CHAPTER 3: ROUTE AND CONNECTION SUSTENANCE IN COGNITIVE MOBILE SECONDARY USER NETWORKS

In the earlier chapter, we have developed an enhanced spectrum sensing method. The results indicate that, with the inclusion of enhanced spectrum sensing method, there is an improvement in detection rate which will impact the Quality of Service in the CRN.

As discussed in the introduction chapter, the throughput achievable for the secondary user is dependent on the route sustenance time and connection sustenance time available in a CRN network. The main constraint in CRNs for having a reliable route for secondary user emerges from the fact that: when primary user comes back, the secondary user has to vacate the current band and sense for other free licenced band. During this period of identifying and latching onto a new band and consequently a different route, some packets may get lost and latency also will increase. In this scenario, due to dynamic nature of the mobile secondary users the route sustenance time and throughput of the network will be of importance for successful secondary network operation. These issues are addressed in this chapter and a solution is proposed.

Thus, in this chapter, the aim is to find the feasible relay. This study is taken up by modelling an appropriate CRN scenario and extensive simulation on same. For simulation purpose, we have considered vehicular and pedestrian traffics to calculate route sustenance time and connection sustenance time.

3.1 Background

Based on the theory of partially observable Markov decision processes a framework is provided in [77]. Transition matrix of channel availability is known to CU's which is anticipated to follow a markov chain. The dynamic channel selection problem is stated as a multi-armed bandit problem in [78], [79]. By assuming recall (i.e., one of the formerly sensed channels) and guess (i.e., channel which is not sensed yet), channel searching and transmission policy [80], [81] are allowed. It is apparent that, whenever primary user accesses the wireless network, the secondary user has to vacate the corresponding channel in the licensed band and search for another potential channel. The secondary user's decision should also account for path loss in the wireless environment. Due to the natural diffusion of the signal wave front, absorption, and diffraction signal will attenuate, and called as Path loss. Depending on these factors, the CU, who is away from base station can either connect directly to a base station, or, create a two-hop link using a relay CU.

In this chapter, secondary users are used as relays to have end to end communication and the mobile secondary users are not part of fixed wireless system. A unique feature of mobile CU relays is that their location cannot be determined. Performance metrics like likelihood of establishing a connection and the anticipated duration that a connection sustains are derived. Enhanced spectrum sensing [82] is used by CU's to find the reliable spectrum.

3.2 System Model

In this chapter the system consisting of a Base Station (BS) and an end user with multiple probable cognitive user relays is shown in Figure 3.1. The area covered by the BS, relaying is not required and is normalized to a unit radius of circle by positioning BS at the origin. Location coordinates (r,Θ) are given to the fixed end user hence the coverage is normalized, r>1 corresponds to users who are away from BS while r≤1 corresponds to end user with in the circle of unit radius.

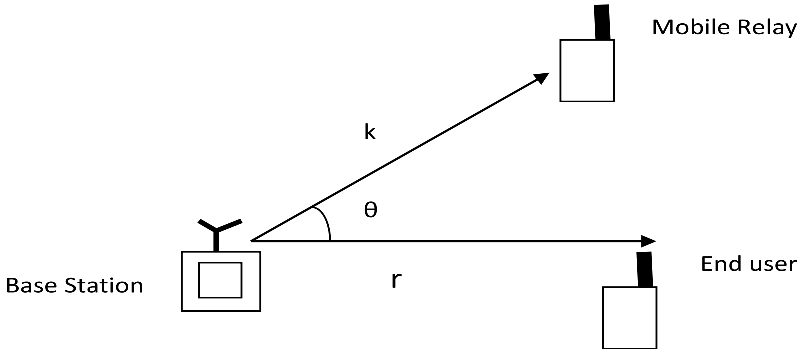

Figure 3-1 Triangle formation of End user, Mobile Relay and Base station

To determine relay mobility M/M/∞, queuing model is used. In our work downlink transmission is considered at the edge of coverage area. BS is able to generate a received SNR of Υ_1 at unit distance. Likewise each relay will generate a received SNR of Υ_2. It is assumed that relays are not much powerful than the BS ($\Upsilon_1 > \Upsilon_2$). Half duplex transmission and a time division decode-and-forward relay strategies are implemented. The channels are modelled as additive white Gaussian noise (AWGN) with loss attenuation path. The path loss exponent α, ($2 <= \alpha <= 4$) is considered.

