



Pre-emptive Spectrum Access in Cognitive Radio for Better QoS

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Abstract. Cognitive radio techniques are becoming very popular to overcome the spectrum scarcity. For dynamic channel access, spectrum latency is a major bottleneck to achieve good QoS. In this paper, we have proposed distributed proactive channel scanning for different channel assignment policies of primary users (PUs). From periodic channel scanning, secondary users (SUs) store recent history of channel occupancy, and based on that decide the order of channel selection when demand comes, and switch channels proactively, if any better channel appears. For various channel allocation strategies of primary users, different channel selection algorithms are presented for secondary users to improve the spectrum latency as well as the channel switching overhead per call. Through simulation, the performance of the proposed strategies is compared with that of conventional cognitive radio. Results show that by the proposed scheme, the call drop/block rate decreases by more than 30% with significant reduction in interference, and hence improving the QoS of the system.

Keywords: Cognitive radio · Spectrum latency · Channel history · Channel selection · QoS (Quality of Service)

1 Introduction

In recent days, wireless spectrums are getting congested due to the rapid increase in the number of licensed users. The main reason for spectrum scarcity is the static channel assignment for licensed users that results both under utilization and unavailability of channels. Cognitive radio (CR) is the technology by which wireless networks can overcome the scarcity of the spectrum. Unlicensed users can utilize the unused spectrum of licensed users opportunistically. In cognitive radio, an unlicensed SU can communicate through a licensed channel after sensing it idle. However, as soon as a PU appears on the channel, the SU must release it and attempts to find another idle channel to switch. This switching procedure is called *reactive switching*. For this *reactive switching*, an SU must be

equipped with two transceivers to enable it for simultaneous scan and transmission. This introduces noise in PU's communication and degrades QoS for SU's. In this paper, we have proposed a proactive channel switching technique for SU that eliminates the need of multiple transceivers in SU but still maintains better QoS for SUs and helps to minimize the interference with PU. It is obvious that though cognitive radio attempts to increase the spectrum utilization by opportunistic use of licensed spectrum, interference with PU is not desired. Our work may be a good solution to this problem. Simulation studies show a significant improvement in terms of interference, throughput, call block rate, and drop rate.

In cognitive radio networks, to avoid simultaneous communication and scan, one solution may be periodic scan with one transceiver and to stop communication while scanning. But for periodic scanning, if a PU starts to transmit data on a channel which is in use by a SU, then interference will occur, and it will degrade QoS for both PU and SU. So, it would be better if an SU can predict the probability of occurring interference on a channel, and based on that can select the channel with least probability of interference during its communication time. In this work, we have addressed this problem using light weight channel usage prediction algorithms depending on different channel assignment techniques of PU network that enables an SU to preempt channels based on its dynamic estimate of idle time.

The rest of the paper is organized as follows: In Sect. 2, related work on this area is presented. System model of the work is described in Sect. 3. In Sect. 4, details of algorithms and different spectrum access techniques have been described. Section 5 presents the details of the simulation studies with results. Finally, the paper is concluded in Sect. 6 with future work.

2 Related Work

The relevant work on dynamic spectrum access in cognitive radio is mostly dominated by reactive spectrum access which means that an active SU will switch transmission to a different channel only when a PU arrives in the current channel. Some works on proactive spectrum access in cognitive radio have been appeared in literature. In [1], two channel selection and switching techniques are presented to minimize interference after predicting the future spectrum availability from the past channel history. In [2], the authors propose two channel selection schemes: minimum collision rate channel selection algorithm and minimum hand-off rate channel selection algorithm based on spectrum hole prediction under the constraint that the collision probability is bounded. In [3], authors follow the partially observable Markov decision process (POMDP) framework to derive optimal sensing and access policies. Another work in [4] also proposes a POMDP framework for dynamic sensing and channel access considering that the cognitive users have perfect knowledge about the distribution of the primary signals. The work in [5, 6] proposes a new access policy that utilizes the channel access opportunities by combining not only the channel state information but also channel quality information for exploring the optimal trade-off between the throughput of secondary users and the interference to the primary users. The

