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Improved Spectrum Handover scheme in Cognitive Radio Ad Hoc Networks using Backup Channels

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Abstract: - **The advancement in wireless technologies demands dynamic spectrum allocation in an effective way. Cognitive radio networks can fulfill these demands by allowing secondary users to access licensed spectrum when primary users are not utilizing it. Dynamic utilization of available spectrum can be accomplished by spectrum handover. Spectrum handover occurs when a primary user approaches a channel which is already engaged by a secondary user. Spectrum handover has an unfavourable effect on the link maintenance of secondary user. In this paper, Dynamic Spectrum Access using unlicensed channels as Backup channels (DSAB) technique is proposed for decreasing spectrum handovers in cognitive radio ad hoc networks. A broad mathematical model is analysed to estimate the performance of DSAB in terms of two metrics: link maintenance probability and expected number of spectrum handovers. Performance evaluation of proposed DSAB technique is compared with the existing techniques which result in an improvement in the mentioned metrics parameters.**

Keywords: - **Cognitive radio, Dynamic Spectrum Access using unlicensed channels as Backup channels (DSAB), link maintenance, non-cognitive user, primary user, secondary user, spectrum handover.**

I. INTRODUCTION

Classical ad hoc networks are quickly heading towards spectrum scarcity issue because these networks operate on a fixed channel assignment strategy. On the other hand, significant regions of licensed bands are underused. Cognitive Radio Ad Hoc Networks (CRAHNs) can overcome this spectrum scarcity problem. A mobile node dynamically accesses the spectrum holes in licensed bands through Dynamic Spectrum Access (DSA) strategy in CRAHNs. DSA strategy allows to share the licensed bands to the secondary user (SU) along with the primary user (PU) in an opportunistic manner. Cognitive Radio (CR) [1][2] is an intelligent radio because it can recognize the underused channel in radio environment. On appearance of PU in the same channel which is already occupied by SU, then SU shift to other unoccupied channel for the consistent communication. This process of channel switching by SU is referred as spectrum handover. The practical realization of CR has immense number of challenges. Spectrum handover is one of the major challenge. There are two steps in spectrum handover such as, PU detection and link maintenance. On spotting a PU arrival, SU has to leave the channel for PU. Then, SU will execute link maintenance to restore data transmission with another available channel. Spectrum handover can be classified into: proactive, reactive, hybrid spectrum handover. In proactive approach [3][4], on the basis of PU traffic model, SU approximates PU arrival. After that SU executes spectrum sensing before handover triggering action happens and vacate the channel. In reactive approach [5][6], once handover triggering action happens, SU executes spectrum sensing to detect a new channel for spectrum handover. In hybrid approach, SU executes spectrum sensing in proactive way and handover action in reactive way. In all the previously explained handover schemes, handover is executed totally in licensed bands. But none of the spectrum handover approach executes handover in the unlicensed bands. Although, number of channels are limited in unlicensed bands, but they may become vacant and hence, in accordance to [7] probability of availability of unlicensed bands for link maintenance can be taken into consideration. In this paper, we examine the issue of reduction in spectrum handover in CRAHNs using a new spectrum access technique named dynamic spectrum access using unlicensed channels as backup channels (DSAB). So, CR ad hoc devices can operate in both licensed and unlicensed spectrum bands by using DSAB spectrum access technique. The performance of DSAB is examined by a wide mathematical model. The remaining paper is structured as follows: Section II, provides related work done in this field. Section III, provides an overview of DSAB technique. Section IV, provides proposed model for cognitive radio ad hoc networks. Section V, provides the link maintenance probability. Section VI, provides the spectrum handover survey. Section VII,

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provides the performance evaluation of DSAB technique. Section VIII, the conclusion of the work is provided.

II. RELATED WORK

In [8], an effect of spectrum handover over the link maintenance of an SU is studied. In [9], for reducing spectrum handovers of SUs, spectrum matching algorithms are used. In [10], a three-dimensional Markov chain model has been used to examine the SUs performance, but here spectrum handover of SUs is not involved to examine SUs performance.

