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Prediction Based Channel Selection for Cognitive Radio Networks

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ABSTRACT

This paper proposes a novel prediction based packet delivery combined with novel medium access control (MAC) scheme for multichannel cognitive radio (CR) ad hoc networks, which achieves high throughput of CR system while protecting primary users (PUs) effectively. In designing the scheme, we consider that the PU signal may cover only a part of the network and the nodes can have the different sensing result for the same PU even on the same channel. By allowing the nodes to use the channel on which the PU exists as long as their transmissions do not disturb the PU, the proposed MAC scheme fully utilizes the spectrum access opportunity. In addition, based on the past behavior we select the primary channel to use. To mitigate the hidden PU problem inherent to multichannel CR networks where the PU signal is detectable only to some nodes, the proposed MAC scheme adjusts the sensing priorities of channels at each node with the PU detection information of other nodes and also limits the transmission power of a CR node to the maximum allowable power for guaranteeing the quality of service requirement of PU. The performance of the scheme is evaluated by using simulation. The simulation results show that the CR system with the proposed MAC accomplishes good performance in throughput and packet delay, while protecting PUs properly.

Keywords— Security, CR networks, denial of sleep attack, ARIMA, SARIMA

I. INTRODUCTION

COGNITIVE radio (CR) has been attracting great attention from researchers as one of the most feasible solutions to the problem of spectrum scarcity in wireless communications. In CR systems, the nodes search spectrum band not being used by the licensed primary user (PU), called a spectrum hole, and use a part (or the whole) of the spectrum hole as their communication channel [1]. Since a CR system should not interfere with the PU, it has to release the channel as fast as possible when the PU is activated. Therefore, the spectrum sensing for finding empty channels and the channel switching to another empty channel at the PU appearance are the key operations of CR systems that distinguish them from the conventional wireless networks [2], [3].

Recently, a standard for wireless regional area networks (WRANs) that adopt the CR technology for providing internet access to sparsely populated rural and remote areas has been developed by IEEE 802.22 Working Group [4], and IEEE 802.11h Task Group completed the enhancement of IEEE 802.11 standard for operating 802.11 wireless local area networks (WLANs) on the 5 GHz licensed band in Europe [5]. Also, various wireless networks that utilize the CR technology under ad hoc environment have been proposed in the literature (e.g., [6]).

Most of the CR-based ad hoc networks proposed up to recently operate on multiple channels in order to fully utilize the spectrum access opportunity without a centralized controller [7], [8], [9], [10], [11], [12], [13], [14]. In these networks, a CR node transmits data traffic using one or more channels that are identified as empty at the time of data transmission, and releases the channels immediately after transmission. Therefore, the design of the medium access control (MAC) scheme for these multichannel CR ad hoc networks is focused on the efficient sensing of multiple channels rather than the channel switching.

Some multichannel CR ad hoc networks (e.g., [8], [9]) adopt the policy to lower the possibility to use the PU existence channels at the cost of the increased data transmission delay of CR nodes, by carrying out the channel sensing just before the transmission of data traffic (just-before-transmission sensing). In [8], when a CR node wants to transmit traffic, it first reserves a data channel and then checks whether the channel can be or not used for traffic transmission, by sensing it. Since the CR node repeats the work to reserve a channel and sense it until an empty channel is got, the node may suffer a long delay to obtain the channel for traffic transmission. To reduce this delay, [9] has proposed the scheme where the nodes having data traffic contend for obtaining the right of using the entire channel and the winner acquires all channels. Then, the winner senses sequentially the channels until finding as many empty channels as it needs, and transmits its traffic over the found empty channels. Since only the winner can use the data channels, the concurrent transmission by several nodes is not allowed even though there remain empty channels.

Under the environment that the PU signal covers only a part of the network, since the nodes can have different sensing outcomes, the channel state information of a node may be worthless to other nodes. Thus, each node should sense individually all channels for getting more vacant channels. However, since a CR node usually senses one channel at a time, the channel state information may be inaccurate due to the long sensing interval of each channel.

