Spectrum Detection in Cognitive Networks by Minimizing Hidden Terminal Problem

Yenumula B Reddy
Department of Computer Science, Grambling State University, Grambling, LA 71245, USA
ybreddy@gram.edu

Abstract — In the wireless network, the node is visible but is not available for communication. Similarly, the primary signal is present and difficult to detect. The primary signal problem is similar to hidden node problem, but currently interpreted as false alarms. In this research, two models (probability based and Drake’s equation) were designed and tested through simulations. The results show that Drake’s equation with probability-based model performs better than basic probability-based model to detect the hidden signal.

Keywords: cognitive user, primary user, cooperative spectrum sensing, hidden node, exposed terminal, spectrum holes.

1. INTRODUCTION

Hidden terminal problem occurs when a node is visible from the access point but cannot communicate to the nodes within communication distance. Star network is the best example. One of the well known hidden node problem in wireless networks is a three node problem as shown in Figure 1. For example, the node A try to broadcast to node B and node C try to broadcasts to node B during the same time. The node A and node C cannot see each other and trying to broadcast at the same time the packets collide at node B. This is another example of hidden node problem. In Figure 1, node A cannot hear the transmission from node C by sensing the medium. Similarly, node C cannot sense the transmission from node A; therefore, they try to communicate and collide at node B. The third example is provided through Figure 2 (waiting forever). The node A is communicating to node D through node B and node C (Figure 2). In the beginning, the node A assumes that channel 2 is free. Once the packet reaches node B it understood that node C is in communication with node C for channel 2. That is node C sends the request for communication (RTS: request to send) to node B for channel 2. The node B is waiting to get the signal clear to send (CTS) from node C for channel 2. Both nodes are waiting for channel 2 at node B and cannot move further. This is a waiting forever problem. The RTS/CTS mechanisms implemented in MAC (medium access control) protocol that helps to eliminate the hidden terminal problem.

The RTS/CTS problem further introduces exposed terminal problem (Figure 1). For example, if node B is transmitting to node A and node C try to transmit to node D. The node C and node B are in the transmission range of each other. Therefore, after carrier sense, transmission of node C interferes the transmission of node B. Further, node D can still receives the transmission of node C without interference, if the nodes C and B are synchronized with the same packet size and data rate (IEEE 802.11 RTS/CTS). If the nodes are not synchronized, the neighboring node may not hear the CTS during transmission and exposed terminal problem may occur.

The unsuccessful transmissions are proportional to number of hidden or exposed terminals from the transmitting terminal. The RTS/CTS implemented in IEEE 802.11 solve the problem with the conditions explained above. Similar problem occurs if the presence of the primary signal cannot be detected by cognitive radios due to interference or noise of neighboring cognitive radios (hidden node). The RTS/CTS may not help in such cases. The cognitive radios can solve the problem in a cooperative spectrum sensing. Cognitive radios sense the spectrum holes at each hop and utilize the opportunity of allocating the channels in an optimum manner. In multi-hop cognitive network (MUCON), users can use different frequencies depending upon the availability of spectrum. In MUCON, a common control channel is used to control the available channels. The number of channels available at each hop is depending upon the presence of the primary user (PU), because the complete path of the primary user is dedicated. Therefore, the number of channels available to secondary user or cognitive user (SU/CU) is fixed. In the current problem, the number of channels available to secondary user or cognitive user (SU/CU) is fixed. In the current problem, the number of channels available to secondary user or cognitive user (SU/CU) is fixed. In the current problem, the number of channels available to secondary user or cognitive user (SU/CU) is fixed. In the current problem, the number of channels available to secondary user or cognitive user (SU/CU) is fixed.

The spectrum sensing is used to detect the presence of the PU in the frequency band. The unused spectrum (spectrum holes) detected by the CU helps the control channel to allocate the needed spectrum to CU on the communication path. Further, the energy detectors are used to detect the presence of PU and determine the current status of PU in the geographical area. Therefore,
collaborative approach will improve to find the current statue of the PU in the geographical area. The collaborative approach further helps to minimize the false alarms.

