MULTI-BAND ROUTING FOR AD-HOC COGNITIVE RADIO NETWORKS

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ABSTRACT

In this paper, we propose a novel multi-band routing method for cognitive radio using ad-hoc networks. The cognitive radio is considered being used for the secondary radio systems under the frequency bands assigned to the primary systems. In order to realize such systems, the method for minimization of giving interference toward the primary systems is required. As one of the solution for the inter-system interference, multi-hop communication networks with small transmit power of each terminal have been considered. In cognitive radio systems, we can use multiple frequency bands for communication. However, these bands are also used by the primary systems so the link quality is often changed. In such situation, the routing is complicated for establishing the reliable multi-hop communication. Therefore, in this paper, we consider the stable routing method suitable for multi-hop cognitive networks with small power by using multi-band for improving the performance of the secondary cognitive networks.

1. INTRODUCTION

The cognitive radio has attracted researchers' attention in these days for realizing frequency sharing system at the frequency bands assigned to primary systems [1][2]. In the cognitive radio, the secondary cognitive terminals transmit the signals on the frequency band assigned to the primary system by sensing the radio frequency band in order to avoid the interference toward the primary systems [3]. However, an active receiver of a primary system is difficult to be recognized because the receiver terminal does not transmit the signals. As a result, the method avoiding interference toward the active receiver before transmitting at the secondary terminal is a serious problem in the cognitive radio. In order to solve the problem giving interference toward the primary system, a cognitive radio using ad-hoc networks has been considered [4][5]. Ad-hoc networks can expand the communication area by relaying the data through neighboring terminals. Moreover, since each terminal transmits the signal with small transmit power, the interference toward the neighboring terminals are also small. However, in order to establish the ad-hoc networks, the routing from the source node to the destination node should be decided. Although a lot of routing algorithms for ad-hoc networks have been proposed, these methods are not suitable for utilizing to the cognitive radio under the interference from the primary systems. In cognitive networks, the interference situation is fluctuated in terms of time, frequency and location. Therefore, the basic routing technique is not effective for applying to the ad-hoc cognitive networks. In this paper, we propose a novel routing method for ad-hoc cognitive networks for supporting multi-band communication networks under the fluctuated interference from the primary systems.

The proposed routing algorithm is based on the flooding method for establishing the route from the source node to the destination node by using a route request packet (RREQ) and a route reply packet (RREP). In the original RREQ and RREP method, only one route with minimum-hop is established before the data transmission. However, in the cognitive networks, the route is often interfered because the primary users can transmit the signals in the same frequency band. In order to solve this problem, we consider using multi-band channel. The interference situation is different in each frequency band, so the interference can be avoided by changing the used frequency band. Therefore, in this paper, we propose a novel multi-route and multi-band routing method to have resistance to the interference from the primary systems.

In order to evaluate the effectiveness of the proposed method, the computer simulations are performed. From the results of the computer simulations, we can confirm that the packet loss probability can be reduced by using the proposed multi-band routing method when the interference situation from the primary systems is changed. As a result, we can confirm that the proposed multi-band routing method is suitable for use in the ad-hoc cognitive radio networks.

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2. AD-HOC COGNITIVE RADIO NETWORKS

In the secondary cognitive radio system, the avoidance of the interference toward the same frequency primary system is the most important issue. In order to avoid giving interference toward primary systems, a carrier sense at the cognitive terminals before signal transmission is considered. However, the carrier sense only can recognize the transmitter of the primary system and the active receiver cannot be recognized. In order to solve this problem, we have been proposed the ad-hoc cognitive radio concept, in which the cognitive terminals transmit the signals with small power not to give the interference toward the primary systems [4][5]. Moreover, the multi-hop communication is used for expanding the area of the secondary cognitive system. The image of the ad-hoc cognitive radio is shown in Fig. 1. In order to realize the ad-hoc cognitive radio, we have to decide the relay nodes for relaying the data packet from the source node to the destination node. In ref. [4], we have proposed a routing-less ad-hoc cognitive radio systems called the STBC distributed ARQ. This system can realize a reliable communication without routing method from the source node to the destination node. However, the data packet is expanded to the all directional so the power consumption of the total system becomes large. In order to reduce the transmission power, utilizing the routing method is a simple solution. In ad-hoc communication systems, a lot of routing protocols such as ad-hoc on-demand distance vector routing (AODV), dynamic source routing (DSR), etc. have been proposed [6]. However, if we use these protocols under the existence of the primary systems, the reliability of the communication is not high due to the fluctuated interference from the primary systems.