authors in [7,8] carry out very insightful studies on how to find the available spectrum opportunities efficiently and fast, through sensing sequence selection and sensing period optimization. The paper [9] proposes a selective opportunistic spectrum access (SOSA) scheme which estimates the probability of a channel appearing idle based on past statistics and chooses the best spectrum-sensing order to maximize spectrum efficiency. A slotted transmission protocol for secondary users using a periodic sensing strategy with optimal dynamic access is proposed in [10]. In [11]; a multi-channel selection algorithm is proposed that predicts the spectrum opportunities to limit the interference to the primary as well as to enhance the spectrum utilization. The problem of target channel sequence selection is addressed for proactive spectrum-hand off in [12]. Many other works [13] use sophisticated machine learning algorithms to predict the spectrum availability in the future time slots after training the models with past dataset long enough for accurate prediction. These models provide very high degree of accuracy, the problem with these kinds of advanced machine learning based-prediction is that it is too expensive to train the model in real time. Only off-line processing is possible for these models, thereby making it difficult to predict dynamic scenario where the spectrum usage of the PUs changes rapidly with time (Fig. 1).

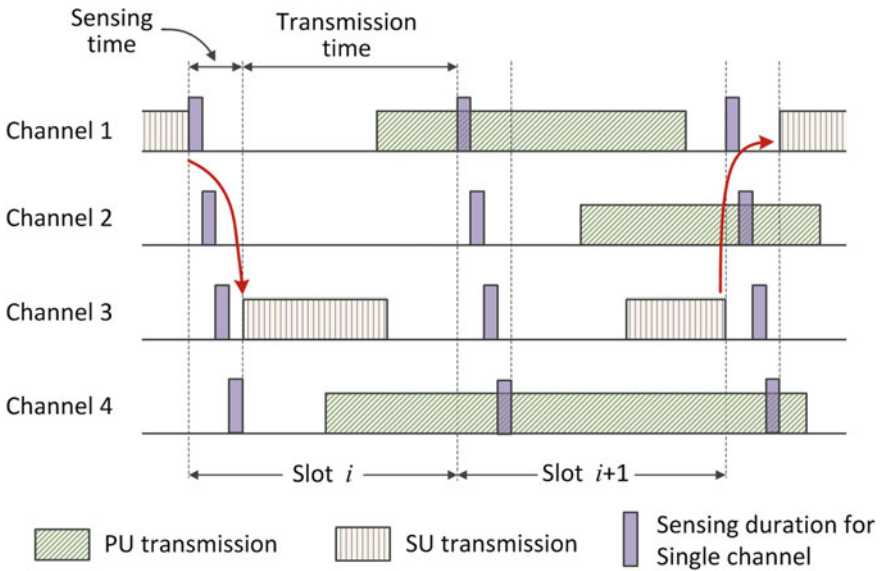


Fig. 1. Spectrum access by SU

In this paper, a simple and fast on-line learning scheme is proposed based on the statistical data about the ON and OFF duration and the current status of the channel to predict which of the channels will remain idle for the longest

duration and SUs will switch the channels accordingly. Most of the papers in literature considers that the channels used by the PUs are independent and ON and OFF durations are exponentially distributed. But this is not always true. Our work considers three different primary assignment policies and investigates how the secondary access schemes are influenced by different primary channel assignment strategies.

