An energy saving scheduling scheme for OFDMA two-hop relay systems

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3 AUTHORS, INCLUDING:

Xuming Fang

Southwest Jiaotong University

An Energy Saving Scheduling Scheme for OFDMA Two-hop Relay Systems

Yanan Huang, Xuming Fang, Shufang Lin
1212nanan@163.com, xmfang@swjtu.edu.cn, ssihiay@163.com
Key Lab of Information Coding and Transmission
Southwest Jiaotong University, Chengdu 610031, Sichuan, China

***Abstract*—Being a new feature of next generation of wireless networks, MMR (Mobile Multi-hop Relay) is proposed for the purpose of coverage extension and throughput enhancement in IMT-Advanced, IEEE 802.16j/m. Besides, with the help of relay, the system energy consumption could be well saved. In this paper, an energy saving scheduling scheme is proposed for OFDMA based two-hop relay systems. The novel scheme adjusts the modulation and coding (MC) mode and allocates the transmitting power dynamically according to the resource usage. It can also guarantee the QoS of different services by setting the scheduling priority. The simulation results show that the novel scheduling scheme can not only save system energy but also achieve higher throughput.**

Keywords-scheduling, relay, energy saving, QoS, OFDMA

I. INTRODUCTION

By introducing multi-hop relay technology in new generation wireless networks, such as IMT-Advanced and 802.16j/m, the network performance of transmission rate, signal coverage, and power consumption are all improved[1-3]. However, the scheduling schemes for the network resource allocation should be redesigned by the introduction of relay stations (RSs).

Currently, the scheduling algorithms for wireless networks mostly belong to rate adaptive schemes, which maximize the system throughput with the fixed transmission power. The typical scheduling algorithms are Round Robin (RR) scheduling, Maximum Carrier-to-Interference Rate (Max C/I) scheduling and Proportional Fair (PF) scheduling[4][5]. The Max C/I scheduling algorithm allocates the resource to the user with the best channel condition. But the user under poor channel condition may not get the fair opportunity to get resource. The PF scheduling algorithm allocates the resource to the user not only according to the instant user's transmission rate, but also in accordance with the user's average throughput achieved during a window of past transmissions. Therefore, the algorithm can achieve a balance between the system throughput and fairness. In [6], the Enhanced Proportional Fair (EPF) scheduling algorithm is proposed for OFDMA MMR system, which aims to improve fairness between the direct users and relaying users, especially the users at the edge of a cell. The above scheduling algorithms we mentioned totally aim to maximize the system throughput, but do not concern about the energy consumption. However, the energy resource is of great significance to the operator. It is obvious that how to balance the throughput and energy consumption is a dilemma.

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II. SYSTEM MODEL

In this paper, we focus on the centralized scheduling scheme for OFDMA two-hop relay systems. The packets scheduling process is controlled by base station (BS). After the packets arriving at the network and waiting in the scheduling queue, BS decides which and how many packets should to be transmitted in an OFDMA frame.

A. Two-hop relay networks

The network consists of 19 cells with the target cell locating at the center. Each cell has one BS and six RSs which are regularly deployed around the BS in a hexagon. Referring to 802.16m[7], the cell is divided into three sectors, and two RSs are deployed in each sector. The distance between BS and RS is equal to 3/8 of the site-to-site distance. The BS and RSs utilize directional and omni-directional antennas respectively.

The antenna pattern utilized for each BS sector is specified as:

$$A(\theta) = -\min\left[\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right] \tag{1}$$

where $A(\theta)$ is the antenna gain in dBi in the direction θ, $-180° \le \theta \le 180°$, and θ_{3dB} is the 3dB beamwidth (corresponding to θ_{3dB}= 70°), and A_m=20dB is the maximum attenuation.

