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Resource Allocation based on Quantized Feedback for TDMA Wireless Mesh Networks

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***Abstract*:** Resource allocation based on quantized feedback plays a critical role in wireless mesh networks with a time division multiple access (TDMA) physical layer. In this study, a resource allocation problem was formulated based on quantized feedback for TDMA wireless mesh networks that minimize the total transmission power. Three steps were taken to solve the optimization problem. In the first step, the codebook of the power, rate and equivalent channel quantization threshold was designed. In the second step, the timeslot allocation criterion was deduced using the primal-dual method. In the third step, a resource allocation scheme was developed based on quantized feedback using the stochastic optimization tool. The simulation results show that the proposed scheme not only reduces the total transmission power, but also has the advantage of quantized feedback.

***Keywords*:** Wireless mesh networks, TDMA, Quantized feedback, Resource allocation, Stochastic optimization tool

1. Introduction

Wireless Mesh Networks (WMNs) have attracted considerable interest from researchers because their economical and easy deployment, which are dynamically self-organized, self-configured and a multi-hop network [1]. The typical WMNs architecture contains mesh routers and gateways. The mesh routers are connected to each other in a multi-hop manner to form the network. To provide an all-wireless ambience to the suburban or rural area of interest, mesh routers can be set up at premises in the neighborhood to form a resilient mesh network [2]. TDMA-based WMNs have become a hot topic in recent research [3], such as IEEE 802.11s because TDMA-based MAC implementation for WMNs is more suitable than contention-based MAC implementation.

Key research challenges in building a high performance wireless mesh backbone include the design of high-capacity in mesh routers and the resource allocation techniques are the efficient tool [4-6]. Currently, there are many resource allocation schemes that are proposed to provide high-speed WMNs with quality-of-service (QoS) assurance, but resource allocation based on quantized feedback for TDMA WMNs has not been investigated extensively. In addition, the constraints of different transmission rate requirements for different links should be considered for TDMA WMNs. Moreover, resource allocation technology with the goal of minimizing the total transmission power can provide a solution to constructing green communication for WMNs [7, 8]. Because reducing the feedback overhead of the resource allocation algorithm is the key to resource allocation technology for TDMA WMN, this study examined the resource allocation problem for minimizing the total transmission power based on the quantized feedback for TDMA WMNs.

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The main contribution of this study is as follows:

- Utilizing the primal-dual method and stochastic optimization tool, a resource allocation scheme was proposed based on the quantized feedback for TDMA WMNs. This scheme can achieve good network performance in terms of the total transmission power. Moreover, the feedback overhead of the proposed scheme is limited.

The outline of this paper is as follows. In section 2 describes the related work. Section 3 develops a system model and optimization problem formulation. Section 4 proposes a resource allocation scheme based on quantized feedback. Section 5 presents the simulation results and Section 6 concludes the paper.

2. Related Work

Resource allocation problems for wireless networks have been studied extensively [9-19]. Most studies of resource allocation for TDMA networks can be divided into two categories. The first focuses on the resource allocation problem with full feedback for the TDMA network. In [9], an adaptive resource allocation strategy for a TDD-TDMA frame structure was deduced in terms of slot allocation for cooperative relaying transmission. An interference-aware channel and time-slot allocation algorithm for TDMA WMNs was proposed in [10]. A resource allocation protocol for a packetized voice in a TDMA short-range wireless network was proposed in [11]. Jointly adaptive time sharing and power allocation for users in accordance with causal channel side information was proposed for an energy-efficient multiuser TDMA network in [12]. The performance of the resource allocation schemes in TDMA network of metropolitan area using HiperLAN type 2 standard was examined in [13]. On the other hand, the resource allocation schemes in [9-13] utilize the perfect channel state information (PCSI), and utilizing the PCSI is not realistic in practice. The second category considers the resource allocation problem based on quantized feedback for a TDMA network. Mecking et al. proposed a 1-bit quantized feedback strategy and TDMA with a random scheduling strategy for fading multiple–access channels [15]. Marques et al. examined energy efficient TDMA over fading channels with finite-fate feedback in the power regime and proposed two joint quantization and resource allocation approaches [16]. Marques et al. divided the complicated problem at hand into three minimization sub-problems that relied on a coordinate descent approach to iteratively affect the energy efficiency for the TDMA network [17]. A power-efficient resource allocation scheme based on limited-rate feedback for the TDMA network was proposed in [18].

