COOPERATIVE RELAY SELECTION APPROACH IN COGNITIVE RADIO NETWORKS

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Abstract
In a communication system with multiple cooperative relays, the best relay selection utilizes the available spectrum more efficiently. However, relay selection impose a different problem in underlay cognitive networks compared to the traditional cooperative networks. In spectrum leasing, licensed users (PUs) and unlicensed users (SUs) interact with each other to obtain mutual agreement on channel access in order to increase their respective network performance. While most of the works assume that secondary user transmissions are interference to primary users, in this paper, it is considered that secondary users as positive cooperators of primary users. In particular the problem of cooperative relay selection is considered. Here the PUs selects the SUs as relay node to improve the transmission performance. Main challenge for this cooperative relay selection problem is to select a relay efficiently and economically. Since the number of SUs is increased day by day due to the rapidly growing number of wireless communication devices, it is impractical to scan all the SUs and then pick the best. Mainly PU transmitter sequentially observes SUs. A set of SUs is selected based on transmission criteria. The relay selection scheme chooses the best relay from a set of available relays which are selected based on transmission criteria of cooperative links. After observing a relay PU need to make decision regarding whether to stop its observation and to choose that as best relay or to skip to observe next relay. This problem is addressed by optimal stopping theory and optimal stopping rule. Here optimal observation order of SUs is discussed. To evaluate the performance of proposed scheme, it is compared with random selection policy through simulation results. Extensive simulation study is conducted so that impacts of different system parameters are investigated and algorithm proposed can satisfy different system requirements.

Keywords: Cognitive radio networks (CRNs), cooperative relay selection, optimal stopping theory, spectrum leasing, optimal observation order

I. INTRODUCTION

Cognitive radio is one of the most promising technology for next generation wireless networks to improve spectrum utilization. According to the information obtained from the environment, CR can change its transmission parameters such as frequency, transmission power, modulation, bandwidth etc. Communication between cognitive users can only be performed through common existing bands between a pair of CR users. In CRN, only when the same band exists between the two users, they can communicate with each other. If there is no common band, then no direct communication can be performed. When no direct path exists between two cognitive users, the concept of cooperative relay has been incorporated into CRNs.

Wireless networks are characterized with limited resources accessed by a large number of mobile stations with distinct capabilities. Major importance factor to mitigate the limitations of such challenged wireless networks, such as the impact of low data rate stations and wireless channel oscillations is the dynamic control of resources. Such augmented usage of wireless resources can be incorporated based upon cooperative relaying schemes, which have the potential to support the network lifetime and desired system performance. However, the introduction of cooperative relay raises several problems such as the relay selection issue and resource allocation. Due to the significant number of different cooperative relaying techniques, this article aims to provide a systematic analysis of cooperative relay selection procedure, and to identify the most suitable evaluation methods as well as open research directions for an efficient analysis of different system parameters.

Future generation wireless networks are expected to provide services that require high performances as well as bandwidth efficiency. This means that as the number of wireless terminals increases, higher system capacity is needed to provide the required data rate levels. However, wireless networks present low performance levels although they provide easy connectivity and fast deployment. The major limitation of wireless networks comes from the shared medium, unstable wireless channels and limited resources devices. Channel conditions in wireless networks are subjected to fading variations, including interference that can affect both reliability and throughput. Thus receivers may get multiple copies of the transmitted signal, each having travelled through a different path. So that multipath fading increases with the number of errors in the transmission, and decreases the network throughput because of required additional re-transmissions. The application of cooperative communications ranges from self organizing networks to vehicular networks, sensor networks and dynamic spectrum management. The technological challenges increase when nodes have intermittent access to a network infrastructure, which can happen due to the presence of low data rate stations and in mobile scenarios. In the former case, network performance will decrease since low-data rate devices will grab the radio spectrum for long periods of time. In such a situation high-data rate devices will act as relays which will help the low-data rate devices to release the spectrum earlier, contributing to increase the overall system performance.

The direct transmission from primary transmitter to primary receiver is severely damaged due to unstable environment in wireless networks. Thus, in this paper, cooperative relaying framework is considered in which Pus select SU which have a better channel condition than primary transmitter. Here the problem of relay selection is focused, how to efficiently find an appropriate relay that can satisfy primary transmitter's requirement. This is termed as cooperative relay selection.

