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An energy-saving scheduling scheme for two-hop relay networks

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Abstract: An energy-saving proportional fair (ESPF) scheduling scheme for OFDMA-based two-hop relay networks is proposed. By defining a proportional fair factor which is based on the upper limit of delay for different types of services and the energy consumption per bit, a packet scheduling algorithm and a flexible resource allocation scheme are proposed to avoid the waste of resources. Simulation results show that the proposed scheduling scheme can effectively decrease system energy consumption and improve system throughput while still satisfying the QoS requirements for different types of services.

Key words: multi-hop relay; energy saving; scheduling; OFDMA; IMT-Advanced; IEEE802.16j/m
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一种用于两跳中继网络的节能调度方案

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摘要：针对两跳OFDMA中继蜂窝网络，提出一种节能比例公平调度方案．根据不同业务类型的时延需求和单位比特能耗等QoS参数来设计业务调度优先级因子，并给出一种高效的资源分配方案．数值仿真结果表明，本文给出的调度方案在保证不同类型业务QoS需求的同时，能有效降低系统能耗，提高系统吞吐量．

关键词：多跳中继；节能；调度；正交频分多址；IMT-Advanced；IEEE802.16j/m

0 Introduction

Recently, by taking advantage of relay station (RS) and OFDMA technique, the IMT-Advanced and IEEE802.16j/m mobile multi-hop relay (MMR) cellular networks are becoming an attractive solution for the coverage extension and throughput enhancement over the current cellular

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networks[1~3]. In addition, on the condition of keeping certain capacity, the total power consumption of the MMR system can be further decreased. However, there is a mutual restriction with coverage extension, throughput enhancement and power saving, and they cannot be optimized simultaneously.

As one of the current typical new standards, IEEE802.16 family specifies five types of services and each of them has its own quality of service (QoS) requirement (such as delay, jitter, minimum request bandwidth)[4,5]. Obviously, QoS requirements can be satisfied by fair resource allocation/packet scheduling approaches. The signaling mechanism for resource request and allocation is defined in the standard, but how to allocate the bandwidth to subscribers is not specified but left for alternative implementations[4,5].

Since RSs and Adaptive Modulation and Coding (AMC) scheme are applied to the IMT-Advanced and IEEE802.16j/m MMR networks[4], the capacity asymmetry between BS-RS link and RS-MS link exists, which can only support the lower data rate of two links and result in resource waste. Power adaptation and AMC scheme can reduce resource waste and maximize the data rate of the multi-hop relay OFDM(A) system. However, it is a non-linear problem and the solution is hard to find[6]. In order to solve this problem, an effective resource allocation strategy is proposed in this paper.

1　System Model

1.1　System structure

We consider a single cell and a two-hop relay structure for the MR network as shown in Fig. 1. In two-hop relay systems, there are three kinds of link: BS-MS, BS-RS, and RS-MS links. The target center cell consists of one MR-BS (Multi-hop Relay BS) located in the cell's center and six fixed RSs symmetrically distributed within it and each cell is divided into three sectors. The RSs are located in the 2/3 of the cell's radius. We assume that each RS in the target center cell just receives two furthermost neighbor BSs' interferences as shown in Fig. 1 and the interference received by the mobile station (MS) from the adjacent cell is omitted for simplification. It is assumed that the frequency resource of the target center cell is fully shared in all co-sectors. More details about the setting of system parameters are shown in Tab. 1[7].