The present paper adopted the method of the primal-dual method and stochastic optimization tool to design the resource allocation scheme based on quantized feedback for TDMA WMNs. The proposed scheme could improve the energy efficiency and reduce the feedback overhead.

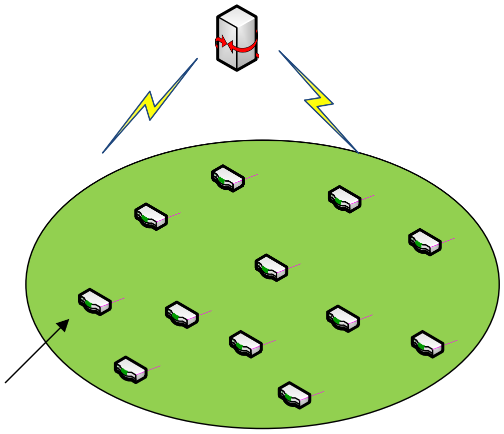

Fig. 1. Wireless mesh networks.

3. System Model and Problem Formulation

3.1 System Model

In the proposed model, a number of mesh routers were scattered around the wireline gateway to form a multi-hop network (see Fig. 1.). One mesh router was selected as a head node and the head node performed resource allocation scheme. Each mesh router was equipped with a single ominidirectional transceiver so that it could not transmit and receive simultaneously. A mesh router can be a transmitter, relay or receiver at different times. In this study, the network topology for WMNs was static and the channel gain can be estimated accurately in the receiver of each link. M active links in WMNs were assumed and TDMA technology was employed at the physical layer and a set of timeslots in a frame were assigned to each link. With TDMA technology, each mesh router can choose a set of timeslots for data transmission or reception.

3.2 Problem Formulation

Let $R_m^{\min}$ be the minimum transmission rate of the m th link and $\mathrm{BER}_m^{\mathrm{target}}$ be the target bit error rate (BER) requirement of the m th link. The optimization objective minimizes the average sum-power. The constraint condition is the minimum average transmission rate requirement for each link. With the above consideration, the optimization problem can be expressed as

$$\min : \sum_{m=1}^{M} \mathrm{E}_{h_m}\left[\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} p_{m,j}^i w_{m,j}^i(n)\right] \quad (1)$$

$$s.t. : \mathrm{C1.}\,\mathrm{E}_{h_m}\left[\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} b_{m,j}^i w_{m,j}^i(n)\right] \ge R_m^{\min}, \forall m \quad (2)$$

$$\mathrm{C2.}\sum_{m=1}^{M}\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} w_{m,j}^i(n) = 1,\, w_{m,j}^i(n) \in \{0,1\}, \forall m,j,i,n \quad (3)$$

$$\mathrm{C3.}\,\mathrm{BER}_m \le \mathrm{BER}_m^{\mathrm{target}}, \forall m \quad (4)$$

$$\text{C4.} b_{m,j}^{i} \ge 0,\ p_{m,j}^{i} \ge 0, \forall m, j, i \qquad (5)$$

where h_m is the equivalent channel gain of the m th link which is normalized by the noise power. $\mathrm{E}_{h_m}[\ ]$ represents the operation of solving the expectation value over h_m. $\left(b_{m,j}^{i}, p_{m,j}^{i}\right)$ represents the i th transmission rate and power mode pair over the j th equivalent channel quantization interval of the m th link. $w_{m,j}^{i}(n)$ represents the timeslot allocation indicator, such as $w_{m,j}^{i}(n)=1$, which represents the i th transmission mode over the j th equivalent channel quantization interval of the n th timeslot that is allocated to the m th link. BER_m represents the practical BER of the m th link. J_m is the number of equivalent channel quantization intervals for the m th link. I_m^j is the number of transmission modes over the j th equivalent channel quantization interval for the m th link.