BS-MS (mobile station) link and RS-MS link both take the following link model [9]:

$$\begin{aligned} PL = 40(1 - 4\times10^{-3} h_{BS})\log_{10}(d/10^3) - \\ 18\log_{10}(h_{BS}) + 21\log_{10}(10^3 f_C) + 80, \sigma = 8 \end{aligned} \tag{2}$$

BS-RS link takes 802.16j EVM Type D link model as follows:

$$PL = \begin{cases} 20\log_{10}(4\pi d/\lambda) & d \le d_0^{'}, \sigma = 3.4 \\ A + 10\gamma\log_{10}(d/d_0) + \Delta PL_f + \Delta PL_h & d > d_0^{'} \end{cases} \tag{3}$$

where

$$A = 20\log_{10}(4\pi d_0^{'}/\lambda) \tag{4}$$

$$d_0 = 100m;\ d_0^{'} = d_0 \times 10^{-\frac{\Delta PL_f + \Delta PL_h}{10\gamma}} \tag{5}$$

$$\gamma = a - b h_{BS} + \frac{c}{h_{BS}} \tag{6}$$

$$a = 3.6;\ b = 0.005;\ c = 20 \tag{7}$$

$$\Delta PL_f = 6\log(f_C/2) \tag{8}$$

$$\Delta PL_h = \begin{cases} -10\log_{10}(h_{RS}/3), & h_{RS} \le 3m \\ -20\log_{10}(h_{RS}/3), & h_{RS} > 3m \end{cases} \tag{9}$$

In this scenario, by convention, we only consider the inter-cell interference which comes from adjacent cells in the BS-RS link. The interference takes WINNER B5f model, which is given by:

$$PL = 23.5\log_{10}(d) + 57.5 + 23\log_{10}(f_c / 5.0), \sigma = 8 \qquad (10)$$

where, d(m) is the distance between transmitter and receiver. h_{BS} and h_{RS} are the heights of BS antenna and RS antenna. f_c(GHz) is the carrier frequency. And σ is the standard deviation of lognormal shadowing.

B. OFDMA System

Suppose the system works in OFDMA-TDD mode. In an OFDMA frame, time axis is divided into 48 symbols and the frequency axis is divided into different subchannels. The smallest resource unit, namely slot, consists of several symbols in time domain and a subchannel in frequency domain. It is assumed that different packet occupies different slots in an OFDMA frame. Because the subcarriers composing a subchannel are mutually orthogonal and the slots are not reused, there is no interference among users in the same cell. OFDMA system adopts the DL PUSC subcarrier permutation mode in which the subcarriers of a subchannel are spread into the entire frequency band. Therefore, the channel gain of each channel is considered to be approximately equivalent, which means the gains in the different slots are the same too.

One frame can be divided into uplink sub-frame and downlink sub-frame. The downlink sub-frame we researched consists of access link (BS-MS or RS-MS) and relay link (BS-RS).

III. Analysis of Scheduling Scheme

It is assumed that all packets in the scheduling module have selected the transmission path in advance. The greedy algorithm is taken as the path selection scheme, which selects the most energy-saving path[10]. The scheduling algorithm is executed in every OFDMA frame interval (5ms). Aiming to save energy, we also consider the power allocation algorithm together with our scheduling scheme in the downlink.

C. Power Allocation Associating with Resource Intensity

Every data packet which has entered the scheduling model should be classified and put into different traffic queue. In each scheduling interval, the scheduling priority of packets in the queues will change dynamically. An important factor impacting the priority is the transmitting power for each packet. Normally the transmitting power P^i, including the transmitting power P_{BS} in BS and the transmitting power P_{RS} in RS, for each packet is fixed, and the adaptive modulation and coding (AMC) scheme is applied. With the objective of saving energy, in our scheme, the transmitting power is a variable to meet the minimum throughput requirement. The MC mode in 802.16e is an example shown in Table I.

Table I The MC mode in 802.16e

Rate ID	MC mode	bits/symbol	SNR
1	QPSK (1/2)	1	5.0
2	QPSK (3/4)	1.5	8.0
3	16QAM (1/2)	2	10.5
4	16QAM (3/4)	3	14.0
5	64QAM (2/3)	4	18.0
6	64QAM (3/4)	4.5	20.0

We can see that each MC mode corresponds to a minimum requirement of signal to noise ratio (SNR) and an achievable rate. With the objective of saving energy, we choose the lowest MC mode as the best choice, which implies reducing the number of bits transmitted in a slot. However, when the traffic is too heavy and the system resource is insufficient, lower MC mode will lead to the reduction of system throughput and packets lose. Especially when the packets are strictly constrained by a delay limit, the impact is even grater. Aiming to solve the problem stated before, we propose a power allocation solution which adjusts MC mode according to the resource tensity at each scheduling interval. The detail solution is as follows:

