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An Improved QoS Awareness Scheduling Scheme for CR Mobile Ad hoc Networks

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Abstract— **This paper proposes an improved QoS scheduling scheme, called the Modified Proportional Fairness with Multi-Hop (MPF-MH) algorithm for Cognitive Radio Mobile Ad Hoc Networks (CR MANET). Within the context of multi-channel MAC enabled networks, mobile nodes can experience simultaneous transmission across multiple channels. Benefiting from the proposed cross layer design, the real-time channel conditions provided by CR function permits adaptive sub-channel selection for each transmission. MPF-MH adaptively schedules the radio resources for serving different types of service in order to optimize network resources without decreasing the quality of service.   Simulation results confirm that MPF-MH provides good QoS guaranteed performance across a variety of CR MANET scenarios.**

Keywords- *Cognitive Radio, QoS, Multi-channel, cross layer*

I.   INTRODUCTION

Recent years, Cognitive Radio (CR) [1] has been identified as one of the promising techniques which is being adopted within wireless research to improve the utilization of scarce spectrum resources. Along with the fast evolution of hardware, it can be foreseen that in the near future, every device could be CR enabled. Ad hoc networks, with their independence from pre-defined network infrastructure, are recognized as a popular network structure in the Internet Of Things concept. As long as the nodes in the ad hoc network are equipped with the self-organized conversation capability, a sufficient device-to-device communication network can be auto deployed anywhere on demand. Recent research activities [2] [3] show that CR also has significant effects on upper layer performance in wireless network, especially in MANET. MANET enables wireless devices to dynamically establish networks without necessarily using a fixed infrastructure. Therefore, CR technology plays an important role in helping nodes establish networks owing to its dynamic access capability.

Multi-channel MAC protocol allows different users to communicate through different channels without interfering with each other simultaneously. The simultaneous transmission mode enables different users to transmit data, consequently, the corresponding delay and throughput can be improved. However, this scheme brings about obvious problems, including the competition over the same channel among different users, and the information interaction between sender and receiver, and etc. In CR MANET, there are many authorized user systems, while the spectrum of different authorized user system may be nonadjacent. To make best use of the available spectrum, many cognitive users can transmit packets with these rest channels. In this case, multi-channel MAC protocol is more suitable for CR MANET. Besides, Multi-channel scheme in MAC layer shows a better performance for solving the problem of hidden terminal and exposed terminal and can obviously improve throughput of the network.

Work in [4] proposed a Cognitive Radio Enabled Multi-Channel MAC protocol, which is based on special control channel transmission mode. Authors in [5] proposed a Hardware-Constrained Cognitive MAC, which focus on how to sense spectrum for cognitive users. One distributed MAC protocol is proposed in paper [6] which is on the basis of Markov chain, and the main idea is get channel sensing results as long as transmitting data packets. However, all these papers focus on channel sensing and selecting, and the service travel is simulating using a very simple model which largely ignores QoS scheduling of different applications.

Therefore in this paper, we propose a novel cross layer QoS aware scheduling algorithm, called Modified Proportional Fairness with Multi-Hop (MPF-MH), for use with CR Mobile Ad Hoc Networks (CR MANET). With perfect knowledge of frequency usage and radio link conditions from the Physical layer, the MAC layer works efficiently to provide suitable multi-channel selections for data forwarding and transmission. Furthermore, the MPF-MH algorithm takes into account the multi-hop nature of CR MANET together with the real time QoS information whilst scheduling radio resources for different types of service to better utilize the overall network.

The rest of the paper is organized as follows: Section II introduces some related work. Section III addresses the algorithms in details. The simulation results are evaluated in Section IV and conclusions are presented in Section V.

