Abstract—Channel accessibility by a secondary user (SU) in cognitive radio networks (CRNs) depends on the availability of the spectrum based on primary user and other SU activities. A new SU request may be blocked and an ongoing SU service may also be discarded if no sufficient spectrum is available. So far, little work has been done to analyze the reliability and availability aspects of CRNs from the perspective of the dependability theory. In this paper, we introduce the concept of availability for spectrum access in multi-channel CRNs, which is defined as the fraction of time that a CRN can allocate at least the minimum number of required channels for a new SU request. Through a proposed continuous-time discrete-state Markov model, we analyze the performance of CRN channel access schemes in terms of a few reliability-relevant metrics such as mean channel available time and mean time to first channel unavailability. Furthermore numerical results are also presented in this paper and the correctness of the derived theoretical models are verified through simulations.

I. INTRODUCTION

Cognitive radio (CR) is a promising technology to solve the problem of spectrum scarcity and utilization inefficiency. Channel access in a CR network (CRN) is achieved by allowing secondary users (SUs) to access the channels which are not occupied by primary users (PUs), in an opportunistic manner. Due to the dynamics of PU activities, channel occupancy status in CRNs varies over time. Once all the channels in the CRN are occupied, the new SU requests will be blocked. This would lead to temporal channel unavailability for new SU services until an ongoing PU or SU service is completed.

Despite tremendous efforts on spectrum sensing and channel access mechanisms to improve the performance of SU services, more attention needs to be paid on the reliability and availability aspects of CRNs. Hence, how to model channel access availability in a CRN becomes an interesting and essential topic in order to utilize spectrum in a more efficient manner. Indeed, reliability and availability have long been used as quantitative measures in computing and communication systems. These concepts are used to evaluate the system performance in terms of the time that the system can function without failure and the fraction of time that a system is operational respectively.

Precise assessment of the available channels based on channel utilization status is one of the essential tasks in CRNs [1]. Accurate channel availability measurements help the secondary network to appropriately select the available channels. This would lead the CRN to minimize the instability problem for SU connections and the interference to PU services while facilitating optimal resource allocation [3]. This can be achieved by building an availability map for the channels that can be used by SUs [1], [2]. Therefore, the probability of channel being available for a given time period is a useful parameter to evaluate the performance of a CRN.

To evaluate channel idleness and occupancy, a validated probabilistic model was developed in [4]. Therein, real-time measurements of spectrum utilization, e.g., transmission power, center frequencies and time duration of operations are used to determine the PU occupancy patterns. However, the model developed in [4] does not provide a method for evaluating the overall spectrum availability. Thereafter, a follow-up study [5] focused on building a predictive model on spectrum availability based on publicly available and accredited data over several spectra. A combined approximation of Poisson and normal distributions called Poisson-Normal approximation was used in [5] to determine the distribution of the number of idle channels. However, important parameters such as mean channel idle time and mean channel busy time are not evaluated in [5]. In general, although there exist many studies on reliability and availability in CRNs, they are not pursued from the dependability perspective. Those approaches involve typically high modeling and computation complexity for evaluating channel availability and system times. The definitions of reliability metrics in dependability theory supply tracks on system times effectively. Therefore, we introduce in this paper new definitions of availability measures which are analogous to the concepts of availability in the classical dependability context, however are tailored to channel access in CRNs. The main goal of our work is to develop a mathematical model to evaluate both channel availability and average channel available time duration without involving real-life data sets about spectrum occupancy. To achieve this goal, we first define the reliability metrics in CRNs and then derive analytical relationships for system times and the steady state channel availability. In the analytical results, we examine the variation of channel availability and other metrics as a function of the arrival rate and service rate of PU and SU services.

The rest of this paper is organized as follows. In Sec. II, we introduce the network scenario and channel access scheme. The reliability concepts in communication networks and CRNs are briefly presented in Sec. III. The procedures of the proposed analytical models to calculate channel availability are explained in Sec. IV and numerical results are illustrated in Sec. V. Finally, the paper is concluded in Sec. VI.
II. NETWORK SCENARIO AND ACCESS STRATEGY

In this section, the network scenario and the channel access strategy adopted in this study are presented.

