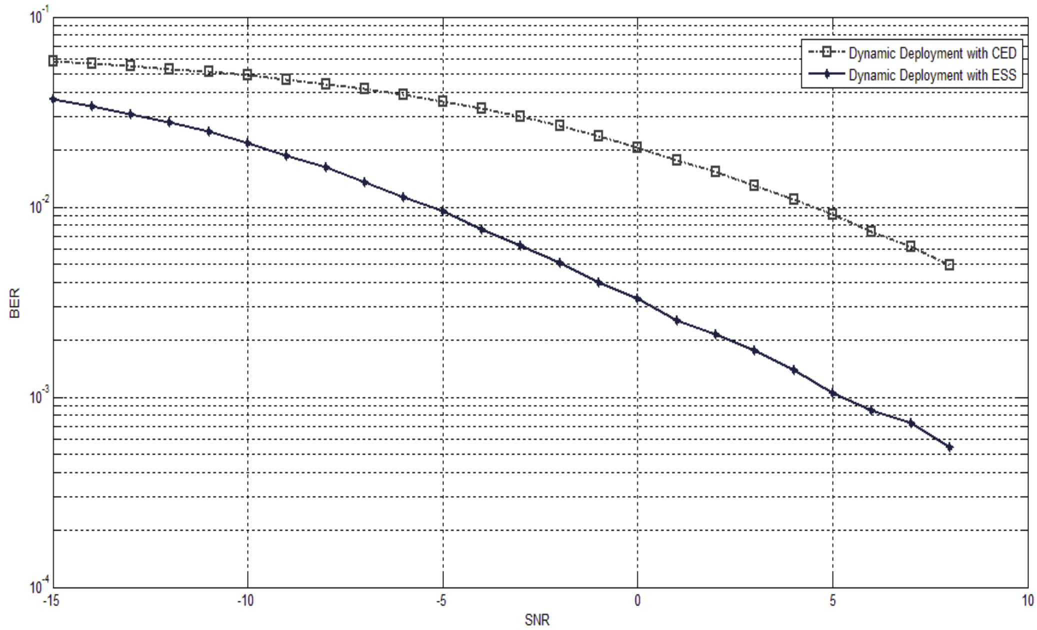

Figure 5-2 BER vs. SNR with CED and ESS at each and every node

In Figure 5.2 the comparison is between dynamic deployment with conventional energy detector (CED) and dynamic deployment with enhanced spectrum sensing (ESS) [82]. In [82] probability of false alarms and enhancement of probability of detection is clearly discussed with CED and ESS on cognitive cell networks. As probability of false alarms are more in CED the detection rate is less. If there is issue in the spectrum sensing itself, obviously disruption paths (PUs reclaim) will increase a lot and there is impact on BER which is evident from Figure 5.2. We have tested our routing algorithm on CED and ESS on a dynamic deployment for comparison. The plot is analyzed between BER and SNR. It is observed that how enhancement in spectrum sensing algorithm plays a role in decreasing the BERs. In our proposed work, with the proposed routing metrics we simulated dynamic CR based IoT network with CED and ESS to observe BERs.

