Characterization of spectrum mobility and channel availability in CRMANETs

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***Abstract*— Cognitive radio (CR) is the most enterprise solution to spectrum scarcity. The time and space varying nature of spectrum bands necessitates the spectrum handoff in which the secondary user (SU) must vacate the frequency band when the primary users (PUs) reuse the spectrum band. The variation in spectrum band is called spectrum mobility. Hence, characterization of spectrum mobility and channel availability, which is the most influential factor in CR networks, is essential. In this paper, we investigate an analytical model to show the effect of different events on channel availability and spectrum mobility in mobile cognitive radio Ad hoc networks (CR-MANETs). We also integrate the effect of different events on the channel availability, which is essential for performing integrated mobility and handoff management.**

***Keywords*- Cognitive Radio, Spectrum Mobility, Handoff Management, node mobility**

I. INTRODUCTION

According to the frequency chart of the Federal Communication Commission (FCC), the fixed spectrum allocation has led to poor spectrum efficiency. This low efficiency is because of the underutilized spectrum usage for a significant amount of time. Cognitive radio is the most influential technology that promises to improve the spectrum efficiency. Based on the [1], the term cognitive radio is defined as an adaptive and intelligent radio which is aware of its surrounding environment. The SUs can capture the temporal and spatial spectrum bands in an opportunistic manner.

The existence of free spectrum holes is arbitrary because of the randomness PU’s appearance and unpredictability of user mobility. The spectrum holes always are shifting over time due to the PU’s appearance as well as over space due to the user mobility. The spectrum holes shifting and spectrum band changing is defined as spectrum mobility. Spectrum mobility leads to spectrum handoff, which refers to changing the operation frequency of a cognitive user. During the spectrum mobility, PU reclaims the particular licensed band occupied by the SU and the SU’s ongoing call transfers to another empty band of the spectrum. Hence, the characterization of spectrum band availability is critical in CR networks.

In this paper, we characterize the spectrum holes availability in CR-MANETs and explain the effects of different events on it using an analytical model.

The rest of this paper is organized as follows. In Section II, we investigate an analytical model to describe the effects of different mobility event on the channel availability in CR networks especially in CR-MANET. In section III, we have a discussion of the results. In Section IV, we introduce different scenario for handoff initiation, and introduce the challenges in integrated handoff management. Finally, in Section V, we conclude the paper.

II. EFFECTS OF DIFFERENT EVENTS ON SPECTRUM AND CHANNEL AVAILABILTY IN CRMANETS

In CR-MANET, the available spectrum bands vary not only over time but also by change in the SU’s location. Hence, to develop handoff management protocol for a CR-MANET, the spectrum mobility, user mobility, and channel quality degradation must be considered jointly [2].

Considering a route (Fig. 1) from the source node S, to the destination node D, we want to show the effects of different above mentioned event on channel availability on this route. Hence, we propose the following analysis considering the number of nodes, network area, node transmission range, channel transmission range and the maximum number of channels. Table .1 elaborates the different parameters and their definitions used in this analysis.

In a cognitive network, each node can send and receive data along different channels depending on PU’s activities. At least one common channel is necessary to establish a link between two different nodes which are the ends of one hop. Since the channel availability on each node is independent of other nodes, to calculate the probability of successful rerouting, we can consider different hop separately.

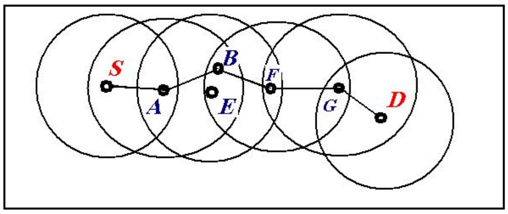

Figure 1. An established route in CR-MANETs

Considering p as the probability of single channel availability at a node, which shows the PU's activity, we can conclude the following probabilities:

