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Energy Sharing-Based Energy and User Joint Allocation Method in Heterogeneous Network

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ABSTRACT Heterogeneous network, which is a key technology of fifth generation(5G) mobile communication system, can effectively solve the spectrum resource shortage in the communication system. However, with densified deployment of base stations (BSs) and growth of user quantity and communication data size, the system energy consumption of BSs has imposed enormous economic pressure on network operators. As a result, energy consumption decreases and cost of communication system becomes a problem that requires urgent solutions. Renewable energy power generation devices of BSs have provided an opportunity for solving this problem with the development of smart power grids. However, the production rate of renewable energy sources presents intense volatility because of the influence of weather factors. This condition brings new challenges to the energy allocation of communication system. Therefore, an energy sharing link between BSs was established in a heterogeneous wireless network, and the distance between macro-BS and micro-BS was taken as an index. The energy consumption-based energy and user joint allocation method and energy cost-based energy and user joint allocation method were proposed. The two multi-objective optimization problems were converted into two convex optimization problems, and the optimal allocation strategies were solved using convex optimization toolbox. Simulation results indicate that the energy consumption-based allocation method takes energy consumption as the optimization objective and makes the shared link transmit energy sources as few as possible. This way reduces energy consumptions of the link and the system. Starting from the economic angle, the energy cost-based allocation method considers the influence of energy price, coordinates energy allocation between BSs based on energy cost using the shared link, and optimizes energy allocation among BSs at each time slot. Therefore, the method can reduce the energy cost of the system by a large margin.

INDEX TERMS 5G, energy sharing, green communication, energy allocation, user allocation, convex optimization.

I. INTRODUCTION

In recent years, the energy consumption of information and communication technology (ICT) has become an economic issue for operators and a major challenge for sustainable development. The energy consumption of the ICT industry accounts for approximately 3% of global annual energy consumption, and this figure is growing at an annular rate of 15%–20% [1]. With the rapid development of wireless communication technology and Internet of Things (IoT) technology [2], the quantity of equipment connected to wireless communication base stations (BSs) will present exponential growth in the future. By 2020, the demand for high-speed data traffic, such as high-quality wireless video streaming, social networking services, and IoT communication, will grow by 1,000 times [3]. If effective measures are not taken, then mobile communication will consume more energy sources with large-scale deployment of 5G systems within global scope. In reality, the wireless access part is the primary energy consumption part in the traditional wireless network system and accounts for over 70% of total energy consumption [4]. Therefore, overcoming challenges brought by continuous growing demand for energy consumption and communication throughput and reasonably allocating energy sources and users needing services among the BSs will be important.

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By 2025, the quantity of connecting devices in wireless network will increase swiftly to 30 billion. For such a large quantity of IoT equipment, network energy consumption has become a critical issue, and the traditional thermal power-based solutions are no longer sustainable for high cost and environmental problems of traditional energy sources [5]–[8]. Equipping BSs with a certain quantity of renewable energy power generation devices to provide energy sources for BSs in large-scale IoT systems has become a potential solution. Renewable energy sources not only can mitigate the impact of greenhouse gases on the environment but also can effectively lower the energy cost of BS systems. Renewable energy productivity is seriously impacted by weather conditions. Thus, their production rate presents strong volatility, and providing energy for BS systems purely by using renewable energy power generation devices will probably seriously influence the performance of cellular networks. Therefore, the hybrid energy supply mode of renewable and traditional energy sources not only can avoid communication outage caused by fluctuation of production rate of renewable energy sources but also can realize energy saving of BS systems and effectively reduce the energy cost of cellular network communication systems [9].

Literature [10]–[12] comprehensively studied the use of renewable energy sources as an alternative method of power supply for cellular networks. Renewable energy power generation devices, such as solar cell panels and wind turbines, are installed at sites of a BS to provide the possibility for the mobile operator to acquire green and low-cost electricity. This approach relieves the dependence on external energy retailers and contributes to lowering the pressure from downward energy price. Literature [13] investigated multilevel energy distribution and multi-station energy balance problems to realize grid-connected energy saving. The energy shortage of the BS can be compensated by purchasing electric power from smart power grids due to smart two-way electricity flow provided by smart power grids, and the residual power can be sold back to power grids. If a common energy infrastructure is constructed between BSs to collaborate distributed renewable energy sources for jointly serving energy demands of all BSs, then the cost effectiveness will increase [14].

Energy sharing can make BS take better advantages of locally produced RE and further lower the energy cost by reducing the procurement from smart grid (SG). However, an effective energy transmission mechanism is needed to realize energy sharing between BSs. SG can realize virtual energy transmission by selling additional energy at a BS and purchasing the same amount of energy from another BS. Energy cost and operator income are very sensitive to the change in SG's price policy. Another energy sharing method is to connect BSs through physical power lines. Even though long-distance transmission cannot be realized due to high installation cost, resistance power consumption, and limitation of right of transit, physical power lines can be installed in a micro-cell to realize energy sharing between BSs. In this way, operators will not share any additional energy cost within short distances, and their profits will robustly influence the energy transaction price of SG [15].

Cellular network traffic presents great nonuniformity and spatiotemporal fluctuation, which will introduce opportunities and challenges to planning and management of cellular networks. Deploying micro-BSs (PBSs) to shorten the distance between BS and user equipment can effectively solve the spatial nonuniformity problem to unload overload business in macro-cell and enhance the capacity and energy efficiency of wireless networks. Multilayer heterogeneous network constituted by micro-cells and micro-cell cells (e.g., micro micro-cell, femto-cell, and relay node) has become a critical technology of 5G systems [16]. Multilayer cell heterogeneous network can deploy micro micro-cell in hotspot regions in macro-cell to improve the coverage area and increase the system capacity exceeding the macro-cell under initial deployment. Thus, this network is promising and can satisfy continuously growing data traffic demand and reduce the energy consumption. Heterogeneous network helps in solving the network coverage and elevating the network capacity; however, many important problems with regard to heterogeneous network remain to be solved, such as user allocation, resource allocation, and quality of service (QoS) configuration [17]–[22].