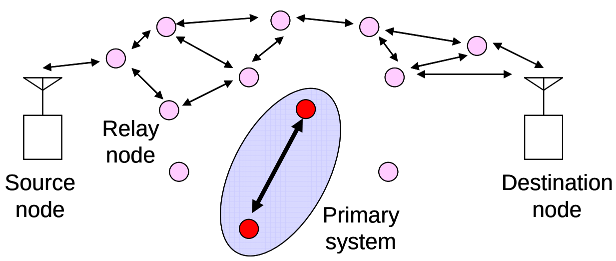

Fig.1 Ad-hoc cognitive radio.

3. PROPOSED MULTI-BAND ROUTING

Therefore, in this paper, we propose a novel multi-band routing technique, which is suitable for use in the cognitive radio under the existence of the primary system. In the proposed method, we prepare plural frequency bands for communication by using the cognitive radio technique. Cognitive radio can find the unused frequency bands for use in the secondary cognitive systems. So the plural frequency bands can be used. However, the traditional routing technique for multi-band does not consider the communication under the existence of the primary systems. In this paper, in order to improve the reliability of the ad-hoc cognitive radio networks, the routing method by using the plural frequency bands are proposed. The policy of the proposed multi-band routing method is shown below,

1. Plural frequency bands are used for communication of the cognitive radio.
2. Route is established in each number of available frequency channels.
3. If the interference from the primary system is detected, the redundant frequency route is selected.
4. The proposed method has the robustness toward the fluctuated interference situation from the primary systems.

The proposed routing protocol is based on on-demand routing protocols using RREQ and RREP. In general on-demand routing protocols, firstly the route from the source node to the destination node is established by using the RREQ and RREP. In this protocol, RREQ is flooded from the source node to the neighboring nodes. The neighboring nodes receiving the RREQ also flood the RREQ. These operations are repeated until the RREQ is reached to the destination node. Then the destination node returns the RREP toward the source node according to the route transmitted by RREQ. The route can be established when the RREP is reached to the source node. In this protocol, one route with a small number of hops can be selected.

In this paper, we apply this RREQ and RREP protocol for multi-band cognitive radio networks. In the cognitive radio, the interference from the primary systems is fluctuated according to the communication status of the primary systems. In order to improve the reliability of ad-hoc networks, multi-route routing techniques are often used. However, in the cognitive radio networks, multi-route may not be effective. This is because the frequency band of all area may be interfered by the communication of the primary system. In particular, the cognitive radio systems under the primary system with large communication area like TV broadcasting band. Therefore, the multi-route routing is not perfect solution. In this paper, we propose a novel multi-band multi-route routing protocol based on RREQ and RREP protocol for suitable use in the cognitive radio.

In the proposed method, a route is established in each number of available channels throughout the end-to-end communication. Therefore plural routes with different number of channels are established. In order to establish such plural routes, the RREQ and RREP are exchanged on the plural frequency bands simultaneously. The proposed route establishment procedure is shown below and the image of decided route is summarized in Fig. 2.

1. The source node transmits the RREQ by using the all available frequency channels toward the neighboring nodes. Each RREQ has RREQ ID for checking the number of frequency channels of the route. The initial

RREQ ID is the number of transmitting channels at the source node.