The main critical challenge for cooperative relay selection is its selection efficiency. Here optimal stopping theory is implemented because the number of SUs is larger due to rapidly growing mobile communication devices day by day. The main goal of this optimal stopping theory is to stop early and avoid scanning all relays. Different observation order of secondary user relays possesses different performance when stopping theory is applied. Therefore second challenge is to construct optimal observation sequence to decrease the number of secondary user scanned.

Major contributions can be stated as following. The problem of cooperative relay selection is formulated as optimal stopping problem and optimal stopping rule is derived. The stopping criteria considers effective bit rate (instantaneous reward) and expected throughput (expected reward) of the system. The criterion is that instantaneous reward is at least the same as the expected reward. Select the first relay which satisfies this criterion. Next, the impact of observation order is investigated and optimal order is obtained which maximizes observation efficiency. It is found that random selection policy leads to irregular and uncontrollable result in relay selection. Finally extensive simulation is conducted to validate the performance of proposed scheme with random relay selection scheme. The impact of different parameters is also investigated and a thorough analysis on system parameters is presented.

The rest of the paper is organized as follows. The literature review is done in section II. The system model and framework relaying is illustrated in section III. The proposed optimal stopping policy is described in section IV. Theoretical analysis and discussions are presented in section V. the performance evaluation is reported in section VI. The conclusion is presented in section VII.

II. BACKGROUND WORK ON PROPOSED SCHEME

The performance of cooperative relaying strongly depends upon the efficiency of the relay selection process which is independently operating only at the link layer or in combination with cooperative diversity schemes at the physical layer.

The basic mechanism for relay selection proposed in [2] defines an opportunistic behavior in which overhearing nodes will estimate the network Channel State Information (CSI) based on which they set a timer such that nodes with better channel conditions which broadcast their qualification as relays, or even data to be relayed. In Chen et al. [5], the sources include their power level on Request-to-Send (RTS) packets, allowing all overhearing nodes to estimate CSI, which make optimal power allocation. The selection of relay decision depends upon the relay transmission power and CSI, as well as the power of source and relay nodes. Other proposal in [7] where the source sends in RTS packet which contain its maximum transmit power. The overhearing nodes compete for selection on the basis of signal strength combined with the overheard power information. These techniques contend similar to basic mechanism in [2], the difference is that it just consider the channel estimation and not energy considerations. K. Hwang et al. [4] modified the basic opportunistic approach [2] by decreasing the number of channel estimations. It defines a predefined SNR threshold and the relay will select only if it satisfies such threshold. The aim is to save power consumption, but it relies on channel estimations. The threshold at relay is set based on Bit-Error-Rate (BER) in [8]. The relay will decode and forward the information only when the quality of received signal is above that threshold. But this does not guarantee that symbols are correctly decoded. All previous relay selection techniques assume that relays are always needed. An opportunistic approach in which relay selection is only triggered by the destination when the estimated (by the destination) CSI is lower than a pre-defined threshold is proposed by Adam et al. in [6]. This minimizes energy consumption. However relay selection still relies on overhearing Ready-to Send (RTS) and Clear-to-Send (CTS) frames which leads to an increase of the communication overhead, especially in multi-hop scenarios. Various relay selection approaches [13]–[19] have been explored for cooperative relaying in general wireless networks. Many of them require channel-related information from all the candidate relay nodes, and it becomes inefficient when the number of candidate relays is large.

Cheng and Zhuang [23] proposed a simple descending order based on SNR and proved that it is optimal when the user stops at the first free channel. Jiang et al. [24] presented a dynamic programming approach to find an optimal observation order and investigated the optimal order in some special cases. Fan and Jiang [25] proposed two suboptimal algorithms to find the optimal order in a two-user case. An approach for searching an optimal order dynamically based on reinforcement learning is proposed in [26]. The proposed approach employs the effective data rate to define the observation order, and prove that this order is most efficient in terms of observation time.

III. SYSTEM MODELS

A. *Network model and Assumptions*

Here Amplify and Forward (AF) is adopted to illustrate the design. In AF, a relay node amplifies the signal of the received packets and then delivers them. Consider a simple CRN that consist of primary transmitters and primary receivers and a number of SUs. A typical primary transmitter, which is denoted by Pt, transmits its packets to a typical primary receiver, which is denoted by Pr, with the assistance from one of M SUs represented by S_i, i= 1, 2, . . . , M, as shown in figure, where Pt and Pr form a primary transmission pair. When Pt needs to transmit packets to Pr, a free SU, which has a better channel condition compared with Pt, can be selected as a relay node by the PU pair. The M SUs, which have the ability to transmit packets for the primary system, are called candidate relays, and the SU finally selected by the PU pair is called a cooperative relay.