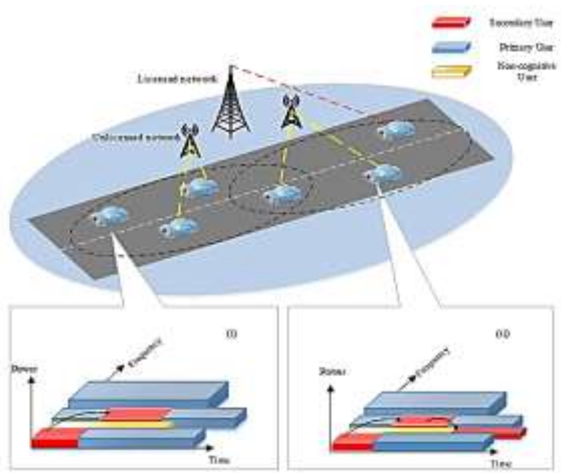

Fig. 1. Shows the spectrum handoffs of a SU. (i) Shows incomplete transmission of SU. (ii). Shows spectrum access using DSAB technique, which leads to SU transmission completion.

Hence, in all the previous works spectrum handover has not been completely discussed, licensed channels are only used for doing spectrum handovers. The works in [11] [12] [15] are almost relative to our work. In [12] and [15], SUs performance is examined subject to the link maintenance probability and the expected number of spectrum handovers. But in [12] only LCs are used for spectrum handover and in [15] both LCs and UCs are used for spectrum handover. This paper is extension of the work done in [15]. The DSAB technique is explained in the next section. Dynamic Spectrum Access Using Unlicensed Channels As Backup Channels (DSAB) In future, majority of wireless devices will have CR ability and very few wireless devices will be without CR ability. Because licensed bands traverse a large geographic space and considerable parts of the licensed spectrum are underused such as TV bands. So, in CRAHNs using DSAB technique a SU will use the licensed spectrum as operating spectrum and the unlicensed spectrum as backup spectrum at the instant of PU arrival. At the time of PU arrival, SU should instantly do spectrum handover to unlicensed channels. Here two cases arise: (i) if there are free unlicensed channels available, then SU will shift to a new unlicensed channel and, (ii) if there are no free unlicensed channel available, then SU again do spectrum handover to the licensed channel. For case (ii) again two more sub-cases arise: (a) if there are free licensed channels available, then SU will shift to a new licensed channel and, (b) if there are no free licensed channel available, then SU will halt for a duration with utmost value T_m, So that if any licensed channel becomes free with in duration T_m, then SU will shift to that licensed channel to achieve link maintenance. If no channel becomes free during T_m, then both link maintenance and spectrum handoff of SU will fail. In DSAB technique, when channels are available for spectrum handover proactive approach of spectrum handover is used, but for T_m duration reactive approach of spectrum handover is used. Work done in this paper is an addition to the work done in [15]. Different category of users influences the DSAB's performance: (1) primary users (PUs), (2) secondary users (SUs), (3) non-cognitive users (NCUs). NCUs will use only unlicensed bands. The main benefits of utilizing unlicensed bands in DSAB technique are:

- For unlicensed bands all users, whether they are SUs or NCUs, have the identical rights to access them.
- Reduction in spectrum handover count.
- Improvement in link maintenance.

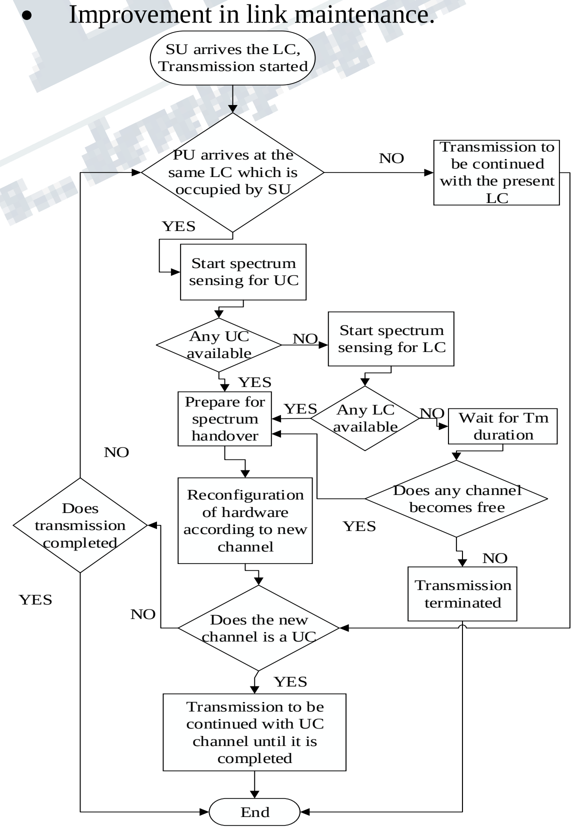

Fig. 2. Flowchart of proposed DSAB technique.

