

The 7th International Conference on Wireless Communications, Networking and Mobile Computing



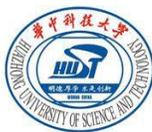
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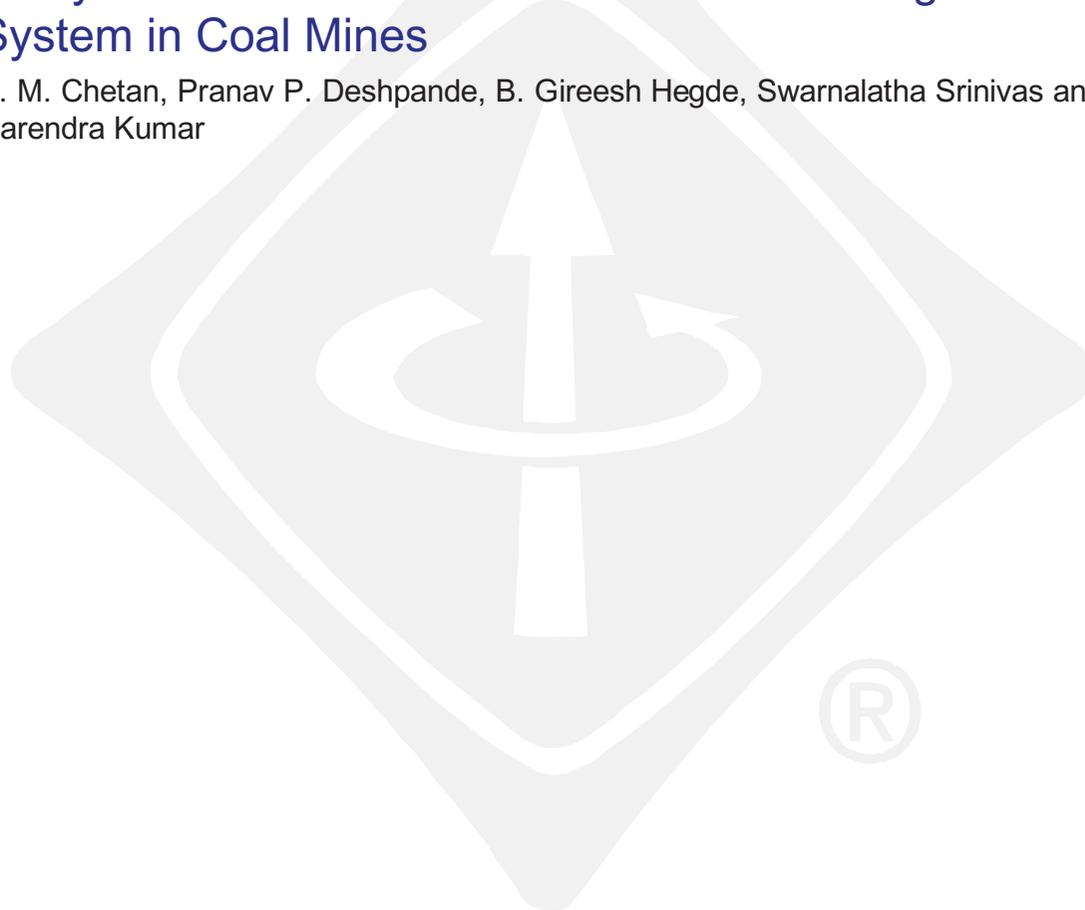
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