Literature [23] set the priority level for service equipment, investigated user relevance (e.g., BS selection, channel allocation, and mode selection) and power control and optimized uplink energy efficiency of secondary users and BS communication system to solve the user and energy allocation problem of heterogeneous network and improve the reasonability of renewable energy utilization in BS system. In consideration of a large-scale MIMO heterogeneous cellular network, Literature [24] designed a relevance strategy realizing weighting and energy maximization and studied the effects of quantity of large-scale antennas and transmitted power of each PBS on relevance performance. Literature [25] proposed a smart energy management system by constructing microgrid between macro-BS and PBS and judged whether to share energy sources according to energy consumption of users served by MBS and surplus of renewable energy sources stored at PBS. Literature [26] built an energy sharing model under multi-BS conditions, proposed two indexes constructed by energy sharing link, and realized energy sharing under three circumstances, namely, unknown, partially known, and completely known productivity information. Energy costs of BSs with and without energy sharing were compared as well.

Renewable energy power generation device will have surplus energy in some cases when supplying power for BS, while the energy may be insufficient at other times. The energy sharing mode can effectively solve this problem. In the allocation process for each user, the role played by renewable energy sources in reducing the energy cost can be fully exerted and partial surplus renewable energy sources can be supplied to BS. This way provides additional service for this user in way of energy compensation via energy sharing link to allocate energy sources reasonably while realizing user allocation. Meanwhile, this approach can help further reduce the energy cost of the communication system.

The user and energy joint allocation problem under random energy and communication traffic at MBS and PBS in heterogeneous network was considered in this study. Minimizations of energy consumption and cost were taken as objective functions, and energy compensation was conducted through energy sharing link in the process of user allocation of BS system to reduce energy pressure of BS serving many users. As a result, the heterogeneous network could reasonably use renewable energy sources of BS and effectively reduce system energy cost while satisfying the rate needed by users. The objective functions were two multi-objective optimization problems, the restrictive condition satisfied convex optimization condition, and the objective functions were solved through the convex optimization scheme. By comparing the two schemes, the joint allocation scheme taking energy consumption as objective function could realize the minimum energy consumption, while the joint allocation scheme taking the energy cost as the optimization objective increased price constraint conditions. The final optimization result could minimize the system energy cost and reduce the network operating cost. The proposed joint allocation scheme can also be applied to IoT system. The equipment quantity and data size needing processing in IoT are enormous, which is similar to the challenge of the proposed communication network. Therefore, the proposed joint allocation scheme can effectively solve the energy and equipment allocation problem.

The remainder of this paper is organized as follows. Section II introduces the system model and provides the power and energy consumption model. Section III describes the energy and user joint allocation schemes, namely, joint allocation schemes with minimizations of energy consumption and cost being the objective functions. Section IV gives and analyzes the simulation results. Section V elaborates the conclusions.

II. SYSTEM MODEL

A downlink system model of two-layer heterogeneous network constituted by an MBS and N_P ($N_P = N - 1$) PBSs is constructed. The total number of BS is $n = \{1, 2, \ldots, N\}$. For the convenience of analysis without loss of generality, $n = 1$ represents MBS and $n \neq 1$ is PBS. The MBS is configured with L_M ($L_M > 1$) antennas, each PBS is configured with $L_P (1 < L_P < L_M)$ antennas, and MBS and each PBS serve K_M ($K_M \leq L_M$) and K_P ($K_P \leq L_P$) single-antenna users at every time slot. Users are assumed to present a random distribution within the coverage of each BS. As shown in Fig. 1, all BSs share the same frequency spectrum within the same time slot, and each BS is equipped with mutually independent renewable energy power generation and energy storage devices. BS energy in the system is driven by three parts: energy supply by power grids, energy supply by renewable energy power generation devices, and energy sharing between other BSs. MBS differs from PBSs in aspects such as transmitted power, propagation characteristics, backhaul, operating cost, and deployment convenience. No delay of link backhaul is assumed between BS and user, and state information is assumed to be completely known.

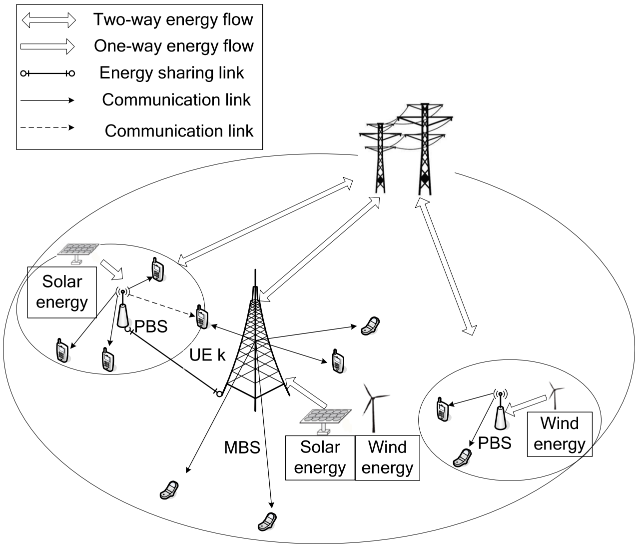

FIGURE 1. **System model.**

The baseband signal received by user k in macro-cell is

$$y_{1,k} = \underbrace{\sqrt{\beta_{1,k}} h_{1,k}^{H} v_{1,k} s_{1,k}}_{\text{useful signal}} + \underbrace{\sum_{i \in K_M/\{k\}} \sqrt{\beta_{1,k}} h_{1,k}^{H} v_{1,i} s_{1,i}}_{\text{UE interference(come from MBS)}} + \underbrace{\sum_{n \in N_P} \sum_{j=1}^{K_P} \sqrt{\beta_{n,k}} h_{n,k}^{H} v_{n,j} s_{n,j}}_{\text{BS interference(come from PBS)}} + n_{1,k}, \quad (1)$$