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NCUs arrivals will affects the SUs link maintenance, so their effects are considered in the next section. DSAB technique is very useful in case when we have to transmit a huge amount of data, i.e., it is better to wait for T_m duration for getting a channel instead of directly terminating the transmission when no free channel is available because if transmission gets terminated than the amount of data which was already transmitted previously has to be retransmitted, which results in wastage of energy as well as time. DSAB technique is very useful for futuristic machine to machine communication.

IV. PROPOSED MODEL FOR COGNITIVE RADIO AD HOC NETWORKS (CRAHNS)

This proposed mathematical model discussion by presuming n_1 LCs and n_2 UCs, which are used by nodes of CRAHNs. The partakers of n_1 LCs will be PUs and SUs, partakers of n_2 UCs will be SUs and NCUs. In case of LCs, SU should leave the channel when licensed user of that channel appears. However, in case of UCs there will be no takeover for any partaker of UCs once it acquires the channel.

A. Licensed users

It is presumed that PU will utilize only licensed channel for its communication motive. It is further presumed that λ_{11} indicates arrival rate of a new PU, whose arrival is a poisson process. PU inter-arrival time will be denoted by a random variable (RV) $I_{PU_{a`}}$, which will be described as inter-arrival time between $(a'-1)^{th}$ and a'^{th} PU, with general form I_{PU}. Also PU inter-arrival time I_{PU} obeys an exponential distribution. Hence probability density function (pdf), $f_{I_{PU}}(t)$, of RV I_{PU} will be expressed as $f_{I_{PU}}(t) = \lambda_{11}e^{-\lambda_{11}t}$. Let PU call holding time will be denoted by RV C_{PU} with expectation $\frac{1}{\mu_{11}}$, pdf $f_{C_{PU}}(t)$, cumulative distribution function (CDF) $F_{C_{PU}}(t) = (1 - \Pr(C_{PU} < t))$. The residual call holding time of a PU will be denoted by a RV $R_{PU,a`}$, which will be described as an interval from an in-between instant to the instant of PU work completion, with general form R_{PU}. Using Residual Life Theorem, pdf of residual call holding time of PU will be expressed as $f_{R_{PU}}(t) = \mu_{11}(1 - F_{C_{PU}}(t))$. Assuming ρ_{11} denotes PU traffic density, i.e., $\rho_{11} = {\lambda_{11}}/{\mu_{11}}$. The variable a` which was defined earlier denotes the number of licensed channels currently occupied by PUs, i.e., $0 \le a` \le n_1$. Let P_{11} be a RV representing number of PUs owing to steady state probability distribution, which is denoted by $p_{11_{a`}}$ (where, $0 \le a` \le n_1$), given as

$$p_{11_{a`}} = \frac{\rho_{11}{}^{a`}}{a`!} \frac{1}{\sum_{a`=0}^{n_1} \frac{\rho_{11}{}^{a`}}{a`!}} \qquad \text{eqn(1)}$$

B. Cognitive users

Cognitive users are also called secondary users (SUs). It is presumed that SUs will utilize at least one channel for their communication motive. It is further presumed that λ_{22} indicates arrival rate of a new SU, whose arrival is also a Poisson process. Let SU call holding time will be denoted by RV C_{SU} with expectation $\frac{1}{\mu_{22}}$, pdf $f_{C_{SU}}(t)$, CDF $F_{C_{SU}}(t) = \Pr[C_{SU} < t]$ and complementary CDF $\overline{F_{C_{SU}}(t)} = \Pr[C_{SU} > t] = 1 - F_{C_{SU}}(t)$.