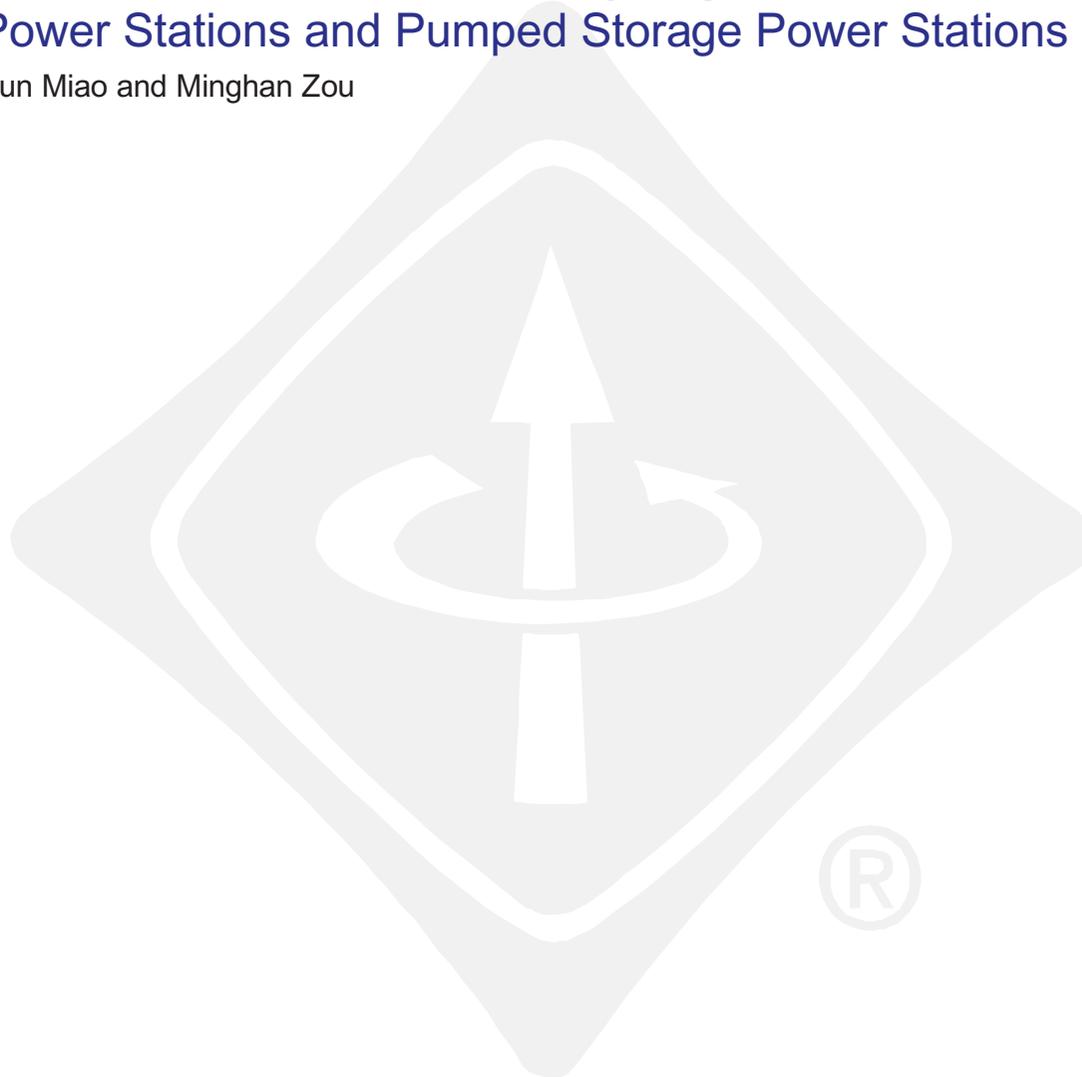
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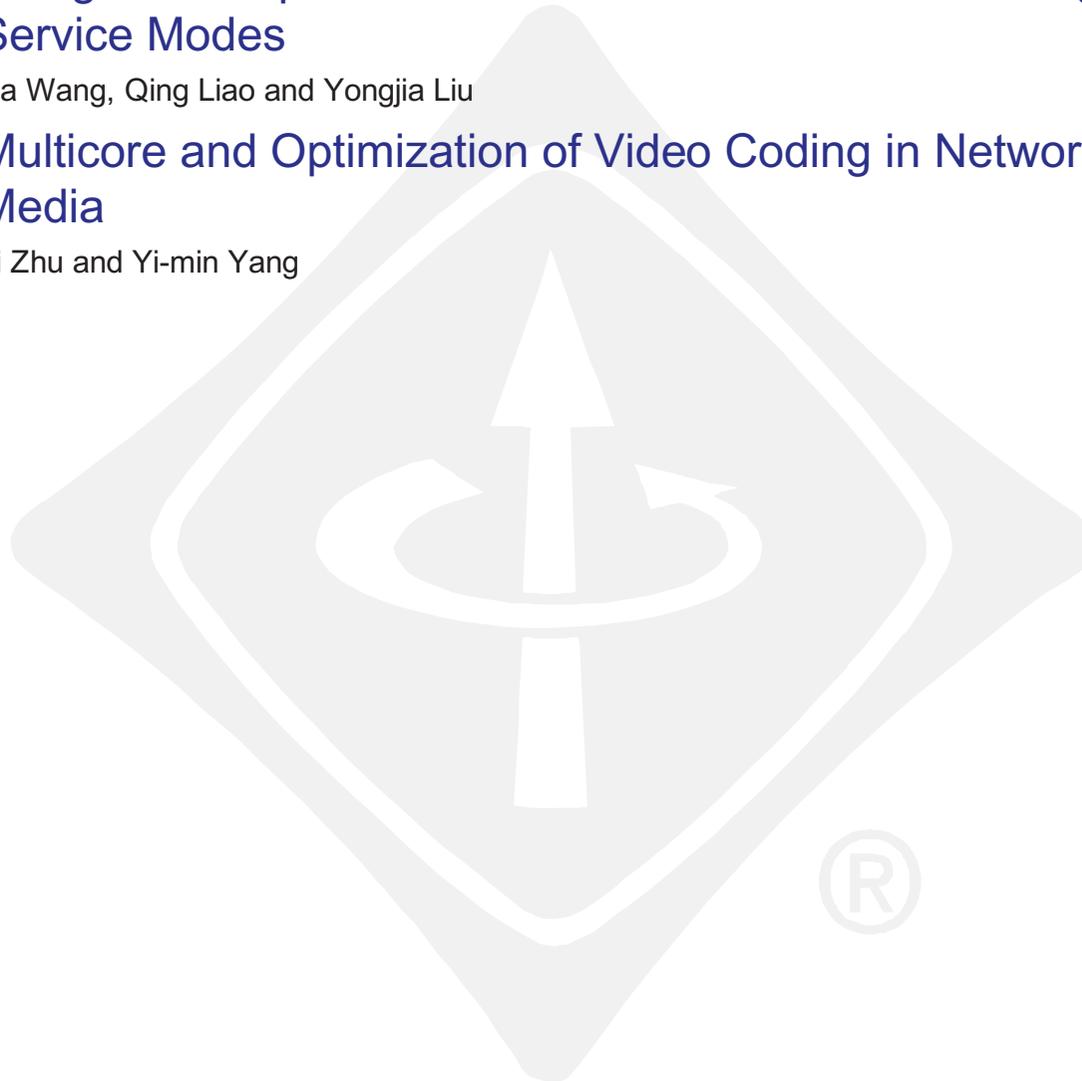