II. RELATED WORK

In [7], the authors propose a cross-layer resource allocation scheme for OFDMA cellular networks. It considers three types of application: real-time packet service, non-real-time service and best effort service. Besides the MAC layer providing different scheduling priority based on each service type's QoS criteria, the authors also suggest schemes for allocating how many sub-channels to assign to each user and the location of these sub-channels in the OFDMA system. The cross layer design was realized in terms of the sub-channel power distribution scheme that is applied to the Physical layer. Based on the simulation results, the authors declare that the joint scheduling of the MAC layer and Physical layer provide better performance compared with Channel State Dependent Packet Scheduling (CSDPS) in [9]. However, as the scenario adopted in [7] is a traditional cellular network, which does not support CR and mobile users connect directly to base station for data transmission, the scheduler priority in [7] is not suitable for CR MANET.

The authors in [8] consider QoS awareness scheduling for CR networks. They propose a Modified Proportional Fairness scheduling algorithm with Interruption Factor (MPF-IF) that is described by Formula (1) below

$$\Pr_{n,i}(t) = PF * Q * I \qquad (1)$$

(Formula 3 in [8])

It introduces the Q factor and Interruption factor together with the Proportional Fairness (PF) factor when calculating the scheduling priority for each type of service. In (1), the PF factor indicates the throughput while Q factor represents the delay. The Interruption factor reflects the influence of the primary users' ON-OFF activities. The MPF-IF algorithm is compared with the PF algorithm in an OFDMA system at the end of this paper. The result shows that with a tiny degree of throughput cost, the fairness among traffic is improved with better QoS guaranteed for the VoIP service. Similar to [7], this work proposes an improved QoS algorithm for CR OFDMA networks only. For instance, the Q factor is defined as below

$$Q: \begin{cases} \exp(\dfrac{W_N - D_i^{th}}{D_i^{max}})+c & D_i^{th} \le W_N \le D_i^{max} \\ \dfrac{W_N}{D_i^{max}} & 0 \le W_N \le D_i^{th} \end{cases} \quad c = \dfrac{D_i^{th}}{D_i^{max}}-1 \quad (2)$$

This is Formula (4) in [8], where only the waiting time in the queue before the first transmission is regarded as delay.

Given multi-hop situation in ad-hoc networks, when introducing more hops along the transmission path, the network performance suffers greater packet loss and delay. Therefore the scheduling priority for each packet may change at every node along the path before reaching the destination.

The proposed MPF-MH algorithm in this paper is designed for CR MANET while taking the multi-hop environment into account. In order to guarantee the end-to-end QoS, the scheduling priority is updated at every intermediate node with the real-time network performance data. The next section will describe the scheme in detail.

III. CROSS LAYER ALGORITHMS DESIGN

A. Cross Layer Structure

Unlike typical CR network scenarios, users in the TV frequency band are not considered as the primary users in this paper. Actually for the CR MANET described in this paper, all nodes capable of CR, have the same access opportunities to the ad-hoc network frequency band. There is no concept of primary user and secondary user. We assume that every node in the CR MANET can perform ideal CR sensing and the performance cost is not considered at this time. As CR studies are not central to this paper, we assume that the radio channel conditions can be fully sensed by CR users and the sensing duration and interval has no influence on data transmission.

Similar to [7], three types of service, streaming media (SM), background (BG) and best effort (BE), are adopted as typical services to be considered by the MPF-MH algorithm. According to PCP field in the 802.1Q VLAN Tag and the QoS BASELINE of CISCO, the priority of BE service is 0, that is, it receives no quality guarantee, but adequate bandwidth should be assigned to this service. The priority of BG is 1, which means it is necessary to transmit this application to the destination and it cannot be abandoned, but it can tolerate transmission delays. This service should have a moderate bandwidth guarantees but should be constrained from dominating a link. The priority of SM is highest among the three applications and is assigned a value of 4; it requires guaranteed bandwidth depending on the encoding format and rate of the video stream. Therefore SM is granted to be the highest priority and a streaming media packet will be sent across three sub-channels simultaneously; BG receives medium priority and a background service packet requires one sub-channel to be transmitted; the priority of the BE service is lowest and one sub-channel can be used to transmit a best effort service packet. Besides, streaming media and best effort services do not need retransmission support while background service requires it. So before each background service transmission, the retransmission buffer of background service will be checked, if there are any packets in retransmission buffer, they will be transmitted first.