When PU arrives, it will choose a specific licensed channel with probability $\frac{1}{n_1 - a`}$, her a` denotes number of licensed channels currently occupied by PUs. If out of $(n_1 - a`)$ licensed channels, arrived PU selects that channel which is occupied by a SU, then SU will perform a spectrum handover. Let P_{sh} denotes SU handover probability, given as

$$P_{sh} = (1 - e^{-\lambda_{11}t}) \sum_{a`=0}^{n_1} \frac{1}{(n_1 - a`)} p_{11a`}$$

Let P_{22} be a RV representing number of SUs engaged available licensed channels owing to steady state conditional probability distribution, which is denoted by $p_{22_{b`|a`}}$ $(0 \le a` \le n_1, 0 \le b` \le n_1 - a`)$, where variable b` denotes number of licensed channels occupied by SUs. Then probability $p_{22_{b`|a`}} = \Pr[P_{22} = b`|P_{11} = a`]$, will be given as

$$p_{22_{b`|a`}} = \frac{\lambda_{22}{}^{b`}}{b`!\,(\mu_{22} + P_{sh})^{b`}} p_{22_{0|a`}} \qquad \text{eqn(2)}$$

Where, $(\rho_{22} = {\lambda_{22}}/{\mu_{22}})$ and $p_{22_{0|a`}}$ may be provided using standardization condition $\sum_{b`=0}^{n_1 - a`} p_{22_{b`|a`}} = 1$.

Non-cognitive users

It is presumed that λ_{33} indicates arrival rate of a new NCU, whose arrival is a Poisson process. NCUs call holding time follows exponential distribution with parameters μ_{33}. Let, P_{33} be a RV representing number of NCUs and SUs engaged available unlicensed channels owing to steady state probability distribution, which is denoted by $p_{33_{a`}}$ (where, $0 \le a` \le n_2$), given as

$$p_{33_{a`}} = \frac{\rho_{33}{}^{a`}}{a`!} \frac{1}{(1 + \sum_{a`=0}^{n_2} \frac{\rho_{33}{}^{a`}}{a`!})} \qquad \text{eqn(3)}$$

where, $\rho_{33} = \frac{P_{sh} + \lambda_{33}}{\mu_{22} + \mu_{33}}$.

V. LINK MAINTENANCE PROBABILITY

To prevent service termination in the course of handover, CR users carry out link maintenance operation to resume communication. Let L_s stands for net link maintenance

probability. The probability of successful link maintenance of SU when SU departs from the channel is known as link maintenance probability.
Over UCs the link maintenance is stated as
$L_u = P_{sh}(1 - p_{33_{n_2}})$.
If there are no available unlicensed channels, then also link could be preserved successfully, if there is a free LC. If there is no free LC, link could be still preserved successfully if any LC becomes free within T_m time. If no LC becomes free within T_m time, then link maintenance is terminated. T_s denotes actual waiting time for SU, which is equal to least of every PU call holding times, given as

$$T_s = \min(R_{PU,1}, R_{PU,2}, \ldots, R_{PU,n_1-1}, C_{PU,n_1})$$

Over LCs the link maintenance is stated as
$L_l = P_{sh} p_{33_{n_2}}((1 - \Omega) + \Omega \Pr(T_s < T_m))$
where,
$\Omega = \sum_{a`=1}^{n_1} p_{11_{a`}} p_{22_{n_1-a`|a`}}$.
On solving, $\Pr(T_s < T_m)$

$$= \Pr\left(\min\left(R_{PU,1}, R_{PU,2}, \ldots, R_{PU,n_1-1}, R_{PU,n_1}\right) < T_m\right)$$
$$= 1 - ((\Pr(R_{PU} > T_m))^{n_1-1} \Pr(C_{PU} > T_m))$$
$$= 1 - (\Phi^{n_1-1}\Psi)$$

where,

$$\Phi = \Pr(R_{PU} > T_m) = 1 - \lambda_{11} \int_0^{T_m} (1 - F_{C_{PU}}(y))\, dy$$
$$\Psi = \Pr(C_{PU} > T_m) = 1 - \int_0^{T_m} f_{C_{PU}}(y)\, dy$$

Then, L_l becomes

$$L_l = P_{sh} p_{33_{n_2}}((1 - \Omega) + \Omega(1 - \Phi^{n_1-1}\Psi))$$

Net link maintenance probability is stated as

$$L_s = L_u + L_l$$
$$L_s = P_{sh}\left(1 - p_{33_{n_2}} \Omega \Phi^{n_1-1}\Psi\right) \qquad \text{eqn}(4)$$