3.3 Coverage Extension

A minimally acceptable spectral efficiency is termed as connectivity. Assuming that end CU is away from BS area (r>1), the modelled CU relay can extend coverage to it only when a two hop connection from base to relay of end CU with a spectral efficiency is as high as transmitting directly from BS to receiver at cell boundary[83].

3.3.1 Analysis

CU relay at distance k from the BS forms an angle Θ between end user and CU relay at the BS. The distance between both of them is $\sqrt{(k^2 + \mathrm{r}^2 - 2krcos\theta)}$ **.** The time required for two hop transmission is given as [83]

$$T_{2h} = \frac{1}{\log(1+\Upsilon_1 r^{-\alpha})} + \frac{1}{\log(1+\Upsilon_2 (k^2+r^2-2kr\cos\theta)^{-\frac{\alpha}{2}})} \tag{3.1}$$

The time taken for direct transmission is given as

$$T_{ref} = \frac{1}{\log(1+\Upsilon_1)} \tag{3.2}$$

For an end user to have extended coverage, it is required to maintain $T_{2h} \leq T_{ref}$. By adopting this inequality solved in [83] we get

$$\cos\theta \geq -\frac{\left[\frac{1}{\Upsilon_2} exp\left(\frac{1}{\frac{1}{log(1+\Upsilon_1)} - \frac{1}{log(1+\Upsilon_1 k^{-\alpha})}}\right) - \frac{1}{\Upsilon_2}\right]^{\frac{-2}{\alpha}}}{2kr} + \frac{k}{2r} + \frac{r}{2k} \triangleq f(k) \tag{3.3}$$

Above equation clearly defines the relay CU at location (k, Θ) is feasible. For k ∈ (0, 1), and if *f(k)* > 1 there is no feasible location. All positions within the angle [-*arccosf(k)*, *arcosf(k)*] are feasible when *f(k)* ≤1. Area of feasible region is calculated as [83]

$$A = \int_0^1 2k\ arccos[min\{1, f(k)\}]\ dk \tag{3.4}$$

$$ds = \sqrt{dk^2 + k^2 d\theta^2} = \sqrt{1 + k^2 \left(\frac{d\theta}{dk}\right)^2}\ dk \tag{3.5}$$

$$\frac{d\theta}{dk} = \frac{d}{dk}\arccos f(k) = \frac{-1}{\sqrt{1-f^2(k)}}\, f'(k) \tag{3.6}$$

Integrating *ds* in (3.5) over the region where *f(k)* < 1, the length of the perimeter of the feasible region is calculated as

$$L = \int_0^1 2I_{[f(k)<1]}\sqrt{1+\left(\frac{r\, f\prime(k)}{\sqrt{1-f^2(k)}}\right)^2}\, dk \tag{3.7}$$

3.3.2 Outage Probability

For a given out of coverage end user, the number of feasible relays is a poisson distributed random variable. Hence the probability that there are no feasible relays is given as

$$\mathrm{P_f} = \exp(-\rho \mathrm{A}) \tag{3.8}$$

where A is area given in eq(3.4) and ρA is the mean. In the above equation the end user distance, relay SNR at unit distance and base station, and channel propagation conditions are captured by the area of the feasible region A, while the density parameter ρ characterizes the relay availability.