As a result, there may be the channels which are not actually empty but are regarded as empty by the node, i.e., the channels with hidden PU. The occurrence of hidden PU on a channel can be reduced with the shorter sensing interval of the channel. When a node should sense all channels one at a time, it can shorten the sensing interval of a channel by optimally setting the channel sensing duration. Liang et al. [16] have designed the optimal sensing duration for maximizing the achievable throughput of CR system while protecting PU sufficiently. On the other hand, a CR node may find the hidden PUs by exploiting the channel state information of other nodes. Nan et al. [10] have partially solved the hidden PU problem, by letting both the sender and receiver nodes inquire of their neighbors about vacancy of candidate channels before selecting a data channel. Although this scheme decreases the occurrence rate of hidden PUs, there may exist still the channels with hidden PU. Therefore, the CR networks should provide the mechanism for protecting the hidden PUs. Salameh et al. [17] have designed a CR MAC protocol to protect PUs, by limiting the transmission power of a CR node so as that the total interference power at a PU receiver does not exceed a threshold with given probability.

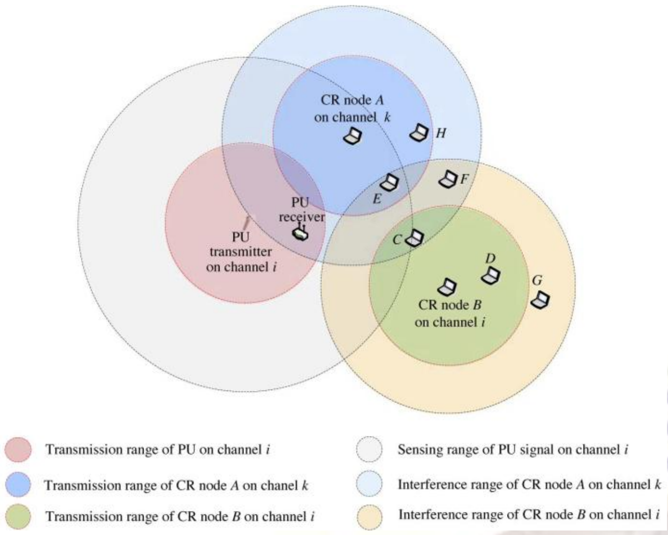
Once the primary user becomes available, the other users using the channel has to relinquish the channel. The data transfer must be started once again by acquiring the channel. This reduces the throughput of the system & also increases the data latency. In this paper, we study the above problem in detail and propose a solution to prevent this problem and increase the throughput & reduce the latency.

II. Literature Survey

"A Novel MAC Scheme for Multichannel cognitive radio adhoc networks" proposed by Wha Sook Jenon is the most recent work on cognitive work which is base on which our work is based.

They considered a CR-based ad hoc network using multiple channels. There are one control channel and N data channels within the network. It is assumed that CR network will not be disturbed by PUs in accessing the control channel. The transmission power of a CR node on the control channel is set to be high enough that the packets transmitted through the control channel can be decoded by all nodes within the CR network. In other words, the transmission range of a CR node on the control channel covers the whole network. The data channels are licensed to PUs and can be opportunistically used by the CR nodes. In the environment under consideration, the PU signal can have influence not on the whole CR network but on only a part of the CR network. That is, there exist the nodes that cannot detect the PU activation, within the CR network.

On the other hand, a CR node should transmit data traffic with the controlled power as low as possible so as not to largely disturb PU even when it does not know the existence of a PU by failing to detect the PU. For example, in Fig. 1, the node A which has detected the PU signal on the channel i uses another channel (let's say, the channel k) to transmit its data traffic, whereas the node B located out of the sensing range of the PU signal cannot find the PU and may transmit data traffic through the channel i. In this case, the transmission power of the node B should be controlled so that the signal from the node B does not seriously interfere with the PU. We consider the networks where the CR nodes transmit data traffic with power lower than the maximum allowable power, which is defined as the maximum transmission power for guaranteeing the QoS requirement of the PU. In Appendix, available in the online supplemental material, we calculate the maximum allowable transmission power of a CR node for maintaining the outage probability of PU transmission below the predefined value. When a CR node does not detect the PU signal on a data channel, the node is allowed to access the channel with transmission power lower than the maximum allowable power, irrespective of the sensing results of other nodes. The maximum allowable power is unlikely to be high enough that all nodes within the network can overhear the packets on a data channel. Thus, only some nodes adjacent to the sender node can decode the data packets. We will call these nodes one-hop neighbors of the sender. In Fig. 1, the nodes C and D are one-hop neighbors of the node B.