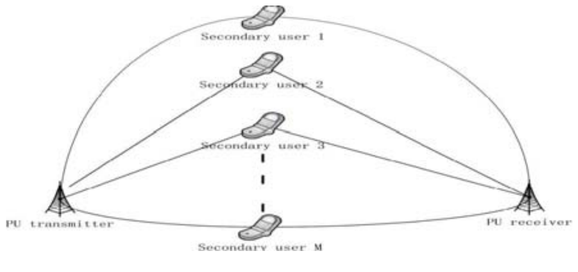

Fig.1. Network model.

B. *Cooperative Relaying Scheme*

It is assumed that the proposed network system is time slotted, the cooperative relay selection is performed at each time slot, and the duration of a time slot is T. Here it assumed that each PU pair can select, at most, one SU as a cooperative relay and that each SU candidate relay node can only be selected by, at most, one PU pair. In addition, one user can only transmit or receive at one channel per time slot because each user is equipped with only a simple transceiver. For simplicity, here the network scenario where there exists only one primary pair and *M* SUs is considered.

Cooperative communication exploits spatial diversity inherent in multi user systems by allowing users relay each other's data to destination. The transmitter and receiver not only have difference in available spectrum, but also have distance in space. To make efficient use of such diversity in both spectrum and space and a novel cooperative relay scheme. Thus a cooperative relay node is introduced to relay data from transmitter to receiver with different available spectrum. This scheme will increase the SINR considerably compared to general scheme. Besides spectrum sharing between Pus and SUs. Thus a general scenario is studied.

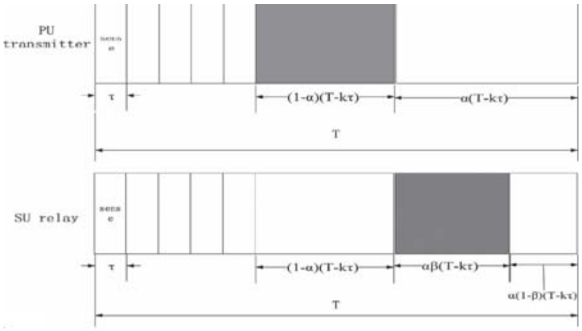

Fig.2. Time slot structure

As shown in figure each time slot of length T is partitioned into several components. Let τ be the time needed for observing a potential relay. It is assumed that τ is similar for different SUs and for different time slots. Denote by {s1, s2, . . . , sM} an observation order, which is a permutation of the SU candidate relay index set {1, 2, . . . , M}. At the beginning of a time slot, transmitted power, Pt starts to observe the SU candidate relay nodes sequentially according to the observation sequence. If the reward of the kth observation satisfies a particular criterion, Pt stops at the kth SU candidate relay node and then delivers its packets (intended to the PU receiver Pr) to the secondary relay node for a fraction (1 − α), 0 ≤ α ≤ 1 of time (T − kτ) shown by the shadow part in the first subgraph. For the rest of the time slot α(T − kτ), the selected secondary node relays Pt's data over a fraction of β, 0 ≤ β ≤ 1 fraction of α(T − kτ) shown by the shadow part in the second subgraph and then sends its own packets during residual time (α(1 − β)(T − kτ)). Note that the assumed condition Mτ < T always holds.

IV. OPTIMAL STOPPING POLICY

A. *Problem Defintion*

Here the problem of cooperative relay selection in a CRN is focused where a PU pair observes the SU candidate relay nodes based on an observation sequence and decides whether to stop and select the current SU node under observation as the cooperative relay node. The PU pair makes the decision based on comparing the result of the instantaneous reward and the expected reward of future observations to maximize the reward of the selection. The instantaneous reward can be indicated by the channel quality of the candidate relay being observed, and the expected reward of future observations is the reward that the PU pair can obtain if it continues observing the following candidate relays. In other words, the PU pair may stop and receive the current reward/relay or continue observing the rest of the SU relays to find a better relay. Therefore, the relay selection problem can be formulated as a sequential decision problem and it can be implemented by applying the optimal stopping theory. Here the concept of stopping theory is discussed and then the problem of cooperative relay selection is formulated as an optimal stopping problem.