Choosing the lowest MC mode when the system resource is sufficient, that is, taking QPSK (coding rate is 1/2). The more the packets (especially the packets which will be discarded in the next several frame) waiting in the queue are, the tenser the system resource is. This means more packets have to wait for the resource in the queue until they are overtime or extra resource is released. In this situation, the higher MC mode should be selected to ease the resource tensity. The MC mode i the user packets applied in the scheduling interval t can be expressed as:

$$\frac{\sum_{j=1}^{k} x_j}{N_{slot} \cdot T_{slot}} \in \left(R_{i-1}, R_i\right] \qquad (11)$$

where, x_j is the size of the packets which will be discarded in the next 10 scheduling interval (t+10×5ms). We call these packets as urgent packets and indicated by the size k. N_{slot} denotes the total number of slots in a frame. T_{slot} is the frame duration. R_i is the attainable transmission rate in a frame. We can get the MC mode i by calculating the rate needed to transmit all the urgent packets in a frame. Then, according to Table I, we can get the minimum SNR threshold required. The transmitting power P^i (P_{BS}, P_{RS}) can be calculated as:

$$SNR_i = \frac{P^i \times G \times H}{(\sigma^2 + \gamma)} \rightarrow P^i = \frac{SNR_i \times (\sigma^2 + \gamma)}{G \times H} \qquad (12)$$

where, SNR_i represents the minimum SNR requirement when choosing the MC mode i. P^i is the transmitting power in corresponding link. H is the link gain. σ^2 is the Gaussian white noise. And γ is the interference in the relay link (BS-MS) from the adjacent cell.

D. Scheduling Algorithm Description

In this scheduling algorithm, a dynamic scheduling priority is defined for each packet in the scheduling queue. This priority inherits the idea of PF algorithm[8], that is, taking into account both the fairness and throughput. Aiming to save energy, the power factor is also included. Moreover, the algorithm also utilizes the traffic weighting factor to differentiate different services and the delay urgent factor to guarantee the QoS requirement, especially the delay requirement.

Let's take 802.16 as an example, which supports four types of service with different QoS requirements. Unsolicited Grant Service (UGS) has the strictest real-time requirement, which should be given the highest priority. The Real-time Polling Service (rtPS) supports real-time data streams consisting of variable-size data packets, and it should be provided periodic request opportunities. Non-real-time

Polling Service (nrtPS) supports delay-tolerant data streams consisting of variable-sized data packets. But the real-time requirement for rtPS is stricter than that for nrtPS. Best Effort (BE) service supports data streams without strict QoS requirement. There are some preconditions we should define:

a) Each service has its own scheduling queue and the length of the queue is limitless.
b) In each scheduling frame interval, the system resource (slots) which can be used to transmit data is limited. The scheduling scheme will choose a packet with the highest priority, and then transmit it in the available slot. The procedure is repeated until no packet needs to be transmitted or the available slots are used up.
c) Assignment of the link resources: The slot resource in a frame is divided into relay link (BS-RS) resource and access link (BS-MS or RS-MS) resource. And we don't fix the proportion of them.

In order to satisfy the QoS requirement of different service, and achieve the target of saving energy consumption, the scheduling scheme is operated as follows.

1) Scheduling for UGS Packets

System provides bandwidth for UGS service actively, so the priority of UGS packet is highest. As long as there is UGS packet in the queue, we will schedule the packet preferentially. If there are many UGS packets need to be transmitted, we will schedule the packet whose priority is the highest.

The scheduling priority $\phi_{i,t}$ of UGS packet i in the scheduling time t is defined as:

$$\phi_{i,t} = \frac{C_i(t)}{R_i(t-1)}\frac{1}{P_i Q_i} \tag{13}$$

where

$$C_i(t) = \begin{cases} C_{direct}^i(t), & \text{ith direct user} \\ \min\left\{C_{relay}^{(1)}(t), C_{relay}^{(2)}(t)\right\}, & \text{ith relaying user} \end{cases} \tag{14}$$

$$P_i(t) = \begin{cases} P_{BS}^i(t), & \text{ith direct user} \\ P_{BS}^i(t) + P_{RS}^i(t), & \text{ith relaying user} \end{cases} \tag{15}$$

$$\overline{R_i(t)} = \left(1 - \frac{1}{T_w}\right)\overline{R_i(t-1)} + \frac{1}{T_w}C_i(t) \tag{16}$$

$$Q_i(t) = \frac{T_{\max\_delay}^i - T_{delay}^i(t)}{T_{\max\_delay}^i} \tag{17}$$