Figure 1 illustrates the proposed cross layer structure for the QoS scheduler. Three buffers are provided to host the packets of each type before sending at every node. When a packet arrives, it will enter a process buffer first. Then this process buffer will distribute each packet into one of three service buffers based on its service type.

The end-to-end performance analysis phase is responsible for getting all QoS related factors ready for the priority calculation. The steps in Figure 1 are repeated for every transmission. By using real-time network performance feedback within the scheduling algorithm, MPF-MH utilizes

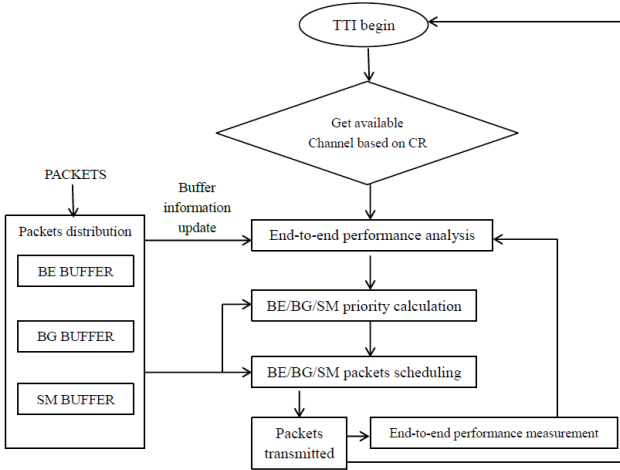the scarce network resource with some degree of QoS guarantee.

Figure 1 QoS Scheduler Architecture

B. MPF-MH scheduling shcemes

We use $\Pr_{i,N}(t)$ to denote the scheduling priority on the N_{th} node of the i_{th} connection, and it is updated dynamically by QoS factors for different services.

For the SM service, we employ Formula (3) as below.

$$\Pr_{i,N}^{SM}(t) = TH * Q * \beta_{SM} \qquad (3)$$

TH here represents the throughput factor, which is used to guarantee the minimum throughput requirement. Q represents the delay factor and it represents an important QoS requirement for real-time SM services. β_{SM} is the initial priority of the SM service.

The TH factor of SM can be described by Formula (4).

$$TH = \frac{1}{\dfrac{\overline{C}_i(t)}{C_{SM\,min}}} \qquad (4)$$

$\overline{C}_i(t)$ is the average throughput on the single connection i till time t and it can be calculated from Formula (5). $C_{SM\,min}$ is the minimum bit rate requirement of the SM service.

$$\overline{C}_i(t+1) = \frac{t}{t+1}\overline{C}_i(t) + \frac{1}{t+1}C_i(t+1) \qquad (5)$$

The Q factor is described in formula below,

$$Q = \begin{cases} N\log H_i(\exp(\dfrac{\sum\limits_{N=1}^{N}W_{i,N} - ND_i^{th}}{ND_i^{max}}) + c) & D_i^{th} \le \dfrac{\sum\limits_{N=1}^{N}W_{i,N}}{N} \le D_i^{max} \\[4mm] N\log H_i\dfrac{\sum\limits_{N=1}^{N}W_{i,N}}{ND_i^{max}} & 0 \le \dfrac{\sum\limits_{N=1}^{N}W_{i,N}}{N} \le D_i^{th} \end{cases} \qquad (6)$$

Where $c = \dfrac{D_i^{th}}{D_i^{max}} - 1$ to allow the equation consistence when the delay equals to D_i^{th}.

$\sum\limits_{N=1}^{N}W_{i,N}$ denotes the total waiting time from source node to node N in connection i, including the transmission time and queuing time in the buffers. D_i^{max} denotes the maximum end to end delay tolerance for this packet and D_i^{th} is a threshold between 0 and D_i^{max}. For real-time services such as SM, if D_i^{max} is reached, the packets will be dropped. If the average waiting time $\dfrac{\sum\limits_{N=1}^{N}W_{i,N}}{N}$ is between 0 and the threshold, it means that the situation is not so urgent. Therefore the Q factor will increase slowly resulting in a slow growth of the SM priority. However, when the average waiting time exceeds the threshold value, the Q factor will increase exponentially to give higher priority.