Definition 1: A stopping problem is defined by two sections:

- a sequence of random variables, i.e., X1,X2, . . ., with a known joint distribution; and
- a sequence of reward functions, i.e., y0, y1(x1), . . . , y∞(x1, x2, . . .), which are the real-valued functions of the variables previously discussed.

The objective is to find out the variable Xi in the sequence such that the reward function indicated by yi(x1, x2, . . . , xi) is maximized. To make sure that the packets relayed by the cooperative relay node securely arrive at the destination, some conditions/ restrictions should be satisfied, which can be described as follows

$$0 < (1-\alpha)R_{ps}^{r}\ (\mathrm{t}) \leq \alpha\beta\ R_{sp}^{r}\ (\mathrm{t}) \qquad (1)$$

where R_{ps}^{r} (t) denotes the transmission rate between the PU transmitter and the SU relay, and R_{sp}^{r} (t) denotes the transmission rate between the SU relay and the PU receiver. The intuition behind this equation is that the amount of data transmitted from the primary transmitter should not exceed the transmitting capability of the relay. The value of α is controlled by the PU transmitter. Given α, minimum value of β can be derived ,i.e., β_{low}= (1- α) / α when it is assumed that $R_{ps}^{r}(t) = R_{sp}^{r}(t)$. Here $0.5 \leq \alpha \leq 1$ and $0 \leq \beta_{low} \leq 1$.

In a cognitive communication network, an SU may not be available to serve the PUs due to the secondary communication carried out by SUs. Therefore, the PU transmitter should examine the availability of the SU candidate relays. When the PU transmitter observes the channel condition of an SU, the SU returns a value for β. It is assumed that the SU is always in saturated transmission mode, which means that the SU candidate relay never returns a parameter β = 1. Note that the SU is available if the returned value is larger than or equal to β_{low}, and vice versa. Let θ denote the probability that the SU candidate relay is available. Then, Θ is defined as the indicator function of the availability of the SU candidate relay, which is given by

$$\Theta=\begin{cases} 0, if \beta < \beta_{low} \text{with probability } (1-\theta) \\ 1, if\ \beta > \beta_{low} \text{ with probability } \theta \end{cases} \qquad (2)$$

It is assumed that the channel is flat Rayleigh fading channel to further investigate channel quality in cooperative relay selection problem. The instantaneous SNR received by destination is having exponential distribution with probability density function given by

$$\mathrm{f}(\Upsilon)=(1/\ddot{\Upsilon})e^{-(\frac{\Upsilon}{\ddot{\Upsilon}})} \qquad (3)$$

where $\ddot{\Upsilon}$ denote average SNR in channel model. Here Rayleigh fading channel is modeled as Finite State Markov Chain (FSMC). In FSMC, SNR is partitioned into U intervals and SNR is divided into finite state space. When the PU pair observes the channel of SU relay, the probability of SU being in state u for the channel can be given by

$$q_u = \int_{\Upsilon_u}^{\Upsilon_{u+1}} f(\Upsilon)d\Upsilon = e^{-(\frac{\Upsilon_u}{\ddot{\Upsilon}})}\text{-}e^{-(\frac{\Upsilon_{u+1}}{\ddot{\Upsilon}})},$$

$$\mathrm{u}=1,.,\mathrm{U} \qquad (4)$$

Thus the achievable transmission rate is viewed as a metric for channel quality in wireless networks. Let r_k denote the achievable transmission rate between PU pair and SU candidate relay node k. according to Shannon's theorem, r_k is calculated as:

$$r_k=\mathrm{W}\log(1+\Upsilon_k) \qquad (5)$$

where W denote the bandwidth of spectrum in which a wireless user can transmit or receive data. Thus, data rate, which is denoted as R=$\{r_1, r_2 r_3 r_4, \ldots r_U\}$ is modeled as discrete random variable with distribution given by

$$\Pr\{\mathrm{R}=r_U\}=q_u \qquad (6)$$

The PU pair acquires achievable transmission rate of channel between itself and SU relay by executing relay selection observation procedure. At each observation step, PU transmitter send a Request–To–Send (RTS) frame to candidate relay. After receiving RTS frame, candidate relay returns a Clear-To –Send (CTS) frame, which contain the information for calculating the achievable rate. The valid transmission rate of Kth observation step is defined as X_k=$R_k\Theta$. The distribution of X_k can be calculated as