A. Network scenario

Consider an infrastructured CRN with one CR base station and \( M \) independent and homogeneous channels as shown in Fig. 1. Resource allocation for the secondary network is performed by the base station. PU and SU service arrivals follow Poisson process with arrival rates \( \lambda_P \) and \( \lambda_S \) respectively. The service completion for both PU and SU services is exponentially distributed with service rates per channel \( \mu_P \) and \( \mu_S \) respectively. To achieve better bandwidth utilization, channel aggregation and spectrum adaptation can be adopted when multiple idle channels are available [6]. Depending on the number of available channels, one SU flow may occupy a minimum number of idle channels in order to perform its service. In such context, channel availability is regarded as the fraction of time that the CRN can allocate at least the minimum number of required channels for a new SU request.

B. Dynamic channel access strategy

The channel access strategy which is utilized for the CRN considered in this study is one of the dynamic channel access strategies proposed in [6], i.e., dynamic fully adjustable (DFA). However, it is worth mentioning that the analytical model proposed in this paper applies to any CRN channel access scheme as well.

In the DFA scheme, both channel aggregation and spectrum adaptation are adopted, meaning that one SU service can utilize multiple channels if available. Two parameters, \( W \) and \( V \), are introduced in DFA to represent the lower bound and the upper bound of the number of aggregated channels for an SU service respectively. That is, the number of assembled channels for an ongoing SU service is adjustable from \( W \) channels to \( V \) channels. Moreover, the service rate for one SU service with \( k \) aggregated channels is \( k \mu_S \).

III. RELIABILITY IN COMMUNICATION NETWORKS AND CRNs

Prior to analyzing channel availability in CRNs, we will review in this section, the general reliability and availability concepts developed over the years that would be needed to develop an accurate channel availability model in CRNs.

A. Reliability in communication networks

The reliability function of a system, \( R(t) \), is defined as the probability that a system can provide its required services (under stated conditions) for a given time interval. Most complex systems, such as automobiles, communication systems, etc., are not replaced when they fail and can be repaired. System availability is a random variable defined as the fraction of time that the repairable system is operational during a period of time [7]. Herein, mean up time (MUT) is the terminology which represents the average time between the recovery of a system to its operational mode and the next failure. Conversely, mean down time (MDT) is the average time interval from a system failure to the next system recovery. Therefore, the steady state availability of a system, \( A_{ss} \), can be expressed as, \( A_{ss} = \frac{MUT}{MUT+MDT} \). Other than this, in some cases we are also interested in finding the mean time to the first failure (MTTFF) of the system.

B. The concepts of reliability in CRNs

In this subsection, we define the dependability metrics in the context of CRNs while preserving their original conceptual meaning. Let a system referred in the classical reliability model be a CRN with one or multiple channels and these channels are available for SU access if they are not used by PUs. Then, a system failure represents the instant when there is no opportunity to access channels for a newly arrived SU request. Once the system is in a state in which the new SUs are blocked, the system is regarded as in the failed mode correspondingly. When the system is in a state in which the new SUs can commence their transmission, the system is in the operational mode.

In a CRN, MUT is defined as the mean channel available time, \( T_A \), indicating the average time duration during which the system resides in the operational mode. Furthermore, mean channel unavailable time, \( T_U \), is the associated metric in a CRN to represent the system failure and it is defined as the average time duration during which the system resides in the failed mode. In a CRN, MTTFF is defined as the mean time to first channel unavailability, \( T^{(F)}_{CU} \), indicating the expected time interval from network initiation to the instant when a new user request is blocked for the first time. In Sec. IV-C, we will give...
the definitions of channel availability and related system times mathematically. Fig. 2 illustrates the concepts of up time (UT), down time (DT) and time to first failure (TTF) in CRNs as well as their relationships with channel availability.

C. Exemplary illustration of channel availability

We provide here a simple example by considering a CRN with 2 channels as shown in Fig. 3. Let a PU service always occupy one single channel while an SU service occupies one or two channels depending on channel availability. The notation \((x, y, z)\) in Fig. 3(a) represents the feasible states of the system where \(x\) denotes the number of PU services in the system, \(y\) and \(z\) denote the number of SU services which have single channel and two channels respectively. As an example, in state \(S_2\) \((1, 0, 0)\), one channel is occupied by a PU service while the other one is idle. Thus, it is a channel available state for new SU requests. Similarly, states \(S_1\) and \(S_3\) are also channel available states while states \(S_4, S_5\) and \(S_6\) are channel unavailable states since new SU services cannot be commenced in those states. Furthermore, Fig. 3(b) illustrates a channel occupancy scenario of this CRN with respect to time. It is shown that, a new SU service occupies one channel during \(T_6 - T_5\) and \(T_8 - T_7\) while it occupies two channels during \(T_7 - T_6\). As mentioned in Sec. III-A, steady state channel availability of this CRN, \(A_{ss}\), can be expressed as \(\frac{T_6 - T_5}{T_6 - T_0}\) given that the observation period \(T_0 - T_0\) is sufficiently long.