where $\sqrt{\beta_{1,k}}$ is the large-scale fading from MBS to user k; $\mathbf{h}_{n,k} = \left[h_{1,k}, \ldots, h_{n,k}, \ldots, h_{N,k}\right]^T$ is the small-scale fading from BS $n\,(n \in N)$ to user k, and $h_{n,k} \in \mathcal{CN}\,(0, 1)$; $v_{1,k} \in \mathbb{C}^{N_M}$ is the pre-coding vector from MBS to user k; $s_{1,k}$ is the information sent by MBS to user k; $v_{1,i} \in \mathbb{C}^{N_M}$ denotes the pre-coding vector from MBS to user i in the macro-cell; $s_{1,i}$ is the information sent by MBS to user i in the macro-cell; $\sqrt{\beta_{n,k}}$ is the large-scale fading from PBS $n\,(n \in N_P)$ to user k; $v_{n,j} \in C^{N_P}$ and $s_{n,j}$ are the pre-coding vector and information from PBS $n\,(n \in N_P)$ to user j in the micro-cell; $n_{1,k} \sim \mathcal{CN}\left(0, \sigma_k^2\right)$ is Gaussian noise.

The baseband signal received by user k in micro-cell $n\,(n \in N_P)$ is

$$y_{n,k} = \underbrace{\sqrt{\beta_{n,k}} h_{n,k}^{H} v_{n,k} s_{n,k}}_{\text{useful signal}} + \underbrace{\sum_{i=1}^{K_M} \sqrt{\beta_{1,k}} h_{1,k}^{H} v_{1,i} s_{1,i}}_{\text{BS interference(come from MBS)}} + \underbrace{\sum_{j' \in K_P \backslash \{k\}} \sqrt{\beta_{n,k}} h_{n,k}^{H} v_{n,j'} s_{n,j'}}_{\text{UE interference(come from PBS}n)} + n_{n,k}, \quad (2)$$

where $v_{n,k} \in \mathbb{C}^{N_P}$ is the pre-coding vector from PBS $n\,(n \in N_P)$ to user k; $s_{n,k}$ is the information sent by PBS $n\,(n \in N_P)$ to user k; $v_{n,j'} \in C^{N_P}$ is the pre-coding vector from PBS n to other users $j'\,\left(j' \neq k\right)$ in this cell; $x_{n,j'}$ is the information sent by PBS n to other users $j'\,\left(j' \neq k\right)$ in this cell; $n_{n,k} \sim \mathcal{CN}\left(0, \sigma_{n,k}^2\right)$ is the Gaussian noise.

The interference between multiple users in each cell is eliminated following the ZF pre-coding technology reported in Literature [30]. For macro-cell users, $\mathbf{H}_{1,K_M} = \left[h_{1,1}\ h_{1,2}\ \ldots\ h_{1,K_M}\right]$, where $L_M \gg K_M$, the transposed matrix is $\mathbf{H}_{1,,K_M}^H = \left[h_{1,1}^H; h_{1,2}^H; \ldots; h_{1,K_M}^H\right]$, and $\mathbf{V}_{1,K_M} \triangleq \mathbf{H}_{1,K_M}(\mathbf{H}_{1,K_M}^H\mathbf{H}_{1,K_M})^{-1} = \left[v_{1,1} \ldots v_{1,K_M}\right]$ is defined. Then,

$$\begin{aligned}\mathbf{I} &= \mathbf{H}_{1,K_M}\mathbf{V}_{1,K_M}\\ &= \begin{bmatrix} \mathrm{h}_{1,1}^{\mathrm{H}}v_{1,1} & \mathrm{h}_{1,1}^{H}v_{1,2} & \cdots & \mathrm{h}_{1,1}^{H}v_{1,K_M}\\ \mathrm{h}_{1,2}^{H}v_{1,1} & \mathrm{h}_{1,2}^{H}v_{1,2} & \cdots & \mathrm{h}_{1,2}^{H}v_{1,K_M}\\ \vdots & \vdots & \vdots & \vdots\\ \mathrm{h}_{1,K_M}^{H}v_{1,1} & \mathrm{h}_{1,K_M}^{H}v_{1,2} & \cdots & \mathrm{h}_{1,K_M}^{H}v_{1,K_M}\end{bmatrix}\\ &= \left[\mathrm{h}_{1,i}^{H}v_{1,j}\right]_{(i,j)\in K_M\times K_M}.\end{aligned} \tag{3}$$

Thus, $\mathrm{h}_{1,i}^{H}v_{1,i} = 1$ and $\mathrm{h}_{1,i}^{H}v_{1,j} = 0\ \forall i \neq j$. The normalized vector is $\tilde{v}_{1,k} \triangleq v_{1,k}/\left\|v_{1,k}\right\|, k = 1, \ldots, K_M$, the pre-coding vector of MBS is $v_{1,k} = \tilde{v}_{1,k}\sqrt{p_{1,k}}, k = 1, \ldots, K_M$, and the multi-user interference in macro-cell is eliminated: $h_{1,k}^{H}v_{1,i} = 0\ \forall k \neq i$.