$$p_0=\Pr\{X_k=x_0=0\}=(1\text{-}\theta) \qquad (7)$$

$$p_u= \Pr\{X_k=x_u=r_u\}=q_u\theta \qquad (8)$$

$$\text{for } 1\leq \mathrm{u} \leq U, 1 \leq k \leq M$$

Next, the reward function denoted by Y_k based on sequential variables and number of secondary user candidate relays are derived. A scaling factor c_k is defined if PU pair stop at kth observed candidate relay node, given by

$$c_k = 1 - \frac{k\tau}{T} \qquad (9)$$

From this equation it can be inferred that as k becomes larger, c_k become smaller. When the SU candidate relay observed is more in number, cooperative relay selection process efficiency decreases. The payoff after kth observation is represented as

$$Y_k=\frac{X_k(T-k\tau)}{k\tau+(\mathrm{T}-k\tau)} \qquad (10)$$

The numerator in the above ratio indicates the amount of data that is transmitted in one slot. The denominator is the total time cost for a time slot. The reward represent the average throughput PU pair obtains at current time slot if PU pair stop after observing K_{th} SU candidate relay node as cooperative relay. Thus the average throughput is defined as

$$Y_k=c_k X_k \qquad (11)$$

which is the function of observation variables and number of observation steps k. The optimal stopping problem is evaluated after introducing the reward function. After K_{th} observation PU pair receives the reward and it make decision on whether to stop at current candidate relay or continue to scan the next relay.

The PU pair receives the reward Y_k after the K_{th} observation. Then, the PU transmitter takes a decision on whether to stop at the current candidate relay or continue to observe the next candidate relay based on the reward. Here no recall is allowed since the channel quality is rapidly changing in CRNs due to complicated conditions such as the mobility of the users.

V. OPTIMAL STOPPING RULE

Optimal stopping rule is derived as the solution to cooperative relay selection problem. The solution approach is formulated as backward induction. The maximum return that the PU transmitter can obtain after obtaining j_{th} candidate relay is denoted by $V_j^{(M)}(x_1, x_2, \dots x_j)$, given by $V_j^{(M)}(x_1, x_2, \dots x_j)$=max$\{y_j(x_1, x_2, \dots x_j)$,E$\{V_{j+1}^{(M)}(x_1, x_2, \dots x_{j+1})\times| X_1{=}x_1, \quad X_2{=}x_{2,} \dots, X_j{=}x_j\}$ (12)

where $y_j(x_1, x_2, \dots x_j)$ represent the instantaneous reward after K_{th} observation, and E$\{V_{j+1}^{(M)}|X_1{=}x_1, \ X_2{=}x_{2,} \dots, X_j{=}x_j\}$ represents the expected reward achieved by skipping to observe next SU relay.

When $V_j^{(M)}(x_1, x_2, \dots x_j){=}\, y_j(x_1, x_2, \dots x_j)$, it is optimal to stop scanning the relays. The optimal stopping rule is achieved when the following condition is satisfied

$y_j(x_1, x_2, \dots x_j) >$ E$\{V_{j+1}^{(M)}(x_1, x_2, \dots x_{j+1}) \ \times| X_1{=}x_1, X_2{=}x_{2,} \dots, X_j{=}x_j\}$ (13)

Backward induction is clearly understood when the expected reward, E$\{V_{j+1}^{(M)}\}$ is defined as Z_{M-j}, if PU pair proceed to scan next SU relay which is given by

Z_{M-j} =E$\{V_{j+1}^{(M)}(x_1, x_2, \dots x_{j+1})\times| X_1{=}x_1, X_2{=}x_{2,} \dots, X_j{=}x_j\}$ (14)

The set $\{X_1, X_2, \dots X_M\}$ for SU candidate relays are mutually independent. Thus Z_{M-j} is a constant that only depend on M-j, the number of remaining steps to continue.

Optimal stopping rule is as follows. PU pair observes candidate relays based on observation sequence S and obtain instantaneous reward y_k after kth observation. Then the value of y_k with the value of Z_{M-k} is compared and decide to stop at kth step if $y_k > Z_{M-k}$ and to continue observing next relay otherwise. If the PU pair observe the last relay in the observation sequence and the condition is not satisfied and it is forced to take that last relay in the sequence as cooperative relay. This is called worst case relay selection.