VI. SPECTRUM HANDOVER

Total spectrum handovers for an SU from the instant its transmission initiated to the instant its transmission completed or its transmission forcefully ended is denoted by a discrete random variable N. Now consider those PUs which entered in system after the SU entered in it. Since $I_{PU_{a`}}$ denotes inter-arrival time between $(a' - 1)^{th}$ and a'^{th} PU. Let sum of all inter-arrival times (γ_m) of PUs which entered in system after the SU entered in it is given as

$$\gamma_m = I_{PU_1} + I_{PU_2} + \cdots + I_{PU_{m-1}} + I_{PU_m}, \quad m = 1,2,3, \ldots.$$

Since PU arrival is a poisson process. Therefore γ_m obeys Erlang distribution and thus pdf $f_{\gamma_m}(t)$ of γ_m is given as [14]

$$f_{\gamma_m}(t) = \frac{\lambda_{11}(\lambda_{11}t)^{m-1}}{(m-1)!} e^{-\lambda_{11}t} \qquad \text{eqn}(5)$$

N=0
That means the SU will not do spectrum handover, this will be possible only if
Call holding time of the SU is shorter than inter-arrival time of PU, that means SU finishes off its transmission prior to PU arrival.
Numerous PUs arrives throughout the SU call holding time, but all this PUs adopts other channels against the one occupied by the SU.
Then probability for N=0 that means probability for zero spectrum handover for SU is given as
$P[N = 0]$

$$= \Pr[C_{SU} < I_{PU}] + \sum_{m=1}^{\infty} \Pr[\gamma_m < C_{SU} < \gamma_{m+1}](1 - P_{sh})^m$$
$$= f^*_{C_{SU}}(\lambda_{11} P_{sh}) \qquad \text{eqn}(6)$$

N =m, (m≥1)
That means the SU will do m spectrum handovers during its call holding time. Hence three cases arise:

Case 1
The SU performs $(m - 1)$ handovers on LCs and after that finally acquires UC in the m^{th} handover. This case includes following prospects. During call holding time of the SU $(m + b`)$ PUs arrivals will happen. Out of total PUs the 'm' number of PUs will call for the same channel occupied by the SU, remaining b` PUs will join channels other than the one occupied by the SU. Then Pr[case1] is given as
Pr[case1]

$$= \sum_{b`=0}^{\infty} \Pr[C_{SU} > \gamma_{m+b`}] \binom{m + b` - 1}{b`} (P_{sh} p_{33_{n_2}}((1 - \Omega) + \Omega(1 - \Phi^{n_1-1}\Psi)))^{m-1} (1 - P_{sh})^{b`} P_{sh}(1 - p_{33_{n_2}})$$
$$= \frac{\left(\left(-\lambda_{11} P_{sh} p_{33_{n_2}}((1 - \Omega) + \Omega(1 - \Phi^{n_1-1}\Psi))\right)^{m-1} (\lambda_{11} P_{sh}(1 - p_{33_{n_2}}))\bar{F}^{*(m-1)}_{C_{SU}}(\lambda_{11} P_{sh})\right)}{(m-1)!}$$

Case 2
The SU performs m handovers on LCs till its transmission completes, i.e., the SU fails to occupy UCs m times. This case includes following prospects. During call holding time of the SU $(m + b`)$ PUs arrivals will happen. Out of total PUs the 'm' number of PUs will call for the same channel occupied by the SU, remaining b` PUs will join channels other than the one occupied by the SU. Then Pr[case2] is given as

Pr[case2]

$$= \sum_{b`=0}^{\infty} \Pr[\gamma_{m+b`} < C_{SU} < \gamma_{m+b`+1}] \binom{m+b`-1}{b`} \left(P_{sh}p_{33_{n_2}}((1-\Omega)+\Omega(1-\Phi^{n_1-1}\Psi))\right)^m (1-P_{sh})^{b`}$$

$$= \frac{\left(\left(-\lambda_{11}P_{sh}p_{33_{n_2}}\left((1-\Omega)+\Omega(1-\Phi^{n_1-1}\Psi)\right)\right)^m \bar{f}_{C_{SU}}^{*(m)}(\lambda_{11}P_{sh})\right)}{(m)!}$$