The design of cognitive radio (CR) in spectrum sensing poses more challenges since it requires sensing the spectral environment and flexibility to adapt transmission parameters. The design of CR must detect the weak signals and strong signals. The possible solutions include notch filtering, banks on radio frequency (RF) chip, and spatial filtering RF beam forming through adaptive antenna arrays.

![Figure 1: Hidden and exposed node problem](image)

The remaining paper discusses the literature survey including recent advances in cooperative spectrum sensing to minimize hidden nodes, problem formulation, detecting primary user and spectrum holes, Drake’s equation to minimize the hidden node, simulations, conclusions, and future research.

2. LITERATURE SURVEY AND RECENT DEVELOPMENTS

Hidden terminal problem is not new. The implementation of RTS/CTS in IEEE 802.11 minimizes the hidden terminal problem. The introduction of cognitive radio (CR) will have PU detection problem and transferring the packets on mobile network. The hidden node problem on multi-hop cognitive radio network (MCRN) was discussed in [5]. The authors introduced alternative MAC protocol on multi-hop cognitive radio networks (CRN) to avoid common control channel. The authors further claims that the synchronized protocol for MCRN avoids the denial of service (DoS) attacks. Jeong et al [4] discussed the hidden node problem with a mathematical model and simulated through NS2. The authors claim through NS2 simulations that the results are considerably accurate.

Cooperative spectrum sensing in dynamic CRN and optimization in CRN were discussed in [1, 8]. Biswas et al [1] used cognitive-based node to collect the spectrum holes. The authors further claim that the model effectively detects the PU with minimum energy. Zang et al [8] proposed a fast spectrum sensing algorithm with minimum cognitive radios to perform the cooperative spectrum sensing with minimum errors.

Solutions to hidden node problem were discussed in [2]. The authors introduced floor acquisition multiple access (FEMA) protocols to carrier sensing and claimed that the throughput of FEMA is better than ALOHA and CSMA (carrier sensing multiple access). Jayasuria et al [3] discussed the hidden vs exposed terminals and concluded that RTS/CTS degrade the performance. The MAC protocol for multi-hop networks was studied in [9] by proposing pair-wise ID (identity detection) countdown. The hidden terminal problem using directional antennas was studied in [10]. They claimed the performance does not depend on network topology and network pattern.

Experimental study of Hidden terminal problem was discussed in [6, 7]. In [6], hidden terminal jamming problem presented in IEEE 802.11 for ad hoc networks was discussed. They claimed that signal differential 2dB is sufficient for the stronger transmission and effectively jam a weaker signal. In [7], the impact of hidden nodes in both infrastructure and multi-hop an ad hoc network was studied. The authors claim that RTS/CTS degrade the throughput and may not solve the hidden node problem.

The detection of the primary signals (PS), spectrum holes, and allocation of the spectrum holes was discussed in [11, 12, 13]. In [12, 13], Drake’s equation [14] was used to detect the primary signal and allocate the spectrum efficiently. In [11], the algorithm RASH (Random access by sequential search and hash organization) was proposed to improve the spectrum utilization. In the current research, a probability-based primary signal detection model was developed to detect the PS. Further, the Drake’s equation with probability model was designed to minimize the false alarms (undetected signals) similar to detecting the hidden nodes in cognitive networks.

The Contribution: The contribution includes the signal detection model in a decodable space, adjusting the parameters of Drakes equation to space occupancy of PS in decodable space, and eliminating the hidden terminal using these models. Further, the simulations of probability-based model and Drake’s equation with probability based model to minimize the hidden terminal problem were presented.
3. Problem Formulation

The cognitive radio improves the spectrum utilization through quick detection of the primary signal (PS). The detection and utilization process creates the interference to PS. To avoid the interference, the CR uses energy detecting (ED) hardware, which measures the energy through signal strength indicator in the input wave over a specific interval. The detection process has false detection due to noise, low PS strength, and interference of CRs. The detection process requires one ED to each channel.