If the PU pair stops and selects a suitable cooperative relay more quickly when observing the SU candidate relays based on an observation order denoted by S1 compared with another observation order denoted by S2,say that the order S1 is more efficient than the order S2. First, consider a random observation order strategy in which the PU pair constructs the observation sequence randomly at every time slot. Since the observation variable set $\{X_1, X_2, \dots, X_M\}$ is independent for each time slot, the efficiency of this order strategy is uncontrollable. Due to the poor performance of the random observation order strategy, take into consideration an intuitive order.

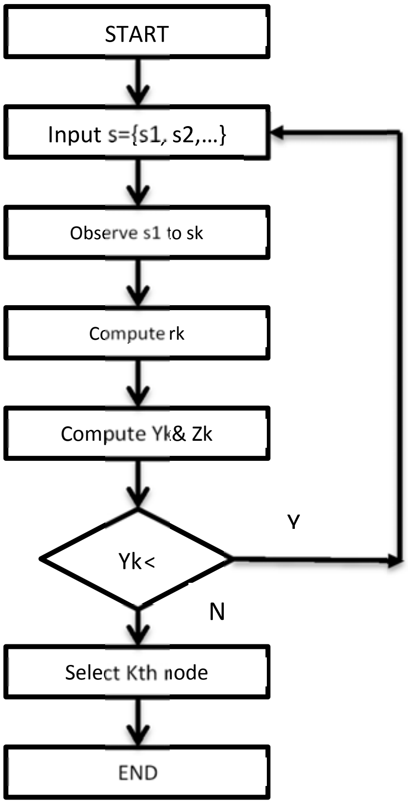

Fig.3 Flow chart of Cooperative Relay Selection

To find a proper cooperative relay, the PU transmitter observes the candidate relay nodes to obtain their channel quality at each time slot. Then, the PU pair decides whether to select a candidate relay as the cooperative relay node based on a cooperative relay selection algorithm. It is assumed that the observation results are error free. Here the following spectrum leasing strategy is adopted that can motivate the candidate secondary relays to help the PU pair with their packet transmissions: The PUs own the spectrum resource and have the right to decide whether to lease the spectrum to candidate secondary relays in exchange for cooperation, and the candidate secondary relays have the right to decide whether to cooperate with the PU pair on the basis of the corresponding fraction of time leased for secondary transmissions.

The major critical concern for cooperative relay selection is efficiency. The number of SUs could be large due to the rapidly growing number of mobile communication devices, it is impossible to scan all the candidate relays for a primary transmitter. Thus, the optimal stopping theory is proposed for cooperative relay selection, with an objective to stop early enough to avoid scanning all the candidate relays. Apparently, different observation orders of the SU candidate relays may result in different performance when applying the stopping theory. Therefore, second challenge is to construct an optimal observation sequence to decrease the number of candidate relays that must be scanned before stop.

Here the flow chart of optimal stopping rule is given in figure3. In this flow chart, the set s={s1,s2,..sk} is the set of SU,s and Z_k is the expected reward which is the throughput. Here the problem of cooperative relay selection in a CRN is focused where a PU pair observes the SU candidate relay nodes one by one based on an observation sequence and decides whether to stop and select the SU node currently under observation as the cooperative relay node. The PU pair makes the decision based on the result of comparing the instantaneous reward and the expected reward of future observations to maximize the reward of the selection.

The instantaneous reward can be represented by the channel quality of the candidate relay being observed, and the reward that the PU pair can obtain if it continues observing the following candidate relays is the expected reward of future observations. In other words, the PU pair may stop and receive the current reward/relay or continue observing the rest of the SU relays to find a better relay.

VI. PERFORMANCE EVALUATION

The performance of proposed stopping policy is evaluated by extensive simulation study. It is assumed that the duration of a time slot in the system is 0.2ms. SNR is partitioned into U=20 intervals. The average SNR in Rayleigh fading channel is 30dB. The bandwidth of the system W is set as 1MHz. The numerical results are obtained are averaged over 100 independent runs.

Initially, a simple random relay selection is carried out and then optimal stopping policy is implemented and the results are compared. In optimal stopping policy, the impact of time duration for each observation, τ and the parameter α on system performance in terms of observation steps and average reward for PU pair.

- Performance comparison between optimal policy and random policy

The performance of proposed policy with that of random policy is compared and analyzed. Here the observation duration is set to be 3μs, and number of secondary user relays 15 to 60.