The rate of user k in macro-cell is

$$r_{1,k} = B\log\left(1 + \frac{p_{1,k}\beta_{1,k}\left|h_{1,k}^{H}\tilde{v}_{1,k}\right|^2}{\sigma_{1,k}^2}\right). \tag{4}$$

The power of PBS is far smaller than that of MBS. Thus, the multi-user interference in PBS is neglected. For micro-cell users, $\mathbf{H}_{n,K_P} = \left[h_{n,1}\ h_{n,2}\ \ldots\ h_{n,K_P}\right]$, where $L_P \geq K_P$, the transposed matrix is $\mathbf{H}_{n,K_P}^H = \left[h_{n,1}^H; h_{n,2}^H; \ldots; h_{n,K_P}^H\right]$, and $\mathbf{V}_{n,K_P} \triangleq \mathbf{H}_{n,K_P}(\mathbf{H}_{n,K_P}^H\mathbf{H}_{n,K_P})^{-1} = \left[v_{n,1} \ldots v_{n,K_P}\right]$ is defined. Then,

$$\begin{aligned}\mathbf{I} &= \mathbf{H}_{n,K_P}\mathbf{V}_{K_P}\\ &= \begin{bmatrix} \mathrm{h}_{n,1}^{\mathrm{H}}v_{n,1} & \mathrm{h}_{n,1}^{H}v_{n,2} & \cdots & \mathrm{h}_{n,1}^{H}v_{n,K_P}\\ \mathrm{h}_{n,2}^{H}v_{n,1} & \mathrm{h}_{n,2}^{H}v_{n,2} & \cdots & \mathrm{h}_{n,2}^{H}v_{n,K_P}\\ \vdots & \vdots & \vdots & \vdots\\ \mathrm{h}_{n,K_P}^{H}v_{n,1} & \mathrm{h}_{n,K_P}^{H}v_{n,2} & \cdots & \mathrm{h}_{n,K_P}^{H}v_{n,K_P}\end{bmatrix}\\ &= \left[\mathrm{h}_{n,i}^{H}v_{n,j}\right]_{(i,j)\in K_P\times K_P}.\end{aligned} \tag{5}$$

Thus, $\mathrm{h}_{n,i}^{H}v_{n,i} = 1$ and $\mathrm{h}_{n,i}^{H}v_{n,j} = 0\ \forall i \neq j$, the normalized vector is $\tilde{v}_{n,k} \triangleq v_{n,k}/\left\|v_{n,k}\right\|, k = 1, \ldots, K_P, , n = 1, \ldots, N_P$ the pre-coding vector of MBS is $v_{n,k} = \tilde{v}_{n,k}\sqrt{p_{n,k}}, k = 1, \ldots, K_P, n = 1, \ldots, N_P$, and the multi-user interference in PBS is eliminated: $h_{n,k}^{H}v_{n,i} = 0\ \forall k \neq i$.

The rate of user k in PBS n is

$$r_{n,k} = B\log\left(1 + \frac{p_{n,k}\left|h_{n,k}^{H}\tilde{v}_{n,k}\right|^2}{\sum\limits_{i=1}^{K_M}\beta_{n,k}\left|h_{n,k}^{H}\tilde{v}_{1,i}\right|^2 + \sigma_{n,k}^2}\right), \tag{6}$$

where $P_{n,k}$ and P_k are the powers allocated by PBS n and MBS to the served user k and B is bandwidth.

III. ENERGY AND USER JOINT ALLOCATION PROBLEM

A. POWER MODEL

In this study, the power consumption of each BS contains three parts: the first part is the static power consumption of BS, which is mainly used to maintain basic circuit operation of the system, and static power consumptions of MBS and PBS are recorded as $P_{1,static}$ and $P_{n,static}\ (n \in N_P)$, respectively; the second part is the power consumption of antenna circuit, antenna power consumptions of MBS and PBS are recorded as $P_{1,\text{antenna}}$ and $P_{n,\text{antenna}}\ (n \in N_P)$ respectively, and it is related to the quantity of served users; the third part is the power consumption allocated by MBS and PBS to each served user, and power consumptions of MBS and PBS n are

$$P_{MBS} = P_{1,static} + K_M P_{1,antenna} + a_M\sum_{k=1}^{K_M}P_{1,k}, \tag{7}$$

$$P_{n,PBS} = P_{n,static} + K_P P_{n,antenna} + a_p\sum_{k=1}^{K_P}P_{n,k}, \quad n \in N_P. \tag{8}$$

The total power consumption of PBSs is

$$\begin{aligned}P_{PBS} &= \sum_{n=1}^{N_P}P_{n,PBS}\\ &= \sum_{n=1}^{N_P}\left(P_{n,static} + K_P P_{n,antenna} + a_p\sum_{k=1}^{K_P}P_{n,k}\right),\end{aligned} \tag{9}$$

where a_M and a_P are the power amplification coefficients of MBS and PBS, respectively.

The additional power and energy consumptions needed by the user s served by a PBS in each time slot are

$$P_{n,s} = P_{n,antenna} + a_p P_{n,k} \quad n \in N_P, \tag{10}$$

$$\Delta E_{n,s} = P_{n,s} \times \Delta t \quad n \in N_P. \tag{11}$$

The additional power and energy consumptions needed by the user s served by MBS in each time slot are

$$P_{1,s} = P_{1,antenna} + a_M P_{1,k} \tag{12}$$

$$\Delta E_{1,s} = P_{1,s} \times \Delta t. \tag{13}$$

The energy consumption of BS n in each time slot is

$$\Delta E_{n,t} = \begin{cases} P_{MBS} \times \Delta t, & n = 1\\ P_{n,PBS} \times \Delta t, & n > 1, n \in N,\end{cases} \tag{14}$$

B. ENERGY SHARING LINK

An energy sharing link will be established among BSs within a certain energy sharing range in way of physical connecting lines in this study. The energy sharing link can realize effective utilization of renewable energy sources of BSs, but the installation of energy sharing links is restricted by distance between BSs because operators need to pay additional installation cost to lay physical connecting lines. Notably, a large distance corresponds to large shared energy consumed by circuit consumption on physical connecting lines. The distance between MBS and PBS is small in heterogeneous network. Thus, the physical link laying method can be considered for energy sharing. For long distance where physical wiring is impossible, SG infrastructure can be used to implement energy transmission between BSs. However, SG will charge a certain expense for this service, which is reflected by the difference in selling and buying prices.