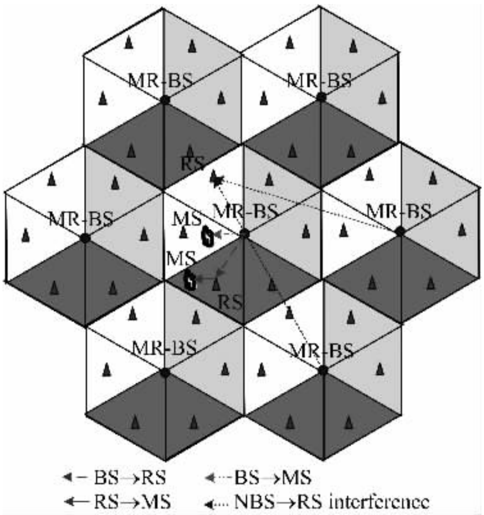

Fig. 1　The system structure

Tab. 1　The summary of system parameters

parameter name	value
side to side	1000 m
carrier frequency	2 GHz
channel bandwidth	10 MHz
FFT size	1024
frame duration	5 ms
UL/DL duplexing scheme	TDD (28 symbols for DL, 9 symbols for UL, 11 symbols for frame overhead)
subcarrier permutation mode	PUSC
number of sub-channels DL	30
sub-carrier frequency spacing	10.94 kHz
useful symbol time (T_b)	91.4 μs
guard time ($T_g=T_b/8$)	11.4 μs
OFMDA symbol duration ($T_s=T_b+T_g$)	102.9 μs
MR-BS/RS/MS transmit power	46/38 dBm
MR-BS/RS/MS antenna height	25/15/1.5 m
MR-BS-MS minimum distance	≥30 m
RS-MS minimum distance	≥10 m
thermal noise spectral density	−174 dBm/Hz

1.2 Channel model

In this paper, the propagation loss models proposed in Ref. [8] are considered, including WINNER B5a model, WINNER B5f model, and WINNER C2 model. The shadow fading is assumed to be Gaussian distribution with mean zero and standard deviation of σ dB. B5a model is a line-of-sight (LOS) model and used for modeling the propagation loss of MR-BS-RS link. B5f model is a non-line-of-sight (NLOS) model and used for modeling the propagation loss from adjacent BS to the RS of the target center cell. WINNER C2 model is a LOS/NLOS model and used for modeling the propagation loss of BS-MS link and RS-MS link.

1.3 Adaptive modulation and coding

For IMT-Advanced and IEEE802.16j/m networks with centralized scheduling, the MR-BS performs the scheduling process based on the status information of all queues. Each MS or RS sends the MR-BS its channel quality information (CQI) through the feedback channel. CQI includes the information of the RSSI (received signal strength indicator) and SINR (signal-to-interference-plus-noise ratio)[4,5]. Based on the specific value of SINR, the MR-BS can choose an appropriate modulation and coding scheme (MCS) for a transmission. The specific SINR thresholds can be obtained from Tab. 2, which is specified in the standard for evaluation[5].

Tab. 2 The used MCS

level	modulation	coding rate	slot size /bits	receiver SINR threshold/dB
1	QPSK	1/2	48	5
2		3/4	72	8
3	16QAM	1/2	96	10.5
4		3/4	144	14
5	64QAM	2/3	192	18
6		3/4	216	20

1.4 QoS requirements of services

As one of the current typical new standards, IEEE802.16e standard specifies five types of services, including unsolicited granted service (UGS), real time poll service (rtPS), non real time Poll Service (nrtPS), Best effort (BE), and extended rtPS (ertPS)[5]. Without losing generality, in this paper, we only consider four types of services except ertPS based on the efficiency of both UGS and rtPS. For each type of service, one typical type of traffic is provided and its delay requirements are listed in Tab. 3[7].

Tab. 3 QoS requirements of services

type	UGS	rtPS	nrtPS	BE
typical traffic	VoIP	Video	FTP	Data
maximum delay T_s/ms	50	250	1000	10000
characteristics of each traffic	constant bit rate	variable bit rate	variable bit rate	variable bit rate

1.5 Frame structure

The MR-BS and RS frames are subdivided into Downlink (DL) and Uplink (UL) sub-frames to support TDD operation[4]. Both DL and UL sub-frames are further subdivided into access zone and transparent zone respectively. For the DL sub-frame with the two-hop relay structure, based on IEEE802.16j/m suggestion, we assume that MR-BS can operate in the access zone and the transparent zone for the direct-user (MR-BS-MS) transmissions. The access zone can also be used for the transmissions from MR-BS to RS and the transparent zone can be used for those from RS to relay users (RS-MS). According to IEEE802.16 standard family, the minimum allocable resource unit is one slot and each slot contains 48 data symbol sub-carriers[5]. In this paper, there are 420 slots in DL sub-frame for data transmission with the given parameters in Tab. 1. Additionally, we assume that the both the access zone and the transparent zone have 210 slots respectively. For different MCS orders, each slot contains a different number of bits as shown in Tab. 2.