3.3.3 Route Sustenance Period

The next criterion is the duration until how much period route sustains once the route is established. It's clearly discussed in [84][85] that average number of relays move out of region / unit time is given as

$$\mathbb{E}[\mathcal{M}] = \frac{\rho \mathbb{E}[v] L}{\pi} \tag{3.9}$$

Where L is the length of the region's perimeter and $\mathbb{E}[\nu]$ is the average speed of the CU relays. In our work L is given by (3.7). In addition, the average number of CU relays in the feasible region is given by $\mathbb{E}[N]$ =ρA, by applying Little's law [86]. The average relay sustenance time is

$$\mathbb{E}[\tau] = \frac{\mathbb{E}[\mathcal{N}]}{\mathbb{E}[\mathcal{M}]} = \frac{\pi A}{\mathbb{E}[\nu]L} \tag{3.10}$$

3.3.4 Connection Sustenance Period

If the current mobile CU relay is no longer feasible due to its movement we have to re-route again. The term connection sustenance period provides insight into how long a session can be maintained by re-routing. The figures 3.2 and 3.3 explains the scenario of PU communication between source and destination with the help of cognitive user relays in overlay mode. The flow of simulation is as follows:

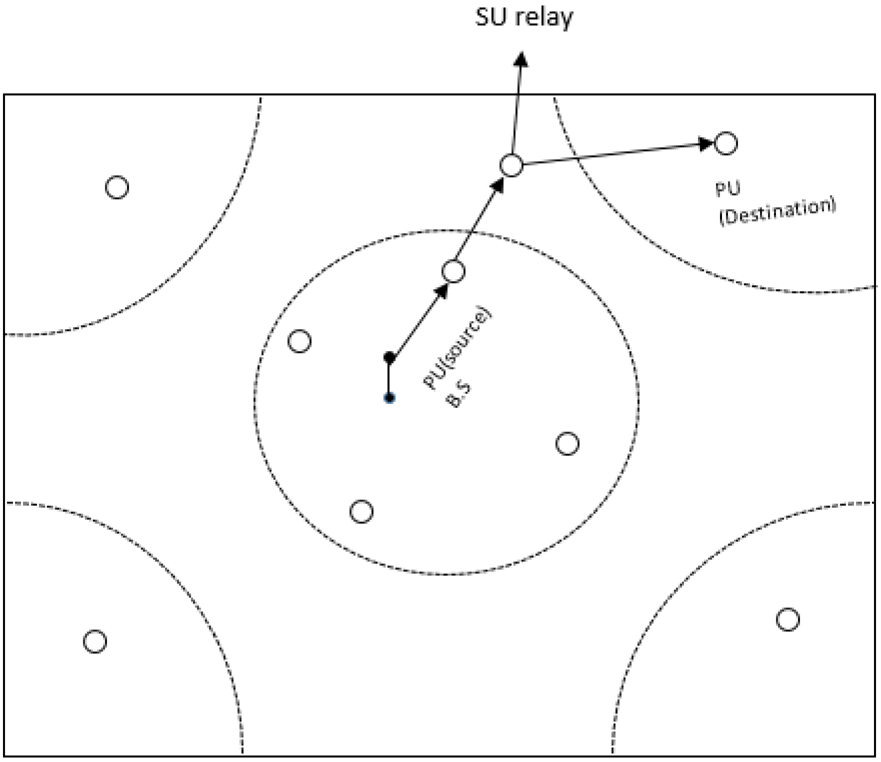

Figure 3-2 First scenario of source communicating with destination via CU relay

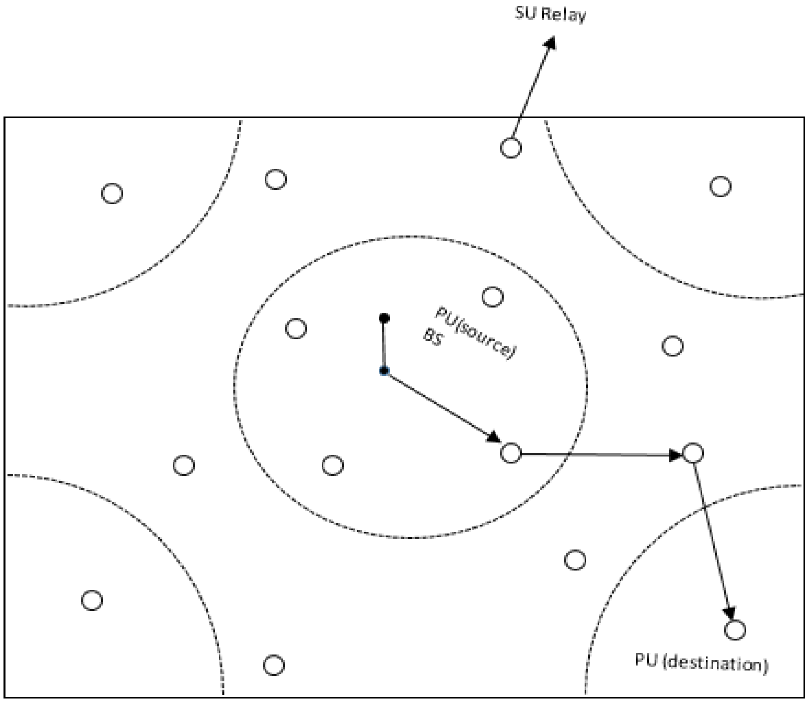

Figure 3-3 Second scenario of source communicating with destination via CU relay

- A reliable route is established between source and destination with CU relays in the selected route. It can be seen from above figures.
- If CU relay drops or the PU band used by CU relay becomes busy, rerouting has to happen and communication has to continue.
- By doing rerouting the destination will be served by new route calculated. With the help of new route what is the total connection sustenance time is calculated.
- The parameters considered in these simulations are, if the destination user is 5% , 10%, 15% and 20% away from the basestation and CU relays are considered to be moving in pedestrian and vehicular speeds.
- It is observed that the success rates are higher for pedestrian speed traffic though vehicular traffic is comparatively low but finding feasible relays and availability of number of relays will help the success rate of vehicular traffic.

3.4 System Simulation

In this chapter use of mobile secondary users as relays are considered for developing a cognitive network. These mobile relays were either pedestrian based relays, vehicular based relays or a combination of both. Considering the dynamic nature of these mobile relays, the focus was on capturing the effect of these mobile relays on the route sustenance and outage of an established connection. The flow diagram followed was given in Figure 3.2 for clear understanding. A dynamic network (N=20 represent low density network and N=100 represent a high density network) is created for analysis purpose using Matlab. As the network is dynamic the CU relay nodes will be moving in and out of the coverage area. If there is any node failure, rerouting is done without loss of any information through available CU relays to the destination.