3 System Model

Let us consider a system with a part of wireless spectrum containing L non-overlapping channels which are used by the PUs. The channels are also opportunistically used by M SUs. Any of the SUs can access any of those channels if it senses the channel as idle that means if there is no activity on that channel. It is assumed that every SU is equipped with a single transceiver, and therefore, SU cannot sense and transmit simultaneously. To accumulate current knowledge of channel usage, each SU periodically senses the channels in order. Time is slotted, and each slot of duration, say T is further subdivided in two parts: sensing time of duration T_s and transmission time of duration T_t . Thus $T = T_s + T_t$. In general, $T_t \gg T_s$. During the sensing time T_s in each slot, each SU suspends any transmission activity and senses the channel status on the L channels sequentially in round robin fashion. Moreover, it is assumed that the SU's co-ordinate and co-operate among themselves such that the sensing slots of SU's do not overlap. To minimize switching delay, it is assumed that SUs initiate switching at the end of a sensing slot only.

The arrival of PU traffic is assumed to follow Poisson process with an average rate λ_{PU} and the call holding time is exponentially distributed with average holding time $\frac{1}{\mu_{PU}}$. Three types of channel allocation process is considered for the PUs:

1. Least ID-based channel assignment
2. Round robin channel assignment
3. Random channel assignment.

In *least ID-based channel assignment*, the channels have a predefined ordering with identification (ID) numbers $1, 2, \dots, L$ decided by the base station (BS) and when a PU call arrives, the BS assigns an idle channel which has the least ID among the available channels. In *round robin channel assignment* also, the channels are ordered according to their ID numbers. The PU calls are assigned sequentially to channel with ID number 1, then ID number 2, then ID number 3, and so on whenever available. After the channel with ID number L , the next PU call will be assigned to channel with ID number 1 if it is free, otherwise to the next idle channel available. Finally, in *random channel assignment*, when a PU call arrives, the BS selects a channel randomly among the available channels and assigns the channel to the PU call. Depending on the PU usage pattern, the behaviour of individual channel activity is modeled as a continuous-time, alternating renewal process in which the channel alternates its state between ON

(busy) and OFF (idle) periods. The channel state is ON during a PU transmission on the channel and the channel state is OFF if there is no PU transmission on that channel. Let us denote by T_{on_i} and T_{off_i} the random variables which represent the ON and OFF duration for channel i , respectively.

The SU traffic is also modeled similar to primary traffic with traffic arrival rate following Poisson process at an average rate λ_{SU} and call holding time exponentially distributed with average duration $\frac{1}{\mu_{SU}}$.

4 Spectrum Access Scheme of SU

The SU should follow different spectrum access schemes in accordance with different channel allocation strategies for the PU. It is assumed that the channel allocation policy for the PU is known in advance to the SU.

4.1 Least-ID PU Channel Assignment

To derive a proactive spectrum access strategy for SU, the channel statistics information regarding the channel status must be perfectly known to the SU in advance. But, in practice, this is not always possible especially when the PU activity varies with time. The SU must therefore estimate channel behaviour statistics such as the average idle duration for each channel i from the past data. To estimate the average idle duration, the SU must collect and update information about the number of consecutive idle encountered so far through sensing. The decision about channel selection for SU should be handled on a slot-by-slot basis to minimize interference with PUs as well as to minimize the number of switching between channels. The objective for the SU is to select the best possible channel denoted by C^k for transmission at the beginning of k th slot. The sensing result in i th channel during k th slot is denoted by $Z_i^k \in \{0, 1\}$, where busy means $Z_i^k = 1$, and idle means $Z_i^k = 0$. Let $\gamma_{0_i}^{(k-1)}$ be the length (number of zeros) in the last (or current) run of zeros obtained in the i th channel during $(k-1)$ th slot, $n_{0_i}^{(k-1)}$ represents the number of runs of zeros encountered by the SU so far in i th channel during $(k-1)$ th slot and the average estimated idle duration of the i th channel is denoted by $T_{off_i}^{(k)}$. There are four possible transitions $Z_i^{(k-1)} \rightarrow Z_i^{(k)}$ in sensing results in the i th channel that can occur in going from $(k-1)$ th slot to k th slot: (i) $0 \rightarrow 0$, (ii) $1 \rightarrow 0$, (iii) $0 \rightarrow 1$ and (iv) $1 \rightarrow 1$.