2 Energy-saving scheduling algorithm

2.1 Packet scheduling algorithm

In this paper, we just focus on the DL resource allocation and the transparent centralized scheduling mode with only one intermediate RS between MS and MR-BS. MS can also connect MR-BS directly based on the given criteria. Four types of services have different QoS requirements. Hence, the scheduler should consider the characteristics of each service type, such as maximum delay and minimum data rate requirements. Based on their QoS requirements, UGS service is sensitive to delay and it should be scheduled with high priority. Accordingly, the other types of delay sensitive traffic can be categorized as rtPS and nrtPS. Generally, rtPS traffic is more sensitive to the packet delay. In contrast, nrtPS traffic is not sensitive to packet delay[5]. The BE traffic is the best effort traffic and has no delay restriction. Therefore, in the system supporting multi-traffic service, a BS scheduler should guarantee the QoS of rtPS and nrtPS traffic[9] and provide a certain opportunity for BE traffic to be scheduled. We assume that each user only has one of the four service types and the scheduling interval is typically the length of a frame.

The scheduling strategy is summarized as follows: MR-BS allocates slot resource for all the UGS traffic first, then the free slots can be used for scheduling rtPS, nrtPS and BE traffics. Each of them is scheduled by the proposed ESPF algorithm. ESPF algorithm considers the average energy consumption per bit and has a proportional fair factor defined as follows

$$\varphi_i(k)=\frac{r_i(k)}{\overline{R_i(k)}}=\frac{1}{\bar{E}_i(k)} \tag{1}$$

where $r_i(k)/\overline{R_i(k)}$ is a normalized value of the transmission state. If it is higher, user i will obtain more opportunities to be scheduled. $r_i(k)$ is the required minimum data rate for user i, which is different from that of the normal PF algorithm and defined in subsection 2.2. $\overline{R_i(k)}$ represents the average throughput for user i which is smoothed by a low-pass filter at the scheduling frame k and can be computed as

$$\overline{R_i(k)}=\begin{cases}\left(1-\frac{1}{T_c}\right)\overline{R_i(k-1)}+\frac{1}{T_c}C_i(k), \\ \qquad \text{user } i \text{ scheduled} \\ \left(1-\frac{1}{T_c}\right)\overline{R_i(k-1)}, \\ \qquad \text{user } i \text{ not scheduled}\end{cases} \tag{2}$$

where T_c is the length of the smooth time window, and $C_i(k)$ is the throughput for user i in the current frame k. $\overline{R_i(k)}$ is updated after the transmission of each frame. From equation (2), it can be observed that when a user has not been scheduled for a long time, its average throughput will decrease and the user will get more opportunities to be scheduled during the next scheduling frame. $\bar{E}_i(k)$ denotes the average energy per bit for user i in frame k and is given by

$$\bar{E}_i(k)=\begin{cases}\bar{E}_{0,i}(k), & \text{direct user } i \\ \bar{E}_m(k)+\bar{E}_{m,i}(k), & \text{relay user } i\end{cases} \tag{3}$$

Users estimate and feedback CQI such as SINR to their attached MR-BS. Then, the SINR will be used to determine the allocated resource and MCS order. After achieving the MCS order and transmitting power, the average energy consumption for transmitting one bit can be computed according to Tab. 2. For the direct-user, average energy per bit is equal to that of the access link (BS-MS) denoted by $\bar{E}_{0,i}(k)$ based on MCS order. The average energy per bit for the relay-user of relay m is equal to the summation of the relay link (BS-RS$_m$) denoted by $\bar{E}_m(k)$ and the access link (RS$_m$-MS$_i$) denoted by $\bar{E}_{m,i}(k)$. $\bar{E}_{0,i}(k)$, $\bar{E}_m(k)$ and $\bar{E}_{m,i}(k)$ are respectively computed by

$$\bar{E}_{0,i}(k)=T_b\bar{P}_{\mathrm{BS},i,k}/f_{0,i}(\mathrm{SINR}_{0,i,k}) \tag{4}$$

$$\bar{E}_m(k)=T_b\bar{P}_{\mathrm{BS},m,k}/f_m(\mathrm{SINR}_{m,k}) \tag{5}$$

$$\bar{E}_{m,i}(k)=T_b\bar{P}_{\mathrm{RS},i,k}/f_{m,i}(\mathrm{SINR}_{m,i,k}) \tag{6}$$