A functional relation of shared energy on connecting lines can be constructed with the length of ligature, and its expression [31] is

$$E_{n,loss}\left(E_{n,s}, l\right)=I_n^2 R_n(l)\Delta t=\frac{P_n^2 R_n(l)}{V^2}\Delta t=\frac{E_{n,s}^2 R_n(l)}{V^2\Delta t} \tag{15}$$

where I is the current of a physical connecting line, $R_n(l)$ is the resistance of the energy sharing link between PBS $n\,(n \in N_P)$ and MBS, l is the link length, and $R_n\,(l) = \rho l$. $E_{s,n}$ is total energy shared through the physical connecting line, and V is the root-mean-square voltage. This energy sharing model is only applicable to small cells with small BS spacing to avoid large loss of shared energy. The energy sharing link in this study is established only between BSs with distance satisfying $l \leq r$ km. From the perspective of an operator, establishing an energy sharing link only needs additional installation cost without any need of additional operating cost. The energy sources shared through physical links are not controlled by power grid. BS providing energy sources is named supplier BS and that receiving energy sources is named receptor BS. Shared energy sources are free for receptor BSs. The energy sharing circumstances in the link are as follows:

a. In the current time slot, number of servers served by the BS reaches the upper limit of antenna quantity in this BS. The BS is then forced to hand users in the cell over to a nearby BS to be served and shares partial energy sources through the link.

b. When the output of renewable energy sources exceeds the upper limit of energy consumed by all users, which are served by the BS, the surplus renewable energy sources will be shared to other BSs through the energy sharing link. This way reduces the system demand for traditional energy sources.

c. When the optimal user allocation strategy is calculated through the objective function and users in the cell are allocated to other BSs, the amount of shared energy sources will depend on the optimization result of the objective function.

If no energy sharing link exists between BSs under circumstances a and b, then energy sources will not be shared.

C. ENERGY AND JOINT ALLOCATION SCHEMES

For the multi-BS collaborative communication system, two energy and user joint allocation strategies were proposed in this study to optimize the amount of shared energy between BSs through physical connecting line and reduce total energy consumption and energy cost of the system. The joint allocation schemes are shown in Fig. 1. The BS system allocates users and energy sources by taking the minimizations of energy consumed by the served users and energy cost as objectives. During the user allocation process, the BS system will decide to share partial energy sources with BSs serving many users through the energy sharing link depending on the energy consumed by the users additionally served by the BS. As a result, the energy cost consumed by BSs serving many users can be decreased.

The energy shared by BS n through the physical connecting line is

$$E_{n,s}=\sum_{k=1}^{K_s}\Delta E_{n,s}=\sum_{k=1}^{K_s} x_{k,n}P_{n,s}\times\Delta t, \tag{16}$$

where K_s is the number of users additionally served by BS n within this time slot. $E_{s,n}$ is the energy shared through physical connecting line, and its value is negative at supplier BS side and positive at receptor BS side, depending on the energy needed by the receptor BS to serve this user within unit time slot. $x_{k,n}$ represents the allocation situation for user k in the cell; when it is equal to 1, this user is served by BS n; when it is 0, the user is not served by BS n.

The total energy consumption of MBS is

$$\mathrm{E}_{1,t}=\Delta E_{1,\mathrm{tra}}+\Delta E_{1,r}. \tag{17}$$

The total energy consumption of PBS n is

$$\mathrm{E}_{n,t}=\Delta E_{n,\mathrm{tra}}+\Delta E_{n,r},\quad n\in N_P, \tag{18}$$

where $E_{1,\mathrm{tra}}$ and $E_{n,\mathrm{tra}}$ ($n \in \{2, 3, \ldots, N\}$) are the consumptions of traditional energy sources by MBS and PBS, respectively. $E_{1,r}$ and $E_{n,r}$ ($n \in N_P$) are the consumptions of renewable energy sources by MBS and PBS, respectively.

Minimizations of total energy consumption and cost of the communication system were taken as the objective functions to perform joint energy and user allocation. The allocation scheme, which took energy consumption as objective function, mainly considered the minimization of BS energy consumption while ignoring energy price. However, the allocation scheme based on energy consumption further considered the effect of energy price on operator expense in BS energy consumption and explored the network operating cost problem.

D. JOINT ALLOCATION SCHEME BASED ON ENERGY COMSUMPTION

User k is assumed to be served by PBS1 within time slot t. In time slot $t+1$, the system energy consumptions allocated by the user to PBS1 and MBS are calculated according to user rate, received power, and generation situation of renewable energy sources. The minimal system energy consumption is taken as the optimization objective. If the user is still served by PBS1 within time slot t + 1, then energy sources will not be shared through the link. If the user k is allocated to MBS within time slot t + 1, then PBS1 shares partial energy sources to MBS through the energy sharing link. This way compensates for the energy cost consumed by the user k, which is served by MBS.

In this allocation scheme, the minimization of total energy consumed by the communication system is taken as the objective function:

$$\underset{t\in T}{\text{minmize}}\ \mathrm{E}_t = \sum_{n=1}^{N} \Delta E_{n,t} \tag{19}$$

$$\textbf{s.t.} \sum_{n=1}^{N} x_{k,n} = 1, \quad \forall k \in K, x_{k,n} = \{0, 1\}, \tag{19a}$$

$$\sum_{n=1}^{N}\sum_{k=1}^{K} x_{k,n} = K, \tag{19b}$$

$$E_{1,s} = \sum_{n=2}^{N} E_{n,s} - E_{n,loss}, \quad n \in \{2, 3, \ldots, N\}, \tag{19c}$$

$$\sum_{n=1}^{N} x_{k,n} P_n \leq P_n^{\max}, \quad P_n \geq 0, \tag{19d}$$

$$\sum_{n=1}^{N} x_{k,n} r_{k,n} \geq r_{k,n}^{\min}, \tag{19e}$$

where (19a) indicates that each user can only be served by one BS and (19b) implies that the total sum of numbers of users served by all cells is equivalent to the total number of users in the heterogeneous network system, namely, each user can be served by a BS without communication outage event. (19c) expresses that the shared energy received by MBS is equivalent to the difference value between energy provided by supplier BS and link loss, namely, meeting the law of conservation of energy. As shown in (19d), the transmitted power of BS shall not exceed the upper limit of its transmitted power. (19e) indicates that user's receiving rate should satisfy the demand for minimum receiving rate. Except for (19c), optimization objective and constraint condition are linear. The constraint condition (19c) contains a convex quadratic term, which is already given in Formula (15). Therefore, the minimization problem of Formula (19a) can be solved using the existing convex optimization scheme [28].