$N\log H_i$ is used to reflect the multi-hop situation in CR MANET. N stands for the N_{th} node in the i_{th} connection. It indicates the location of the packet along the whole path, and the closer to the destination node it is, the bigger the Q factor will be, as is the SM priority. H_i is the total hop count of connection i. A path with more hops results in a higher Q factor.

As for the BG service, only the throughput factor is considered a QoS requirement, so we have BG priority as below.

$$\Pr_{i,N}^{BG}(t) = TH * \beta_{BG} \qquad (7)$$

The TH factor here is similar to that in Formula (4); only the minimum throughput of BG packets matters.

$$TH = \frac{1}{\dfrac{\overline{C}_i(t)}{C_{BG\,min}}} \qquad (8)$$

$$\overline{C}_i(t+1) = \frac{t}{t+1}\overline{C}_i(t) + \frac{1}{t+1}C_i(t+1) \qquad (5)$$

The BE service is the simplest case as stated in Formula (9)

$$\Pr_{i,N}^{BE}(t) = \beta_{BE} \qquad (9)$$

Since no QoS requirements are prescribed for the BE service, its scheduling priority is the pre-defined priority β_{BE}.

C. MAC layer Sub-channel selection algorithm

Provided the participation of a given node is confirmed as being along the route from the source to the destination, the MAC layer will create an up-to-date priority list of the available sub-channel(s) for the next hop transmission, subject to procedures below.

All sub-channels in the available list are sorted in decreasing order of their SNR. If the SNR values of two or more sub-channels are equal, the delay will be considered as a further factor in sorting these sub-channels. The reordered list is called the priority list.

The MAC layer picks the corresponding channels according to the QoS requirements of each packet data transmission by selecting the top of the priority list and adjacent priority list entries if further sub-channels are required.

Right after each sensing, every node will update its neighbor table contents accordingly. Therefore all the values will be recalculated and the sub-channel priority list will be automatically refreshed ready for the next packet transmission event.
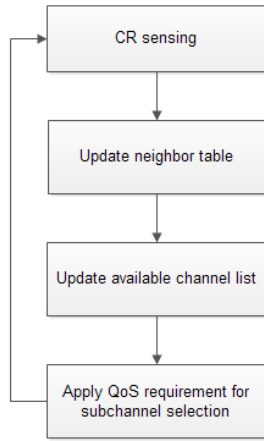

Figure 2 Sub_Channel Selection Flow Chart

Let SNR_{c_j} denote the SNR of each sub-channel $c_j (j = 0,1,...,x)$ and $Delay_{c_j}$ is the delay value of sub-channel c_j, j=0,1,…x. x is the total number of sub-channels.

$$SNR_{c_j}^{ik}(dB) = 10.0 \times \log 10(\frac{P_{rcvd}^{k}}{N_{accum}^{ik} + N_{bkg}^{ik}}) \qquad (10)$$

where P_{rcvd}^{k} is the received power at node k, N_{accum}^{ik} is the accumulated noise and N_{bkg}^{ik} is the background noise.

Let SNR_{th} be the SNR threshold.

Let C_{avail} denote the set of all available sub-channels, which can be used to send data packets.

If $SNR_{c_j}^{ik} \geq SNR_{th}$, $c_j \in C_{avail}$.

All sub-channels in C_{avail} are sorted in decreasing order of their SNR value. The sorting result can be taken as the priority list, and denoted by C_{sort}.

According to the QoS scheduling mentioned in previous section, the MAC layer selects corresponding channels from the top of the priority list C_{sort}.

Right after each sensing, each node will update its neighbor's table contents. Therefore the SNR of each sub-channel will be recalculated and the priority list C_{sort} will be automatically refreshed ready for the next packet transmission.

IV. SIMULATION AND EVALUATION

A. Simulation Settings

Opnet [10] is adopted in this work as the simulation platform. As OFDMA is the most promising radio access technology for future wireless networks and OFDMA itself has sub-channel features, we use 802.11a as the air interface for this work.