Case 3

The SU performs $(m-1)$ handovers on LCs ans then its transmission forcefully ended in the m^{th} handover, i.e., the SU fails to occupy LCs as well as UCs in the m^{th} handover. This case includes following prospects. During call holding time of SU $(m+b`)$ PUs arrivals will happen. Out of total PUs the 'm' number of PUs will call for the same channel occupied by the SU, remaining b` PUs will join channels other than the one occupied by the SU. Then Pr[case3] is given as

Pr[case3]

$$= \sum_{b`=0}^{\infty} \Pr[C_{SU} > \gamma_{m+b`}] \binom{m+b`-1}{b`} \left(P_{sh}p_{33_{n_2}}((1-\Omega)+\Omega(1-\Phi^{n_1-1}\Psi))\right)^{m-1} (1-P_{sh})^{b`}(P_{sh}\Omega p_{33_{n_2}}\Phi^{n_1-1}\Psi)$$

$$= \frac{\left(\left(-\lambda_{11}P_{sh}p_{33_{n_2}}\left((1-\Omega)+\Omega(1-\Phi^{n_1-1}\Psi)\right)\right)^{m-1} (\lambda_{11}P_{sh}p_{33_{n_2}}\Omega\Phi^{n_1-1}\Psi)\bar{F}_{C_{SU}}^{*(m-1)}(\lambda_{11}P_{sh})\right)}{(m-1)!}$$

Now, net probability for m handovers done by the SU during its call holding time is given as

$$P[N=m] = \Pr[case1] + \Pr[case2] + \Pr[case3] \quad \text{eqn(7)}$$

$$= \frac{\left(\left(-\lambda_{11}P_{sh}p_{33_{n_2}}\left((1-\Omega)+\Omega(1-\Phi^{n_1-1}\Psi)\right)\right)^{m-1} \left(\lambda_{11}P_{sh}(1-p_{33_{n_2}}(1-\Omega\Phi^{n_1-1}\Psi)\right)\bar{F}_{C_{SU}}^{*(m-1)}(\lambda_{11}P_{sh})\right)}{(m-1)!} + \frac{\left(\left(-\lambda_{11}P_{sh}p_{33_{n_2}}\left((1-\Omega)+\Omega(1-\Phi^{n_1-1}\Psi)\right)\right)^m \bar{f}_{C_{SU}}^{*(m)}(\lambda_{11}P_{sh})\right)}{(m)!}$$

Now, average of $P[N=m]$ is given as

$$E[N] = \sum_{m=1}^{\infty} m(P[N=m]) = (1-p_{33_{n_2}}(1-\Omega\Phi^{n_1-1}\Psi))[1-\bar{f}_{C_{SU}}^{*}(\lambda_{11}P_{sh})] - \frac{\left(p_{33_{n_2}}\left((1-\Omega)+\Omega(1-\Phi^{n_1-1}\Psi)\right)\left[1-\bar{f}_{C_{SU}}^{*}(\lambda_{11}P_{sh}(1-p_{33_{n_2}}(1-\Omega\Phi^{n_1-1}\Psi))\right]\right)}{(1-p_{33_{n_2}}(1-\Omega\Phi^{n_1-1}\Psi))}$$

VII. PERFORMANCE EVALUATION OF DSAB TECHNIQUE

In this part, the performance of DSAB is examined in terms of link maintenance probability and expected number of spectrum handovers. The following operative parameters are picked: $\lambda_{22} = 0.5\ {}^{SU}/_{sec}$, $\mu_{11} = 0.15\ {}^{PU}/_{sec}$, $\mu_{22} = 0.5\ {}^{SU}/_{sec}$, $T_m = 1sec$, call holding times of PU and SU follows 2-stage erlang distribution.

The SU link maintenance probability is examined using three distinct scenarios. 6 LCs and 0 UCs are taken in the first scenario. In the second scenario, 6 LCs and 2 UCs are taken, but here T_m is not taken into consideration. In the third scenario (DSAB scenario), 6 LCs and 2 UCs are taken, but here T_m is taken into consideration. In addition, low traffic, moderate traffic and high traffic conditions in UCs due to NCUs are also examined to compare the effect of NCUs on DSAB. Fig. 3,4,5 shows the link maintenance probability of SU in terms of λ_{11} for low traffic, moderate traffic and high traffic conditions in UCs. In all the three traffic conditions DSAB scenario performs better in comparison to the other two scenarios in terms of link maintenance probability. This can be elaborated as follows. In DSAB, SUs performs the spectrum handovers to the UCs along with the LCs, SUs can halt for T_m duration if there is no free channel available.