where $\bar{P}_{\mathrm{BS},i,k}$ is the allocated average power per sub-carrier for direct-user i at frame k. $\bar{P}_{\mathrm{BS},m,k}$ is the allocated power per sub-carrier from BS to RS$_m$ and $\bar{P}_{\mathrm{RS},i,k}$ from RS$_m$ to user i at frame k. $f_{0,i}(\mathrm{SINR}_{0,i,k})$, $f_m(\mathrm{SINR}_{m,k})$ and $f_{m,i}(\mathrm{SINR}_{m,i,k})$ are the coding rates for BS-MS$_i$, BS-RS$_m$ and RS$_m$-MS$_i$ links, respectively. In addition, T_b is the useful symbol time shown in Tab. 1. Notice that, with the definition in (1), when the allocable slots are not enough for all users, the users with a low average energy per bit will tend to have more opportunities to be scheduled. In the proposed algorithm, we assume that the total power of the system is allocated averagely to each sub-carrier including the pilot sub-carrier. After receiving the pilot signal, MS or RS calculates the SINR which are used by MR-BS to select the MCS order. $\bar{P}_{\mathrm{BS},i,k}$, $\bar{P}_{\mathrm{BS},m,k}$ and $\bar{P}_{\mathrm{RS},i,k}$ are the thresholds of the selected MCS order.

2.2 Calculation of the required minimum data rate

Since each type of service has a maximum delay shown in Tab. 3, we assume that the packet with the maximum delay will be dropped. In Ref. [10], one method to calculate required minimum data rate has been proposed and it can be used to calculate the required bit rate $r_i(k)$. Herein, let $l_{i,n}(k)$ denote the number of bits of the nth packet of the ith user in kth frame, then the amount of bits that should be transmitted until the transmission of the mth packet in the packet queue of ith user are given by

$$B_{i,m}(k) = \sum_{n=1}^{m} l_{i,n}(k) \tag{7}$$

Let $f_{i,m}(k)$ be the elapsed time of the mth packet of ith user from the arrival time to the instantaneous time of the kth frame. Then, the maximum available timeout for transmission of this packet is

$$TO_{i,m}(k) = D_{\max,i} - f_{i,m}(k) \tag{8}$$

Here $D_{\max,i}$ is the maximum packet delay. The required minimum data rate to guarantee that no packet is dropped due to timeout is given by

$$v_{i,m}(k) = \frac{B_{i,m}(k)}{TO_{i,m}(k)} \tag{9}$$

The optimum bit rate (OBR) for the ith user in the kth frame is given by

$$r_i(k) = \max_{m=1,\cdots,L_i} \{v_{i,m}(k)\} \tag{10}$$

Here L_i is the number of packets for the ith user. From equation (10), it can concluded that the required minimum data rate of rtPS is higher than that of the nrtPS when their amounts of bits are the same, since the maximum delay of rtPS is smaller than that of nrtPS. Hence rtPS traffic can get more opportunities to be scheduled than nrtPS traffic, and BE traffic will get fewer opportunities than both rtPS and nrtPS traffic.