(1) is the objective function. (2) guarantees the minimum transmission rate requirement for each link. (3) ensures that each timeslot can be allocated to only one link. (4) guarantees the target BER requirement for each link. (5) ensures that the resource allocation solution is feasible.

4. Resource Allocation Scheme based on quantized Feedback

h_m was assumed to be estimated accurately at the receiver. If h_m belongs to the quantization interval of $\left[q_m^j, q_m^{j+1}\right)$, h_m is replaced with q_m^j. q_m^j represents the j th equivalent channel quantization threshold of the m th link. $\left[q_m^j, q_m^{j+1}\right)$ represents the j th equivalent channel quantization interval of the m th link. Set $q_m^1=0$ and $q_m^{J_m+1}=+\infty$. The upper bound of Eq. (1) is minimized because the above optimization problem is difficult to solve.

4.1 Codebook Design of the Power, Rate and Equivalent Channel Quantization Threshold

Firstly, the codebook of the equivalent channel quantization threshold and the expression of the probability density function (PDF) $f_{h_m}(h)$ were deduced first. Set $h_m=|\gamma_m|^2/N_o$. γ_m denotes the channel gain of the m th link. N_o denotes the variance of the zero-mean additive Gaussian white noise. In this study, the hybrid channel model, which contains the path loss, shadow fading and small-scale fading, was considered. Because they are independent of each other, set $\gamma_m = g_m\sqrt{PL(d_m)S_m}$. g_m, S_m and $PL(d_m)$ denote small-scale fading, shadow fading and path loss, respectively. d_m denotes the distance between transmitter and receiver for the m th link [20]. Set $\Omega_m = PL(d)S_m/N_o$ and $h_m=\Omega_m|g_m|^2$.

Because $|g_m|^2$ obeys the exponential distribution with the mean equal to 1, and S_m obeys the lognormal distribution with the mean equal to 0, Ω_m obeys the lognormal distribution. The PDF could be yielded for Ω_m by (6)

$$f_{\Omega_m}(\omega)=\frac{\xi_m}{\sqrt{2\pi}\omega\sigma_m}\exp\left[-\frac{\left(10\log_{10}\omega-\mu_m(d_m)\right)^2}{2\sigma_m^2}\right] \qquad (6)$$

In (6), $\mu_m(d)=10\log_{10}\left(PL(d_m)/N_o\right)$ and $\xi_m = 10/\ln 10$. σ_m is the standard deviation of $10\log_{10}S_m$. The conditional PDF $f_{h_m|\Omega_m}(h|\omega)$ obeys the exponential distribution, so h_m obeys the Gamma-Lognormal distribution [21]. PDF for h_m can be obtained using (7).

$$f_{h_m}(h)=\int_0^{+\infty}\frac{1}{\omega}\exp\left(-\frac{h}{\omega}\right)f_{\Omega_m}(\omega)\,d\omega \qquad (7)$$

In this paper, the equal probability quantization method was used to design the codebook of the equivalent channel quantization threshold and q_m^j could be obtained using (8).

$$\int_{q_m^j}^{q_m^{j+1}} f_{h_m}(h)dh=\frac{1}{J_m},\quad j=1,\cdots,J_m \qquad (8)$$

Let $S_m=\left\{\left(b_{m,j}^{i}, p_{m,j}^{i}\right)\middle| j=1,\cdots,J_m; i=1,\cdots,I_m^j\right\}$ denote a set of the transmission rate and power mode pair, and was designed according to the nonzero uniform random samples of the continuous water-filling solution [22]. S_m was stored in the transmitter and receiver of the m th link. When the receiver of the m th link estimates $h_m(n)$ and knows $\mathrm{BER}_m^{\mathrm{target}}$, the effective transmission mode set $ES_m(n)$ can be obtained by (9). $h_m(n)$ is the equivalent channel gain of the m th link at the n th timeslot. $ES_m(n)$ is the effective transmission mode set of the m th link at the n th timeslot.

