클러스터 형태의 다중 인터페이스 다중 홉 인지 라디오 네트워크를 위한 제어 채널 접근 기법

(A Control Channel Access Scheme for Clustered Multi-interface Multi-hop Cognitive Radio Networks)

이지운 †　　전화숙 ††　　정동근 †††
(Ji Wun Lee)　(Wha Sook Jeon)　(Dong Geun Jeong)

요 약 이 논문은 클러스터 형태의 다중 인터페이스 다중 홉 인지 라디오 환경을 위한 효율적인 제어 채널 접근 방식을 제안한다. 인지 라디오 대역 안에서 전체 네트워크 영역에 걸친 공통 채널을 확보하는 것이 어렵기 때문에, 대부분의 멀티 인터페이스 멀티 홉 인지 라디오 네트워크는 라이센스 사용자의 채널 사용 현황과 같은 제어 정보의 교환을 위해 인지 라디오 대역 밖에 제어 채널을 두고 하나의 인터페이스를 제어 채널에 고정시켜 할당한다. 그러나 이러한 방식은 네트워크 인터페이스의 낭비를 초래한다. 이 연구는 인지 라디오 노드들이 다수의 데이터 채널을 통해 이웃 노드들과 연결되는 클러스터 구조 하에서 멀티 채널 상황에서의 숨겨진 노드 문제없이 데이터 채널과 제어 채널을 수시로 번갈아 가며 접근하는 방식에 대하여 고찰한다. 시뮬레이션을 사용하여 제안한 방식의 성능을 측정한다. 시뮬레이션 결과를 통해 제안한 방식이 하나의 네트워크 인터페이스를 제어 채널에 고정적으로 할당하여 데이터 전송을 하지 않는 방법에 비해 더 높은 네트워크 처리량을 보임을 확인한다.

키워드 : 인지 라디오, 메쉬 네트워크, 제어 채널 접근, 다중 인터페이스 다중 홉 네트워크

Abstract We propose the control channel access scheme for multi-interface multi-hop cognitive radio (CR) environment having a cluster structure. Due to the difficulty of obtaining common channels across the entire CR network, most multi-interface multi-hop CR networks put the control channel outside the CR bandwidth and dedicate one network interface to it in order to exchange the control information such as the activation of licensed users. However, this will be the waste of the network interface. Our focus is how to alternate between the control and the data channel without multichannel hidden node problem under the cluster structure where CR nodes connect with neighbors through multiple data channels. By using simulation, we evaluate the performance of the proposed scheme. The results show that the proposed scheme achieves higher network throughput than the dedicated scheme where one network interface card should dedicate to the control channel and cannot be used for data transmission.

Key words : cognitive radio, mesh networks, control channel access, multi-interface multi-hop networks

---

· 본 연구는 지식경제부 및 정보통신산업진흥원의 대학 IT연구센터 지원사업의 연구결과로 수행되었음(NIPA-2010-(C1090-1011-0004))

† 학생회원 : 서울대학교 전기컴퓨터공학부 연구원
jiwunlee@wn.snu.ac.kr
†† 종신회원 : 서울대학교 전기컴퓨터공학부 교수
wsjeon@snu.ac.kr
††† 종신회원 : 한국외국어대학교 전자정보공학부 교수
dgjeong@hufs.ac.kr

논문접수 : 2009년 10월 8일
심사완료 : 2010년 3월 15일

정보과학회논문지: 정보통신 제37권 제4호(2010.8)

1. Introduction

As the solution to the problems about exhaustion of available wireless spectrum and under-utilization of already occupied counterparts, the cognitive radio (CR) technology has emerged. Among various wireless network environments, the wireless multi-hop network such as mobile ad-hoc network (MANET) and wireless mesh network (WMN) has been receiving a considerable attention since it can derive great benefit from CR by exploiting multiple available channels from spectral holes.

In addition that the CR network can utilize multiple channels which licensed users do not use temporarily, as the size and the cost of wireless network interface controller (WNIC) decreases, it becomes more practical for wireless nodes to have more than two WNICs. Since having multiple channels and WNICs makes more simultaneous transmissions possible in the network by assigning different channels to different wireless links, multi-interface CR networks can be efficient alternative in multi-hop environment.

On the other hand, CR nodes should change channels assigned to wireless links dynamically because of the activities of the licensed users. For this, CR nodes should share network control information including channel and neighbor status periodically. Therefore control information exchange is very important issue in multi-interface multi-hop CR network.