2.3 Resource allocation algorithm

In order to use the slot resources efficiently, we design a resource allocation algorithm to schedule all packets. Let M and N denote the numbers of the available slots of the access zone and the transparent zone respectively. As described in the previous section, all of the UGS traffic will be scheduled first. Then, the available slots left will be allocated to the rtPS, nrtPS, or BE traffic accordingly. We assume that each user with one type of traffic has a queue of packets to be scheduled. The proposed scheduling algorithm for each frame is described as follows:

```
At each scheduling instant {
M=N=210;
while $\varphi_{\mathrm{UGS}} \neq \varphi$ and (M≠0 or N≠0){
update $\varphi_{\mathrm{UGS}}$ and select $i^* = \arg\max_i \{\varphi_i \in \varphi_{\mathrm{UGS}}\}$
if $U_{i*}=0${
  if $\eta \geqslant 1${schedule packets of user $i^*$; update M, $\overline{R_{i*}}$;
      $\varphi_{\mathrm{UGS}} = \varphi_{\mathrm{UGS}} - \varphi_{\mathrm{UGS},i*}$}
  else {schedule packets of user $i^*$,  update N, $\overline{R_{i*}}$;
      $\varphi_{\mathrm{UGS}} = \varphi_{\mathrm{UGS}} - \varphi_{\mathrm{UGS},i*}$;}}
if $U_{i*}=1${schedule packets of user $i^*$; update M and N, $\overline{R_{i*}}$;
    $\varphi_{\mathrm{UGS}} = \varphi_{\mathrm{UGS}} - \varphi_{\mathrm{UGS},i*}$}}
while $\varphi_{\text{non-UGS}} \neq \varphi$ and (M≠0 or N≠0) {
update $\varphi_{\text{non-UGS}}$ and select $i^* = \arg\max_i \{\varphi_i \mid \varphi_i \in \varphi_{\text{non-UGS}}\}$
if $U_{i*}=0${
  if $\eta \geqslant 1${schedule the head of packet queue of user $i^*$;
    if $L_{i*}=0$ {$\varphi_{\text{non-UGS}} = \varphi_{\text{non-UGS}} - \varphi_{\text{non-UGS},i*}$; update M and
    $r_{i*}$, $\overline{R_{i*}}$} else {update M and $r_{i*}$}}
  else {schedule the head of line packet of user $i^*$;
    if $L_{i*}=0$ {$\varphi_{\text{non-UGS}} = \varphi_{\text{non-UGS}} - \varphi_{\text{non-UGS},i*}$; update N and
    $r_{i*}$, $\overline{R_{i*}}$} else {update N and $r_{i*}$}}}
if $U_{i*}=1${
  schedule the head of packet queue of user $i^*$
    if $L_{i*}=0$ {$\varphi_{\text{non-UGS}} = \varphi_{\text{non-UGS}} - \varphi_{\text{non-UGS},i*}$; update M, N
    and $r_{i*}$, $\overline{R_{i*}}$} else {update M, N and $r_{i*}$}}
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}}
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Note:

φ_{UGS}: The set of proportional fair factor for UGS traffic;

$\varphi_{non\text{-}UGS}$: The set of proportional fair factor for rtPS, nrtPS, and BE traffic;

M: The number of free slots of the access zone;

N: The number of free slots of the transparent zone;

U_i: Service type of user i, 0: direct user, 1: relay user;

η: The ratio of free slots of access zone and transparent zone, and $\eta = M/N$;

r_{i^*}: The required minimum data rate of user i^*;

$\overline{R_i}$: Average throughput of user i^*;

L_{i^*}: Number of packets in the packet queue of user i^*.

For the UGS traffic, if the free slots are enough for all packets of user i^*, all packets will be scheduled. Otherwise, only part of them will be scheduled. For the non-UGS traffic, the head of the packet queue is scheduled for each time.

For the direct users, the free slots for both access zone and the transparent zone can be used for transmission depending on the ratio $\eta = M/N$. But the free slots of both the access zone and the transparent zone will be allocated for relay users. This strategy can effectively keep tradeoff of the resource allocation between the access zone and the transparent zone, thus avoiding the waste of wireless resources as the MCS technologies are not the same between the two zones.

3 Simulation results

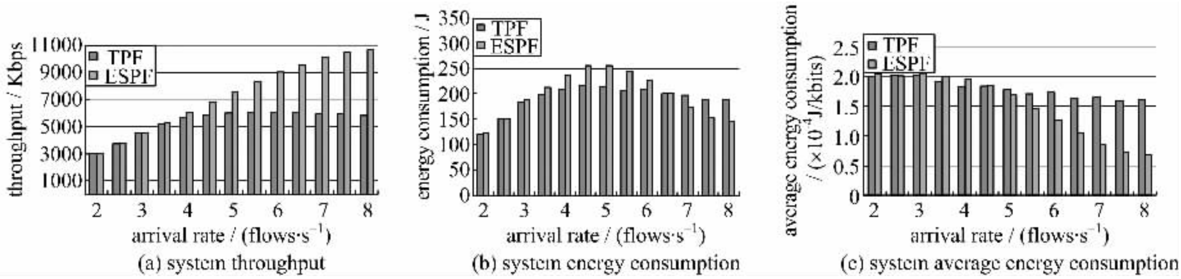
In order to evaluate the performance, we compare our proposed ESPF algorithm with the traditional PF algorithm (TPF). Normally PF algorithm only considers the proportional fair factor $\varphi_i(k) = r_i(k) / \overline{R_i(k)}$. $r_i(k)$ is the request data rate of the access link related to the received signal to interference and noise ratio (SINR) of user i. The normal resource allocation strategy in Ref. [11] is adopted for TPF. The access zone is used for transmissions from MR-BS to RS and the direct user and the transparent zone is used for those from RS to the relay user (RS-MS).

3.1 Throughput and energy consumption of the system