The packet i selected to be scheduled preferentially can be acquired as:

$$i^* = \arg\max_i \left\{\phi_{i,t}\right\} \tag{18}$$

We can see that, the power factor P_i is included in the priority formula (13), and can be obtained by (15), which can be applied to both direct users and relaying users. The smaller the power P_i is, the higher the scheduling priority is, and the packet i has more opportunities to be transmitted. Consequently, the energy consumption can be reduced to some extent, and the target of saving energy can be achieved. The priority also include $C_i(t)/R_i(t-1)$ proposed in the PF algorithm[1], where, $C_i(t)$ is the capacity that packet i will get in time t. $R_i(t-1)$ denotes average data rate of the user whom the packet i belongs to. This value is used to improve the fairness among the users. And T_W in (16) is the time window determining how much channel and link information of past time is included in the average rate. T_W is taken 100 in this paper. The QoS of different service mainly takes into account the delay requirement. Therefore the delay urgent factor Q_i is proposed in (17). T_{max_delay} denotes the maximum delay limit of packet i. Different service has different T_{max_delay}. $T_{delay}^i(t)$ is the current delay in time t. When $T_{delay}^i(t)$ approaches to T_{max_delay}, Q_i approaches to 0. The priority in this situation is higher than the situation that $T_{delay}^i(t)$ is small and Q approaches to 1. When $T_{delay}^i(t) > T_{max\_delay}$, the packet i should be discarded from the queue.

2) Scheduling for rtPS and nrtPS Packets

For rtPS and nrtPS packets, the scheduling priority $\phi_{i,t}$ in scheduling time t is set as:

$$\phi_{i,t} = \beta \times \frac{C_i(t)}{R_i(t-1)}\frac{1}{P_i Q_i} \tag{19}$$

where, β denotes the traffic weighting factor. Because the real-time requirement of rtPS packets is more strict than nrtPS packets, so $\beta_{rtPS} > \beta_{nrtPS}$.

3) Scheduling for BE Packets

Since the QoS requirement is very low and there is no delay requirement for BE packets, the scheduling priority $\phi_{i,t}$ for BE packets in scheduling time t is defined as:

$$\phi_{i,t} = \beta_{BE} \times \frac{C_i(t)}{R_i(t-1)} \tag{20}$$

where, $\beta_{rtPS} > \beta_{nrtPS} > \beta_{BE}$.

The scheduling rules are: Schedule the UGS packets. If there are many UGS packets competing for the resource, choose the UGS packet with the highest priority. If there are some slots left after all USG packets are transmitted, calculate the priorities of the rtPS, nrtPS and BE packets waiting in the three queues and transmit the packet i^* whose priority is the highest among them $\left(i^* = \arg\max_i\{\phi_{i,t}\}\right)$. Carry out the operation until there is no available slot or no packet waiting in the queues.

IV. Simulation Results

The scalable OFDMA (S-OFDMA) system is applied in the simulation. FFT size is 1024, system bandwidth is 10MHz. System adopts PUSC permutation mode in downlink. The number of subchannels is 30. One slot is one subchannel by two OFDMA symbols. There are 48 symbols in a frame and 28 of them are used to transmit data in downlink. The number of available slots is 420 (28×30/2). Other parameters may reference to [7,9].

Four types of traffic are considered in this simulation. They are UGS, rtPS, nrtPS and BE service. UGS adopts VoIP traffic model, and the service arrival at the target cell is in accordance with Poisson process. The traffic rate is 12.2 kbps. rtPS adopts IPTV traffic model, and the rate jumps among eight states. The packet size is constant. nrtPS adopts FTP traffic model which follows Pareto distribution, and the packet size is flexible. BE service model follows the data model. The delay limits for UGS, rtPS, nrtPS and BE are 50, 250, 1000, and 10000 ms respectively. The simulation lasts 200 s.

We simulate and compare the Max C/I, PF and energy saving (EA) scheduling algorithms with the jointed power allocation. The throughput of three scheduling algorithms is shown in Fig.2 and Fig.3. When the arrival rate of traffic flow is low (λ<5), the resource is sufficient and the influence of MC mode is small. All the packets can be transmitted, so the throughput is almost the same. But when the arrival rate increases ($\lambda \geq 5$), the packets waiting in the queue increase. According to the EA algorithm we proposed, MC mode is changed to a higher mode. So the throughput is improved greatly compared with the other algorithms. From Fig.3, we can see that the throughput of BS is higher than RS. The reason is that we only take into account the interference in the relay link.