$$\begin{cases} ES_m(n)=\left\{(j,i)\middle|\mathrm{BER}\left[b_{m,i}^{j}, p_{m,i}^{j} \mid h_m(n)\right]\le \mathrm{BER}_m^{\mathrm{target}}\right\} \\ \mathrm{BER}\left[b_{m,i}^{j}, p_{m,i}^{j} \mid h_m(n)\right]=0.2\exp\left(-\frac{1.6p_{m,i}^{j}h_m(n)}{2^{b_{m,i}^{j}}-1}\right) \end{cases} \qquad (9)$$

4.2 Timeslot Allocation Criterion

Secondly, the timeslot allocation criteria were deduced. Because Eqs. (4) and (5) have been satisfied by (9), the above optimization problem could be rewritten as

$$\begin{aligned} &\min : \sum_{m=1}^{M} \mathrm{E}_{h_m}\left[\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} p_{m,j}^{i} w_{m,j}^{i}(n)\right] \\ &s.t.: \mathrm{C1.}\ \mathrm{E}_{h_m}\left[\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} b_{m,j}^{i} w_{m,j}^{i}(n)\right] \ge R_m^{\min}, \forall m \\ &\quad \mathrm{C2.}\sum_{m=1}^{M}\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} w_{m,j}^{i}(n) \le 1, w_{m,j}^{i}(n) \ge 0, \forall m, j, i, n \end{aligned} \tag{10}$$

The optimization problem in (10) could be solved using the primal-dual method. Let $\alpha_m^b(n)$ be the Lagrange multiplier associated with $C1$ in (10). The Lagrange function $f_L\left(\alpha_m^b(n), w_{m,j}^i(n)\right)$ without considering $C2$ in (10) could be expressed as

$$\begin{aligned} f_L\left(\alpha_m^b(n), w_{m,j}^i(n)\right) &= \sum_{m=1}^{M} \mathrm{E}_{h_m}\left[\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} p_{m,j}^{i} w_{m,j}^{i}(n)\right] \\ &-\sum_{m=1}^{M} \alpha_m^b(n)\left\{\mathrm{E}_{h_m}\left[\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} b_{m,j}^{i} w_{m,j}^{i}(n)\right] - R_m^{\min}\right\} \end{aligned} \tag{11}$$

Define the Lagrange dual function, $f_{LD}\left(\alpha_m^b(n)\right)$ as

$$f_{LD}\left(\alpha_m^b(n)\right) = \min_{w_{m,j}^i(n)} f_L\left(\alpha_m^b(n), w_{m,j}^i(n)\right) \tag{12}$$

The dual optimization problem of (10) can be expressed as

$$\max_{\alpha_m^b(n)} f_{LD}\left(\alpha_m^b(n)\right) \tag{13}$$

To solve the optimization problem in (13), it is important to solve the optimization problem in (12). The optimization problem in (12) can be rewritten as

$$\begin{aligned} &\min : f_L\left(\alpha_m^b(n), w_{m,j}^i(n)\right) \\ &s.t.: \mathrm{C1}\ \sum_{m=1}^{M}\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} w_{m,j}^{i}(n) \le 1, \forall n \\ &\quad \mathrm{C2}\ \ w_{m,j}^{i}(n) \ge 0, \forall m, n, j, i \end{aligned} \tag{14}$$