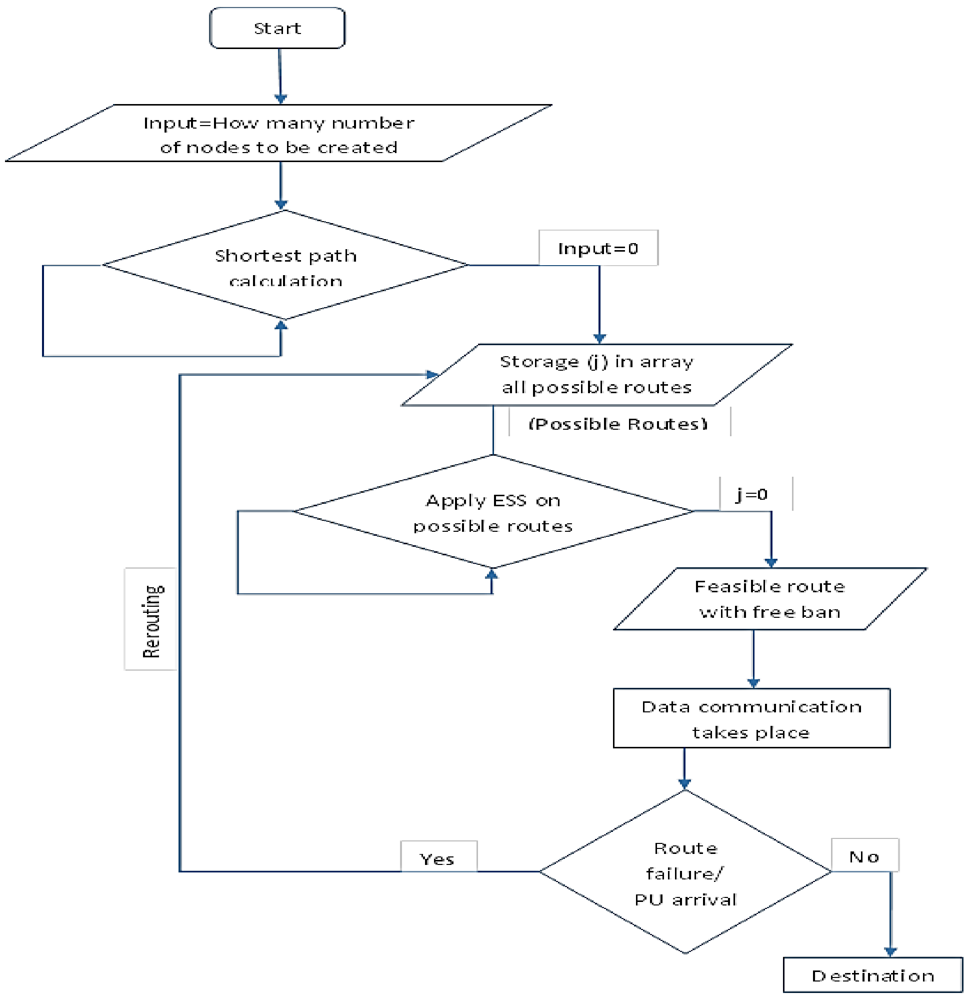

Figure 3-4 Flow chart

During setup phase by applying enhanced spectrum sensing the nodes which are not used by licensed users are detected and 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 CU relay may move out of coverage area. In our work a reliable and feasible CU relays are calculated. In the following results by varying SNR's , considering path loss exponent and by varying the distance of mobile relay CU's from the BS the above mentioned parameters success rate is presented.

3.5 Results and Discussion

We have done case studies on pedestrian and vehicular traffic. The relay density ρ is related to average number of usable relays in the cell coverage area. A network with 20 nodes which represent a low density cell and a network of 50 nodes which represent a high density cell are created and assumption is that a pedestrian can travel the cell diameter in 30 minutes (a normalized distance of 0.001 per second) and it will take 5 minutes (a normalized distance of 0.01 per second) for vehicles. The parameter choices made to illustrate the nature of our results are α=3 and $\Upsilon_1=\Upsilon_2$=3dB (i.e., 1.58 bits per channel at the cell boundary). The term r is represented for end user locations and feasible regions. The area of feasible region decreases when r increases.

The probability of detecting a CU within the feasible region decreases with increasing r which is shown in Figure 3.5. When an end user moves out of the base station coverage area it is very difficult to find the feasible relay, we may get some relays which might be free but there is no guarantee that the relays will be feasible and will transfer the data packets. Hence it is clearly observed from the figure that, as the average number of relays in the cell coverage area are increasing, the success rate to find the feasible relay also increases but when the user moves away from the base station it becomes difficult which is represented with r. when we observe r=1.20 has less success rate than r=1.05.