In random relay selection, PU pair selects the candidate relays in random manner. Since there is no time for relay selection, full time slot, T is used for packet transmission. It can be inferred that transmission time for random relay selection is greater than proposed policy of relay selection. The amount of data transmitted in random policy changes irregularly and sharply with increase in size of network as in figure 4. The optimal stopping policy demonstrates stable transmission status.

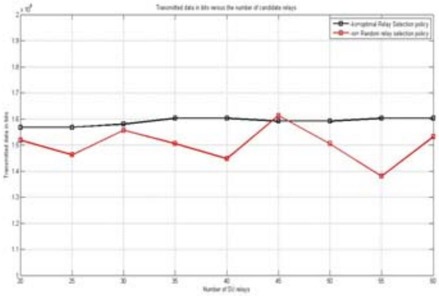

Fig. 4. Transmitted data in bits versus Number of SU relays

- Impact of observation duration; τ

Here α is set as a constant and its value is 0.8. The observation time influences process of relay selection. In figure 5, the number of observation step decreases with increase in time duration. Greater τ, smaller number of observation steps.

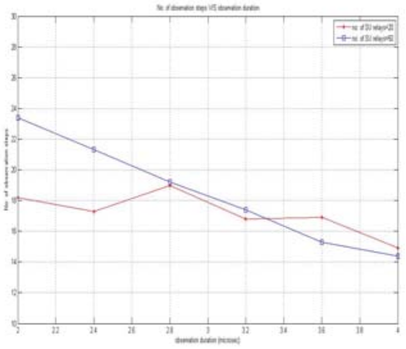

Fig. 5. Transmitted data in bits versus Number of SU relays

The value of τ represent the cost for observing a particular SU relay, PU need to stop early to minimize the cost. If the value of τ is small, observation cost is low, and PU tends to observe more SUs and thus find proper cooperative relay. The number of observation steps is larger with large network size. The three curves for three different networks tend to converge when τ becomes larger.

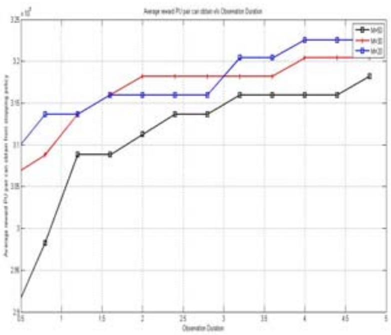

Fig. 6. Average reward PU pair versus observation duration

In figure 6, the average reward obtained by PU pair increases with time duration for each observation. If there exist less observation steps, larger the average reward PU pair can obtain. The observation duration increases up to 3 μs or more, number of observation steps and average reward tend to attain a steady state.

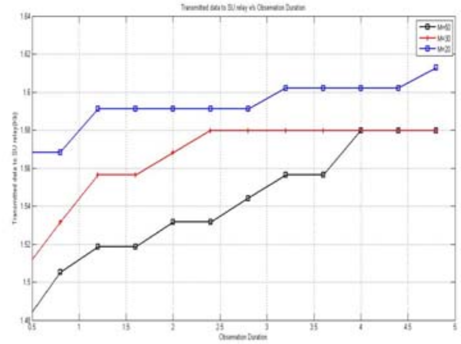

Fig. 7. Transmitted data to SU relay versus observation duration

In figure 7, the amount of data transmitted to relays increases when the time duration for each observation increases and tend to reach constant value. Greater observation duration implies smaller number of observation steps. Thus, the selection of parameter τ is crucial. The right values of τ address this trade off. Thus a proper value of 3μs is selected.

VII. BEST MONITORED RELAY SELECTION

When no relay in the sequence satisfies the transmission criteria, the PU pair is forced to choose the last M_{th} relay as cooperative relay. This is called as worst case relay selection. Thus required performance is not achieved. Thus to improve the performance of the system present channel which doesn't follow the stopping rule is also considered. So when there occur a better channel before the occurrence of optimal stopping rule, that particular channel is selected. Thus a stable transmission status is obtained throughout the range.

Here better relay is been selected by monitoring the present channel with that of optimal policy initiated channel. There occur chances where the present channel provides better performance than that of optimal one. Thus such a channel is selected and thus relay selection is carried out which also minimizes the observation time, which is the prime aim of the work.

There occur chances when the present channel condition out performs the optimal relay selection policy. From the figure it can be inferred that at minimum observation steps a stable transmission status can be maintained. Since the average reward is higher, it leads to maximum throughput of the system. Here 100 iterations are done. The probability for obtaining better channel is also higher. Thus best relay is being selected by maintain lower observation steps. Since best relay is being obtained at the earliest, that channel will be the best and thus the system throughput is higher. For best relay selection, the number of observation steps and average reward tend to reach a steady state range. This implies the best monitored relay selection results in a steady state relay selection system.