Let $\alpha^w(n)$ and $\beta_{m,j,i}^w(n)$ be the Lagrange multiplier with C1 and C2 in (14), respectively. The Lagrange function, $ff_L\left(\alpha^w(n), \beta_{m,j,i}^w(n)\right)$, of (14) can be expressed as

$$\begin{aligned} ff_L\left(\alpha^w(n), \beta_{m,j,i}^w(n)\right) &= f_L\left(\alpha_m^b(n), w_{m,j}^i(n)\right) \\ &+\sum_{n=1}^{+\infty} \alpha^w(n)\left(\sum_{m=1}^{M}\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} w_{m,j}^{i}(n) - 1\right) \\ &-\sum_{n=1}^{+\infty}\sum_{m=1}^{M}\sum_{j=1}^{J_m}\sum_{i=1}^{I_m^j} \beta_{m,j,i}^w(n) w_{m,j}^{i}(n) \end{aligned} \tag{15}$$

Set the derivative of $ff_L\left(\alpha^w(n), \beta_{m,j,i}^w(n)\right)$ with respect to $w_{m,j}^i(n)$ equal to zero and use the KKT condition. (16) could be derived and $C_{m,j}^i(n)$ was defined as the m th link quality indicator function of the i th transmission mode over the j th equivalent channel quantization interval at the n th timeslot.

$$\begin{cases} C_{m,j}^i(n) f_{h_m}(h) + \alpha^w(n) - \beta_{m,j,i}^w(n) = 0 \\ C_{m,j}^i(n) = p_{m,j}^i - \alpha_m^b(n) b_{m,j}^i \end{cases} \tag{16}$$

Theorem 1: The timeslot allocation criteria are that the n th timeslot is allocated to the link with the minimum link quality indicator function.

$$w_{m^*,j^*}^{i^*}(n) = \begin{cases} 1, \left(m^*, i^*, j^*\right) = \arg\min\limits_{m,i,j} C_{m,j}^i(n) \\ 0, \text{else} \end{cases} \tag{17}$$

Proof: Assume that the network has three active links and the n th timeslot is allocated to the link 1, so $w_{1,j}^i(n) = 1$ and $\beta_{1,j,i}^w(n) = 0$. (18) can be obtained using (16)

$$C_{1,j}^i(n) f_{h_1}(h) + \alpha^w(n) = 0 \tag{18}$$

Assume the hybrid channel PDF for all active links are the same. (19) can be obtained using (16).

$$\begin{cases} C_{2,j}^i(n) f_{h_2}(h) + \alpha^w(n) - \beta_{2,j,i}^w(n) = 0 \\ C_{3,j}^i(n) f_{h_3}(h) + \alpha^w(n) - \beta_{3,j,i}^w(n) = 0 \end{cases} \tag{19}$$

(18) was placed into (19) to yield (20).

$$\begin{cases} f_{h_1}(h)\left[C_{2,j}^i(n) - C_{1,j}^i(n)\right] - \beta_{2,j,i}^w(n) = 0 \\ f_{h_1}(h)\left[C_{3,j}^i(n) - C_{1,j}^i(n)\right] - \beta_{3,j,i}^w(n) = 0 \end{cases} \tag{20}$$

According to the KKT conditions and $w_{2,j}^{i}(n)=0$, $w_{3,j}^{i}(n)=0$, $\beta_{2,j,i}^{w}(n)>0$, $\beta_{3,j,i}^{w}(n)>0$ and $C_{2,j}^{i}(n)>C_{1,j}^{i}(n)$, $C_{3,j}^{i}(n)>C_{1,j}^{i}(n)$ could be obtained using (20). Therefore, $C_{1,j}^{i}(n)$ is the minimum link quality indicator function.

According to theorem 1, the timeslot allocation scheme (TAS) is proposed.

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Timeslot Allocation Scheme (TAS)

Step 1: Find the most effective transmission mode of the $m^{th}$ link at the $n^{th}$ timeslot by (21).

    $\left(j_n^*, i_n^*\right) = \arg\min_{(j,i)\in ES_m(n)} C_{m,j}^{i}(n)$        (21)

Step 2: Find the most effective link at the $n^{th}$ timeslot by (22).