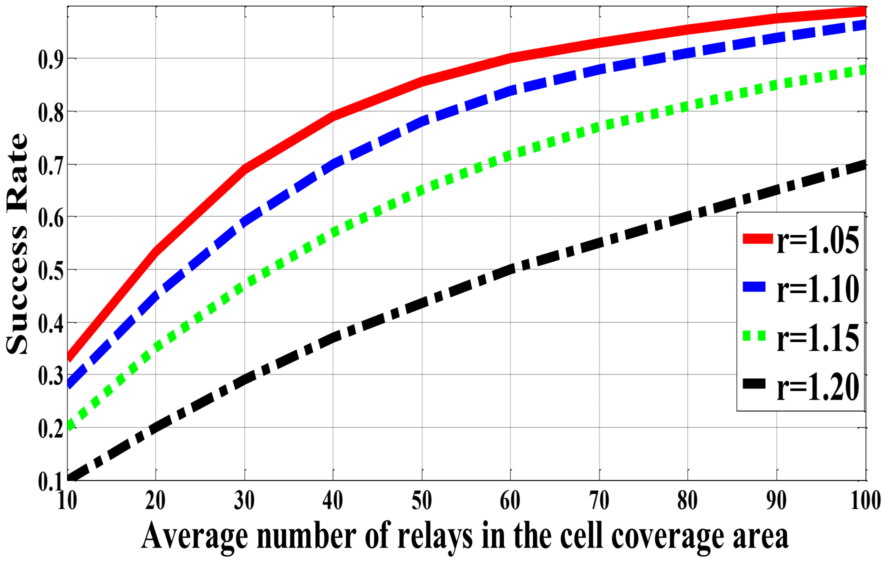

Figure 3-5 Probability of finding a feasible CU relay with path loss exponent α=3 and ϒ1=ϒ2= 3 dB

Figure 3.6 shows two hop routing success probability for an end user 10% away from BS coverage area(r=1.1). For two hop relaying to be useful the relay SNR Υ_2 must be closer to the base station SNR Υ_1 as Υ_1 increases. It is also noticed that even with $\Upsilon_1 = \Upsilon_2$, higher SNRs reduce the probability of feasible relays. Since the result in [81], this is expected that two hop relaying is less favourable in high SNR regions for line networks. Note that Υ_1=3dB and 5dB (1.58 and 2.06 bits per channel) are relatively high for cell edge users. The figure clearly explains about the role played by Υ_1 and Υ_2 on two hop success routing probabilities.

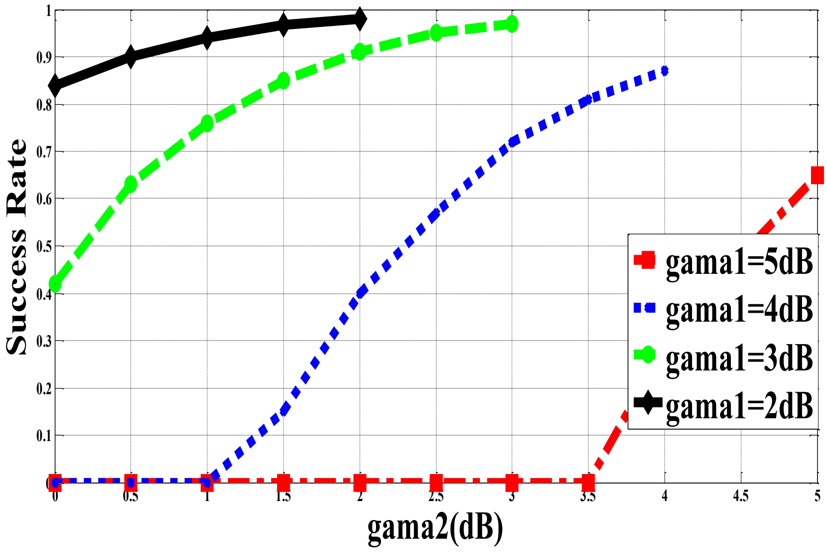

Figure 3-6 The probability of finding a feasible relay as a function of relay SNR at unit distance Υ_2, with path loss exponent α=3 and r=1.1