In their proposed MAC, each CR node is equipped with two transceivers: one is dedicated to the control channel (the control transceiver) and the other is used to sense data channels and transmit/receive traffic on data channels (the data transceiver). The CR node uses the control channel to transmit channel management packets or to reserve a data channel for traffic transmission. For simple description, a data channel will be called shortly a channel, if there is no confusion with the control channel. In addition, we regard a data channel not being used by all CR nodes within the network as an idle channel. An empty channel means a data channel where a PU is not activated.

Time for channel sensing is not regularly arranged on a channel time. Thus, whenever its data transceiver is not being used for data transmission/reception, a CR node selects the idle channel with highest sensing priority and carries out sensing for the selected channel (opportunistic time for channel sensing is not regularly arranged on a channel time. Thus, whenever its data transceiver is not being used for data transmission/reception, a CR node selects the idle channel with highest sensing priority and carries out sensing for the selected channel (opportunistic sensing), independent of other nodes. The sensing priority of a channel will be explained in detail later. Since each CR node is able to sense one data channel at a time, even though the PU has appeared on a channel, the CR node does not know the PU activation until the node itself senses the channel. This detection delay can be shortened if the nodes receive an explicit notice for PU appearance. With the proposed scheme, a CR node that has found earliest the PU appearance on a channel within the network broadcasts an urgent sensing request (US_REQ) packet so that the other nodes carry out quiet sensing on the corresponding channel as soon as possible. It is noted that all nodes within the network can hear this packet since the transmission range of the control channel covers the whole network. The node that receives the US_REQ packet senses the channel as soon as its data transceiver becomes idle (urgent sensing).

III. Overview of Proposed Solution

The current solution in cognitive network uses the primary channel till the time primary users are available. Once the primary users are sensed, then the channel must be released immediately. The ongoing data transfer should be aborted. This will reduce the overall throughput of the system and the data transfer should be started again, it will increase the packet delivery length. To solve this problem we propose a mechanism based on the prediction of availability of channel.

Once the channel availability time is predicted, the time to occupy the channel can be calculated. Based on this time, the data transfer can be scheduled. This mechanism will improve the throughput of the system & also effectively manage data latency.

IV. DETAILS OF PROPOSED METHOD

In the proposed solution secondary users must sense the use of primary user channels. Based on the monitoring of the primary user channels, it constructs a time series model to predict the usage trend of primary channel.

ARIMA is a popular family of time-series models that are commonly used for studying weather and stock market data. Seasonal ARIMA models (also known as SARIMA) are a class of ARIMA models that are suitable for data exhibiting seasonal trends and are well-suited for sensor data. Further they offer a way to deal with non-stationary data i.e., whose statistical properties change over time [1]. Last, as we demonstrate later, while seasonal ARIMA models are computationally expensive to construct, they are inexpensive to check at the remote sensors—an important property we seek from our system.