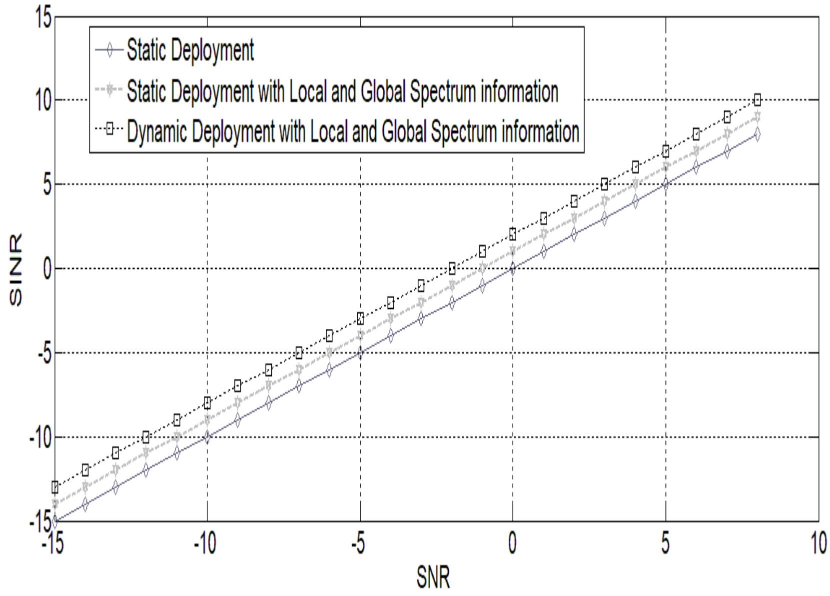

Figure 5-3 SINR vs. SNR of varying deployments with local and global information

The Figure 5.3 is plotted for SINR and SNR between static deployment, static deployment with local and global spectrum information and dynamic deployment with local and global spectrum information. SNR is defined as the total signal to noise ratio of the dynamic deployment. In our simulation different SNR's from -15dB to 10dB are considered and tested. SINR is defined as the power of certain signal of interest divided by the sum of interference power from all other interfering signals and the power of some background noise. This is considered because the interference can happen with primary user coming back and due to false alarms and missed detections of spectrum sensing methods. As ESS is used in this work, the interferences caused due to false alarms and missed detections will be decreased, and hence it is observed that dynamic deployment with local and global spectrum information has high SINRs when compared to existing and conventional methods.

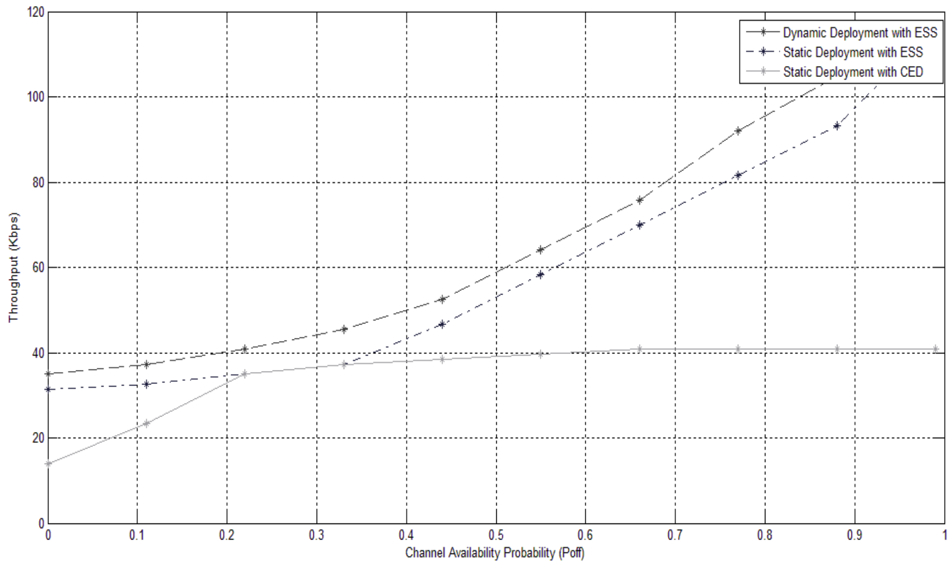

Figure 5-4 Throughput vs. Channel availability probability of varying deployments

The Figure 5.4 is plotted between channel availability probability and throughput. It is observed from the plot that the throughput of dynamic deployment is more when compared with static deployment with ESS and CED. As the availability of local and global spectrum information is available it would be more accurate to get the best reliable channels and hence the improvement.

5.8 Conclusions

Due to the dynamicity in the availability of spectrum channels, routing will become difficult but an important issue to consider in Cognitive radio enabled IoT. In this work, by considering availability and quality of spectrum in the perspective of instant and global information about spectrum, two routing metrics are proposed in Cognitive radio enabled IoT. In the first metric, by considering only one retransmission, to decrease rerouting, delivery success probability is defined. In the second metric average transmission delay over all channels is defined. The proposed routing algorithm is then designed by considering the above two metrics, then with the help of ON-demand routing style, optimal route is calculated. In this work we have considered dynamic nodes, and

ESS is applied at each and every node to minimize bit error rates and to maintain good SINR.