For a reliable control information exchange, a common control channel is necessary. A common control channel can be within or outside the CR bandwidth. If a common control channel is within the CR bandwidth, management and update of it by rendezvous algorithms is not easy since available channels of nodes can be different from each other and change over time according to the presence of licensed users. In case that a control channel is outside the CR bandwidth like the industrial, scientific, and medical (ISM) bands, most algorithms [1,2] dedicate one WNIC to the control channel. However, it seems a waste of the WNIC. Instead, it can be more efficient that nodes tune all WNICs to different data channels and periodically gather neighbor information through the control channel outside the CR bandwidth. For this, we propose alternating scheme between control and data channel while maintaining network connectivity for multi-interface multi-hop CR network.

Without the accurate time-synchronization, alternating scheme may cause the multichannel hidden node problem [3]. Therefore we propose the cluster structure for complementing our control access scheme. Cluster structure for the traditional multi-hop networks has been given a lot of consideration in order to localize broadcasting of routing information and easily control network topology [1-4]. However, there exists an insufficient amount of clustering algorithms taking attributes of multi-interface CR network into account together. Since a cluster head can always overhear other transmissions within the cluster, it can prevent the alternating WNIC from the multichannel hidden node problem.

The rest of the paper is organized as follows. Section II presents the proposed clustering and control channel access algorithm for multi-interface multi-hop CR environment. We discuss the performance of the proposed scheme with simulation results in Section III. Section VI concludes the paper.

2. System Model and Proposed Structure

2.1 System Model

Whole CR bandwidth is divided into multiple data channels with same bandwidth. There is one control channel for sharing the network information. The control channel is outside the CR bandwidth and is shared with a carrier sense multiple access/collision avoidance (CSMA/CA). Data channels can be used with any type of CR-enabled multiple access protocol. A CR node can have multiple WNICs. Each WNIC can change not only its operating frequency but also employed MAC protocol.

2.2 The Basic Concept of Cluster-based CR Network

In multi-hop CR networks, it is difficult for all CR nodes to find a common data channel across the whole network and to communicate through it. Therefore the cluster structure, where the cluster head and its one-hop neighbors only share the same data channel, can be favorable for multi-hop

CR networks.

CR nodes need to exchange channel information with neighbors in order to manage this cluster structure efficiently. In many researches CR nodes generally dedicate one WNIC to a common control channel. However it is more efficient for one of WNICs of a node to alternate between the common control channel and its data channel. We refer this WNIC as alternating WNIC (AWNIC). In the proposed structure, all CR nodes assign one WNIC to AWNIC and periodically tune AWNIC to the control channel where it transmits/listens the beacon (referred as the control beacon). The control beacon includes employed MAC type, the MAC address, channel index (CI), and cluster head indicator (CHI) of its own WNICs and WNICs of neighbors. Cluster head indicator indicates whether the WNIC is cluster head or not.

Whenever a node wants to know neighbor information, it has to be able to obtain it within a limited time duration. Thus, if all nodes periodically transmit at least one control beacon with a common period, the node can receive all control beacons of its neighbors within the period. This period is referred as reporting period (or simply RP) and all nodes have the same length of RP. In order to transmit the control beacon, the node has to periodically tune an AWNIC to the control channel for a while and returns to the previously connected data channel. However, since the AWNIC does not know the channel status just after moving from the control channel (data channel) to the data channel (control channel), transmitting packets can interfere with the licensed user which starts to transmit when the AWNIC operates in the control channel as well as other communicating CR pairs. To cope with this problem, two approaches are applied to the control channel and the data channel. The next subsection describes the scheme of accessing control channel for solving this problem in the control channel and after that, we describe how to form the cluster structure and resolve this problem by the cluster head in the data channel.

2.3 The Way of Accessing the Common Control Channel

Basically the control channel is shared by CSMA/CA. However, in order to periodically broadcast control beacons without collisions, nodes access the control channel via reservation based protocol over CSMA/CA. All CR nodes divide the control channel into frames with the fixed time width same as the length of RP. Note that frame structures of all nodes are independent and the start/end of the frame has no need to be synchronized with all nodes. Then nodes again divide each frame into multiple virtual slots of the same length. The length of one slot is decided to be enough to transmit one control beacon. All nodes pick up one slot independently and broadcast their own control beacon periodically. This slot is referred as the reporting slot (or simply RS) of the node. In order to avoid collisions of selecting a RS, nodes have to listen to the control channel for multiple frames before selecting the RS. Each node finds slots during which no control beacon has been received and chooses one random slot among those. In the RS, the node transmits its own control beacon by CSMA/CA. If the node waiting to transmit the control beacon in the RS receives another control beacon from other nodes, the node discards the RS and selects new RS through the above process. The length of one frame and the number of slots in one frame is determined depending on how many nodes are in one hop range and how frequently nodes transmit the control beacon. The operation of AWNICs is depicted in Fig. 1.