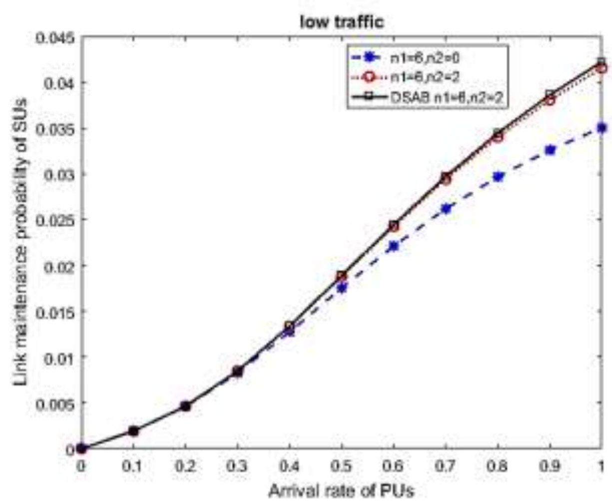

Fig. 3. Link maintenance probability of SUs at low traffic conditions of NCUs.

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Fig. 6 shows the probability for zero spectrum handovers for the DSAB scenario, i.e., probability for $N = 0$. From fig. 6, it is clear that, as λ_{11} increases, $P[N = 0]$ decreases. This can be elaborated as follows. As λ_{11} increases, number of PUs in LCs increases which leads to increase in the chances for spectrum handover for SUs.

The spectrum handover survey which was done in section V is examined using the same three scenarios, the same three traffic conditions in UCs due to NCUs are also considered. Fig. 7,8,9 shows the expected number of spectrum handovers of SUs in terms of λ_{11} for the same three traffic conditions. Here also in all the three traffic conditions, DSAB scenario performs better in comparison to the other two scenarios. The number of spectrum handovers of SUs in DSAB scenario is less in comparison to the other two scenarios.

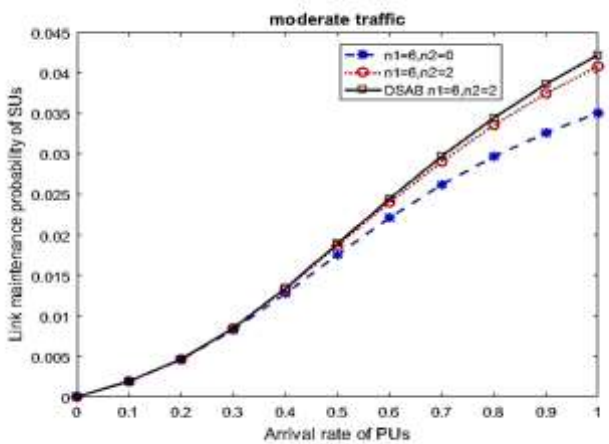

Fig. 4. Link maintenance probability of SUs at moderate traffic conditions of NCUs.

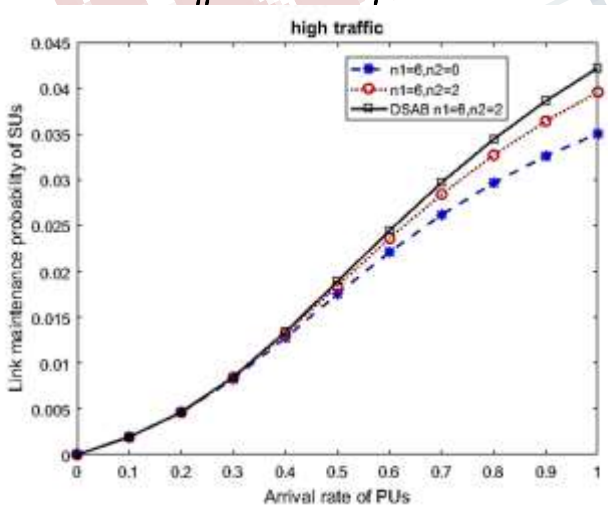

Fig. 5. Link maintenance probability of SUs at high traffic conditions of NCUs.