In $0 \rightarrow 0$ transition, the SU updates the variable γ_{0_i} corresponding to the number of zeros in the current run of zeros by adding one to it. The number of runs n_{0_i} encountered so far will not change. The average OFF duration T_{off_i} of channel i is not changed as the current run of zeros is not considered in calculating the average. The remaining idle duration $u_i^{(k)}$ is estimated as follows

$$u_i^{(k)} = T_{off_i}^{(k)} \left(1 + \frac{1.96}{\sqrt{n_{0_i}^{(k)}}} \right) - \gamma_{0_i}^{(k)} T \quad (1)$$

Here, $T_{off_i}^{(k)} \left(1 + \frac{1.96}{\sqrt{n_{0_i}^{(k)}}} \right)$ is the duration corresponding to 95% confidence interval for the average idle duration $T_{off_i}^{(k)}$ considering that it follows exponential distribution [1]. This means that 95% of the idle duration in i th channel will last less than this duration and therefore $T_{off_i}^{(k)} \left(1 + \frac{1.96}{\sqrt{n_{0_i}^{(k)}}} \right)$ is approximately considered as the upper limit for an idle time duration in i th channel with 95% confidence. The remaining idle duration $u_i^{(k)}$ is therefore this value subtracted by the duration already elapsed.

In $1 \rightarrow 0$ transition, a new run of zeros is started and $\gamma_{0_i}^{(k)}$ is therefore set equal to one. The number of runs n_{0_i} and the average OFF duration T_{off_i} do not change. The remaining idle duration $u_i^{(k)}$ is similarly estimated as before. In $0 \rightarrow 1$ transition, a run of zeros is just completed and therefore number of runs n_{0_i} encountered so far is incremented by one. The average OFF duration T_{off_i} is now updated to a new value according to the following update rule:

$$T_{off_i}^{(k)} = \frac{1}{n_{0_i}^{(k)}} \left(\gamma_{0_i}^{(k)} T + (n_{0_i}^{(k)} - 1) T_{off_i}^{(k-1)} \right) \quad (2)$$

Finally, for $1 \rightarrow 1$ transition, the SU need not update any of the variables γ_{0_i} , n_{0_i} or T_{off_i} at the k th slot.

The task of the SU is to select the channel j such that the estimated idle duration u_j^k is maximum subject to the condition that the channel j is currently idle in k th slot i.e. $Z_j^k = 0$. If no such channel j is found, the SU will drop any ongoing transmission till the next slot. Detailed procedure is described in Algorithm 1.

4.2 Round Robin PU Channel Assignment

For round robin PU channel assignment, the use of average run length of zeros would not provide significant information to predict the future behaviour of the channel. The reason is for round robin PU channel assignment, the average run length of zeros would be more or less equal in the long run for any channel. Instead, we use the $0 \rightarrow 1$ transition time from the past history of the channel usage to predict which of the channels currently idle has the least probability of being busy again. To achieve this, the SU needs to store the past sensing results upto M samples for all the L channels in form of a $L \times M$ sensing matrix \mathbf{SR} where $\mathbf{SR}(i, m) \in \{0, 1\}$, $i = 1, 2, \dots, L$ and $m = 1, 2, \dots, M$ indicates the sensing result for the i th channel and m th sample. The sensing matrix \mathbf{SR} gets updated at every sensing instant. For the k th instant the sensing matrix is denoted by $\mathbf{SR}^{(k)}$. At the start of k th slot, the SU senses all the L channels and form the current sensing result matrix $\mathbf{SR}^{(k)}$ by appending a new column to $\mathbf{SR}^{(k-1)}$ corresponding to the current sensing result and eliminating the first column. From the sensing matrix $\mathbf{SR}^{(k)}$, the SU finds the time instant of the

Algorithm 1: SU channel selection scheme for least-ID PU channel assignment

Input: Sensing period T , length of the last run of zeros, i.e., $\gamma_{0_i}^{(k-1)}$, number of runs of zeros encountered so far denoted by $n_{0_i}^{(k-1)}$ and average OFF-duration estimated so far, i.e., $T_{off_i}^{(k-1)}$ for each channel $i = 1, 2, \dots, L$.