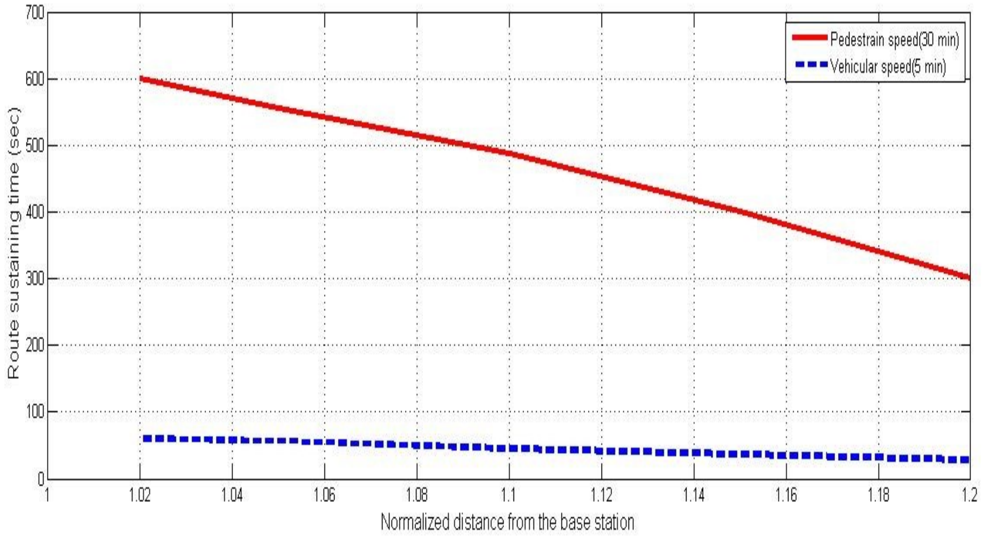

Figure 3-7 The average route sustenance time for relays moving at pedestrian and vehicular speed, with pass loss exponent α=3 and ϒ1= ϒ2=3dB

Figure 3.7 shows average route sustenance time for dynamic relays. Simulations are done on relays moving at pedestrian and vehicular speed. Route sustenance time plays an important role for enhancing the QoS of the total network. If best feasible relay node is found then the route will sustain for longer time. It is clearly observed from the figure that as the normalized distance from base station increases the chance to find feasible relay decreases and obviously route sustenance time also decreases. In vehicular network the nodes movement will be very dynamic when compared with pedestrian network the route sustenance time of pedestrian speed nodes will be higher when compared to vehicular speed.

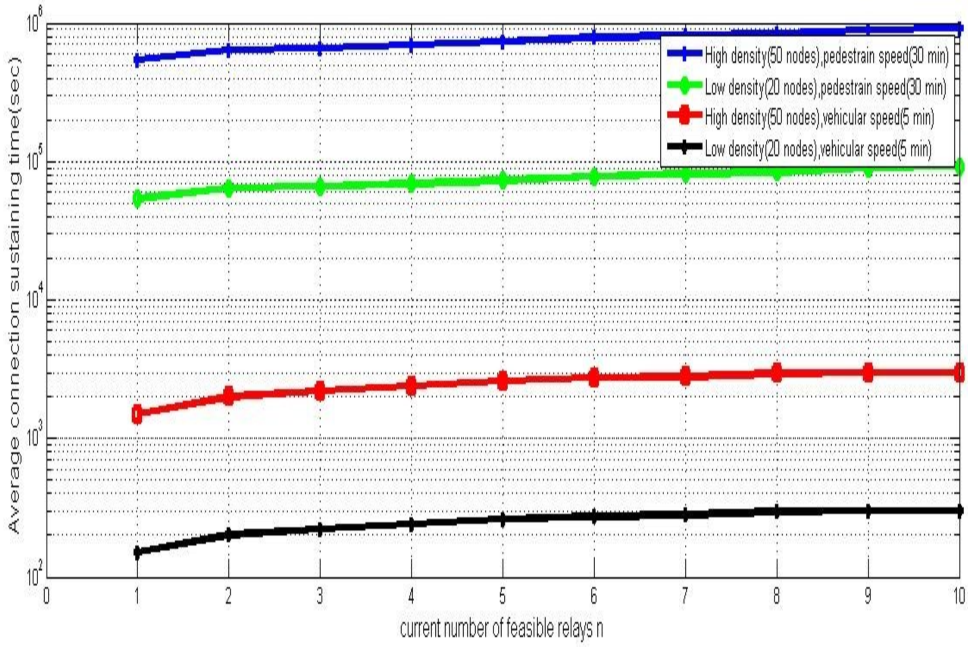

Figure 3-8 Current number of feasible relays vs Average connection sustaining time when r=1.1

Figure 3.8 and 3.9 gives the relation between the number of current feasible CU's and average time until the feasible region is empty i.e., connection sustenance time. Whenever primary user comes back or if any node failure happens the CU's has to change to other route to complete their communication. By doing so, how much time the total connection sustains, is explained in both the figures with end user 10% (r=1.1) and 20% (r=1.2) away from the base station. The pedestrian speed of 30 minutes (normalized to 0.001 per second) and vehicular speed of 5 minutes (normalized to 0.01 per second) is considered. It is known fact that if end user is moving away from the base station the chance of getting feasible relays also will decrease and, if any, route failure happens there won't be any other route to transfer the remaining packets. Figure 3.5 shows that the connection sustenance time is longer due to probability of new CU's arriving the feasible region even as current feasible CU's leave.

