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Frequency Hopping CR MAC Protocol in Cognitive Radio Ad Hoc Network

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Abstract

To insure the fairness for the Cognitive Radio (CR) nodes with various available channels, a frequency hopping CR MAC protocol based dynamic (named DCR-MAC) is proposed. In the case of uneven distribution of frequency spectrum in cognitive Ad Hoc network, based on the numbers of workable channels of each cognitive node, DCR-MAC protocol adjusts access time dynamically, ensuring the node priority access channel number, in order to improve the overall performance of the network. Meanwhile, against the problem of the multi-channel hidden terminal which appears in cognitive network of single wireless interface configuration, through introducing the "data segment" mechanism, and informing present channels occupied condition of adjacent node via receiving node, DCR-MAC protocol broadcast of channel occupation in transmission channel, and prohibit possible data transmission of adjacent node, in order to solve this problem on this account. Finally, proving that DCR-MAC protocol is obviously excelled other FH CR MAC protocols in through put capacity, packet access delay, accessing fairness which through network simulation.

Keywords: *DCR-MAC, CR MAC, Ad Hoc network, frequency hopping*

1. Introduction

Wireless Ad Hoc network (Wireless Ad Hoc Networks) is a kind of open, multiple nodes gathered without preset fixed infrastructure wireless multi hop network form, which is self-organizing, self-generating and self-management. The Ad Hoc network is easy to spread rapidly, the overall system survivability, system and low cost advantages, it can work independently, can also establish a connection with the Internet or cellular wireless network. These features make the self-organizing network can simplify network management for mobile, has good robustness and flexibility, and can make effective use of resources in dynamic environment. Based on the above advantages, as well as the development of wireless communication technology and the improved performance of mobile terminal, Ad Hoc network attracted more and more attention, which not only widely used in the military environment, but also be fully applied in the civilian environment. Wireless Ad Hoc network becomes even the only feasible communication solutions in a lot of special occasions.

Rapidly development of wireless communication technology drives flourishing booming of the field of broadband wireless services, with the increasing of wireless application sharply, limited resources of frequency spectrum becomes an important factor to restrict the development of wireless communication, as a kind of scarce resources, utilization efficiency of spectrum resources get more and more attention and research. It broke the model of long-term spectrum fixed allocation which presenting Cognitive Radio, offering a new solution for a pair of contradictory problems of low spectrum availability and spectrum shortage by dynamic and flexible spectrum utilization. Ensuring

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that main users are in the normal condition of transmission in the authorized frequency ranges, allowing cognitive nodes access to part of the authorized frequency ranges, carrying out self-adaption for its emission parameters according to environmental change, the leading design idea of DCR technology is that using low transmitting power to avoid interference or control the interference in accepted ranges [1]. In environment of dynamic frequency spectrum, giving consideration to availability, transmission parameters of self-adaption and transmission strategy have turned into design goal of lower protocol of cognitive network. The research of this chapter is concentrated in distributed CR MAC protocol of cognitive Ad Hoc network, according to network environment spectrum resources, efficiently accesses and uses free spectrum resources of main users, adjusts transmission parameters of cognitive nodes dynamically, decreases collision of cognitive nodes, develops maximum utility of spectrum resources, reduces interference of authorized users, make sure their data is transmitted. For possible multichannel usage of multi-authorized users, allowing cognitive nodes to transmit in multiple free channels, there is a similarity of design idea which in cognizing MAC protocol [2] and multichannel MAC protocol of fixed channels, cognitive Ad Hoc network can be regarded as a special multichannel wireless network, the design of MAC protocol and design of traditional multichannel MAC protocol are both need to solve two problems: a) Coordinated problem of access; b) Avoiding conflict and solving. Coordinated access is mainly to solve the problem that how sending node to find its target to receive nodes which is sending nodes and target receiving nodes should work in a same channel, this is the basic problem which design of multichannel MAC protocol to solve. Meanwhile, as the spectrum resources are changed with time, space and frequency in cognitive network, so MAC protocol in cognitive Ad Hoc network also needs to consider new content of spectrum sense, spectrum mobility, and allocation of resources and so on.