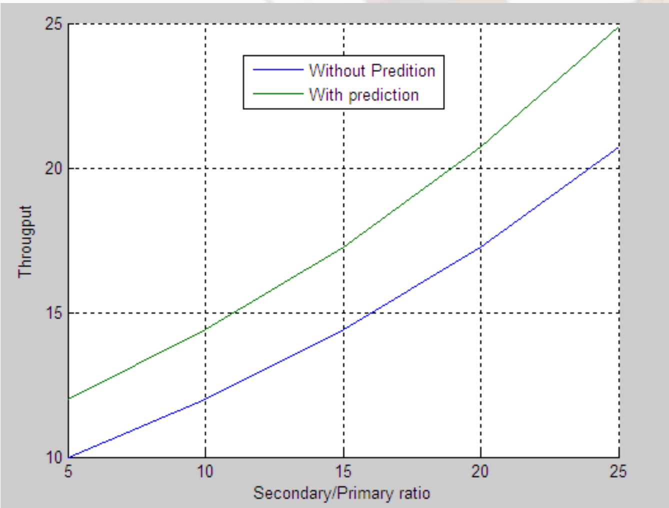
We model the time series of observations at a node as an Autoregressive Integrated Moving Average (ARIMA) process. In particular, the data is assumed to conform to the Box-Jenkins SARIMA model [1]. While a detailed discussion of SARIMA models is outside the scope of this paper, we provide the intuition behind these models for the benefit of the reader. An SARIMA process has four components: auto-regressive (AR), moving-average (MA), one-step differencing, and seasonal differencing. The AR component estimates the current sample as a linear weighted sum of previous samples; the MA component captures relationship between prediction errors; the one-step differencing component captures relationship between adjacent samples; and the seasonal differencing component captures the diurnal, monthly, or yearly patterns in the data. In SARIMA, the MA component is modeled as a zero-mean, uncorrelated Gaussian random variable (also referred to as white noise). The AR component captures the temporal correlation in the time series by modeling a future value as a function of a number of past values.

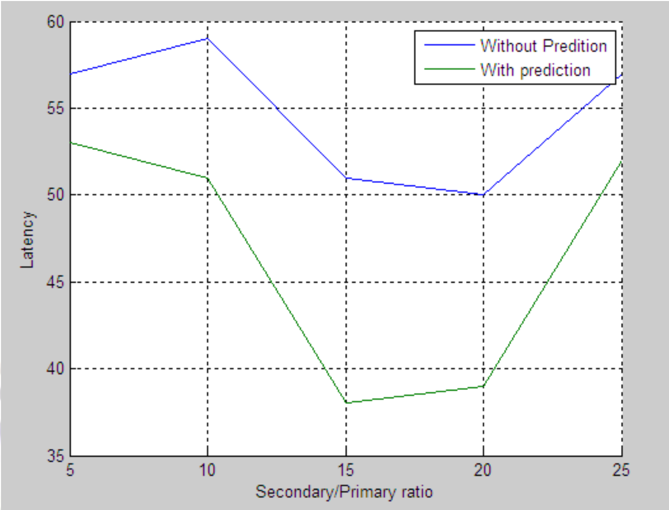
Each cognitive node applies SARIMA method to learn the prediction model for the finding the time at which the primary user is going to use the channel. When the secondary node has some data to be sent, it will use the model to find the time when the channel will be free and duration till it will get occupied once again. Accordingly it will schedule the data transfer. Also in case of selecting among multiple primary channels, it can build multiple SARIMA model for each primary user channel. It will then choose the primary user channel which can transfer the data with no failures. When a single channel usage is alone is not sufficient to send the data, multiple channels can be used or data transfer can be done in batches. This way, delivery latency is also reduced.

V. PERFORMANCE ANALYSYS

We implemented the proposed solution in NS2 and analyze the performance of the system in terms of throughput & data delivery latency. We did this for cognitive networks by varying the secondary to primary user ratio. The rate of channel usage for the primary user is uniform poison distribution. The secondary user use the channel is random distribution. At the end of simulation, we measure the average data delivery latency & the throughput of the system.

From it we found that by using prediction using ARIMA, we are able to reduce the latency by 10% and increase the throughput by around 20%.





VI. CONCLUSION

By introducing the prediction, we were able to increase the throughput of the system. The throughput increases because we have avoided the number of aborted data flows. Also retransmissions have been avoided which decreases the delay.

ARIMA is the prediction algorithm used. In future we plan to add some other prediction mechanism like neural network & SOM to further improve the prediction accuracy. The improved prediction accuracy will contribute to increased throughput.

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