E. JOINT ALLOCATION SCHEME BASED ON ENERGY COST

User k is assumed to be served by PBS1 in time slot t. In time slot $t + 1$, the system energy consumptions allocated by the user to PBS1 and MBS are calculated according to user rate, received power, and generation situation of renewable energy sources. The minimal system cost is taken as the optimization objective. If the user is still served by PBS1 within time slot t + 1, then energy sources will not be shared through the link. If the user k is allocated to MBS within time slot t + 1, then PBS1 shares partial energy sources to MBS through the energy sharing link. Accordingly, the energy cost consumed by the user k, which is served by MBS, can be compensated.

In this allocation scheme, the minimization of total energy cost of the communication system is taken as the objective function:

$$\underset{t\in T}{\text{min imize}}\ Q_t = \sum_{n=1}^{N} \Delta E_{n,t} \times a_t - \sum_{n=1}^{N} E_{r,n} \times a_{re} + \sum_{n=1}^{N} \Delta E_{s,n} \times a_s \tag{20}$$

$$\textbf{s.t.} \sum_{n=1}^{N} x_{k,n} = 1, \quad \forall k \in K, x_{k,n} = \{0, 1\}, \tag{20a}$$

$$\sum_{n=1}^{N}\sum_{k=1}^{K} x_{k,n} = K, \tag{20b}$$

$$E_{1,s} = \sum_{n=2}^{N} E_{n,s} - E_{n,loss}, \quad n \in \{2, 3, \ldots, N\}, \tag{20c}$$

$$\sum_{n=1}^{N} x_{k,n} P_n \leq P_n^{\max}, \quad P_n \geq 0, \tag{20d}$$

$$\sum_{n=1}^{N} x_{k,n} r_{k,n} \geq r_{k,n}^{\min}, \tag{20e}$$

$$0 < a_s < a_{re} < a_t \quad t \in T, \tag{20f}$$

where a_t is the price of traditional energy, which changes with time according to time-of-use electricity pricing strategy. a_{re} is price of renewable energy. a_s is price of shared energy (20a), which indicates that each user can only be served by one BS and (20b) implies that the total sum of numbers of users served by all cells is equivalent to the total number of users in the heterogeneous network system, namely, each user can be served by a BS without communication outage event. (20c) expresses that the shared energy received by MBS is equivalent to the difference value between energy provided by supplier BS and link loss, namely, meeting the law of conservation of energy. As shown in (20d), the transmitted power of BS shall not exceed the upper limit of its transmitted power. (20e) indicates that user's receiving rate should satisfy the demand for minimum receiving rate. (20f) is the constraint condition of energy price factor. The price of traditional energy source is the highest within each time slot. The price is zero (for free) under energy saving mode. The price of renewable energy source is lower than that of traditional energy source but is greater than zero. This part of expense is used to compensate for installation cost of renewable energy power generation devices deployed at BS. Optimization objective and constraint condition are linear. The constraint condition (20c) contains a convex quadratic term already given in Formula (15). Thus, the minimization problem of Formula (20) can be solved using the existing convex optimization scheme [28].

IV. SIMULATION PARAMETERS AND RESULTS

A two-layer heterogeneous communication network constituted by an MBS and two PBSs is mainly considered in this study. As shown in Fig. 1, MBS is located at coordinates (0,0). A total of 20 users are generated within its coverage in each time slot. The position of PBS depends on the hotspot region of actual user distribution. The deployment position of PBS will influence the energy sharing link established between it and MBS. We may assume that 4–6 users are randomly distributed within the coverage of each PBS in each time slot, and the maximum link of shared energy is r = 0.5 km. The MBS and each PBS are equipped with renewable energy power generation devices with different powders. The renewable energy power generation devices used in this study are solar cell panel and wind driven generator. Literature [28] argued that renewable energy power generation cycle is generally approximately 15 min. Thus, the time slot of productivity is $\omega_t = 15\,\text{min}$, and one cycle (namely one day) contains $T = 96$ time slots and recorded as $\Gamma = \{1, \ldots, T\}$. The solar power generation model follows Gaussian distribution, as shown in Formula (21):

$$\text{E\_Solar(t)} = \alpha_s \times E\_S \times \exp(-\frac{(t-\mu_t)^2}{81}), \tag{21}$$

where α_s is the random factor of solar energy productivity, which depends on weather conditions. E_S is the maximum generated power of solar device equipped in each BS, which depends on the scale of this power generation device. $\mu_t = 48$ indicates that the productivity of solar cell panel reaches the peak value at 12:00 at noon.

Wind energy productivity is a random value, and its power generation model is shown in Formula (22).

$$\text{E\_Wind(t)} = \alpha_w \times E\_W, \tag{22}$$

where α_w is the random factor of wind energy productivity, which is decided by weather conditions. E_W is the maximum generated power of wind energy power generation device, which is decided by the scale of this power generation device. Other simulation parameters are set as shown in Table 1.

TABLE 1. Simulation setup.