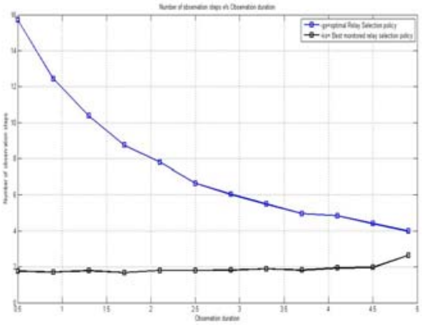

Fig.8. Comparison of Optimal relay selection policy with best monitored relay selection policy

Since a better relay is been selected, which increase the throughput of the system. In figure 8, the number of observation steps versus observation duration is shown for both optimal stopping rule and for best monitored relay selection policy. The result of best monitored policy provides a stable transmission status throughout the observation duration.

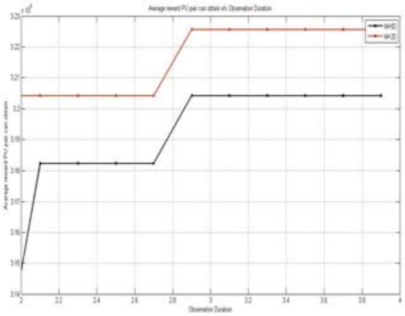

Fig 9. Average reward PU pair can obtain versus observation duration for best monitored relay selection policy

Figure 9 shows the average reward PU pair obtained versus observation duration is shown which is obtained from best monitored relay selection policy. From the plot it can be inferred that a stable transmission status is obtained. When the observation duration is increased, the average reward PU pair obtained will be having a stable transmission status. When the network size is increased, the average reward PU pair obtained decreases. For lower network size, higher average reward for PU pair is increased.

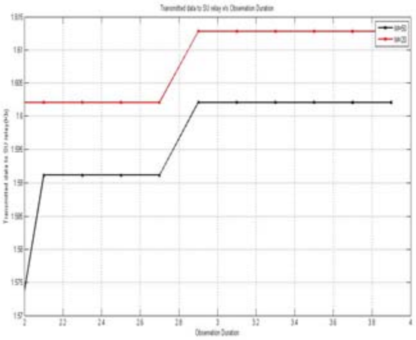

Fig 10. Transmitted data to SU relays versus observation duration for best monitored relay selection policy

In figure 10, the transmitted data to SU relays versus observation duration for best monitored relay selection policy is shown. Here also a stable transmission is obtained. From the plot it can be inferred that a stable transmission status is obtained. When the observation duration is increased, the transmitted data to SU relay will be having a stable transmission status. When the network size is increased, the transmitted data to SU relay obtained decreases. For lower network size, higher transmitted data to SU relay is increased.

VIII. CONCLUSION

In this work, the problem of cooperative relay selection in CRNs is mitigated by optimal stopping policy. PU pair observes SU candidate relays in a sequential manner and select the best relay which satisfies the criterion as cooperative relay. Superiority of the scheme is explained by comparing both random selection policy and optimal stopping policy through numerical simulation. The problem of cooperative relay selection is considered here, in which the PUs actively select appropriate SUs as relay nodes to enhance their transmission performance. In this paper, an optimal stopping policy is proposed to solve the problem of cooperative relay selection in CRNs. Here a PU pair observes the SU candidate relays in certain order and selects one as their cooperative relay if the transmission requirement of the SU is satisfied. An optimal stopping problem is formulated and proved the existence of the optimal solution to the stopping problem. Then, optimal stopping policy is derived to find the optimal solution. An intuitive observation order and proved its optimality from the aspect of efficiency. Best monitored relay selection policy is incorporated to get best relay so that maximum throughput is obtained at minimum scan time. A steady state range is obtained by this relay selection policy. Thus a steady state relay selection policy is obtained. The simulation results also reveal the impact of different parameters on the system performance.

The worst case relay selection of optimal stopping problem is eliminated by best monitored relay selection policy. Here random check of the channel is done combined with optimal stopping policy. So that the probability of getting a better relay with higher data rate is also higher. Thus by selecting a relay with higher data rate leads to high throughput system. Thus a stable transmission status is obtained by best monitored relay selection policy.

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