To improve the robustness of main users activities, CR MAC strategy which based on channel hopping became a new way to solve channel meet problem in present cognitive Ad Hoc network, this strategy belongs to composite CR MAC category, its advantage is as below: a) Existing don't rely on public control channel CCC which is whole network unified, CCC is hard to get in frequency spectrum. b) Effectively overcoming the control packet congestion problem which existing in single CCC. As frequency hopping mode is distributed in all channels, therefore cognitive nodes can choose to compete in multiple different channels to get transmitted chances, in this case, the numbers of competitive cognitive nodes deplete in single channel so that collision probability of control packet decreases; c) High reliability, it enhances network invulnerability by letting control packet scatter in different channels to send, it's not easy to result in whole network paralyze which due to accidental or malicious use. d) As the spectrum resources change dynamically in cognitive network, flexibility of design of frequency hopping let users respond the available channels alternation immediately which because of main users activities, ensuring network connectivity. Thus design of cognitive MAC protocol which based on frequency hopping is the main research direction in the future area.

According to the difference of frequency hopping sequence, CR MAC protocol of frequency hopping can be divided into types: Fixed sequence and Non Stationary Sequences. In the former, as the frequency hopping is fixed between senders and receivers, thus the channels always keep unanimous that two sides used, so there is no "Deaf" problem (Sending nodes are not available to know the channels which receiving nodes settle), the typical protocol is S-MAC [3]; In the latter, sending and receiving nodes calculate its frequency hopping individually based on its present available channels, expecting meeting in a same channel in high probability and getting high link throughput, but design of frequency hopping sequences influences nodes access delay directly, thus new access delay length is not sure, also the problems of multi-channels hidden stations and Deaf are still in, these kinds of protocols include DH-MAC [4], C-MAC [5], MRCC

[6] and AMRCC [7] and so on. The research in this chapter is based on the protocol of hybrid-type CR MAC which based on fixed frequency hopping sequences.

As sensitive node of individual behavior appears alternatively with data transmission normally, both of them need to use radio interface to deal signals, thus recognition time is long or short which affects the time which data transmission occupy [8]. Enough sense is good for judging action of main users, but long recognition time will decrease time of data transmission of cognitive nodes [9-10], so arrangement of recognition time and data transmission time of slot time are one of the research contents in the hybrid-type CR MAC protocol of fixed frequency hopping order. As cognitive technology isn't the major concern in this chapter, so we suppose that cognitive nodes in cognitive network have adopted appropriate cognitive technology according to its own demand [11], it can get a judge of occupied condition of interested frequency range in a certain recognition time [12].

In this chapter, we proposed a protocol of frequency hopping CR MAC which guaranteed fairness. According to condition of present available spectrum resources of each node in network, protocol of DCR-MAC dynamically adjusts access time of cognitive nodes, ensures cognitive nodes which has little channels access to channels preferentially. Comparing normal frequency hopping of DCR-MAC [13], protocol of DCR-MAC can reduce weak transferring nodes in network, realizing sharing spectrum resources fairly during cognitive nodes. Also for the problems of multi-channel hidden stations in network of single radio interface configuration which have proposed a new solution. By introducing mechanism of data segment, and broadcast of channel occupation in transmission channels [14-15] by receiving nodes to inform condition of present channels occupation of adjacent nodes, prohibiting data transmission of potential adjacent nodes, protocol of DCR-MAC completely avoiding the problem of multiple channels hidden stations [16] which due to other users unknown the condition of present channels occupation. As far as we know, this is a solution of single radio interface first time, and present documents are all considering by design of multiple radio interfaces configuration [16-17].

Arrangement in this chapter are as below: Firstly, giving the basic framework of protocol of hybrid-type CR MAC ,introducing and discussing its difficult points in detail on this basis, including problem of multi-channels hidden stations and fairness of accessing channels of cognitive nodes, for the two problems of above, there's a specific solution in next chapter DCR-MAC and its protocol parameters; Finally, by network simulation to checkout DCR-MAC is excelled than protocols of other hybrid-type CR MAC in throughput capacity and access fairness, like S-MAC.

2. The Analysis of System Model in Ad Hoc Network

In this part, we are concentrating on to give a specific solution for the problem of multi-channels hidden stations under configuration of single radio, and expounding in detail why frequency hopping CR MAC brings unfairness for accessing channels of cognitive nodes, also design ideas and implementation plans how protocol of DCR-MAC to solve this problem, at last, deriving the best interval length of time of DCR-MAC protocol by theoretical analysis.