Parameter	MBS	PBS
Number of antennas	30	5
Transmission power (dBm)	40[29]	30[29]
Power amplification factor	4.7[30]	4.0[30]
Coverage radius (m)	500	50
Path loss (dB)	128.1+ 37.6lg dm[29]	140.7+ 36.7lg dp[29]
Bandwidth	10Mhz[30]	
Noise power (dBm/Hz)	-174[30]	
Static power loss (w)	780[29]	13.6[29]
Antenna power (dBi)	18[31]	4[31]
Maximum generating power (kw)	20	2

Figs. 2 and 3 show the total energy consumptions of the system, MBS, PBS1, and PBS2 in each time slot under the energy consumption- and energy cost-based joint allocation schemes, respectively. Fig. 2 shows the energy consumption when energy consumption is taken as the objective function, and the total energy consumption of the system is 5.52×10^4 kW·h. Fig. 3 shows the energy consumption when energy consumption is the objective function, and the total energy consumption of the system is 8.15×10^4 kW·h. The joint allocation scheme based on energy consumption can save more energy sources for the system. Comparison of BS energy consumptions under the two allocation schemes shows that more users in micro-cell are allocated to PBSs in the energy consumption-based allocation scheme. Thus, the energy consumption of PBSs is smaller than that in other scheme. However, the energy cost-based allocation scheme will consider energy cost and hand more users over to PBSs with greater productivity of renewable energy sources. Each time users are allocated, the corresponding energy should also be allocated for compensation. Thus, the energy consumed will be greater under this scheme.

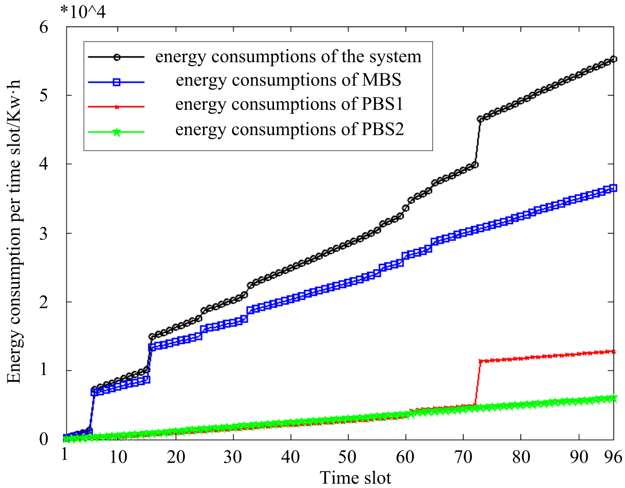

FIGURE 2. Energy consumption of each time slot under the energy consumption-based joint allocation scheme.

Fig. 4 displays the total energy consumptions of the system under different allocation schemes. As observed, the total energy consumption under the traditional energy supply

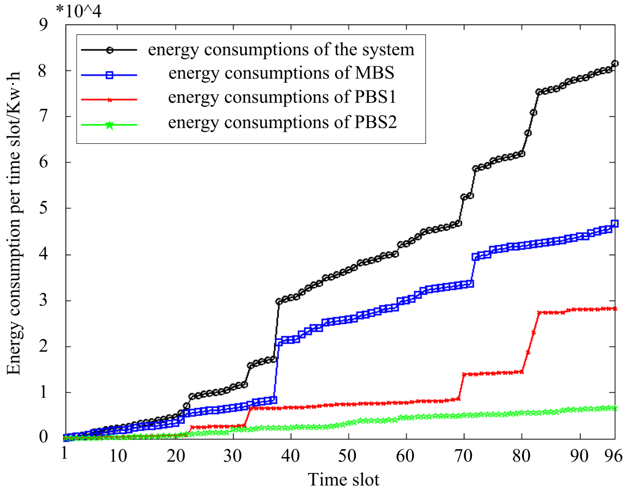

FIGURE 3. Energy consumption of each time slot under the energy cost-based joint allocation scheme.

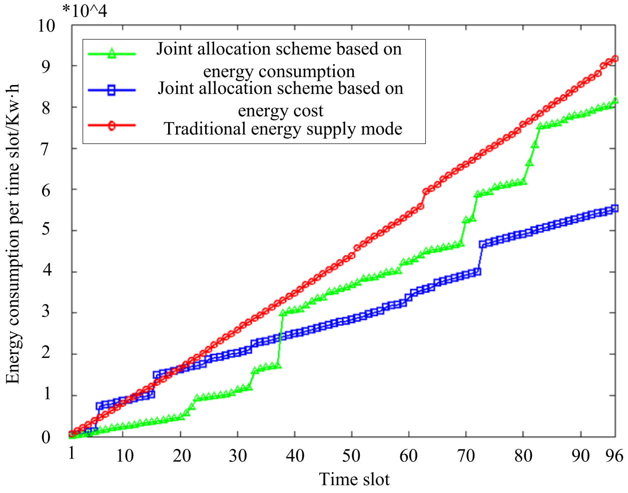

FIGURE 4. Comparison of total energy consumptions of the system under different allocation schemes.

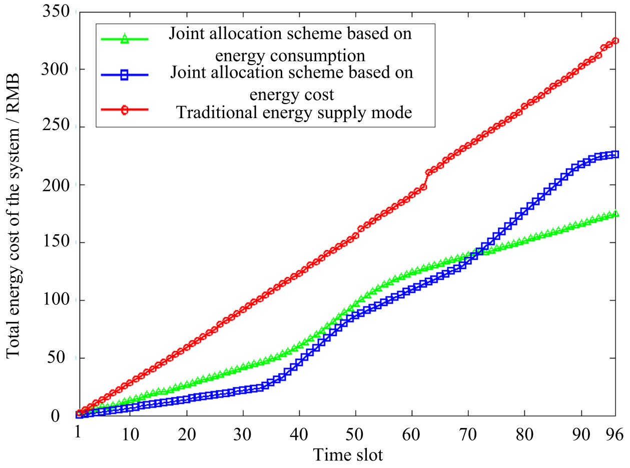

FIGURE 5. Comparison of total energy cost of the system under different allocation schemes.