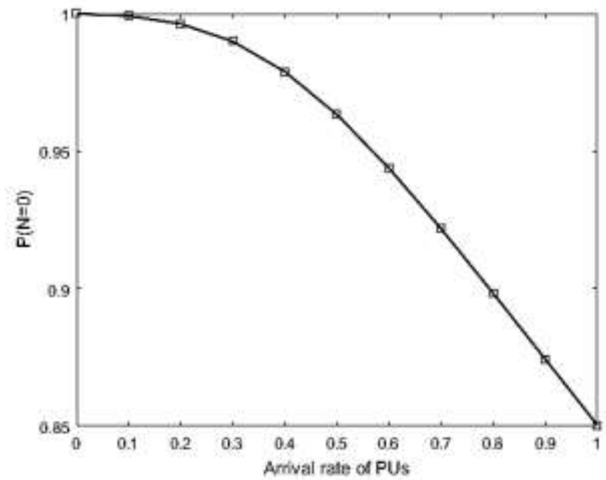

Fig. 6. Probability for zero handovers.

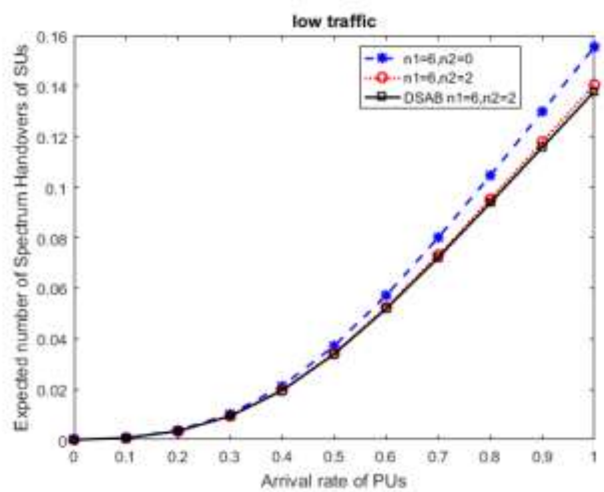

Fig. 7. Expected number of spectrum handovers of SUs at low traffic conditions of NCUs.

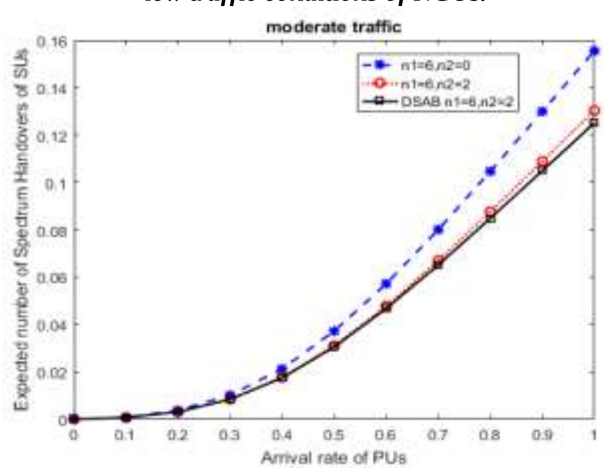

Fig. 8. Expected number of spectrum handovers of SUs at moderate traffic conditions of NCUs.

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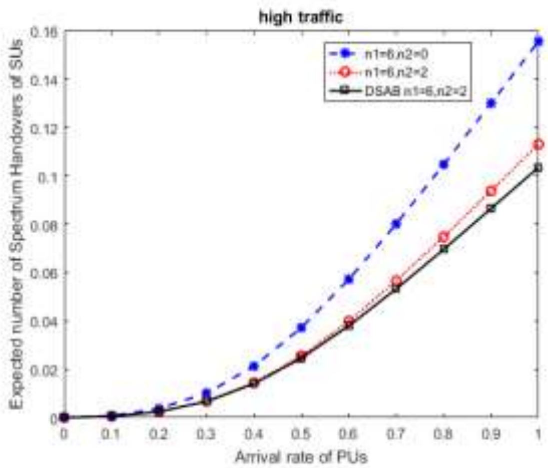

Fig. 9. Expected number of spectrum handovers of SUs at high traffic conditions of NCUs.

VIII. CONCLUSION

In this paper, DSAB technique is used for decreasing the number of spectrum handovers in cognitive radio ad hoc networks. The simulation results show an advancement in SUs performance in terms of link maintenance and expected number of spectrum handovers as compared to the previous works. Until now, there have been only a few techniques available for minimizing the spectrum handover, and more studies are needed in these areas.

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