2.1. System Model of CR MAC

There are N cognitive nodes which distribute averagely in cognitive Ad Hoc network, numerous PU of main users place randomly. Supposing all cognitive nodes configuration in network are same and can move free, each cognitive node equips with a single radio. By means of spectrum sensing, each node can maintain a real-time available channel list, recording the name and parameters of free channels for present cognitive nodes. As Radio environments of main users are different, available spectrum resources of each cognitive node changes with time, place and environment of network transmission diversification.

In topology structure of some or other single channel, cognitive nodes only allowed to communicate with adjacent nodes which appear in Figure 1. Nodes of topological graph in different channels can't communicate directly, even geographical position is close between that two. As actions of main users lead into environments of network spectrum resources changes constantly, therefore, cognitive nodes set changes with that dynamically which of topological graphs appear in different channels, so transmission links during cognitive nodes are with distinct timeliness.

Figure 1 shows diagrammatic sketch of CR MAC protocol of fixed frequency hopping order. Supposing system realizes Schronization or quasi-Schronization, time axis is divided into numerous slots, all slot lengths are same, remarked as T slot, according to fixed frequency hopping order which set by system, and each slot corresponds a fixed channel. Due to each node only has one Radio, its transceiver successively change-over to correspond channels according to known , fixed frequency hopping order, all cognitive nodes in network are allowed to compete date transmission right of this channel in the slot, here adopting competitive channel IEEE 802.11 DCF.

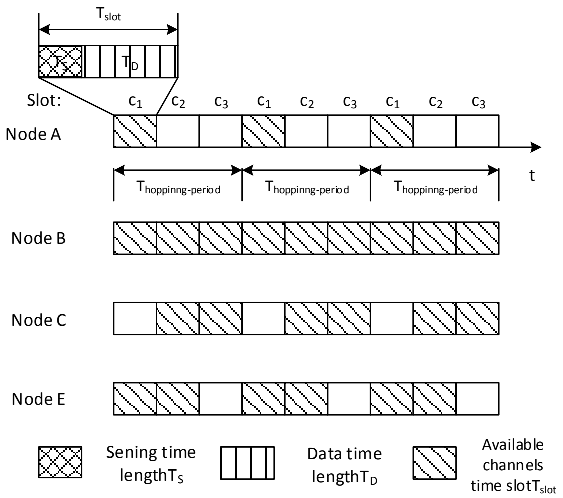

Figure 1. Diagrammatic Sketch of CR MAC Protocol of Fixed Frequency Hopping Order

Supposing there are m channels in network, then m slots consist of a hopping period, time length remarked as $T_{hopping-period}$, each slot corresponds each channel successively of network channels.

Each time slot also can divide into two time part (T_s and T_d) further, represent time of channel sense and data transmission. Cognitive nodes firstly apperceive if the channels available which corresponds with present time slots in each sensing time T_s , then confirming if competing this channel in next data transmission Td.

Similar with initialize of S-MAC, the first node which has finished apperceiving sends Beacon message in its own available channels, other nodes choose to intercept in any channel which is available, after intercepting Beacon message, then update its own adjacent nodes list, If it doesn't receive Beacon message, then it thinks that it uses the first node of this channel, will send Beacon grouping initiative in next channel time slot which is corresponding with frequency hopping cycle. Each node can get one Beacon packet in $T_{hopping-period}$ at least. Beacon packet includes its own ID number and present available channels hub.

2.2. CR MAC Protocol

A frequency hopping cycle is consist of numerous time slots, cognitive node competes individually to access present channel in each time slot, but there's only one node can access to the present time slot successfully in adjacent cognitive node. As the difference of geographical position, transmitted environment of each node, the numbers of available channels of them is different, and cognitive node competes channels in all available time slots in a frequency hopping cycle to achieve transmitting. When it fails to compete in a certain slot, cognitive nodes will continue to compete in available channels. Supposing successful access probability of node i in a frequency hopping cycle is $P_s(i)$:

$$P_s(i) = P_s^1 + (1 - P_s^1)P_s^2 + (1 - P_s^1)(1 - P_s^2)P_s^3 + L + \prod_{v=1}^{k-1}(1 - P_s^v)P_s^k \quad (1)$$