The traffic load is represented by the arrival rate in flows/s and the abscissa shown in Fig. 2 denotes the arrival rate of each type of traffic. When the traffic load reaches a certain value, the free slots will not be enough for scheduling all packets at that time. In this case, the users with lower average energy consumption per bit will get more opportunities to be scheduled and achieve higher throughput. The simulation results shown in Fig. 2 validate the intuition. When the arrival rate reaches 7 flows/s, the system throughput with ESPF increases by 69.8% and outperforms that with TPF. In contrast, the total energy consumption of the system decreases by 12.2%. In addition, the average energy consumption per kilobits of the system decreases by 48.3%.

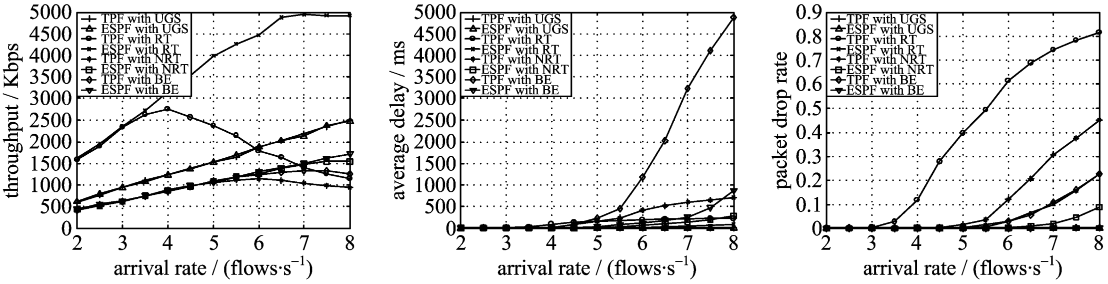
3.2 Throughput of each service type

Fig. 3(a) shows the throughput of each service type, where the axis x denotes the arrival rate of traffic and is represented by the number of traffic flows per second. As expected, the throughput with ESPF can be further improved for non-UGS service than that with TPF, especially for the rtPS type. Since rtPS is more sensitive to delay than other non-UGS traffics, rtPS traffic will get more opportunities to be scheduled when the slot



(a) system throughput (b) system energy consumption (c) system average energy consumption

Fig. 2 Comparison of throughput and energy consumption



(a) throughput (b) average delay (c) packet drop ratio

Fig. 3 Performance of each service type

resource cannot afford all packets.

Moreover, since the energy consumption per bit is considered in the proportional fair factor, the traffic with lower energy consumption per bit will be more likely to be scheduled, namely, the traffic with higher MCS order obtains more opportunities, resulting in the ESPF achieving higher throughput performance than the TPF. Since the UGS traffic is scheduled preferentially, the throughput with ESPF is nearly the same as that with TPF.

3.3 Average delay of each service type

In Fig. 3 (b), it is demonstrated that the average delay of each service type mutates with the traffic load. If the slots are enough for all packets of UGS traffic, all of them will be timely scheduled. So the average delays with ESPF and TPF are nearly the same. However, others have to contend for the free slots. In the simulation, the required data rate of rtPS with lower maximum delay is relatively higher and its proportional fair factor is also relatively higher than that of other types of service. Hence, rtPS has minimum average delay compared with the nrtPS and BE, and the average delay of BE is the highest. Compared with the TPF, the proposed ESPF has lower average delay. The reason for this is that the system with ESPF has higher capacity than that with TPF and the delay requirements are considered in the proportional fair factors of ESPF algorithm.

3.4 Packet drop ratio of each service type

Fig. 3 (c) shows that the packet drop ratio with ESPF is lower than that with the TPF. Since the system with ESPF has higher capacity and considers the delay requirements in the definition of proportional fair factor, more packets are scheduled before they expire. If the delay of the arrival packet is over the maximum delay requirement, it will be dropped. As the maximum delay of the rtPS service is smaller than those of the nrtPS and BE, its packet drop ratio is higher than others. The BE has the maximum delay requirement, so its packet drop ratio is the lowest compared with the rtPS and nrtPS.

4 Conclusion

In this paper, an energy-saving scheduling scheme was proposed, which is assigned to solving the resource allocation for the IMT-Advanced and IEEE802.16j/m MMR cellular network with two-hop topology. This algorithm can effectively save the system energy and improve the capacity of the system. Meanwhile, it can satisfy the QoS requirements of different types of services, including UGS, rtPS, nrtPS, and BE. The simulation results show that the proposed scheme is more effective than the typically used TPF algorithm.

There are some issues left for our future research. In this paper, we just considered the single cell environment and omitted the interference received by MS from neighboring cells. In a more practical environment such as frequency reuse by sectors, MIMO technology, etc., the proposed scheduling strategy needs to be further improved and extended.

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