Output: Channel to be selected by SU for transmission in k th slot denoted by $C^{(k)}$. Sense all the L channels to get the current sensing result denoted by $Z_i^{(k)}$ for channel $i = 1, 2, \dots, L$.

for each channel i do

if $Z_i^{(k-1)} = 0$ **and** $Z_i^{(k)} = 0$ **then**

$\gamma_{0_i}^{(k)} = \gamma_{0_i}^{(k-1)} + 1;$

$n_{0_i}^{(k)} = n_{0_i}^{(k-1)};$

$T_{off_i}^{(k)} = T_{off_i}^{(k-1)};$

$u_i^{(k)} = T_{off_i}^{(k)} - \gamma_{0_i}^{(k)}T;$

$u_i^{(k)} = T_{off_i}^{(k)} \left(1 + \frac{1.96}{\sqrt{n_{0_i}^{(k)}}} \right) - \gamma_{0_i}^{(k)}T;$

if $Z_i^{(k-1)} = 1$ **and** $Z_i^{(k)} = 0$ **then**

$\gamma_{0_i}^{(k)} = 1;$

$n_{0_i}^{(k)} = n_{0_i}^{(k-1)};$

$T_{off_i}^{(k)} = T_{off_i}^{(k-1)};$

$u_i^{(k)} = T_{off_i}^{(k)} \left(1 + \frac{1.96}{\sqrt{n_{0_i}^{(k)}}} \right) - \gamma_{0_i}^{(k)}T;$

if $Z_i^{(k-1)} = 0$ **and** $Z_i^{(k)} = 1$ **then**

$\gamma_{0_i}^{(k)} = \gamma_{0_i}^{(k-1)};$

$n_{0_i}^{(k)} = n_{0_i}^{(k-1)} + 1;$

$T_{off_i}^{(k)} = \frac{1}{n_{0_i}^{(k)}} \left(\gamma_{0_i}^{(k)}T + (n_{0_i}^{(k)} - 1)T_{off_i}^{(k-1)} \right);$

else

$\gamma_{0_i}^{(k)} = \gamma_{0_i}^{(k-1)};$

$n_{0_i}^{(k)} = n_{0_i}^{(k-1)};$

$T_{off_i}^{(k)} = T_{off_i}^{(k-1)};$

Find channel j such that u_j^k is maximum subject to $Z_j^{(k)} = 0$;

if no such j is found then

$C^{(k)} = \text{null};$

else

$C^{(k)} = j;$

most recent $0 \rightarrow 1$ transition for a channel i , and stores it in a variable τ_i . If no such $0 \rightarrow 1$ transition is found for any particular channel l from the sensing matrix, the variable τ_l is set to zero, the lowest possible value so that this channel l will not be placed in the top-most priority list.

The task of the SU now is to select the channel j such that τ_j is maximum subject to the condition that the channel j is currently idle in k th slot. If no such

Algorithm 2: SU spectrum access scheme for round robin PU channel assignment

Input: $L \times M$ binary sensing result matrix $\mathbf{SR}^{(k-1)}$ corresponding to sensing result for L channels in the last M samples at $(k-1)$ th slot.