IV. CTMC MODEL FOR DEPENDABILITY ANALYSIS IN CRNS

Continuous time Markov chain (CTMC) is a well known and efficient technique for system dependability analysis [8]. In this section, we present a stepwise procedure of the proposed analytical model for evaluating channel availability in CRNs by using CTMCs.

A. State space and state transition matrix

The spectrum of interest is divided into \(M\) non-overlapping channels. Assume that the total number of states in a system is \(N\) and they are numbered as 1, 2, 3, ..., \(N - 1\) and \(N\) respectively. Let \(i\) represent a general state in the system and \(\pi_i\) be the steady state probability of being in state \(i\). The set of feasible states of the system is denoted as \(S\). Correspondingly, \(\pi_i\) can be calculated from the global balance equations and the normalization equation, which are given as

\[
\pi Q = 0, \quad \sum_{i \in S} \pi_i = 1, \quad (1)
\]

where \(\pi\) is the steady state probability vector and \(Q\) denotes the transition rate matrix. \(0\) denotes a row vector of 0’s of an appropriate size.

Rearrange the feasible states in a way such that states 1, 2, ..., \(K\) in the system can provide at least the minimum number of required channels for a new SU request, but in states \(K + 1, K + 2, \ldots, N\), the system fails to provide required number of channels for a new SU request. Let \(S_A\) be the set of states that channels are available for new SU requests, i.e., the set of channel available states of the system and \(S_B\) be the set of states that the system blocks new SU service requests, i.e., the set of channel unavailable states of the system. Thus, \(S = S_A \cup S_B\) and \(S_A \cap S_B = \emptyset\). Since \(n(S_A) = K\), then \(n(S_B) = N - K\), given that \(n(S) = N\), where \(n(A)\) denotes the cardinality of a set \(A\). Once the system states are divided into two parts, the transition rate matrix \(Q\) can be written in the following partitioned form.

\[
Q = \begin{bmatrix} A & B \\ C & D \end{bmatrix}, \quad (2)
\]

where the \(K \times K\) matrix \(A\) represents the transition rates from a state in \(S_A\) to another state in \(S_A\) and the \(K \times (N - K)\) matrix \(B\) represents the transition rates from a state in \(S_A\) to a state in \(S_B\) and so on. Note that the main diagonal of \(A\) (and \(D\)) has also contributed the outgoing rates to \(B\) (respectively, \(C\)).

B. Distribution of the time until the first channel unavailability

Define \(P_A(t) \equiv [P_1(t) \ P_2(t) \ \cdots \ P_K(t)]\), as a \(K\) dimensional row vector representing the channel available states with \(i^{\text{th}}\) component, and \(P_i(t)\), the probability that the system is in state \(i\) at time \(t\). Similarly, if \(P_B(t)\) denotes the \(N - K\) dimensional row vector representing the channel unavailable states, \(P_B(t) \equiv [P_{K+1}(t) \ P_{K+2}(t) \ \cdots \ P_N(t)]\). Assume that, at the system initial instant, i.e., \(t = 0\), the system can provide idle channels for new SU requests, i.e.,

\[
\sum_{i=1}^{K} P_i(0) = 1 \quad \text{and} \quad \sum_{i=K+1}^{N} P_i(0) = 0. \quad (3)
\]