2. The neighboring nodes receive the RREQ and the check the error in the received RREQ in each frequency channel. The maximum ID, which is the ID indicating the relayed RREQ ID stored in each node for duplicating relay of RREQ. If the maximum ID is less or the same of the RREQ ID, the RREQ is relayed by according to the procedure from 3. to 7. However if the maximum ID is larger than the RREQ ID, the RREQ is not relayed in this node. The initial maximum ID of all nodes is 0.
3. The number of RREQ without the error is counted as *Mr*.
4. If RREQ ID written in the RREQ is larger than *Mr*, the RREQ ID is rewritten to *Mr*.
5. Before relay the RREQ, the number of frequency channels which can be used in each node is counted as *Mt*.
6. If RREQ ID is larger than the *Mt* the RREQ ID is rewritten to *Mt*.
7. The RREQ is transmitted by using all available channels from each node with RREQ ID and the RREQ ID is stored in each node as maximum ID transmitted in this node.
8. By using such RREQ transmission, the RREQ is generated in each RREQ ID. Therefore, the plural RREQs with different RREQ ID are transmitted though the networks.
9. At the destination node, the RREQ ID is compared with reply ID. The initial reply ID is 0. If the RREQ ID is larger than reply ID. The RREP is returned to the source node with RREP ID = RREQ ID through the route indicated in RREQ. At the same time reply ID is rewritten to RREQ ID.
10. If the relay ID is larger or the same as the RREP ID, the RREP is not transmitted. The destination node continues to receive the next RREQ. If the RREQ ID is the same as the number of prepared frequency channels *M*, all received RREQ that is received after this time is abandoned.
11. The source node waits to receive the RREP. If the RREP is received. The source node checks the RREP ID. The source node generates the route table of each ID. The largest ID of the table stored in the source node is defined as table ID. If the RREP ID is larger than table ID. The routing table is generated by the information stored in the RREP. If the RREP ID is the same as *M*, the final routing table is generated by the information of RREP and the all routes are established at this time.

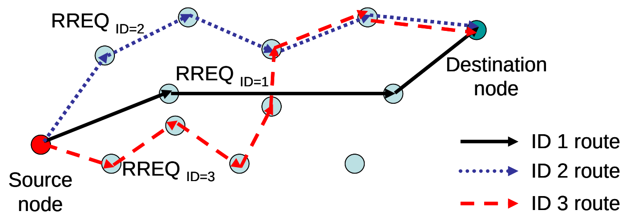

Fig.2 The image of the proposed routing method.

By using the above routing method, we can derive the plural routes with different number of simultaneous effective routes. In Fig.2, we show the image of the proposed routing method with establishing three different routes. The routes established by the proposed method have different number of hops and the different quality of communication. In particular, if the plural separate frequency bands are prepared, the communication distance of each link is different because the propagation loss is different among the used frequency bands. Therefore, the number of hops with ID 1, which has only 1 route is prepared from the source node to the destination node, is small because the route is established with lower frequency bands that is small propagation loss. On the other hand, the route with ID 3 has a lot of hops during the route because the large propagation loss link is included in the route from the source node to the destination node. However, in the view of the quality of the link from the source node to the destination node, the route with ID 3 is better because the redundant frequency channels increase the robustness of link disconnection by switching the frequency band of each link.

In order to utilize these decided route effectively, we have to decide the data packet transmission procedure. In this paper, we consider repeating packet transmission from the small ID to the large ID. When the data packet is generated at the source node, firstly the route with ID=1 is used for communication. The route with ID=1 can connect from the source node to the destination node with a minimum number of hops, so the delay and the power of each terminal can be minimized. However, even if one link is disconnected due to the fading or the interference from other systems, the communication from the source to the destination node is disconnected. Therefore, secondly, if the route with ID=1 is disconnected, the source node selects second route with ID=2. In the route with larger number of ID, the plural effective frequency bands are prepared in each link. Therefore, if one frequency band of the link is disconnected, the other prepared frequency band can be used. So the communication can be continued even if one frequency band of the link is interfered. In this method, the same operations are repeated until the packet is correctly received at the destination node or the route with final ID (ID=3 in the example shown in Fig.2) is tried.

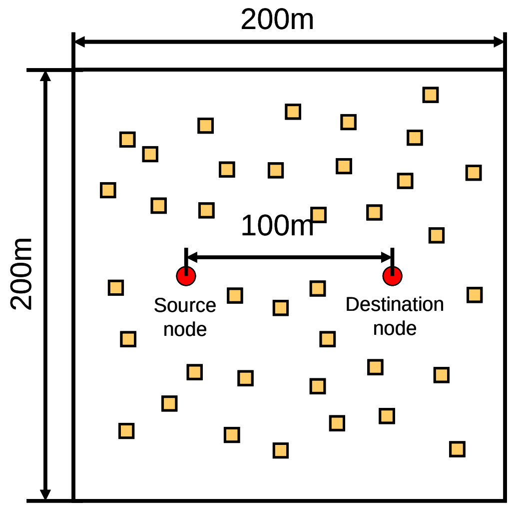

Fig.3 Simulation area.