Output: Channel to be selected by SU for transmission in k th slot denoted by $C^{(k)}$. Sense all the L channels to get the current sensing result vector $\mathbf{Z}^{(k)}$. The current sensing result matrix $\mathbf{SR}^{(k)}$ is formed as follows:

$$\mathbf{SR}^{(k)}(i, m) \leftarrow \mathbf{SR}^{(k-1)}(i, m+1); \forall i, m \neq M$$

$$\mathbf{SR}^{(k)}(i, m) \leftarrow Z_i^{(k)}; \forall i, m = M$$

for each channel i **do**

Calculate the most recent sample index τ_i from $\mathbf{SR}^{(k)}(i, m)$, $m = 1, 2, \dots, M$ at which the channel undergoes a $0 \rightarrow 1$ transition;

if no $0 \rightarrow 1$ transition is found **then**

Set $\tau_i = 0$

Find channel j such that τ_j is maximum and $\mathbf{SR}^{(k)}(j, M) = 0$;

if no such j is found **then**

$C^{(k)} = \text{null}$;

else

$C^{(k)} = j$;

SU channel selection scheme during slot k for round robin PU channel assignment

channel j is found, the SU will drop the call till the next slot. Detailed steps of the procedure are described in Algorithm 2.

4.3 Random PU Channel Assignment

For random PU channel assignment, the activity of PU channels does not follow any pattern that can be learned and hence it is not possible to design any access strategy for SUs compatible with random PU channel assignment. However, for comparison purpose, we follow the same access strategy for SUs as used for the round robin-based PU channel assignment.

5 Simulation Results

For the performance evaluation of our proposed scheme of proactive and preemptive spectrum access by cognitive users, we consider a network scenario consisting of 20 primary channels for our simulation environment. The traffic of the network is generated according to Poisson process and call holding time is assumed to follow exponential distribution with a mean value of 8 s. The proposed scheme is executed for 20,000 s to evaluate our proposed methods.

Figure 2 shows the variation of interference on PU transmission with SU's sensing interval. It is clear that if the sensing interval is small, the interference time is negligible. PU usage is kept at 50%. Finally, we observe that our channel assignment policy, for round robin-based PU channel assignment introduces the least amount of interference.

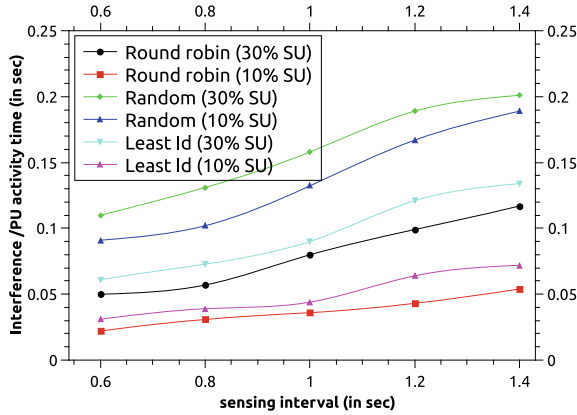


Fig. 2. Interference versus sensing interval

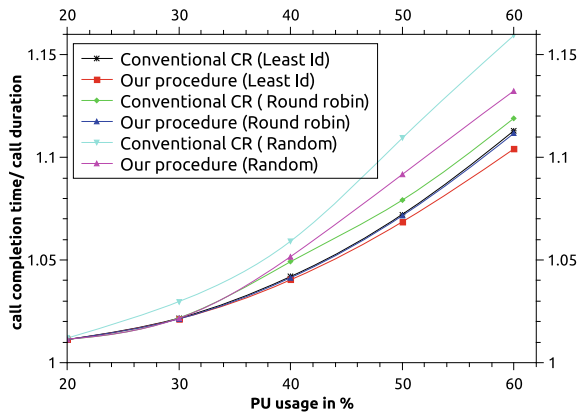


Fig. 3. Latency for call completion

Figure 3 shows the duration of call completion time in comparison with the requested call duration. Here, we compared our procedures with the conventional cognitive radio technique which uses re-active spectrum selection assuming dual transceivers, i.e, simultaneous sensing and communication. Our procedure is showing better result though with single transceiver.