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An Enhanced Synchronized MAC Protocol for Cognitive Radio Networks

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Abstract—Most of the existing media access control protocols for cognitive radio networks are based on global dedicated common control channel (GCC). They use GCC to negotiate for data channels and to protect incumbents. The GCC is prone to saturation problem, DoS attack and wasteful of bandwidth resource. Further, it may be not available in some practical cost-sensitive applications. In this paper, we present an enhanced method for idle channel selection in none-dedicated common control channel based protocol. The simulation results show that the proposed protocol increases networks connectivity and utilizes white spaces efficiently, even without GCC.

Keywords—cognitive radio networks; MAC protocol; common control channel.

I. INTRODUCTION

Radio spectrum resource is limited for wireless communication system but the wireless applications to utilize the resource are experiencing drastic growth in the past few years. Due to the fixed radio spectrum allocation system, some licensed radio spectrum resources are underutilized. On the other hand, the limitation of unlicensed spectrum has become a major bottleneck for the development of next generation radio system. Measurement has shown that large portion of the licensed spectrum remains unused or underutilized. The spectrum policy task force report of the Federal Communication Commission (FCC) [1] shows that over 70% of the allocated spectrum is not in use at any given time, even in a highly dense area where the spectrum is intensive. A survey report by the Defense Advanced Research Projects Agency (DARPA) also shows an average of 6% usage [2].

Cognitive radio [3]-[5] came up with the idea of open spectrum that allows unlicensed opportunistic spectrum users (USU) to utilize these underutilize spectrum bands opportunistically. Most of the existing media access control (MAC) protocols for cognitive radio networks (CRNs) [6][8] need an additional global dedicated common control channel (GCC), which may be not available in some practical cost-sensitive application. Further, GCC may be saturated as the number of users increase and it is wasteful of channel.

An alternative solution of the problem due to the GCC, synchronized MAC (SYN-MAC) [9] proposes non-dedicated

and non-global common control channel based MAC protocol for cognitive radio networks (CRNs). This protocol enables the USU to exchange negotiation packets in data channels such that no GCC is required. However, after the network initialization stage SYN-MAC selects a channel blindly from the available channel set, which is not always the best way. In this paper, we propose sophisticated method to select data channel. Our approach is better in protecting incumbent license users and in achieving higher goodput.

The rest of this paper is organized as follows. Related work is reviewed in Section II. The proposed protocol is described in Section III. Simulation results and performance evaluations are discussed in Section IV. Finally, conclusion is given in Section V.

II. RELATED WORK

Designing an efficient MAC protocol is one of the most challenging issues in CRNs. Though a number of MAC protocols for CRNs exist in the literature, there are many areas where improvements are desirable and possible.

Dynamic channel assignment (DCA) [10] based MAC protocol [11] employs a default control channel while other channels may be used for data transmission. It assumes that each cognitive radio is equipped with two transceivers in which one constantly monitors the common channel, allowing it to avoid the multichannel hidden terminal problem. The other transceiver locates on the data channel. RTS/CTS packets are exchanged in the control channel and serve to negotiate a data channel for Data/ACK transmission. Any node wishing to begin a transmission must ensure that the channel it wants to use is idle. If no channel is available, a node wishing to transfer packets must wait for an idle channel through observation of the common control channel (CCC) and wait for a random back-off time to access the channel again.

SYN-MAC is a non-dedicated CCC based MAC protocol. In this protocol, time is divided into slots and each slot is dedicated to one channel for control message exchange. All USUs in a network are synchronized and switch to the channel in predefined time slots. A node beacons in all its available channels at the beginning of the corresponding time slots. After nodes receive a message, the nodes exchange information

about their channel sets. After a network is initialized, nodes are synchronized and at the beginning of every slot, the control radio of every node tunes to the respective channel. When a SU wants to send data to the receiver, it selects a common channel between them. Then the SU sends control message to the receiver at the beginning of the time slot. After control message exchange, data transfer starts.

Most of the existing MAC protocols for CRNs are based on global CCC. As we mentioned in Section I, GCC may saturate, and can be a victim of DoS attack [12]. Further, allocating one channel just for control packet exchange is wastage of resource for channels constrain (802.11b kind of) networks. SYN-MAC and Channel-hopping based cognitive MAC [13] do not require any GCC, hence, it is free from the above mentioned threats.

Our proposed approach is similar to SYN-MAC; however, SYN-MAC randomly selects a channel from the available channel set. This type of selection may not be efficient, because the channel selected blindly from the available channels sets may be more prone to reclaim by incumbent licensed users. In the worst case, incumbent licensed users may reclaim the channel just after the channel selection. Once incumbent licensed users reclaim the channel, USUs have to wait for the next available control slot.

III. PROPOSED PROTOCOL

In our approach, nodes ‘fast sense’ channels and record the results in the channel status table (CST). Then nodes sort and rank the channels according to the availability for the USUs (2). Same channel can be in different rank in different nodes as per geographical location and time. Nodes select the highest ranked common channel between sender and receiver as a common control channel between two nodes. The second highest ranked channel is a data channel. We describe the detailed ranking procedure in the next section.