    $m_n^* = \arg\min_{m} C_{m,j_n^*}^{i_n^*}(n)$        (22)

Step 3: Obtain the timeslot allocation result by (23).

    $w_{m,j}^{i}(n) = \begin{cases} 1, m = m_n^*; (j,i) = \left(j_n^*, i_n^*\right) \\ 0, else \end{cases}$        (23)
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In TAS, $\left(j_n^*, i_n^*\right)$ is the most effective transmission mode at the n^{th} timeslot. m_n^* is the most effective link at the n^{th} timeslot. Step 1 finds the most effective transmission mode. Step 2 finds the most effective link. Step 3 obtains the timeslot allocation result.

4.3 Resource Allocation Scheme Based on Quantized Feedback for TDMA WMNs

Finally, the resource allocation scheme is proposed based on the quantized feedback (RAQF) for TDMA WMNs.

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Resource Allocation Scheme Based on Quantized Feedback (RAQF)

for $n = 1 : N$
    Step 1: The receiver of each link estimates $h_m(n)$ and quantifies $h_m(n)$ with (24). Use (9) to obtain $ES_m(n)$. The receiver of each link feedbacks the most effective transmission mode $\left(j_n^*, i_n^*\right)$ to the head node by (21).

        $j_m(n) = \left\{ j \middle| q_m^j \le h_m(n) < q_m^{j+1} \right\}$        (24)

    Step 2: The head node uses TAS to obtain the timeslot allocation result. $\alpha_m^b(n+1)$ is updated with (25) using the stochastic optimization tool and broadcasts the resource allocation result to the transmitter of each link.

        $\alpha_m^b(n+1) = \alpha_m^b(n) + \Delta\alpha\left(R_m^{\min} - \frac{1}{n}\sum_{i=1}^{n} R_m^n\right)$        (25)

    Step 3: Because of the codebook of transmission mode previously stored in each mesh router, the transmitter of each link selects the transmission mode according to the broadcasting.
end
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In RAQF, $j_m(n)$ is the quantization index of $h_m(n)$ for the m^{th} link at the n^{th} timeslot. $\Delta\alpha$ is the adjusting step length of $\alpha_m^b(n)$. $\alpha_m^b(n+1)$ is the Lagrange multiplier at the $n+1^{th}$ timeslot. R_m^n is the transmission rate of the m^{th} link at the n^{th} timeslot. N is the total number of simulation timeslots. Step 1 quantifies $h_m(n)$ for each link. Step 2 performs the resource allocation scheme. Step 3 completes the transmission for each link.

4.4 Analysis of the Computational Complexity and Feedback Overhead

In RAQF, the computational complex of step 1 is $O(3MN)$. Step 2 is $O(MN+M+N)$. Step 3 is $O(MN)$. The total computational complex of RAQF is $O(5MN+M+N)$.

In RAQF, the receiver of each active link feedbacks $\sum_{j=1}^{J_m}\log_2\left(I_m^j\right)$ bits to the head node in step 1. The head node feedbacks $\log_2(M)+\sum_{j=1}^{J_m}\log_2\left(I_m^j\right)$ bits to each link in step 2. The total feedback overhead of RAQF is $\sum_{j=1}^{J_m}\log_2\left(I_m^j\right)+\log_2(M)+\sum_{m=1}^{M}\sum_{j=1}^{J_m}\log_2\left(I_m^j\right)$.

5. Simulation Results and Analysis

The WMNs with several mesh routers located in a 1km × 1km coverage area was considered. The noise power was $N_o = 1\times10^{-12}$ W and the available system bandwidth was 500 KHz. The large-scale fading adopted the channel model suggested in [23]. The shadow fading was 10.6 dB. The small-scale fading adopted the Rayleigh fading channel with an exponential power delay. The routing was assumed to be predetermined and the duration of a frame was 9 ms, which contains 450 timeslots. The MORR scheme and WMORR scheme in [13] were adopted to compare with the RAQF scheme. On the other hand, the MORR scheme and WMORR scheme adopted the analog value feedback. The two schemes were improved to make them with quantized feedback.