When we consider the time taken to the first channel unavailability, we can disregard the state transitions from \(S_B\) to \(S_A\) and inside the failed state space \(S_B\), thus \(C = D = 0\). In other words, by making the failure states absorbed, we can compute the mean time to the first failure. Therefore, we have

\[
\frac{d}{dt} P_A(t) = P_A(t)A. \quad (4)
\]

given the state transition matrix \(A\) and initial probability vector \(P_A(0)\) [9]. Similarly,

\[
\frac{d}{dt} P_B(t) = P_A(t)B. \quad (5)
\]
Taking the Laplace transform at both sides of equation (4), we obtain $sP_A(s) - P_A(0) = \bar{P}_A(s)A$, where $P_A(s)$ indicates the Laplace transform of $P_A(t)$, i.e., $\mathcal{L}\{P_A(t) = \bar{P}_A(s)\}$. Further simplifying the formula, we have $\bar{P}_A(s) = P_A(0)(sI - A)^{-1}$, where $I$ denotes the identity matrix. Similarly, $sP_B(s) - P_B(0) = \bar{P}_A(s)B$. Since we assume that the initial state of the system is a channel available state, we have $P_B(0) = 0$. Therefore, $sP_B(s) = P_A(0)(sI - A)^{-1}B$.

As $(N - K)$ components in the row vector $P_B(t)$ represent the state probabilities of channel unavailable states at time $t$, the Laplace transform of the probability density function of time to first channel unavailability can be expressed as, $f_B(s) = s\bar{P}_B(s)U_{N-K}$, where $U_{N-K}$ is a column vector of $N - K$ ones. Therefore, $f_B(s) = P_A(0)(sI - A)^{-1}BU_{N-K}$.

Consider the state transition matrix $Q$ of the Markov process. The diagonal elements are chosen to ensure that the sum of the elements in every row is zero, i.e., $q_{ii} = -\sum_{j\neq i} q_{ij}$, where $q_{ij}$ is the instantaneous transition rate from state $i$ to state $j$. Following this relationship, we can state that $AU_K + BU_{N-K} = 0$. Thus,

$$f_B(s) = -P_A(0)(sI - A)^{-1}AU_K. \quad (6)$$

The moment generating function of a continuous random variable, $X$, is given by $M_X(t) = \int_{-\infty}^{\infty} e^{tx}f_X(x)dx$, where $f_X(x)$ is the probability density function of $X$. The $r^{th}$ moment about the origin of the random variable, $X$, i.e., $\tau_r$, can be obtained by substituting $t = 0$ in the $r^{th}$ derivative of the moment generating function. That is, $\tau_r = \frac{d^r}{dt^r} M_X(t) \bigg|_{t=0}$.

Accordingly, $M_X(-t)$ can be considered as the Laplace transform of the probability density function of $X$ [10]. Therefore, the $r^{th}$ moment about the origin of the time until absorption (time to system failure), $\tau'_r$, is given by,

$$\tau'_r = \lim_{s \to 0} \left[ (-1)^r \frac{d^r}{ds^r} f_B(s) \right]. \quad (7)$$

By substituting the expression for $f_B(s)$ in (6) into (9), we obtain

$$\tau'_r = r!P_A(0)(-A)^{-r}U_K. \quad (8)$$

When $r = 1$, the mean value, i.e., $\tau'_1$, can be obtained as follows.

$$\tau'_1 = P_A(0)(-A)^{-1}U_K. \quad (9)$$

### C. Formulas for channel available time intervals

(9) enables us to determine the mean time to first channel unavailability and the mean value of channel available and unavailable time duration. In what follows, we give the mathematical definitions for the channel available and unavailable time duration in a CRN. Based on the definitions on time duration, an expression for steady state channel availability is derived.

1) Mean time to first channel unavailability, $\bar{T}^{(F)}_{CU}$: It is defined as the expected time interval from system initiation to the instant where a new user request could be blocked by the system for the first time. Considering $t \equiv [t_1, t_2, \ldots, t_K]$ as the corresponding time to first channel unavailability row vector of $P_A(0) \equiv [P_1(0), P_2(0), \ldots, P_K(0)]$ in (9), we will have,

$$-tA = P_A(0). \quad (10)$$

By solving (10), all the elements in $t$ can be determined. Since $t_i$ represents the time to first channel unavailability corresponding to system’s initial state $i$, the summation of all the elements in $t$ equals to the mean time to first channel unavailability as follows.

$$\bar{T}^{(F)}_{CU} = \sum_{i=1}^{K} t_i. \quad (11)$$

2) Mean channel available time, $\bar{T}_A$: Once the system transits to a state in state space $S_A$ from a state in state space $S_B$, the system becomes available. The average time duration that the system resides in $S_A$ before making a transition back to a state in $S_B$ is defined as the mean channel available time.