A. Assumption

We consider cognitive radio devices are the intelligent software defined radio devices with the cognition capacity that can observe, orient, plan, learn, decide and act as mention in the [3]. These devices can form dynamic spectrum access networks utilizing the white spaces. These are capable of switching and work in multiple types of frequencies dynamically. Each cognitive radio device is equipped with two half-duplex transceivers. (a) Control transceiver – it is used for control message exchange and snooping the neighbor’s activities. (b) Data transceiver – it is for data transfer. This transceiver is also responsible for fast sensing and fine sensing. Data transceiver performs fast sensing just before sending beacons. Since fine sensing takes longer time, whenever there is no data to send and receive, nodes start fine sensing into the channels whose status is marked ‘not sure’ in CST by fast sensing, as in TABLE 1.

Further, we consider there are two non-cooperative types of network users- the primary users (PU) and the secondary users (SU). PUs are the licensed user of a frequency band. SUs use free spectrum opportunistically for communication that is not used by the primary users. We use USU and SU interchangeably in this paper.

B. Initialization stage

We assume that there is a set of primary channels (κ). These channels are possible to utilize opportunistically by SUs. Here, channel means a continuum of frequencies in free space with frequency range equal to the maximum and the minimum frequency range defined for that channel. We define the channels are the frequency spectrum (f) divided into mutually exclusive subintervals of equal length.

$$\text{Set of channels } (\kappa) = \{c_1, c_2, c_3, \dots, c_n\},$$

$$f = \{c_1, c_2, c_3, \dots, c_n\} | c_i \cap c_j \neq \emptyset, \quad (1)$$

$$i, j = 1, \dots, n, i \neq j.$$

In the beginning a node waits for a certain predefined time in a randomly selected channel, if it does not hear any activity from any SU, it considers itself is the first node in the network. Then the node divides time into κ equal slots of fixed duration ‘ τ ’. Each slot is dedicated to one channel called default slot for the channel, as in Figure 1.

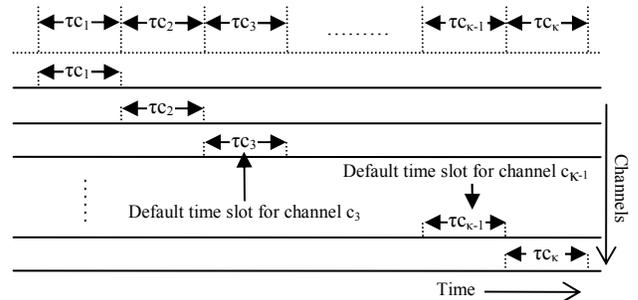


Figure 1. Channels with their default timeslots.

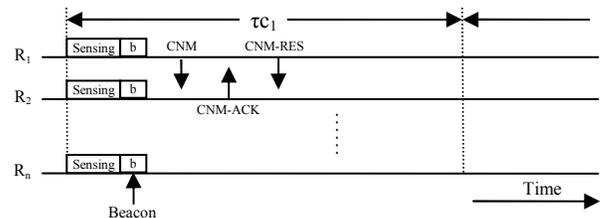


Figure 2. Channel negotiation in default timeslot.

The control transceiver of the node hops into all the channels and sends beacon into all channels at the corresponding time slots. Other nodes in the network then respond sending their available channel set. Entire nodes into the network finish synchronization within $\kappa\tau$ time.

C. Channel negotiation

After network initialization, nodes know the default channel slot for the channel (τ). All the nodes tune their control transceiver into the channel’s default slot. A node that has buffered packets to send, contends for channel access as in 802.11 basic access. Channel negotiation process is shown in Figure 2. The contention winner node (R_1 in the Figure 2) sends channel negotiation message (CNM) to the intended destination (R_2 in the Figure 2). CNM contains preferred channel list (PCL). R_2 sends acknowledgements of channel negotiation message (CNM-ACK) along with a selected

common channel as (4). Finally, R_2 sends channel reservation message (CNM-RES) to the receiver. Other nodes update their channel status table (CST) listening CNM-RES.