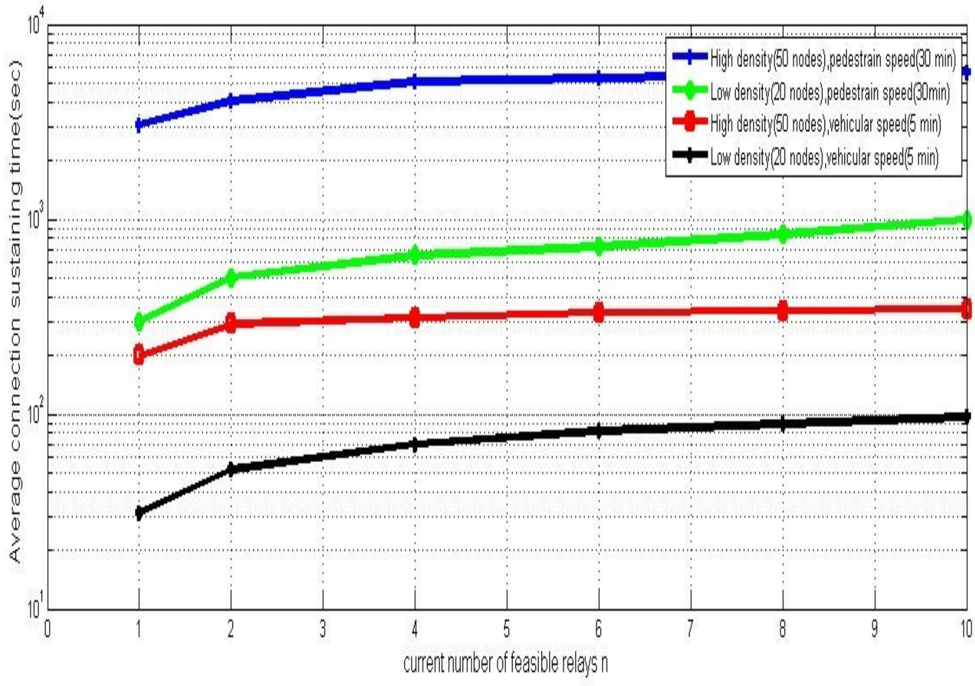

Figure 3-9 Current number of feasible relays vs. Average connection sustaining time when r=1.2

3.6 Conclusions

In this chapter the use of mobile secondary users as relays are considered for developing a cognitive network. These mobile relays were either pedestrian based relays, vehicular based relays or a combination of both. Considering the dynamic nature of these mobile relays, the focus was on capturing the effect of these mobile relays on the route sustenance and outage of an established connection. The availability of mobile relays beyond the usual coverage area of the primary network is also considered. Simulation studies were conducted using a synthetic network consisting of pedestrian relays with a mobility of speed, of crossing one unit, of coverage area. Similarly the vehicular relays are assumed to take 5 minutes to cover the same coverage area. Further the relays which are available at a distance between 1 and 1.2 times usual coverage of primary networks are also considered. The results also show that, by having the mobile relays beyond the coverage of network the route sustenance time improves substantially and also helps in extending the service area.

In chapter 2 and chapter 3 we have discussed about opportunistic spectrum access, where secondary user will use the primary user band if and only if primary user is not using the band. Whenever primary user comes back SU has to leave the band and look for another free band. In the next chapter, we will clearly discuss about two important objectives i) primary user and secondary user doing communication simultaneously without causing interference to primary user transmission and ii) Secondary users helping in transferring failed packets of primary users.