Here, P_s^k is the successful access probability of node i in K channel. Supposing the probability of successful access in each channel is same, remarked as σ , then formula (1) can be written as below:

$$P_s(i) = 1 - (1 - \sigma)^k \quad (2)$$

It's easy to prove $P_s(i)$ is monotone increasing function, if K value is large, then the successful transmitted probability of node is larger, so a large number of available channels of cognitive node is better to compete channels.

$$P_s(E) = \sigma + \sigma(1 - \sigma) > \sigma = P_s(A) \quad (3)$$

Obviously, as competition mechanism in traditional MAC of frequency hopping cognition, cognitive nodes which have less available channels became bottleneck nodes of channel resource in Ad Hoc network, its probability of accessing channel is less than around multi-channel resources nodes, so transmission capability is limited. So in the network, as channel resource which node has is imbalanced, so transmission capability of all nodes in the whole network is imbalanced seriously. Actually, these resource bottleneck nodes are in important geographical position normally which are often in overlay area which main users effect. When all main users are active, then its available spectrum resources reduce quickly. But the geographical position makes this kind of nodes to be important relay node in Ad Hoc network, it needs them to transfer and in the data among nodes of different spectrum resources areas. The transmission capacity of these nodes is low, so it appears serious network segmentation that effecting connectedness of the whole network which is not good for realizing routing protocol of network layer.

3. The Proposed DCR-MAC Protocol

3.1. The Framework of DCR-MAC Protocol

On the basis of introducing problem of Multi-channel hidden terminals, we can get that as long as cognitive node only equips with single Radio, transceiver only can choose to stay in one channel in a certain moment which is controlling channel or data channel, in this case, cognitive node is not able to get the information of another channel, then it appears problem of Multi-channel hidden terminals. DCR-MAC which proposed in this chapter that by introducing data fragmentation mechanism, broadcasting channel occupation grouping BCO in transmitted channels by receiving node, informing condition of present channels occupation of adjacent nodes, prohibiting data sending of potential adjacent nodes, and updating its waiting time NAV until transmission end of present data, thus, solving problem of Multi-channel hidden terminals in single Radio which according to a certain channel expanse, then it do not need extra hardware expense.

As Figure 2 indicates, in DCR-MAC protocol, when cognitive node i has data to send to node j, it's according to available channel condition of its adjacent node to confirm the common channels which they have, and in the light of specified frequency hopping order of channel in system frequency hopping cycle, waiting time slot to appear which corresponds with earliest common channel. Supposing couple-nodes i , c1 is the common channel between j , when time slot begins to start, after sending and receiving node passing through T_s channel sensing, beginning to compete present channel c1 in Td, adopting random back off strategy of binary system of IEEE 802.11 DCF, after waiting a period of time, sending node i sends RTS grouping, all adjacent nodes which receives RTS grouping calculate its network allocation vector NAV , marked as NAV_{RTS} Once receiving node receives RTS , then it backs to CTS, all adjacent nodes which have received CTS grouping calculate its NAV, marked as NAV_{CTS} When sending node i receives CTS grouping, it starts to transmit data. Successfully shaking hands of RTS/CTS which confirms the usage rights of receiving and sending node for present channel c1m, As time slot of each channel only appears once in a complete frequency hopping cycle T hopping-period, so problem of Multi-channel hidden terminals appears only if other nodes also compete to use channel c1 in next c1 channel time slot. Length of NAV_{CTS} is decided by data clustering length of overall data, supposing data clustering of overall data is L payload, then it appears below two situation:

Case l: When in next frequency hopping cycle, before same time slot of channel appear, receiving node has already finished receiving data that is:

$$\frac{L_{playload}}{R} + T_{SIFS} + T_{ACK} \le (m-1)T_{slot} \qquad (4)$$

R is channel rate, T_{SIFS} and T_{ACK} are sending required time of SIFS grouping and ACK grouping. As there is no new allocation time slot which channel c1 is correspond with in receiving node NAV_{CTS} , so there is no problem of Multi-channel hidden terminals.

Case 2: When in next frequency hopping cycle, before same time slot of channel appear, receiving node hasn't already finished receiving data, that is

$$\frac{L_{playload}}{R} + T_{SIFS} + T_{ACK} > (m-1)T_{slot} \qquad (5)$$

NAV_{CTS} of receiving node may across several frequency hopping cycles $T_{hopping-period}$, and allocation time slot which is correspond with channel c1 appears once in each frequency hopping cycle, here adjacent node which don't receive cognitive node j of CTS correctly may compete this channel, thereby bringing about interference of data transmission between node (i, j) , producing problem of Multi-channel hidden terminals.