To calculate $\bar{T}_A$, the steady state probabilities of the state space are required. The steady state probability vector of $S$, can be partitioned as $\pi = [\pi_A \pi_B]$ where $\pi_A \equiv [\pi_1, \pi_2, \ldots, \pi_K]$ and $\pi_B \equiv [\pi_{K+1}, \pi_{K+2}, \ldots, \pi_N]$. A channel available time duration will start in state $J \in S_A$, if the system was in a state $I \in S_B$ and then made a transition from state $I$ to state $J$. Then, the probability of initiating a channel available time in state $J$ can be expressed as,

$$P_{IJ} = \frac{\sum_{I=K+1}^{K+1} \pi_i q_{ij}}{\sum_{I=1}^{K+1} \pi_i q_{iL}} \quad (12)$$

This result implies that:

$$P_A(0) = \frac{\pi_B C}{\pi_B C U_K}. \quad (13)$$

Since $\pi Q = 0$ in the steady state CTMC, $\pi_A A + \pi_B C = 0$. Furthermore, as mentioned earlier, $AU_K + BU_{N-K} = 0$. Therefore, we have

$$P_A(0) = \frac{\pi_A A}{\pi_A AU_K} + \frac{-\pi_A A}{\pi_A AU_K} \quad (14) \quad \pi_A AU_K = -\pi_A A. \quad (15)$$

By substituting the above expression of $P_A(0)$ into (9), we obtain

$$\bar{T}_A = \frac{-\pi_A A(-A)^{-1}U_K}{\pi_A AU_K} = \frac{\pi_A U_K}{\pi_A AU_K}. \quad (15)$$

3) Mean channel unavailable time, $\bar{T}_U$: The average time duration during which the system resides in $S_B$ before making a transition back to a state in $S_A$ is defined as the mean channel unavailable time. By following a similar procedure as in the previous $\bar{T}_A$ calculation, we can derive that,

$$\bar{T}_U = \frac{\pi_B U_{N-K}}{\pi_B U_{N-K}}. \quad (16)$$

4) Steady state channel availability, $A_{ss}$: As already stated in Sec. III-A, the steady state availability is equal to the mean up time divided by the summation of the mean up time and the mean down time. Since $\bar{T}_A$ and $\bar{T}_U$ are the mean up time
Following the normalization equation as in (1), we have

\[ A_{ss} = \frac{\bar{T}_A}{\bar{T}_A + \bar{T}_U} = \frac{\pi_A U_K}{\pi_A U_K + \pi_B U_{N-K}}. \]  

(17)

Following the normalization equation as in (1), we have \( \pi_A U_K + \pi_B U_{N-K} = 1 \). Therefore, (17) is simplified as

\[ A_{ss} = \pi_A U_K. \]  

(18)

V. NUMERICAL RESULTS AND DISCUSSIONS

In this section, we analyze the associated numerical results for each availability metric presented in Sec. IV-C. A centralized CR topology mentioned earlier is considered and the network has 6 channels. Unless otherwise stated, the parameters mentioned in Sec. II-A are configured as \( \lambda_P = 1.0, \lambda_S = 2.0, \mu_P = 0.5 \) and \( \mu_S = 1.0 \) respectively. The units of these parameters could be services per unit of time.

For channel availability evaluation, one of these parameters is varied at a time while the others are kept as the same for each set of results. The DFA strategy [6] is adopted as the channel access scheme, with \( W = 1 \) and \( V = 3 \). Therefore to commence a new SU request, at least one idle channel is required and one SU service may occupy up to 3 channels if available. Furthermore, to validate the correctness of the mathematical analysis, we present the MATLAB simulation results obtained for channel availability in Fig. 4 and Fig. 5 together with the analytical results. As shown in those figures, we ascertain that the results of the analytical model precisely coincide with the obtained simulation results.

A. Steady state channel availability

Fig. 4 and Fig. 5 depict the channel availability variation as a function of \( \lambda_P \) and \( \mu_P \) respectively. Jointly considering the results in those two figures, we observe that, when the PU arrival rate is low and its service rate is high, higher channel availability is achieved in the CRN. Since the channels are less likely to be occupied by PUs at low arrival rates and high service rates, new SU services have high channel access opportunities. However, channel availability becomes lower at higher SU arrival rates, because fewer idle channels are available to new users as more new services arrive in the system. For instance, in comparison with the system at arrival rates of \( \lambda_P = 2 \) and \( \lambda_S = 2 \), the channel availability of the CRN will reduce approximately by 14% if the SU arrival rate increases to \( \lambda_S = 4 \). However, with a large \( \lambda_P \), the difference of channel availability among different \( \lambda_S \) values becomes smaller. The reason is that at a higher PU arrival rate, a large portion of the SU requests are blocked and thus, the impact of SU arrival rate is less significant.