The P_{chat} is defined as the probability of single channel availability between two nodes, which is equal to:

$$P_{chat} = p^2 . \tag{1}$$

Based on (1):

$$\overline{P}_{chat} = 1 - p^2 . \tag{2}$$

The $\overline{P}_{chat,c}$ is also defined as the probability that there is not a single channel among c channels between two nodes, which is equal to:

$$\overline{P}_{chat,c} = (\overline{P}_{chat})^c = (1 - p^2)^c . \tag{3}$$

Concluding from (3), the probability that there is at least one single channel, among c channels, between two nodes is equals to:

$$P_{chat,c} = 1 - \overline{P}_{chat,c} = 1 - (1 - p^2)^c . \tag{4}$$

We define the $P_{car,c}$ as the probability that there is at least one common channel among all hops in a route which is as follows:

$$P_{car,c} = (P_{chat,c})^{n-1} = (1 - (1 - p^2)^c)^{n-1} . \tag{5}$$

The effect of SU's mobility and channel transmission range on the probability of successful routing can be considered as follows:

In channel heterogeneity with different channel transmission ranges, the distance between SUs must also be considered. Suppose that there is the total number of C channels in a heterogeneous network, which are classified into L types according to their different transmission ranges. Different channels occupy different spectrum bands. The number of available channels of each type at each node is c^l in which $l=\{1,2,\ldots,L\}$. It means that $c=c^1+c^2+\ldots+c^L$. The transmission range of channels of type l is R_l. Considering this channel classification, we can model the channel quality degradation. Two SUs can use a channel of type l for communication when their distance is less than R_l.

Table .1 different used parameters and their definitions

N_N	Total number of nodes in the network
A_N	Network area
R_T	Transmission range
n	Number of nodes in a route
C	Total number of available channel
c	Number of possible channels at each node
l	Channel type
L	Total Number of channel type
c^l	Number of possible channels of Each type at each node
p	Probability of a particular channel availability at each node
λ	Poisson density of nodes' spatial distribution in the network
R_l	Transmission range of a channel of type l

By SUs' movement, and when their distance becomes longer than R_l, SUs must change their channel, and choose a channel with a transmission range longer than R_l.

We define the $\overline{P}_{chat,c^l}$ as the probability that there is not a single channel of type l, among c^l channels, between two nodes, which is equal to:

$$\overline{P}_{chat,c^l} = (\overline{P}_{chat})^{c^l} = (1 - p^2)^{c^l} . \tag{6}$$

Based on (6), the probability that there is at least one single channel of type l among c^l channels between two nodes is equal to:

$$P_{chat,c^l} = 1 - P_{chat,c^l} = 1 - (1 - p^2)^{c^l} . \tag{7}$$

We consider that the total number of nodes in a route is equal to n. It means that we have $n-1$ hops. The probability of channel availability between two nodes or within a hop depends on the length of the hop or the distance between two nodes. Suppose that:

The length of r_1 hops is less than R_1 and longer tan R_0, the length of r_2 hops is less than R_2 and longer than R_1,… and the length of r_l hops is less than R_l and longer than R_{l-1}, where $r_1+r_2+\ldots+r_l=n-1$. Considering (7), we define the $P_{car,c}$ as probability that there is at least one common channel among all hops in a route which is as follows:

$$\begin{aligned} P_{car,c} &= P(r_1)(1-(1-p^2)^c)^{r_1} + P(r_2)(1-(1-p^2)^{c-c^1})^{r_2} + \ldots + \\ & P(r_{l-1})(1-(1-p^2)^{c-c^1-\ldots-c^{l-2}})^{r_{l-1}} + P(r_l)(1-(1-p^2)^{c^l})^{r_l} \\ &= \sum_{i=1}^{l} P(r_i)(1-(1-p^2)^{c-\sum_{j=0}^{i-1} c^j})^{r_i} \qquad \& \qquad c^0 = 0 \end{aligned} \tag{8}$$

In which $P(r_i)$ is defined as the probability that the length of r_i hops is less than R_i and longer than R_{i-1} with $R_0=0$.