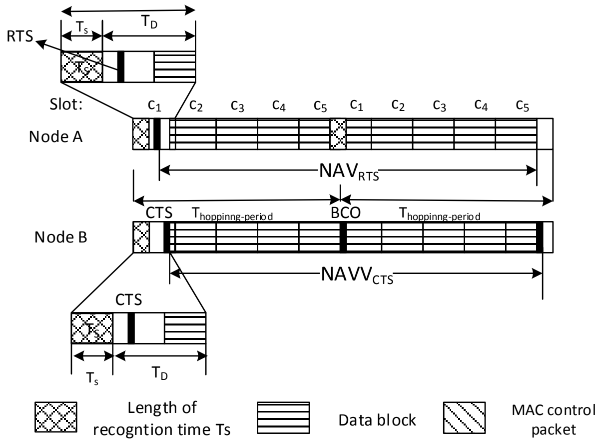

Figure 2. Solution for Problem of Multi-Channel Hidden Terminals in DCR-MAC

So, by importing data block in this chapter, and passing through restraining possible transmission of all nodes in transmission radius of receiving nodes by BCO broadcast packet, to avoid problem of Multi-channel hidden terminals to ensure present ongoing data transmission, the specific implementation is as below, please check Figure 1:

a) Sending node i divides long section data which need to send into numerous data section to make sure that present data segment can be finished sending before each time slot of channel c1 appearing.

b) Receiving node j sends BCO packet before sensing time T_s ending in c1 channel, informing present channel occupation of adjacent node. As all nodes which in sensing time T_s network are all in intercepted condition, so sending BCO packet at present which is able to ensure correct receiving of adjacent node.

c) As cognitive node of each waiting data competes channel in time slot which is correspond with its available channel, so when it receives BCO packet of adjacent node, then it can be confirmed that present channel is used by adjacent node, and data transmission has not finished, it will give up competing channel of this time slot and keeping listening, passing through Duration (k) value of BCO packet to adjust its NAV_{CTS} until data transmission finishes of adjacent node.

d) After receiving BCO packet, sending node i will continue sending of next data block.

3.2 Data Block Packet

"Data block" is the first step to solve problem of Multi-channel hidden terminals, reasonable partition ensures the correct transmission of sending and receiving nodes, realized partition data transmission time and Ts of seasonal sensing time can alternate going. Supposing sum of data block is K, marked: data block 0, data block 1、L， data block $K-1$. The value of K is：

$$k = \left\lceil \frac{L_{playload}}{(m-1)T_{slot} * R} \right\rceil \qquad (6)$$

Above equality, in a frequency hopping cycle, eliminating time slot which corresponds with present transmitted channel, the spare time all can use to transmit data. Then calculating of each segment length $L_{data-segment}(i)$, $i \in (0,1,L,K-1)$ is as below:

$$L_{data-segment}(i) = \begin{cases} (m-1)T_{slot} * R, i = 0 \\ ((m-1)T_{slot} + T_D) * R, 0 < i < K-1 \\ L_{payload} - \sum_{i=0}^{k=2} L_{data-segment}(i), i = K-1 \end{cases} \quad (7)$$

Data block 0 is the FH cycle which RTS/CTS handshaking in, from beginning of receiving CTS packet which of data transmission and from receiving node i; And data block 1 to data block 2 both are fixed length, data transmission time lasts $(m-1)T_{slot} + T_D$; The spare data length is for last segment.

3.3. Frame Format of Data Block Packet

BCO packet is that receiving node j sending through a broadcast in time slot which corresponds with present transmitted channel in each HP cycle before data transmission is uncompleted., and finishing before ending of sensing time T_s, it purpose is: a) Prohibiting data transmission of potential adjacent nodes. In transmitted channel, all nodes which in communicated range of receiving node j can hear transmission of BCO (all nodes in T_s are in listening state), When they hear BCO packet, will get there is node which transmit data in present channel, so they will give up sending data in this channel and updating their waiting time NAV_{CTS} until NAV_{CTS} overtime, therefore it ensures that data transmission of couple-nodes (i, j) is continuous. b) Informing receiving node i continues to send next data block. As BCO is broadcast packet, receiving node will continue to send next data block when receives BCO packet.