The improved MORR scheme is that timeslot allocation criterion adopts the MORR scheme in [13] and the codebook of the rate, power and equivalent channel quantization threshold adopts the codebook designed in our paper.

The improved WMORR scheme is that timeslot allocation criterion adopts the WMORR scheme in [13] and the codebook of the rate, power and equivalent channel quantization threshold adopts the codebook designed in the present paper.

Fig. 2 depicts the relationship between the average transmission rate of each link and the timeslots index for the RAQF. The number of active links was 4. The minimum transmission rate requirements was [50 100 150 200] Kbps. The target BER requirement for the m^{th} link was $\text{BER}_m^{\text{target}} = 1\times10^{-4}$. The number of equivalent channel quantization intervals for the m^{th} link was $J_m = 6$. In each equivalent channel quantization interval, the number of transmission modes was $I_m^j = 6$. Fig. 2 shows that the RAQF could satisfy the minimum transmission rate requirement for each link and the average transmission rate for each link converges rapidly to the minimum transmission rate requirement.

Fig. 3 presents the relationship between the total average transmission power and the timeslot index for different schemes. The number of active links was 6. The minimum transmission rate requirements were [50 50 100 100 100 100] Kbps. The target BER requirement for the m^{th} link was $\text{BER}_m^{\text{target}} = 1\times10^{-4}$. The number of equivalent channel quantization intervals for the m^{th} link was $J_m = 6$. In each equivalent channel quantization interval, the number of transmission modes was $I_m^j = 6$. Fig. 3 shows that RAQF could achieve the smallest total average transmission power, and the total average transmission power of the Improved MORR was the largest.

Fig. 4 shows the relationship between the total average transmission power and number of quantization codebooks for the different schemes. The number of active links was 6. The minimum transmission rate requirements were [50 50 100 100 100 100] Kbps. The target BER requirement for the m^{th} link was $\text{BER}_m^{\text{target}} = 1\times10^{-4}$. Fig. 4 shows that RAQF could achieve a smaller total average transmission power than the Improved MORR and Improved WMORR in all cases. As the number of quantization codebooks increased, the total average transmission power for different schemes decreased and the decreasing trend became slow.

Fig. 5 depicts the relationship between the total average transmission power and the target BER for different schemes. The number of active links was 6. The minimum transmission rate requirements were [50 50 100 100 100

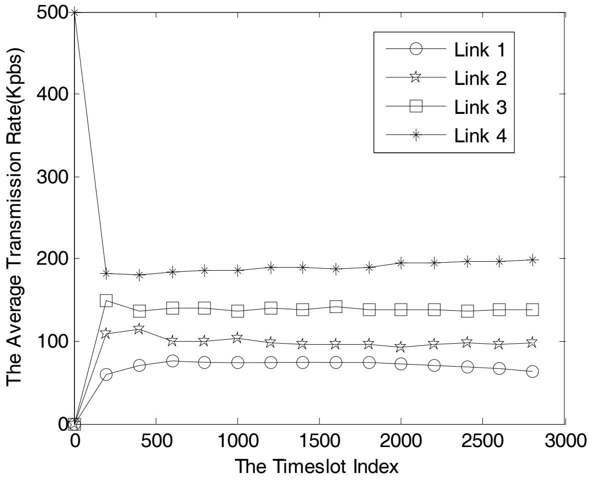

Fig. 2. Average transmission rate of each link as a function of the timeslot index.