In the detection process, we use the shared spectrum concept by dividing the wide bandwidth into a group of channels. Each group of channels (cluster) will have a group of CRs. The detection of PS is sensed by \( i^{th} \) CR in the \( j^{th} \) cluster includes the presence of noise (non-Gaussian) and the variance. The presence of PS detected by \( i^{th} \) CR in the cluster at time \( t \) is formulated as:

\[
PS_j^i = X_j^i(t) = V_j^i(t) \quad (1)
\]

\[
PS_j^i = X_j^i(t) = S(t) + V_j^i(t) \quad (2)
\]

Where

- \( PS_0^i \) Signal not present
- \( PS_1^i \) Presence of the signal (Occupied)
- \( PS_j^i \) Presence of primary signal by \( i^{th} \) CR and \( j^{th} \) cluster
- \( V_j^i(t) \) Zero-mean white Gaussian noise
- \( S(t) \) Presence of the signal detected at time \( t \)
- \( X_j^i(t) \) Detection status by \( i^{th} \) CR in \( j^{th} \) cluster

The probability of the performance of the PS detection (PS\(_d\)) is the ratio of detection of the PS to the presence (existence) of the PS.

\[
PS_d^i = PS_j^i / PS_p \quad ; \quad 0 \leq PS_d^i \leq 1 \quad (3)
\]

The \( PS_p^i \) denotes the presence of primary signal. During the process the channel may not be detected due to low PS strength or leakage in energy detector. The detection process can be improved using the hidden node process.

In the process of hidden node elimination (identifying spectrum holes), detect the status of the PS at time \( \tau \). The cooperative spectrum sensing is useful since the groups of cognitive radios detects and allocate the spectrum efficiently. The status of the primary signal (\( PS_s \)) is given by

\[
PS_s = \frac{T_u}{T_d} \geq 0 \quad (4)
\]

Where, \( T_u \) is average time of communication of the primary signal and \( T_d \) is the duration of the primary signal in communication time. The status of primary signal provides the expected signal rate. The detection rate \( (D_R) \) depends upon the ratio of the detection of primary signal \( (P_D) \) and existence of the primary signal \( (P_E) \). Therefore, the correct detection rate of signal in a decodable space (3 dimensional) is

\[
D_R = \frac{P_D}{P_E} = \frac{R_D}{R_E} \in (0,1) \quad and \quad 0 \leq D_R \leq 1 \quad (5)
\]

Where,

- \( P_D = (4/3)\pi R_D^3 \)
- \( P_E = (4/3)\pi R_E^3 \)

\( R_D \) the radius of PS detection
\( R_E \) the radius of PS existence
\( 1 - D_R \) is the false alarm rate

The detection of signals is done using collaborative effort of cognitive radios. This situation is similar to the solar system with an alien civilization, where the alien signals are detected by our communication system if they are within our communication range. This detection problem is simulated using Drake’s equation with seven parameters. The Drakes equation is discussed in the next section.

4. Drakes Equation:

Let \( N_{ac} \) be the primary signals that occupy the spectrum space at any time. The signals can be detected if they are within the range of energy detectors of our CRs. The signals cannot be detected if they are outside the range of energy detectors appointed by the CRs or signals are not strong enough to detect by the EDs. At any time, we can observe the presence of signals as strong, medium, low, or none. The value of \( N_{ac} \) is calculated with the well known Drake equation [14].

\[
N_{ac} = R^* f_p n_e f_l f_i f_c L \quad (7)
\]

The variables in the above equation may be interpreted in the current situation as:
\( R^* \) = the average rate of PU activation (formation) in the specified spectrum space

\( f_p \) = fraction of those PUs that occupied the spectrum

\( n_e \) = average number of PUs that are potentially supported by spectrum

\( f_i \) = fraction of those channels that will come in contact of ED (energy detector)

\( f_c \) = fraction of those have highly detectable signals

\( f_c = \) fraction of those PUs that have detectable signals

\( L = \) Length of time the primary signals release detectable signals

Note that the probability of spectrum occupied by the primary signals at any time is less than or equal to 1(100%). Better detection will be available by having higher values of \( N_{ac} \) that occupy the spectrum space. If 60% of the spectrum was occupied by the primary signals, then sum of \( f_i, f_c, f_c \) must be equal to 60%. If average number of PUs potentially supported by the spectrum is approximately 50% (percentage can vary), then \( N_{ac} \) depends upon product of \( R^* \) and \( L \). The product of the values of these two variables must be a large number so that \( N_{ac} \) is greater than 2. For example, let us assume that the value of \( N_{ac} \) varies 1 to 100 (maximum occupation 100%). Then the probability of signal detection will be faster as the value \( N_{ac} \) increases. The results are shown in simulations using MATLAB language.