Similar with packet of RTS and CTS, frame format of BCO packet is as Figure 3 indicates:

2bytes	2bytes	6bytes	6bytes	1bytes	4bytes
FC	Duration(k)	TA	RA	CH	FCS

FC:frame control Duration(k):Duration in the kth BCO transmittion
TA:Transmitter address RA:Receiver address
CH:Channel index FCS:Frame check sequence

Figure 3. Frame Format of BCO Packet

In Figure 3, Duration (K) is the service time which BCO packet sending to the ending of whole data transmission at the K time, calculating is as below:

$$Duration(k) = T_{L_{playload - \sum_{i=0}^{k-1} L_{data-segment}(i)}} + (K-1-k)T_S + T_{SIFS} + T_{ACK} \quad (8)$$

Here, $k \in \{1, L, K-1\}$, $T_{L_{playload - \sum_{i=0}^{k-1} L_{data-segment}(i)}}$ is the service time which sends spare data, $(K-1-k)T_S$ is the sum of sensing time which still needs to undergo before data transmission finishing, T_{SIFS} is interval length of SIFS, T_{ACK} is required time of ACK packet sending.

In this way, data transmission procedure among sending and receiving couple-nodes is as Figure 2(b) indicates, totally including 4 different control packet, that's RTS, CTS, BOC and ACK respectively. It can be seen that as adopting data segment mechanism and broadcast strategy of BCO packet, restraining successfully that possible transmission of around adjacent nodes in present transmitted channel. Although sacrificing a certain spectrum resources, this protocol do not need to increase extra hardware cost----by means of professional transceiver monitoring and controlling channels or sending busy signal, only passing through tiny adjustment of MAC protocol, it will stop problem of Multi-channel hidden terminals ultimately in single Radio. Achieving protocol is easy and with strong operability.

4. Simulation and Test Results

In this part, we will use computer simulation evaluation which proposed by protocol performance of DCR-MAC. As protocol of S-MAC is a typical hybrid-type protocol of DCR-MAC, and also adopting fixed HP sequences, so we will compare the performance of the two protocol.

Simulation adopts network simulation platform of NS2.31 to come true. Total number of channels is 4 in network, 3 main users' area, available channel of cognitive node is (c_2, c_3, c_4) in transmission coverage area of main user PU1, available channel of cognitive node is (c_1, c_3, c_4) in transmission coverage area of main user PU2, available channel of cognitive node is (c_1, c_2, c_4) in transmission coverage area of main user PU3. 30 cognitive nodes distribute in the area of 1000m*1000m randomly, according to different geographical position of cognitive users, cognitive users which in transmission coverage area of multiple users, its available channels reduce. In the light of available channel of node is different, network node divides into available cognitive node of single channel, available cognitive node of 2 channels, available cognitive node of 3 channels, inside, available cognitive node of single channel is the cognitive node which has the least available channel resources in network that is bottleneck node. In simulation, Radio transmission distance of each cognitive node is 250 meters, cognitive node adopts business flow of CBR, data packet size in network is 512Bytes, there produces 15 business data flow of CBR randomly in network, packet interval increases from 0.1s to 1.5s gradually, protocol of MAC of cognitive node adopts IEEE 802.11 DCF, total time of simulation is 100s. To reduce the random impact, each test result takes 20 times average value of simulation result.

Parameter definition of simulation performance is as below:

a) Packet loss rate: rate of quantities of lost data packet among sending data packet because of collision.

b) Throughput capacity: bit number of successful transmission data in unit time

c) Time delay of average packet: average value of time difference of successful transmission data packet which calculating from leaving the origin to reach to the destination.

d) Rate of throughput capacity: proportion of node throughput capacity which accesses to channel primarily among throughput capacity of whole network.