Data transfer is carried out in the selected channel as (4) in the 802.11 DCF fashion. If the SU finds that the PU reclaimed the selected channel, it immediately stops sending packets and buffers packet until the SU successfully negotiates for the next data channel. In our protocol, transceiver switches κ times in the corresponding channels' slot in $\kappa\tau$ duration.

D. Channel status table

As we mentioned earlier, each SU maintains CST by sensing the licensed spectrum and overheard from the neighbors' communication. An example of CST is given in TABLE 1. In the TABLE 1, if PU is active in the channel it is marked as 1, if the channel is idle it is marked as 0 and if the node is not sure about the status of the channel it is marked as 2.

Since each SU has the information of the channel's state, they can opportunistically access the channels, which are not occupied by the primary users.

TABLE I. CHANNEL STATUS TABLE

Duration	Channels					
	C_1	C_2	C_3	...	...	C_n
t_1	0	1	0	...	...	0
t_2	0	1	0	...	...	0
t_3	1	2	2	...	...	0
t_4	...	...	...	...	...	...
t_{n-1}	1	1	0	...	...	0
t_n	1	1	0	...	...	1

The availability of channel i for the SUs ($\mu(c_i)$) can be calculated as.

$$\mu(c_i) = \beta(c_i) (1 - U(c_i, \sigma)) \quad (2)$$

$$U(c_i, \sigma) = (1 - \alpha) U(c_i, \sigma - 1) + \alpha U_t \quad (3)$$

Where, $\beta(c_i)$ is the capacity of the channel i , $U(i, \sigma)$ is the average utilization of channel i , σ is the number of calculations, U_t is the channel utilization measured for a period of time. In this, $U(i, \sigma)$ reflects the PUs' behavior in the channel, i.e. it shows that how long the channel is utilized for the past t duration. Equation (3) uses the exponential averaging method which applies weighting factor to recent value.

E. Common channel selection

A channel that has higher availability for SU and common between communication pair is selected as a common channel for data transmission. It can be calculated as

$$C(s, r) = \left(\max_{\mu(c_i) | c_i \in \mathcal{K}(s)} + \max_{\mu(c_i) | c_i \in \mathcal{K}(r) \cap s} \right)_{i=1,2,\dots,n} \quad (4)$$

Where, $C(s, r)$ is the common channel available for sender node s and receiver node r with highest availability.

F. Performance evaluation

We simulate proposed protocol using ns-2. We select SYN-MAC and DCA-based as a representative GCC based MAC protocols to compare with our approach. In all the protocols, we assume that CCC is not free from PUs' intervention. PUs can reclaim any time any channel including CCC. All the simulations are done in four channels including control channel scenario. Number of nodes varies from two to 18. Packet size is 512 bytes. Total 25% of bandwidth is always occupied by PUs.

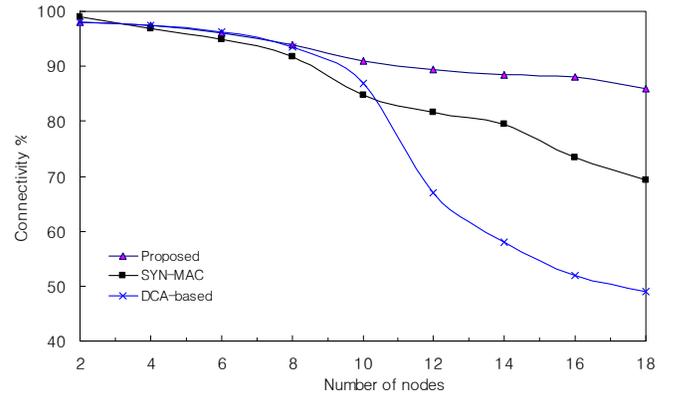


Figure 3. Connectivity vs. number of nodes.