Figures 4 and 5 show the call block rate and call drop rate percentage with different PU usage. SU usage is 20% and scanning interval is kept 0.6s. It is clear from the results that our procedure minimizes the call block rate and drop rate in comparison with the conventional cognitive radio spectrum allocation.

Figure 6 shows the utilization of the channels by PUs and SUs with respect to the total usage of the network. SU usage is assumed to be 20% and PU usage is varying from 30 to 60%, where SU scanning interval is kept 0.6 s. It is clear that our proposed procedure gives better channel utilization than conventional cognitive radio.

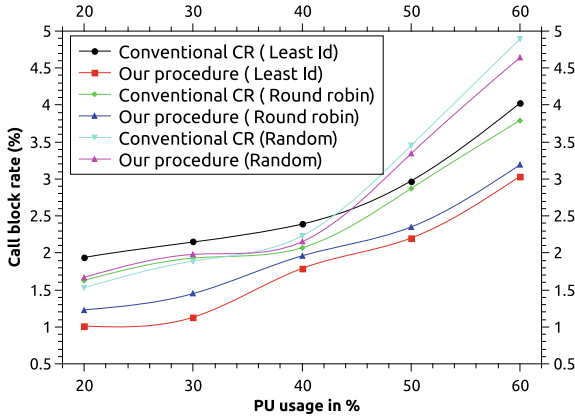


Fig. 4. Call block rate with diff. PU usage

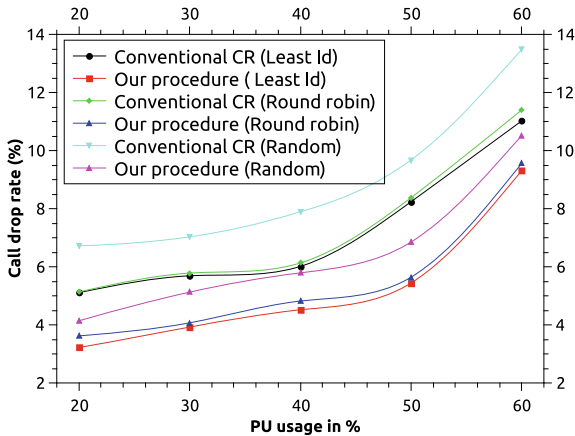


Fig. 5. Call drop rate with PU usage

6 Conclusion

In cognitive radio networks, spectrum mobility is a major concern that determines the spectrum selection latency. In this paper, we have proposed a proactive and pre-emptive spectrum mobility technique to reduce spectrum latency for SUs with single transceiver, eliminating the need for simultaneous scanning and communication. Here, an SU can switch the channel just before the estimated arrival of the PU in that channel, so that interference is minimized for both PU and SU, to improve QoS for the whole network. Assuming different types of channel assignment policies for PUs, based on the recent history of the channels following our proposed algorithms, an SU will decide the next channel to scan. Extensive simulation results show that even with a single transceiver, the proposed schemes enable the SUs to achieve better QoS in terms of interfer-

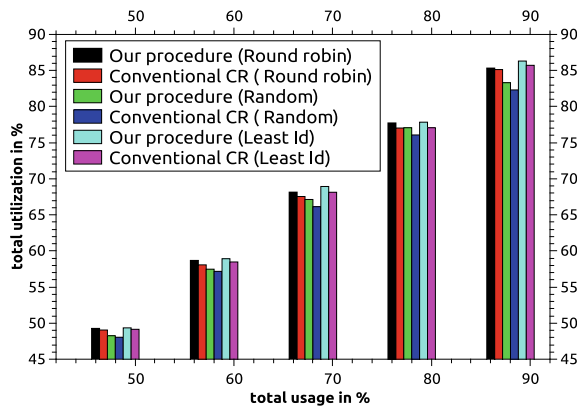


Fig. 6. Total utilization of the network

ence, call drop/block rate, and channel utilization compared to the conventional reactive cognitive radio technique with provision for simultaneous scanning and communication that demands a two-fold increase in transceiver hardware.

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