4.1. Technical Performance of the Proposed DCR-MAC

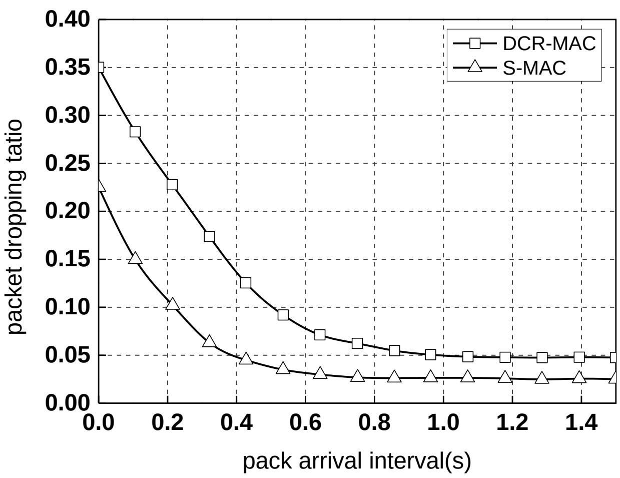

Figure 4. Contrast list of Packet Loss Rate

Figure 4 shows that the relationship between packet loss rate and packet interval, we can see that from picture, with the increasing of packet interval (0.1s to 1.5s), that is business flow decreases unceasingly, packet loss rate of protocol of DCRDCR-MAC and S-MAC both decrease unceasingly. There is no strong influence in low volume of business, but when the business volume is high, packet loss rate is lower than protocol of S-MAC obviously. This is because that to ensure cognitive node which has less available channel resources to access channel preferentially, actually, to distribute business in different channels uniformly, data transmission of nodes which with more channel resources will delay and finish in a relative free channel which balance the volume of business of each channel in network. At same time, nodes which with more spectrum resources delay to access channel, that means the reducing of node number which compete present channel, node collision sharply decreases that makes the packet loss rate reduces obviously.

Figure 5 shows that variation curve of average packet time delay. With the increasing of volume of business, average packet time delay of DCR-MAC protocol is much better than protocol of S-MAC. The main reason is that make bottleneck node of channel resources have priority to access, easing the data transmission blockage of node and lowering time delay of packet transmission.

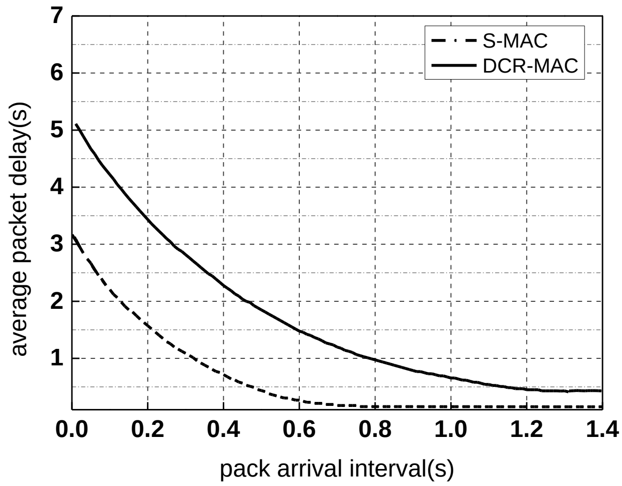

Figure 5. Contrast List of Average Packet Time Delay

Figure 6 shows two contrast lists of throughput capacity which in system of DCR-MAC, from there we can see, throughput capacity of protocol of FCR MAC is higher than S-MAC. Specially, when packet interval is less than 0.3s, that means when volume of business is very high, DCR-MAC has an elevation which more than 20% for throughput capacity. Among all the reasons, in protocol of S-MAC, as node which with less spectrum resources and more spectrum resources compete a certain channel together, once fails, node with less spectrum resources will have continuous blockage when transmitting data, and for other channels, it appears free state because of no node competition, thus throughput capacity is not as good as protocol which proposed in this chapter.