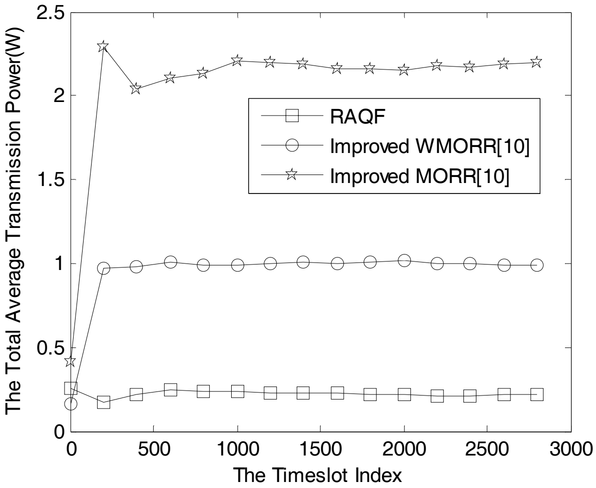

Fig. 3. Total average transmission power as a function of the timeslot index.

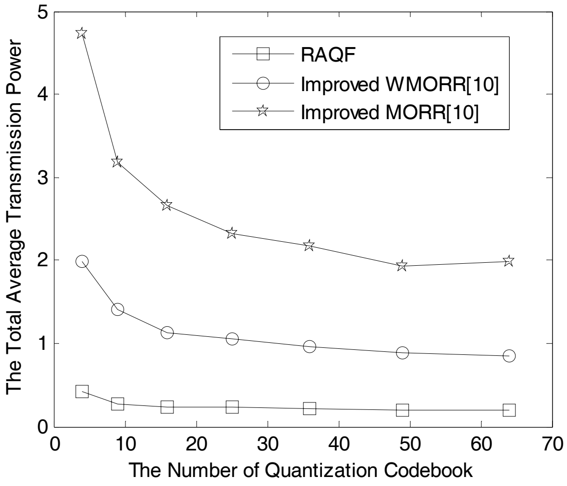

Fig. 4. Total average transmission power as a function of the number of quantization codebook.

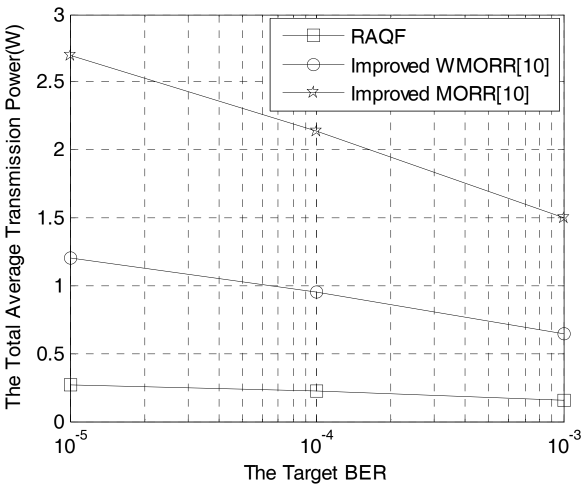

Fig. 5. Total average transmission power as a function of the target BER.

100] Kbps. The number of equivalent channel quantization intervals for the m^{th} link was $J_m = 6$. In each equivalent channel quantization interval, the number of transmission modes was $I_m^j = 6$. Fig. 5 shows that the RAQF has the lowest total average transmission power, and the Improved MORR has the largest total average transmission power in all cases. When the target BER requirement for each link is equal to 1×10^{-3}, the total average transmission power of RAQF was approximately 0.49W smaller than Improved WMORR and the total average transmission power of Improved WMORR was approximately 0.85W smaller than the Improved MORR. Figs. 4 and 5 show that the RAQF not only reduces the total average transmission power effectively, but also has the advantage of quantized feedback.

6. Conclusion

This study examined the resource allocation problem based on the quantized feedback for TDMA WMNs. The resource allocation problem based on quantized feedback was solved in two stages. The first stage designs the codebook of the rate, power and equivalent channel quantization threshold, which is offline computational. The second stage proposes the resource allocation scheme based on quantized feedback (RAQF) for TDMA WMNs, which is online computational, and utilizes the stochastic optimization tool. In the simulation, the RAQF could achieve the tradeoff between the total average power and the feedback overhead.

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