Although in 802.11a, there are 52 sub-channels with 312.5kHz per sub-channel, taking the terminal's RF capability and cost into account, in this work, we assume for each node, only up to 4 sub-channels can be supported. For sending each SM packet, it always takes 3 sub-channels while sending each BG or BE packet only consumes one sub-channel in each case.

$C_{SM\,min}$ is the minimum bit rate requirement of the streaming media service and can be referred to as 3GPP. The value of 384kbps is set in this work together with $C_{BG\,min} = 200kbps$. We also set the scheduler $TTI = 3ms$, $D_i^{th} = 5ms$ and $D_i^{max} = 30ms$. We take $\beta_{SM} = 4$, $\beta_{BG} = 1$, $\beta_{BE} = 0.6$ as pre-defined priority values. All three applications are generated with constant speed during the whole simulation period. .

The simulation employs 6 CR MANET scenarios with hops increasing from 3 to 8 for one connection path. Each scenario runs for 5 simulations with different random seeds. Each simulation lasts 5 minutes. For clarity, only the mean

values are shown in this section. The performance of MPF-MH is compared with the MPF algorithm introduced in [8]. To simply the simulation, the interruption introduced by primary user behavior is not considered.

B. CR MANET Throughput Performance Analysis

All three types of application run simultaneously at all the nodes in every simulation. Due to the differing throughput between the SM and BG/BE, the results are shown in separate diagrams. Measurements are carried out at the Application layer and the throughput and delay results are measured at the destination node.

Figure 3 and Figure 4 provide a throughput comparison for SM/BG/BE services between the MPF and MPF-MH algorithms.
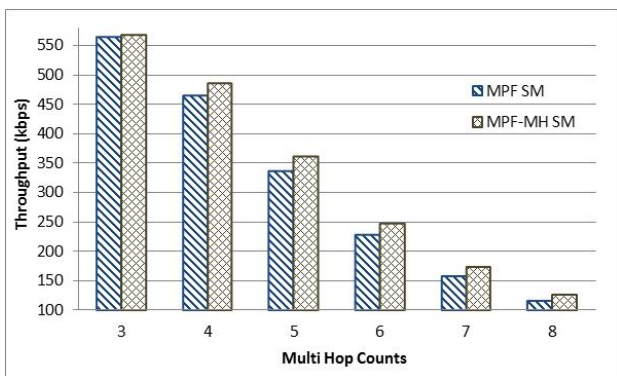

Figure 3 SM Throughput at the Destination

It can be seen from Figure 3 that with the MPF-MH algorithm, when number of hops increases, the SM throughput is improved by 5%- 9% compared with the MPF algorithm. However, the more hops the packets go through, the more packets that will be lost. We can conclude that if the multi-hop count reaches 6 or more, the required minimum throughput for SM service cannot be guaranteed.
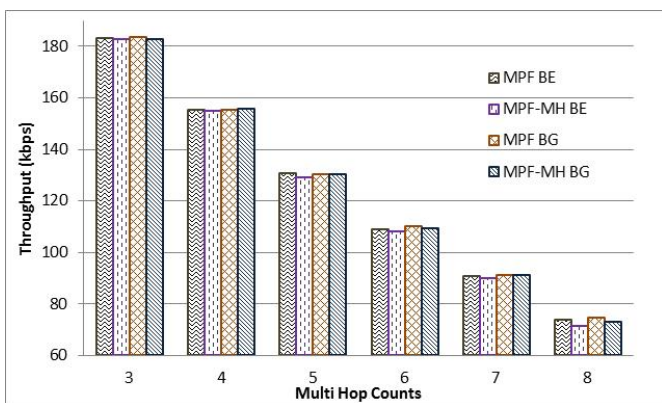

Figure 4 BE/BG Throughput at the Destination

For BG/BE services, as there is always one sub-channel available for sending either BE or BG packets, the variation between these two application types is not large, being about 1%. Similar to SM services, the more hops there are along the path, the greater the packet loss.