B. Mean channel available time

In Fig. 6 we investigate the impact of the PU arrival rate on mean channel available time, \( \bar{T}_A \), which corresponds to MUT in classical reliability analysis. As illustrated in this figure, the mean channel available time decreases as the arrival rate of PUs becomes higher. This behavior is due to the reasons explained below. When the PU arrival rate is higher, the system obtains larger number of active PU services. Correspondingly, the time duration in which a particular channel being in the idle state, i.e., the available time of the channel becomes lower. In other words, it takes shorter time for the system to block the next new service compared with the system with a lower PU arrival rate. The results also clearly demonstrate that the channel available time duration becomes longer when \( \lambda_S \) is at a lower value due to the same reason.

C. Mean channel unavailable time

The mean channel unavailable time as a function of PU service rate is plotted in Fig. 7. From this figure, we observe a continuous descent in the channel unavailable time as the service rate of PUs increases while keeping the arrival rate of PUs constant. When the PU service rate is low, fewer PUs finish their services per unit of time. Then, most of the
channels are occupied by respective PUs and the probability of blocking a new SU request is consequently high. That means, the time interval that the system will reside in the channel unavailable state space is comparatively long. On the other hand, at a higher PU service rate, a comparatively large number of PU services can be finished during unit of time. Thus, the probability that a channel being in a busy state decreases with higher $\mu_P$ and consequently the probability of blocking of a new SU service becomes lower. Due to this reason, the mean channel unavailable time decreases as shown in Fig. 7. Additionally, for a given $\mu_P$ value, the channel unavailable time shows higher value at a low SU service rate compared with a large SU service rate. Again, this is due to the fact that the probability of a channel being in a busy state increases with lower $\mu_S$.

D. Mean time to first channel unavailability

In Fig. 8, the plots with dashed lines indicate the variation in mean time to first channel unavailability with the initial condition that there are no PU or SU services in the system. The plots with solid lines indicate the variation in mean time to first channel unavailability with the condition that there are initially one PU service and one SU service in the system. As expected, when the PU arrival rate increases, all $T_{CU}^{(F)}$ curves decrease gradually. The reason for this behavior can be explained as follows. At low PU arrival rates, more channels are likely to be idle and the newly arrived user requests can be accommodated with the required number of channels. Therefore, the system can operate without blocking any new users for a long period. This result is in sharp contrast with the result under the high PU arrival rate circumstances. Moreover, at a given PU arrival rate, $T_{CU}^{(F)}$ becomes a large value with a small $\lambda_S$ compared with large $\lambda_S$ values. This is because that, at large $\lambda_S$, channels are more likely to be in busy states and the system rapidly reaches a channel unavailable state.

Interestingly, the time taken for the first channel unavailability is depending on the initial state of the system. As we shown in Fig. 8, if the system does not have any existing services in the beginning, $T_{CU}^{(F)}$ shows high value compared with the system with already commenced PU and SU services. When a single PU service and a single SU service have commenced in a CRN with 6 channels, at least 2 channels are occupied at the system initialization. In other words, only 4 idle channels are accessible in the system for new users. Therefore, there is a high probability that this system will move to a channel unavailable state within a shorter period of time in comparison with the system with 6 idle channels in the initial phase.

VI. Conclusions

The reliability and availability aspects of CRNs remain largely un-chartered despite tremendous research efforts within the area of CR during the past decade. In this paper, we define several channel availability metrics for CRNs. Mathematical expressions for those metrics are derived by using a Markov process based analysis. The numerical results show that at steady state channel availability, the mean time to first channel unavailability and the mean channel available time decrease with a larger PU arrival rate and increase with a larger PU service rate. These results can form the basis for designing channel selection schemes in order to maximize the performance of the secondary network. Moreover, the dependability metric definitions and the proposed model in this paper apply generally to channel access in any CRNs irrespective of the channel access scheme employed.

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