5. **Eliminating the Hidden Terminal Problem using Drake’s Equation**

The successful transmission of packets is one way of eliminating the hidden node in a transmission media. In the current case, solution to hidden node is the successful detection of PS using probability based Drake’s model (similar to RTS/CTS). If the PS is not visible to cognitive user, the primary user will be delayed for transmission. Then the purpose of installing the cognitive radios or clustering the cognitive radios to detect the PS is lost. The Drake’s equation (7) provides the amount of time PS occupies the spectrum. Further, we need to calculate the probability of detection of PS on decodable space by cognitive radio cluster. The product of detection rate to the occupation of PS gives the probability of detection PS in the decodable space using Drake’s equation. This is same as the probability of performance in equation (3). The probability of the performance of the PS detection (\( PS_{d} \)) is provided in equation (3). Further, the correct detection rate of PS in decodable space (\( D_p \)) should match the \( PS_{d} \) in equation (5). From equations (3) and (5) we derive:

\[
PS_{d} = D_p
\]  

(8)

The equations (3) and (5) must match the signal detection rate calculated using Drake’s equation (7). The probability of the PS detection in Drakes decodable space is given by

\[
P = Kf_t f_r N_{ac}
\]  

(9)

Where \( K \) is a detection threshold factor (<1), \( f_r \) is the status of the primary signal (0= not present and 1= present) at any time \( t \), and \( f_t \) is the volume of PS in the spectrum space. The comparison of the results using equations (3), (5), and (9) provides the undetectable PS in a particular model. The models include the noise explicitly or implicitly. The noise level contributes to the hidden node problem or undetectable signal. The performance rate and comparison of the models are discussed in the next section.

6. **Simulations and Discussion of Results**

Simulations were drawn for the performance of the probability of detection using equation (3). The primary signal presence was taken randomly with a collaborative effort. The signal noise was set high if the PS was not present and low in the presence of PS. Presence of PS with low energy is very difficult to detect by the energy detectors. Figure 3 shows that the probability model performs better in case of strong presence of the signal. In the case of cluster, false alarm happens with low presence of the signal and the interference of other cognitive users. Low presence of PS and interference of cognitive users is similar to the hidden node problem, since noise and low energy of PS overpowers the detection.

In Figure 4 and Figure 5, rate of performance is calculated using the Drake’s equation. The detection is better for smaller value of \( K \). The detection varies with \( N_{ac} \) (Figure 4) and better in higher values. Further, the detection position was shifted for higher values of \( N_{ac} \). Further, Figures 4 and 5 conclude that the detection rate is better in case of smaller values of \( K \) and \( N_{ac} \).

7. **Conclusions and Future Research**

Detection of the PS is very important in cognitive networks. The detection of PS may fail due to low energy signal and frequent interference (noise) of cognitive radios in the network. The failure to detect the PS due to noise is similar to the hidden node problem, where the node is not available due to interference from neighboring nodes.

The contribution has two models. The probability based PS detection model and model with Drake’s equation. The simulations show that the Drake’s model maximizes the
detection rate. The presence of noise along with weak signals has some effect, but PS has minimum detection effect.

The future research includes the role of game models in detecting primary signals in the presence of noise and interference of other cognitive users. Further, an adaptive models for primary signal detection is recommended for better detection of PS.

Figure 3: Probability of Performance of PS detection

Figure 4: Probability of Performance of PS detection in Drake’s Decodable space for fixed K

Figure 5: Probability of Performance of PS detection in Drake’s Decodable space for variation of K

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