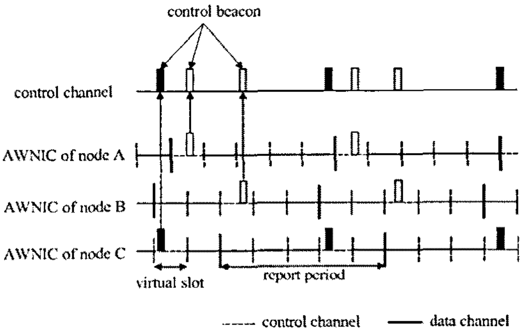

Fig. 1 The operation of AWNICs

In this algorithm, there can be collisions between two-hop neighbor nodes. If two-hop neighbor nodes broadcast the control beacon during similar time, intermediate nodes may not receive control beacons

Algorithm 1: Channel selection algorithm

```
$D$ : the set of total data channels
$K_i$ : the set of WNICs of the node $i$
$N_i$ : the set of neighbors of the node $i$
$C_i$ : the set of data channels which the node $i$ is using
$H_i$ : the set of channels of which the node $i$ is the cluster head
$A_i$ : the set of channels which are not occupied by licensed users near
the node $i$

// find the data channel for node $i$
begin
  // find the empty WNICs
  $E_i \leftarrow \phi$
  forall $x$ in $K_i$ do
    if $x$ is not connected to the channel then
      $E_i = E_i \cup x$
    end
  end
  $k \leftarrow SelectRandom(E_i)$

  // find the channel for joining
  $J_i = ((\bigcup_{j \in N_i} H_j) - C_i) \cap A_i$
  if $J_i \neq \phi$ then
    $c \leftarrow SelectRandom(J_i)$
    $Join(k, c)$
  else
    // find the channel for initiating
    if $k$ is not the AWNIC then
      $O_i = ((\bigcup_{j \in N_i} C_j) \cup C_i$
      $I_i = (D - O_i) \cap A_i$
      if $I_i \neq \phi$ then
        $c \leftarrow SelectRandom(I_i)$
        $Init(k, c)$
      end
    end
  end
end
```

from them due to the collision. For this, all nodes check the neighbor information of their own neighbors. In order to maintain the updated neighbor information, nodes listen to the control channel once in the interval. If the node finds neighbors not recognizing it during the multiple intervals, it means that they could not receive its control beacon. Therefore the node selects another RS.

2.4 Clustering and Data Channel Assignment

Each WNIC of nodes plays one of two roles for its connected channel: Initiating the channel or joining the channel. Initiating the channel means that the WNIC becomes the cluster head of the channel. The cluster head is always resident in the channel and performs some functions for other WNICs which join the channel. Note that the AWNIC cannot be the cluster head since it should alternate the channels. The WNICs which are not the cluster head can start to communicate with other WNICs in the channel by joining. Communications between WNICs in the same channel are achieved through the MAC initiated by the cluster head.

The node which newly enters into the network obtains the neighbor information from control beacons and selects the RS. Before starting to report its own information, the node initiates or joins one data channel (as presented in Algorithm 1). After selecting the data channel, the node broadcasts the control beacon including this channel selection result in the RS. Other neighbor nodes can obtain the updated information of the node through the CI and the CHI field of control beacon. If there are other WNICs which have not yet been connected to the data channel, the node repeats the above procedure in the next RS.

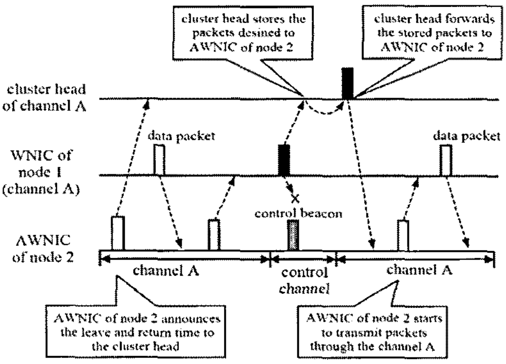

Fig. 2 The operation of the cluster head and AWNICs for solving multichannel hidden node problem

In Algorithm 1, N_i, C_i, and H_i can be calculated from control beacons. A_i can be obtained from out-of-band sensing. The function *SelectRandom(S)* returns one element in the set S randomly. *Join(k,c)* means the operation that joins the channel c through WNIC k and *Init(k,c)* is the operation that initiates the channel c by WNIC k.