4. COMPUTER SIMULATIONS

In order to evaluate the performance of the proposed system, we show the results of computer simulations. In this simulation, we prepare three difference frequency bands as 750MHz, 2.4GHz and 5GHz. The original routing method for ad-hoc networks using only one frequency band for transmitting the data packet from the source node to the destination node. In this paper, the conventional routing method is shown as "1 band." In the proposed method, the plural routes are established by using plural frequency bands. Here, the routes with parallel two and three frequency bands are named as "2 band" and "3 bands," respectively. We consider 200m times 200m squared simulation area as shown in Fig. 3. We set a source node and a destination node at the center of this simulation area with 100m apart each other. 100 relay nodes are set at the random position in this simulation area. The simulation conditions are shown in Table 1. In this paper, we only consider the path loss and the fading and shadowing are not considered. The path loss attenuation factor is set as three and the attenuation level is different in each frequency band according to the propagation theory. The noise level of each node is -95dBm and the threshold signal to noise ratio (SNR) level for the packet without error is decided as 10dB. Therefore, if the received SNR of each packet is more than 10 dB, we regard the packet can be successfully transmitted. In the routing period, the routing is continued if the RREQ is received with SNR more than 10dB. The antenna gain of each antenna is set as 0dBi. In simulations, in order to assume the interference from the primary system with time variance transmission, we consider Pi=10% initial link loss between the nodes in each frequency band. Moreover, we consider variable link status between the nodes by using the probability of changing interference situation after establishing the route as Pv. If Pv is set as 5%, the link status is changed as the probability of 5% from the connected link without error to the disconnected link with error or from the disconnected link to the connected link. The packet collision among the cognitive terminals is not considered in this simulation.

Table 1 Simulation conditions.

Transmit power	Parameter
Path loss attenuation factor	3
Noise level	-95dBm
Threshold SNR for packet success	10dB
Number of frequency bands	Maximum 3
Initial link loss probability Pi	10%
Link status change after route establishment Pv	Parameter

Fist we show the probability of route establishment error by changing the number of prepared frequency bands as shown in Fig. 4. In this simulation, we compare the performance among 1 band (750MHz) system, 2 bands (750MHz and 2.4GHz) system, and 3 bands (750MHz, 2.4GHz and 5GHz) system. In this simulation, even if one route is established by using three frequency bands, we decide that the route establishment is succeeded. It can be seen from the figure, we can confirm that the performance of the route establishing error can be reduced by preparing the plural routes. This is because the link loss due to the interference from the primary systems can be avoided by using the different frequency bands.

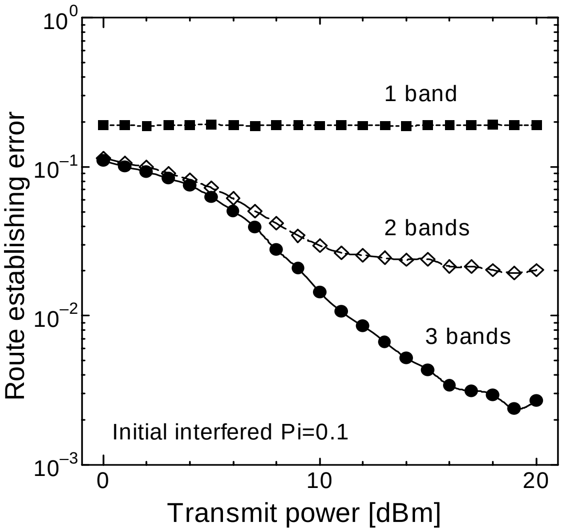

Fig.4 Route establishing error.

Next, we derive the packet loss rate by changing the transmit power of each node as shown in Fig. 5. In this simulation we set Pv=5%. Therefore 5% link is changed the interference status after link establishment. The route establishing error is regarded as a packet loss in this simulation. The performance of packet loss rate is derived after above link status change. It can be seen from the figure, we can confirm that the packet loss probability also can be reduced by preparing the plural frequency bands and plural routes.

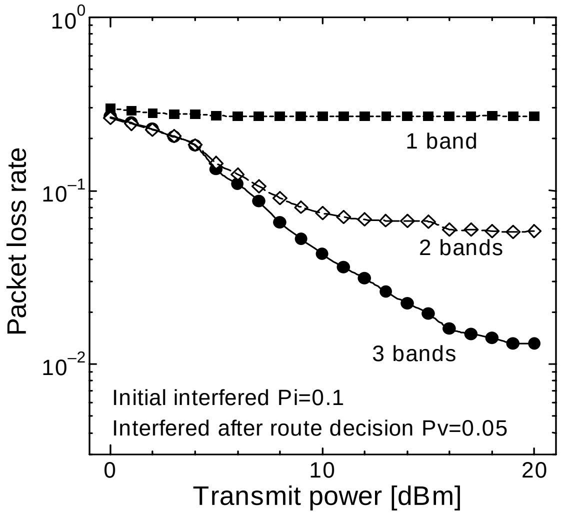

Fig. 5 Packet loss rate performance.