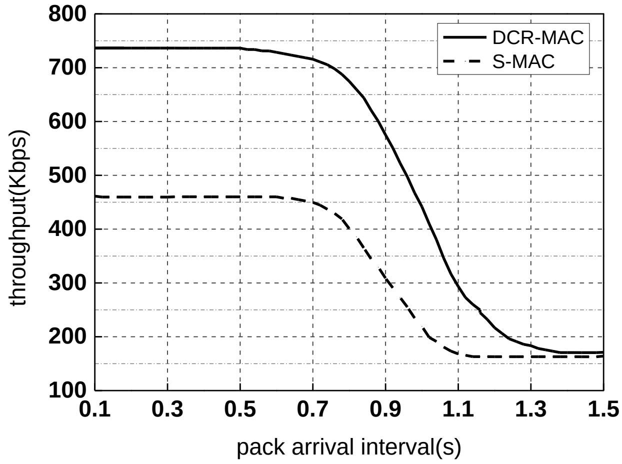

Figure 6. Contrast List of s System through Put Capacity

In above simulation, we observed and studied the influence of protocol of DCR-MAC which ensures node has priority to access on packet loss rate, average packet time delay and throughput capacity for system, it can be seen that in the condition of spectrum resources distribution unbalanced, in Ad Hoc network, make sure node which with less available channels transmits preferentially to improve whole performance of network.

4.2. Channel Resources Performance

We will continue to study the influence of protocol of DCR-MAC on link quality. As the influenced area of main user which nodes are in is different, so their self-available channel numbers is different. In next picture, we will contrast the proportion of node average throughput capacity which has different available channels in average throughput capacity of whole network.

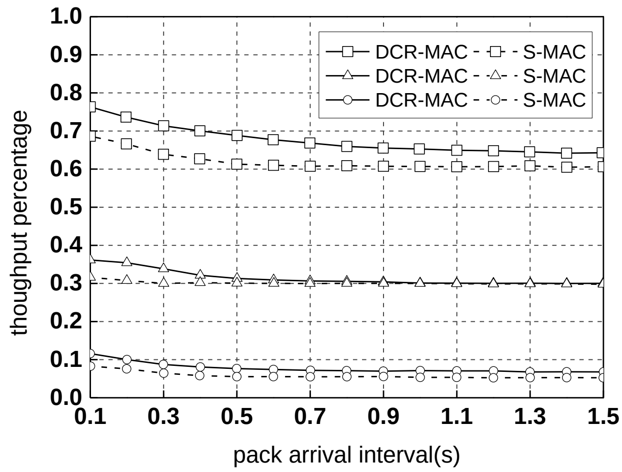

Figure 7. Proportioned Contrast List of Node through Put Capacity which has different Channel Resources

In Figure 7, part of brackets is numbers of available channels of cognitive node. From picture2.10, it can be seen that in the condition of high volume of business, as bottleneck node which with less available channel spectrum resources has priority to access to channel, so the percentage of throughput capacity of this kind increases substantially among throughput capacity of whole network. With the reducing of volume of business, percentage of node throughput capacity which has priority to access to channel and among throughput capacity of whole network decreases gradually. By specific analysis, when packet arriving interval is 0.1s, which is in condition of high volume of business, in the way of adopting indifference access, transmission proportion of bottleneck node of spectrum resources is only 2%, that said most of Radio transmission are occupied by nodes which has many available channels, in this case, node with little available channels becomes genuine vulnerable node in data transmission, upper routing selection must avoid this kind of nodes. But after adopting protocol of DCR-MAC, we can see that, transmission proportion of bottleneck node climbs to 12%, Although harming transmission interest for part of nodes which in high channel resources, getting the increasing of throughput capacity of whole network and balance of transmission capacity of network node. When in the condition of low volume of network business (average arriving interval＞1), the advantage of DCR-MAC is obvious.

5. Conclusion

In this article, we proposed a fair dynamic HP MAC protocol-----DCR-MAC, which can delay access time dynamically according to condition of present available spectrum resources of each node in network. Although DCR-MAC damages transmission interest of part of multiple channel resources node, guaranteeing sharing Radio resources fairly among node which has different available channels, improving the transmission capacity of bottleneck node of spectrum resources, enhancing throughput capacity of network. Network simulation shows that in the condition of available numbers of channel unbalance in cognitive network of Ad Hoc, truly, this protocol can improve the whole performance of network.

Meanwhile, for the problem of Multi-channel hidden terminals in cognitive network which of single Radio access equipment, DCR-MAC passes through quoting mechanism of data segment, and broadcasting control packet BCO by receiving node in its transmission channel, informing condition of present channel occupation of adjacent node, prohibiting potential data transmission of adjacent node, this completely avoiding the problem of Multi-channel hidden terminals which due to other users don’t know the condition of present channel occupation.

In the future, we will keep our focus on the significant performance improvement in network throughput, and DCR for the communication under unknown conditions, *i.e* disaster recovery.

Acknowledgements

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