Some problems may occur due to alternating the channels of the AWNICs. Some WNICs may try to transmit packets to the AWNIC in the control channel. Also AWNIC which just comes back to the data channel and tries to transmits packets may interfere with licensed users or other communicating pairs due to no knowledge about the channel state. In order to cope with this problem, the AWNIC announces leave time and return time to the cluster head. Note that if these are periodic, the AWNIC has only to announce them with the period once. The cluster head has to keep these information of all nodes. When some WNICs transmit packets to the AWNIC which is in the control channel, the cluster head receives and acknowledges them instead of the AWNIC. After return time of the AWNIC, the cluster head transmits the stored packets to the AWNIC. If there is no packet for the AWNIC, the cluster head transmits a small size packet which allows the AWNIC to start transmissions without interference to other nodes. If the AWNIC does not receive any packet from the cluster head for the predetermined time after the AWNIC returns to the data channel, the node performs the new channel selection algorithm for the AWNIC. It is depicted in Fig. 2.

3. Performance Evaluation

3.1 Simulation Model

For the simulation, we implement the proposed algorithm using network simulator-2. In the simulation, there are multiple data channels and one control channel which is outside the CR bandwidth. Each licensed user occupies one data channel and uses data channels for on-periods and vacates it for off-periods. We assume that the length of on-periods and off-periods are exponentially distributed with average 10 seconds and 90 seconds respectively. The transmission rate of the control packet is 1 Mbps and that of data packet is 11 Mbps. We do not assume any specific MAC protocol for data channels in the proposed clustering algorithm. However, we implement a simple CR MAC protocol based on IEEE 802.11 for simulation. The only addition to the IEEE 802.11 is the channel sensing for the licensed user detection. The cluster heads transmit data beacons every 100 ms. After the beacon transmission of the cluster head, all CR nodes stop transmission for a certain period of time (i.e., a quiet period) and sense the channel through energy detection. The decision threshold for the energy detection is -90 dBm. If a node detects a licensed user through a WNIC, it tunes the WNIC to the control channel in order to transmit/receive control beacons and reconfigures the channel of the WNIC. The length of RS is set to 2 ms and the length of RP is 100 ms. In addition, all nodes listens to the control channel once in every 5 seconds for updating information.

Initially, 20 nodes and all licensed users are randomly distributed within the square area with the side length of 300 m. The transmission power of a CR node is set such that the transmission range is about 100 m. The transmission power of a licensed user is 280 mW. No mobility of CR nodes and licensed users is assumed. There are total 5 distinct connection pairs. The two-ray ground propagation model is used for wireless channel. Since the transmission range of a CR node is about 100 m, some connection pairs have to transmit packets in multi-hop manner. The modified version of ad hoc on-demand distance vector (AODV) is used for the routing protocol. If there are two more WNICs to the next hop, routing protocol sends a packet to the WNIC which has the smallest queue length.

Two types of traffic are considered. For evaluating the saturated throughput, we use the constant bit rate (CBR) with a rate of 8 Mbps per one connection. In FTP applications, a session is modeled by a sequence of file transfers, separated by reading time. File sizes are randomly generated using truncated log-normal distribution (mean = 2 MB, standard deviation = 0.722 MB, maximum = 5 MB) and reading time are exponentially distributed (mean = 3 seconds). UDP and TCP are respectively used for CBR and FTP traffic.

3.2 Simulation Result

We compare the proposed algorithm with the dedicated scheme where one WNIC dedicates to the control channel and does not alternate control channel and data channel. The other operation of dedicated scheme is the same as that of the proposed scheme. Fig. 3 shows the aggregated system throughput according to the number of WNICs when all connection pairs use CBR traffic. The system throughput increases as the number of WNICs since there can be multiple channels between neighbors. Since the proposed scheme can use one more WNIC for data transmission, throughput of it outperforms the dedicated scheme. However, performance differences become smaller as the number of WNICs especially when the number of channels is set to 10 since the number of available channels is limited compared to the number of WNICs.