We define the $P(R_i)$ as the probability of communication between two nodes with expected hop length less than R_i and longer than R_{i-1}. Since, the communicating of different two nodes with each other is independent of other nodes we have:

$$P(r_i) = (P(R_i))^{r_i} . \tag{9}$$

Therefore, based on (8), (9) and $\sum_{i=1}^{l} r_i = n-1$ we have:

$$P_{car,c} = \left(\sum_{i=1}^{l} P(R_i)\left(1-(1-p^2)^{c-\sum_{j=0}^{i-1}c^j}\right)\right)^{n-1}, c^0 = 0 \qquad (10)$$

In (10), the $P(R_i)$ is the probability of that the distance between two nodes (D) is less than R_i and longer than R_{i-1} with $R_0=0$.

The R_T is the node transmission range. We suppose that $R1<.....<R_l<R_T$. The probability of $P(R_i)$ is dependent on the density of nodes in the network and R_i. Suppose that the nodes' spatial distribution is modeled as a Poisson variable with densityλ. This means that:

$$\Pr(\textit{there are k nodes in an region with area } S) = \frac{\lambda S^k \exp(-\lambda S)}{k!}, k = 0,1,2,3,.... \qquad (11)$$

The $P(R_i)$ can be calculated as follows[4]:

The number of neighbours of a node in a disk with radius R_T is equal to:

$$N = \lambda \pi {R_T}^2 \qquad (12)$$

The probability that there is no neighbour node in the forward direction in the disk with radius R_T is equal to $e^{-\frac{N}{2}}$, and we have:

$$\mathrm{P}\Big|_{\textit{finding a node in disk with radius } R_T} = 1-\exp\left(-N\!/\!2\right) \qquad (13)$$

Suppose that the random variable d denotes the distant between a pair of transmitter and receiver nodes, and the $f_d\ (R_i)$ represents its probability density function (*pdf*). The probability distribution function of d is as following:

$$F_d(R_i) = \Pr(d < R_i) = \frac{1-\exp(-\lambda\pi R^2{}_i/2)}{1-e^{-\frac{N}{2}}} \qquad (14)$$
$$\textit{in which} \quad 0 < R_i < R_T$$

We have:

$$\Pr(a < X \le b) = F_X(b) - F_X(a)\,. \qquad (15)$$

So we can conclude that:

$$\begin{aligned}\Pr(R_{i-1} < d < R_i) &= F_d(R_i) - F_d(R_{i-1}) \\ &= \frac{1-\exp(-\lambda\pi R^2{}_i/2)}{1-e^{-\frac{N}{2}}} - \frac{1-\exp(-\lambda\pi R^2{}_{i-1}/2)}{1-e^{-\frac{N}{2}}} \\ &= \frac{\exp(-\lambda\pi R^2{}_{i-1}/2) - \exp(-\lambda\pi R^2{}_i/2)}{1-e^{-\frac{N}{2}}}\end{aligned} \qquad (16)$$
$$\textit{in which} \quad 0 < R_{i-1} < R_i < R_T \ \ \& \ \ R_0 = 0$$

Finally, we have:

$$P_{car,c} = \left(\sum_{i=1}^{l} \frac{\exp(-\lambda\pi R^2{}_{i-1}/2) - \exp(-\lambda\pi R^2{}_i/2)}{1-e^{-\frac{N}{2}}} \left(1-\prod_{k=1}^{c-\sum_{j=0}^{i-1}c^j}(1-p^2)\right)\right)^{n-1}. \qquad (17)$$

III. DISCUSSION OF RESULTS

In this part, we show the effect of the different parameters on the $P_{car,c}$. In all of the following figures, we suppose that there are only two types of channels with transmission range of R_1=75 m, R_2=125m, and node transmission range R_T= 150 m. We also suppose that the PU's activity on different channel is identical.

Fig. 2 presents the effect of the number of available channel on the $P_{car,c}$ under the constant PU's activity p=1/2 and N=8. This figure also shows a decreasing trend with increasing in number of hops. It also reveals on the high dependency of the number of available channel and probability of successful routing.

Fig. 3 shows the effect of PU's activity on the $P_{car,c}$. Based on this figure, the $P_{car,c}$ is extremely depended on PU's activity, and it has a decreasing trend with increasing number of hops. Fig. 4 shows the effect of channel type on the $P_{car,c}$. Here, p=1/2, R_1=75m, R_2=125m, R_T=150m, c=10, and N=8.