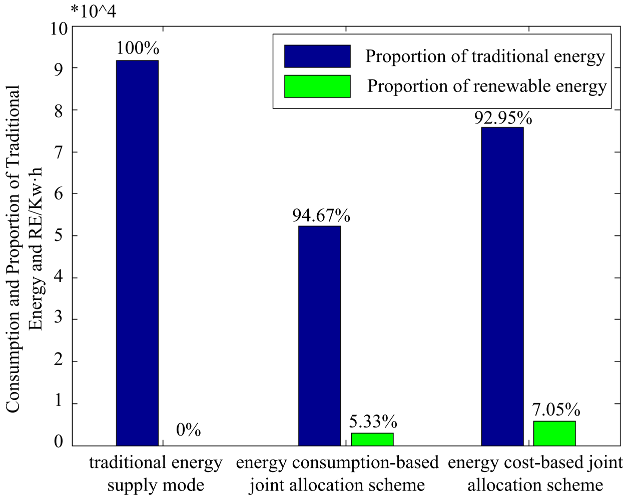

FIGURE 6. Proportion of traditional energy and renewable energy consumption under different allocation schemes.

mode is 9.18 × 10^4 kW·h. The total energy consumption under energy cost-based joint allocation scheme is reduced by nearly 11.2 compared with that under traditional energy supply mode. The total energy consumption under the energy consumption-based joint allocation scheme is reduced by 32.2% on this basis. Therefore, the latter scheme can realize the goal of minimizing the energy consumption. Fig. 5 compares the total energy cost under different allocation schemes. As observed, the total energy cost under the traditional energy supply mode is RMB 325.16, that under energy consumption-based joint allocation scheme is RMB 226.40, and that under energy cost-based joint allocation scheme is RMB 174.77. The simulation results show that the energy cost-based joint allocation scheme can reduce the energy cost of the system by a large margin. Thus, the minimization of the energy cost of the system within the whole cycle is realized.

Fig. 6 shows the ratios of traditional energy consumption to renewable energy consumption under different allocation schemes. As observed, no renewable energy source is used under the traditional energy supply mode. Thus, the ratio of renewable energy consumption is 0%, while the renewable energy consumption under the energy consumption-based allocation scheme is 2,945.71kW·h, which accounts for 5.33% of the total energy consumption of the system. The renewable energy consumption under the energy cost-based allocation scheme is 5,748.28kW·h, which accounts for 7.05% of the total energy consumption of the system. Therefore, both allocation schemes can transfer renewable energy sources through the energy sharing link due its existence. However, the latter considers energy cost and shares users very frequently. Thus, it can transfer more energy sources on the link and avoid the waste of energy due to excess production capacity at some BSs. Therefore, the latter can consume more renewable energy sources.

Table 2 shows the comparison results of number of allocated users, total energy consumption, and total energy cost

TABLE 2. Comparision of allocated users,total energy consumption, and total energy cost under different allocation schemes.

Item	Traditional energy supply mode	Joint allocation scheme based on energy consumption	Joint allocation scheme based on energy cost
Number of MBS service micro-cell 1 users	12	67	215
Number of MBS service micro-cell 2 users	12	32	129
Amount of energy transmitted on the energy sharing link (kW·h)	0	98.20	1654.60
Total energy consumption of the system (kW·h)	91810.03	55235.84	81519.16
Total energy consumption of the system (RMB)	325.16	226.40	174.77

under different allocation schemes. From the data in the first two rows in the table, because there is no shareable renewable energy in the traditional energy supply method, the energy transmitted on its energy sharing link is 0. The system with energy sharing link can realize real-time adjustment of renewable energy sources at each BS via the energy sharing link compared with the system without energy sharing link. MBS can serve users in more micro-cells to avoid the waste of energy caused by excess production capacity at the BSs. As a result, the system can maximize the utilization rate of energy sources within each time slot to realize the minimum energy consumption or cost in the network in the current time slot. Comparison of the data in the last two columns shows that the energy provided by PBS to MBS is 98.2 kW·h in the energy loss-based distribution scheme, while the energy provided by PBS to MBS is 1654.60 kW·h in the energy cost-based distribution scheme. The energy consumption-based allocation scheme will consider the overall energy consumption of the system. Instead of allocating few micro-cell users to MBS, this scheme will allocate more users in the cell to BSs in this cell. Thus, it can reduce energy consumed when serving the users to reach the goal of minimum energy consumption. When providing users for MBS, PBS will consider the existence of energy sharing link or not and the current renewable energy generation conditions at each BS. When the production capacity of renewable energy source at MBS is sufficient, the energy cost-based allocation scheme will allocate more users to MBS to be served. As PBSs are allocating more users to MBS, the energy transferred on the energy sharing link will gradually increase. Therefore, the energy cost-based allocation scheme sacrifices more energy consumption for lower energy cost of the system and thus realizes the minimum system cost within the whole operational cycle.

V. CONCLUSION

A two-layer heterogeneous network communication model was constructed in this study. The energy sharing links between MBS and PBSs were built, and two energy-user joint allocation schemes were proposed, namely, energy consumption- and energy cost-based allocation schemes. The energy consumption-based allocation scheme took energy consumption as the optimization objective. A multi-objective optimization function was constructed and transformed into a convex optimization problem. The optimal allocation scheme in each time slot was determined via the convex optimization solution and then used to reduce the energy consumption of the communication system. On the basis of the energy consumption-based scheme, the energy cost-based allocation scheme increased the energy price factor. This way lowered the energy consumption of the system while completing energy and user allocation. The simulation results manifest that the energy consumption-based joint allocation scheme can optimize the number of allocated users and energy transferred on the energy sharing link. With the minimization of total energy consumed by the system as the objective, this joint allocation scheme reduces the link and system energy consumption. With further consideration of the influence of energy price factor, the energy cost-based allocation scheme starts from the angle of network economic benefit to coordinate energy and user allocation between BSs. Furthermore, this scheme takes the energy cost as the optimization objective and significantly reduces the energy cost of the communication system.

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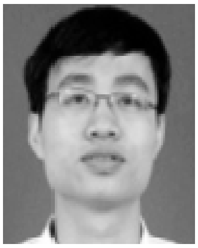

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