In Figure 3, we evaluate the number of connectivity as the number of nodes increases. As the number of channels increases, the percentage of connectivity increases in all the protocols, but the proposed protocol's connectivity is significantly higher. The reason of low connectivity in DCA-based protocol is that as the number of nodes increases, the probability that the CCC is available for at all the nodes decreases, it is because nodes send negotiation packets for every packet. Therefore, the control channel is always crowded. The connectivity difference between SYN-MAC and the proposed protocol have very small; this difference comes from the channels selection strategy in our approach. In SYN-MAC, sometimes the channels may be reclaimed by PU, so the SUs have to wait until next negotiation period. This problem is less in our approach, because channel selection is based on the PUs' behavior on the channels.

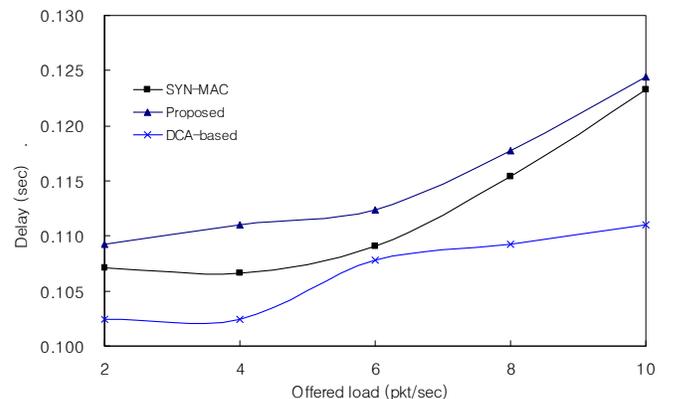
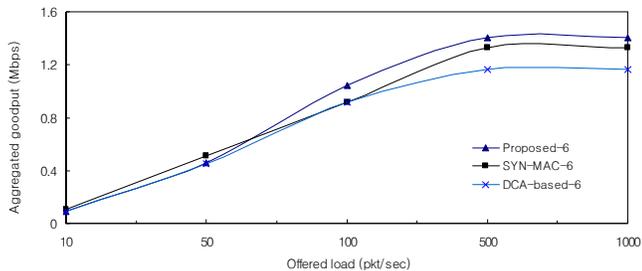
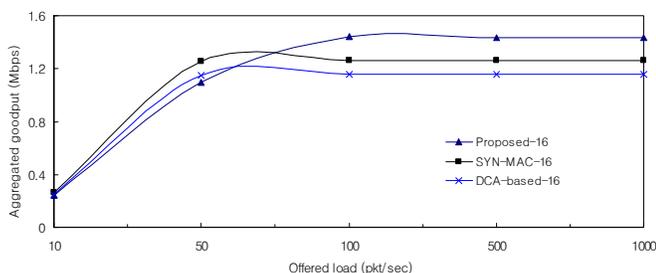


Figure 4. Per packet delay in different offered load.

Figure 4 shows per packet delay comparison of the proposed approach, SYN-MAC and DCA-based protocols. Similar to SYN-MAC, our protocol suffers from slightly higher delay, it is because it has to change channel frequently. DCA-based protocol has a GCC and frequent channel switching for channel negotiation is not necessary. Hence, per packet delay is lower than the rest of the protocols.



(a) 6 nodes scenario



(b) 16 nodes scenario

Figure 5. Aggregated goodput in different offered load.

Figure 5 shows the aggregated goodput of the network in six nodes and 16 nodes scenarios. The aggregated goodput is the average of 10 simulations. The proposed protocol has satisfactory aggregated goodput and better than SYN-MAC in all the scenarios. It is because of our channel selection for the data communication is less prone to claimed by PUs than SYN-MAC.

IV. CONCLUSIONS

We presented a decentralized MAC protocol to solve the problem due to GCC. This approach has many advantages

compare to the existing CCC-based MAC protocols. In this approach, communication is possible even if there is no GCC available. The PUs' activities observation in a particular channel helps selecting most reliable channel for data transmission. This method predicts PUs' arrival, hence helps to protect PUs. The simulation results also show that our protocol works efficiently.

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