In Fig. 4, the system throughput according to the

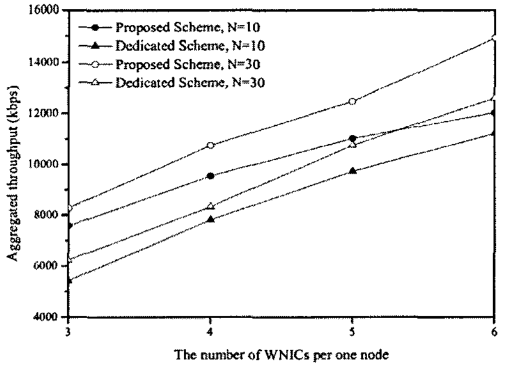

Fig. 3 Aggregated system throughput over the number of WNICs with CBR traffic

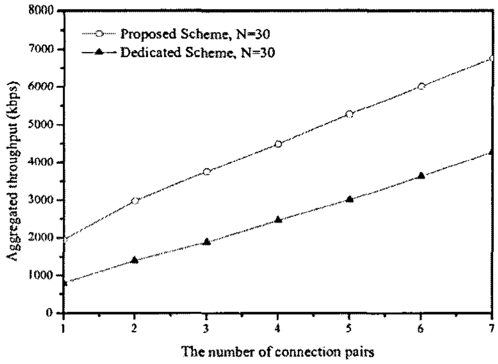

Fig. 4 Aggregated system throughput over the number of connection pairs with FTP traffic

number of activating FTP connection pairs is shown. The number of WNICs is 3 and the number of channels is 30. The result shows that the proposed scheme can get the throughput gain from AWNICs.

4. Conclusion

In this paper, we have proposed an efficient clustering and control access algorithm for multi-interface multi-hop cognitive radio networks. In the dedicated control scheme where one WNIC should dedicate to the control channel and cannot be used for data transmission, a CR node cannot fully exploit the number of WNICs. However, in the proposed structure, a CR node can connect with neighbors as many data channels as possible and can dynamically obtain neighbor information and change the operating channel depending on activation of licensed users.

The performance of the proposed scheme has been evaluated and compared with that of dedicated control scheme. The simulation results show that the proposed scheme outperforms dedicated control scheme in the aggregated throughput. In addition, the proposed scheme is expected to be easily implemented and adopted in CR environment.

References

[1] J. Y. Yu and P. H. J. Chong, "A survey of clustering schemes for mobile ad hoc networks," *Commun. Surveys Tuts.*, vol.7, no.1, pp.32-48, 2005.

[2] T. C. Hou and T. J. Tsai, "An access-based clustering protocol for multihop wireless ad hoc networks," *IEEE J. Sel. Areas Commun.*, vol.19, no.7, pp.1201-1210, 2001.

[3] M. Seo, Y. Kim, and J. Ma, "A multi-channel MAC protocol with snooping for multi-hop wireless networks," In *Proc. IEEE ISWCS*, Reykjavik, Iceland, Oct. 2008.

[4] H. Su and X. Zhang, "Clustering-based multichannel MAC protocols for QoS provisionings over vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol.56, no.6, pp.3309-3323, 2007.

이지운

1999년 서울대학교 공과대학 컴퓨터공학과 학사. 2006년 서울대학교 공과대학 컴퓨터공학과 석사. 2006년~현재 서울대학교 공과대학 컴퓨터공학과 박사 과정. 관심분야는 이동통신망 자원관리, 무선 메쉬 네트워크, 인지 라디오 시스템

전화숙

1983년 서울대학교 공과대학 컴퓨터공학과 학사, 1985년 서울대학교 공과대학 컴퓨터공학과 석사, 1989년 서울대학교 공과대학 컴퓨터공학과 공학박사. 1989년~1999년 한성대학교 공과대학 컴퓨터공학과 부교수. 1999년~현재 서울대학교 공과대학 컴퓨터공학과 정교수. 관심분야는 이동통신망, 고속 네트워크, 통신망 프로토콜 설계, 통신망 성능 평가

정동근

1983년 서울대학교 공과대학 제어계측공학과 학사. 1985년 서울대학교 공과대학 제어계측공학과 석사. 1993년 서울대학교 공과대학 제어계측공학과 공학박사. 1986년~1990년 ㈜한국데이타통신 정보통신연구소 주임 연구원. 1994년~1997년 ㈜신세기 통신 기술연구소 책임연구원. 1997년~현재 한국외국어대학교 전자공학과 교수. 관심분야는 이동통신망, 통신망 프로토콜 설계, 통신망 성능 평가