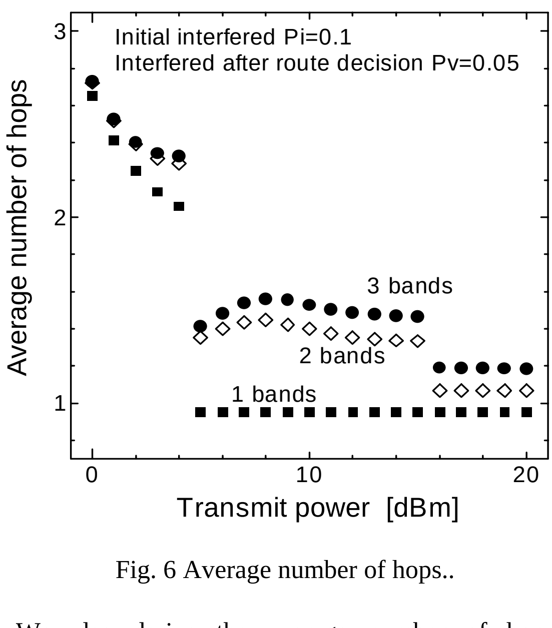

Fig. 6 Average number of hops..

We also derive the average number of hops by changing the number of prepared frequency bands as shown in Fig. 6. In this simulation we also set Pv=5%. This figure shows the number of hops for the data packet is transmitted from the source node to the destination node. It can be seen from this figure, the average number of hops increases by using the large number of frequency bands. This is because the data packet is retransmitted by using the other route with plural frequency bands if the route with lower ID is disconnected due to the interference from the primary system. From this figure, we can confirm that the average number of hops increases if the number of prepared bands increases. However, the increased number of hops is not so large.

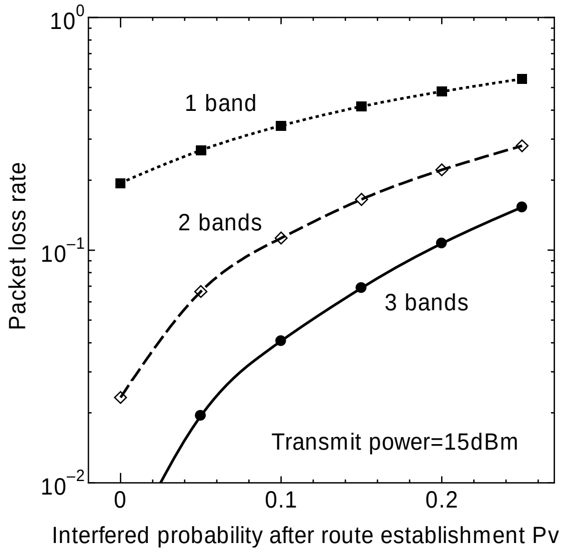

Fig.7 Packet loss rate against the interference status change.

Next, we show the packet loss rate when the Pv is changed as a parameter in Fig. 7. In this simulation we fix the transmit power of each node as 15dBm. The ratio of interference situation of each link after route establishment Pv is changed from 0% to 25%. From this figure, we can confirm that the proposed routing method with large number of frequency bands can improve the performance regardless of link status change. From these results, the interference at the routing period is the most serious for cognitive radio networks in the simulated situation and by using the multi-band communication, the problem can be solved.

5. CONCLUSIONS

In this paper, we propose a routing method for supporting the cognitive radio networks. In this method, the multi-band communication is considered and the plural routes are established by using the multi-band multi-route for deriving the stable route when the interference from the primary systems is fluctuated. By using the computer simulations, we can confirm that the proposed method is suitable for use under the interference from the primary systems when the frequency sharing system by using cognitive radio technique is considered.

6. ACKNOWLIDGEMENT

This work is partially funded by Japanese Ministry of Internal Affairs and Communications under Strategic Information and Communications R&D Programme (SCOPE).

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