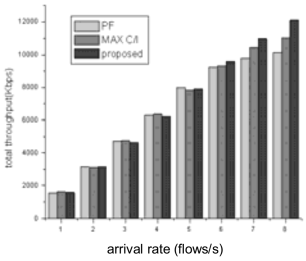

Fig. 2. System total throughput

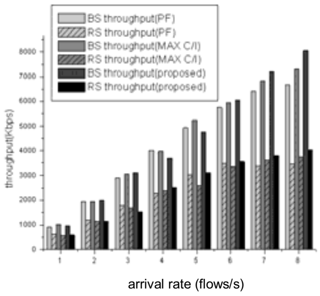

Fig. 3. BS and RS throughput

Average bit energy is an important performance indictor to evaluate the energy saving effect. The physical meaning is the energy required to transmit one bit, with the units J/bit. From Fig.4 and Fig.5, the total energy consumption and average bit energy of EA algorithm are much lower than those of the other two algorithms, especially when the arrival rate is lower. It is because that the MC mode is changed into a lower mode with enough resource, and the corresponding transmitting power is lower. The energy saving benefit can be shown clearly from the following instance: when λ=3, the energy consumption of EA algorithm is only 22.86% of the PF algorithm and the average bit energy is 23% of PF algorithm. With the increase of the arrival rate, the energy saving benefit is more and more trivial, but the throughput is improved obviously compared with Max C/I and PF algorithms.

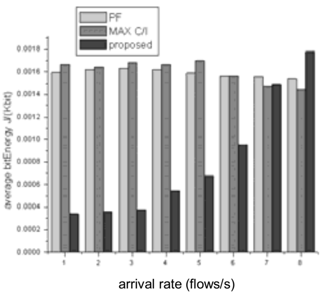

Fig. 4. Average bit energy

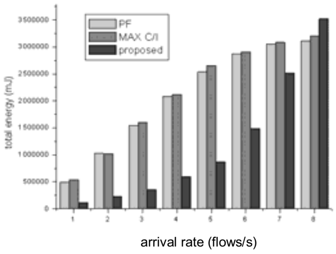

Fig. 5. System total energy consumption

The EA algorithm with joined power allocation and service differentiation also considers the QoS requirement of different service. So we compare the throughput and average packet delay of different services achieved in the PF and EA algorithms we proposed respectively.

Fig.6 and Fig.7 show that the throughput of UGS is same under PF and EA algorithms because UGS packets are transmitted preferentially in each scheduling interval. Besides, the EA algorithm can improve the throughput of rtPS, nrtPS and BE service with the increase of arrival rate. The simulation also reveals that the average delay of EA does not excess T_{max_delay}.

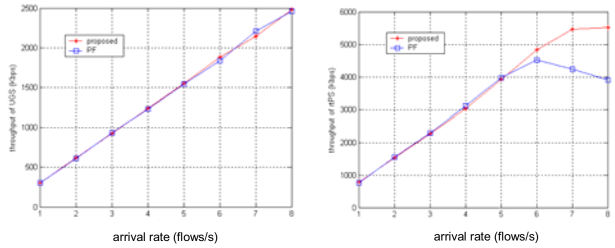

Fig. 6. Throughput of UGS and rtPS

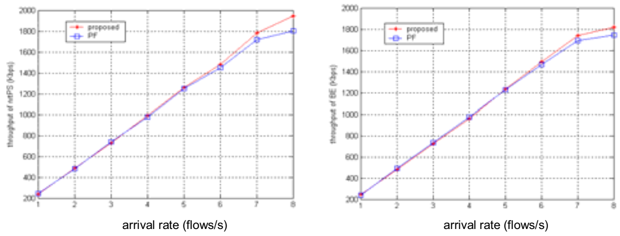

Fig. 7. Throughput of nrtPS and BE

V. Conclusions

This paper proposes an energy saving scheduling scheme for OFDMA based two-hop relay networks, which can provide QoS guarantee for different types of service. The scheme also considers the power allocation with resource tensity. Combined with the power factor introduced in scheduling priority, it can achieve a reasonable balance between the throughput and energy consumption. The aim of saving energy is thereby achieved.

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