C. CR MANET End-to-End Delay Analysis

One of design factors in the MPF-MH algorithm is to assign a higher Q value to those packets experiencing longer delay along the path to the destination for the SM service. The results are shown in Figure 5.
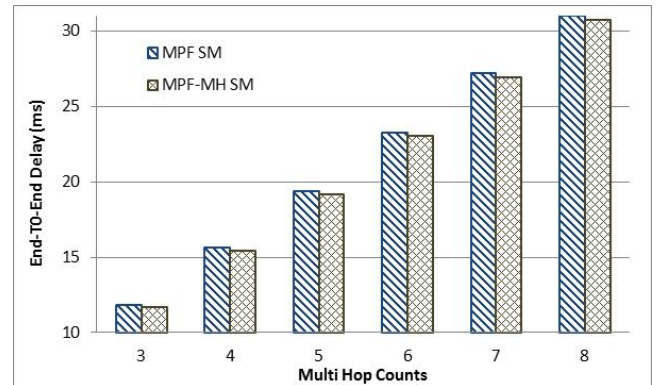

Figure 5 SM End-to-End Delay

The figure shows that the improvement in end-to-end delay is around 1% for all scenarios. The reason for this is that according to the MPF-MH algorithm design, the more hops, the higher Q factor is. However, the final priority assigned to SM is also influenced by the TH factor. It can be seen from Figure 3 that the packet loss is much greater when the number of hops increases so the TH factor has more influence than the Q factor.
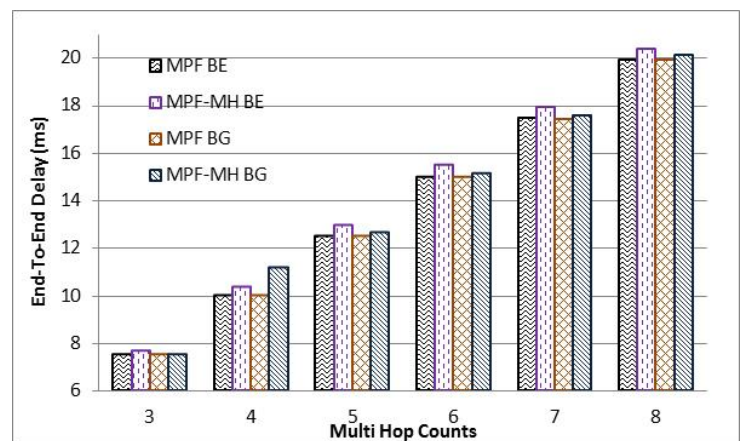

Figure 6 BG/BE End-to-End Delay

According to the design of the MPF-MH algorithm, the Q factor has no influence on either the BG or BE priority.

However, despite the improvement of SM performance, both BG and BE are sacrificed to a certain degree in terms of end-to-end delay, as shown in Figure 6.

V. CONCLUSION

Giving the rapid spread of Internet applications over smart mobile terminals, traditional mobile activities, such as web surfing, are no longer dominant. Real time services, such as video conferencing or online moving playing, are becoming increasingly popular. At the same time we are seeing the introduction of faster networks. Furthermore, scenarios now arise where more than one type of application can simultaneously run over the same device within an ad hoc network. However, without centralized control, the efficient utilization of network resources and the quality of service demands for applications running on each node in the ad hoc network can lead to conflicting goals.

This paper proposed a cross layer QoS scheduling scheme called MPF-MH for CR MANET, which aims to guarantee QoS requirements together with balanced fairness among different service types. Additionally the MAC layer is enhanced with a multi-channel selection capability exploiting information from radio sensing to adaptively compensate for the noisy environment. Simulations are conducted with several scenarios to evaluate the MPF-MH performance compared with the MPF scheduling algorithm. In general, the SM throughput and end-to-end delay performs better in the MPF-MH scheme with little cost in terms of delay for BG/BE services. Nevertheless if there are more hops along the path to the destination the performance will degrade no matter which scheduling algorithm is adopted.

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