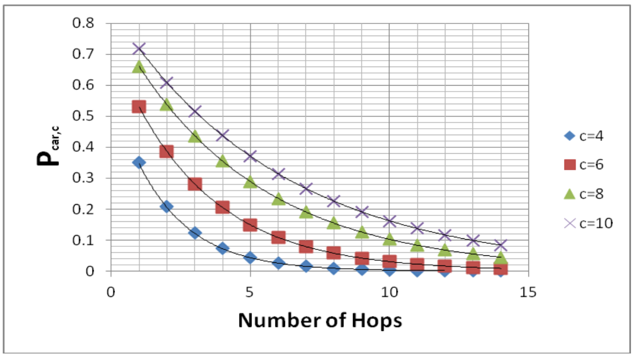

Figure 2. The effect of number of available channel on the $P_{car,c}$

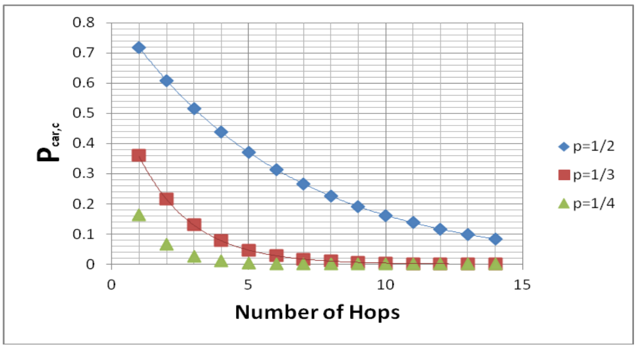

Figure 3. The effect of PU's activity on the $P_{car,c}$

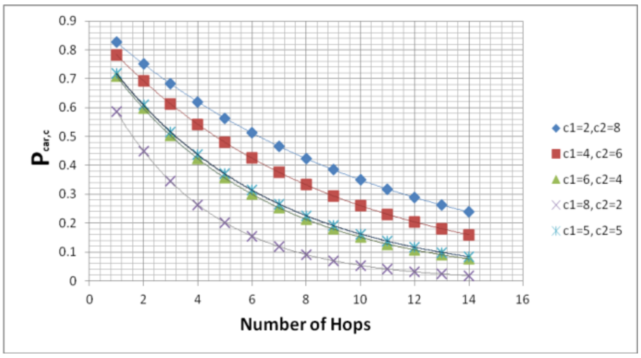

Figure 4. The effect of number of different available channel on the $P_{car,c}$

IV. NECESSITY OF INTEGRATED HANDOFF MANAGEMENT SYSTEM

The fluctuation of PU's activities, channel quality degradation, and SU's mobility makes the issue of maintaining optimal routes in CR-MANET challenging. The handoff management must make a decision on SU's communication based on the mobility event without causing any interference to PUs. The management protocol must adapt to the fluctuating spectrum availability as well as node mobility, while trying to maintain end-to-end connectivity [5]. The main challenge related to handoff management is Dynamic spectrum availability. As we showed, the spectrum availability changes over time and space because of PU activities and SU's movement.

The handoff management system must use an appropriate algorithm to determine candidate spectrum bands based on the channel characteristics, spectrum availability, and node mobility [6]. It also needs an accurate environment and location aware system. Spectrum heterogeneity and SU's mobility have a significant effect on the handoff blocking. These two events increase the blocking probability of spectrum handoff.

V. CONCLUSION

In this paper, we have proposed an analytical model which shows the effect of different mobility event on the channel availability and emphasizes on an integrated handoff management in CR-MANETs. In CR-MANET, the available spectrum bands vary not only over time but also once the SU moves. The fluctuation of PU's activity and the SU's mobility make the issue of maintaining optimal routes in CR-MANET challenging. The channel heterogeneity also must be considered in terms of transmission range, because it increases the blocking probability of spectrum handoff and also leads to handoff initiation. Channel heterogeneity can be considered between two different nodes, which depend on their distance they can use only special channel with special transmission range. Hence, an integrated mobility function, which considers the spectrum mobility in time and space domain as well as topology changing, must be investigated.

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