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Joint Power Control and Scheduling for Two-Cell Energy Efficient Broadcasting with Network Coding

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ABSTRACT

We consider the energy minimization problem for a two-cell broadcasting system, where the focus is devising energy efficient joint power control and scheduling algorithms. To improve the retransmission efficiency, linear network coding is applied to broadcast packets. Combined with network coding, an optimal algorithm is proposed, which is based on dynamic programming. To reduce computational complexity, two sub-optimal algorithms are also proposed for large networks. Simulation results show that the proposed schemes can reduce energy consumption up to 57% compared with the traditional Automatic Repeat-reQuest (ARQ).

Keywords: Power Control; Network Coding; Broadcast; Scheduling; Energy Minimization

1. Introduction

Energy efficiency is an important concern in wireless systems, both for environmental and economical reasons. The information and communication technology (ICT) infrastructure consumes about 3% of the world-wide energy and the CO_2 emissions are as many as one quarter of the CO_2 emissions by cars [1]. The CO_2 emissions from ICT are still increasing at a rate of 6% per year [2]. Besides, the energy bill accounts for a large proportion in the costs of running a network. The operating costs can be significantly reduced by reducing energy consumption [3]. Therefore, energy efficiency is an increasingly important issue. In this paper, we focus on transmit energy minimization for a wireless broadcasting system consisting of two cells.

Linear network coding [4] can be used to reduce energy consumption by improving the retransmission efficiency. The traditional way to retransmit the lost packets is using Automatic Repeat-request (ARQ). The retransmitted packets may not be useful to every user, and therefore the traditional ARQ is energy inefficient. The promising network coding technique [4] has been proved to be an efficient approach for multi-receiver broadcast. Each encoded packet is a linear combination of original packets, where the combination coefficients are drawn from a certain finite field. These coefficients for each packet are grouped together, which is the *encoding vector* of that packet. The encoding vectors are broadcast together with the corresponding packets to all the receiv-

ers. An encoding vector is said to be *innovative to a receiver* if it is not in the subspace spanned by the previously received encoding vectors of that user. An encoding vector is called *innovative* if it is innovative to all the receivers that have not received enough packets for decoding. For easier reading, we say that a packet is innovative if its corresponding encoding vector is innovative. Network coding can be applied into broadcasting systems to improve the retransmission performance.

There are some previous works that apply network coding to wireless broadcasting systems. For example, XOR network coding and random linear network coding (RLNC) are applied to wireless broadcast in [5] and [6], respectively. However, XOR operates in the binary field and innovative vectors cannot be guaranteed when there are more than two receivers. Although RLNC can provide innovative vectors when the finite field is sufficiently large, the large field size increases the computational complexities for encoding and decoding. In [7-8], Kwan *et al.* propose different coding methods which can guarantee innovative encoding vectors while have a relatively low requirement on field size. Their methods only require that the field size is no less the total number of receivers. We will use the method of [8] to improve the retransmission efficiency.

Another way to reduce energy consumption is to control the transmit power of base stations. By controlling the transmit power, we can control the received Signal to Interference plus Noise Ratio (SINR), so as to reduce energy consumption. To our best knowledge, most of the

previous works on energy minimization for broadcasting are based on power control only [9] (and the references therein) [10], without using network coding. Although Tran *et al.* consider both power control and network coding in [5], their network coding method works over *GF*(2) which cannot guarantee that all the encoding vectors are innovative. Note that both our power control scheme and network coding method are different from those in [5].

In this paper, we combine power control together with network coding for broadcasting networks. We focus on the joint power control and scheduling problem for two base stations. The objective is to minimize the expected transmit energy consumption. We use the network coding method proposed in [8] to generate innovative packets for transmissions. Combined with network coding, we propose three joint power control and scheduling algorithms to minimize energy consumption. In the first algorithm, the problem is formulated as a dynamic programming problem, which can provide an optimal solution, in the sense of minimizing the expected energy consumption. To reduce the computational complexity, two heuristic algorithms are also proposed for large networks. Simulation shows that they perform very well.

2. System Model

As shown in **Figure 1**, we consider a time slotted wireless broadcast system consisting of two partially overlapped cells and *K* users. The two base stations are denoted by BS_1 and BS_2, respectively. The transmission range of each base station is a circle with radius *r*. The distance between the two base stations is denoted by *D*. We define a parameter $\delta = D/r$, where $0 < \delta < 2$, to characterize the locations of the two cells. The *K* users are randomly located in the two cells and labeled as U_i, where $i \in \{1, 2, \ldots, K\}$. The distance from BS_b, where $b \in \{1, 2\}$, to user U_i is denoted by d_{bi}. A broadcast file is divided into *N* equal-size packets which are called *uncoded packets*. Both BS_1 and BS_2 have all the *N* uncoded packets. They want to broadcast these *N* packets to all the *K* users by cooperating with each other.
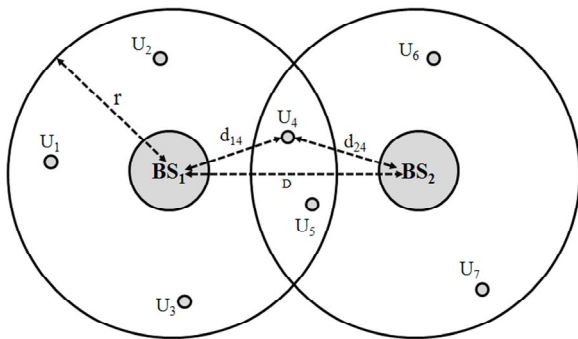
Figure 1. System model.

Both BS_1 and BS_2 can transmit to the users in their own transmission range. To avoid collisions, they are not allowed to transmit simultaneously. At each time slot, both BS_1 and BS_2 can change its transmit power to a value which is chosen from a preset power level collection $\Theta = \{\theta_1, \theta_2, \ldots, \theta_{|\Theta|,}\}$ (in mW units). All downlink channels are modeled as mutually independent channels, across time and across users, which are affected by path loss and Rayleigh fading. A packet is considered to be successfully received if the received SINR is greater than a predetermined threshold Γ (in dB units). Otherwise, that packet will be considered to be lost. We use $R_{bi}(\theta_m)$ to denote the *reliability* of the downlink channel from BS_b to user U_i with transmit power θ_m. The reliability is defined as the probability that the received SINR is greater than the threshold Γ. Since the received signal is subject to Rayleigh fading, the instantaneous SINR is distributed according to an exponential distribution with parameter $1/\overline{S}$ [11], where $\overline{S}$ is the average SINR. According to the cumulative distribution function of exponential distribution, the reliability $R_{bi}(\theta_m)$ can be computed by

$$R_{bi}(\theta_m) = P\{S_r > \Gamma\} = \exp(-\frac{\Gamma}{\overline{S}}), \qquad (1)$$

where S_r is the instantaneous received SINR and $\overline{S}$ is the average SINR (in dB units). Note that $\overline{S}$ is determined by the corresponding distance d_{bi} and transmit power θ_m. Depending on the environment, $\overline{S}$ can be obtained by using the corresponding radio propagation model, such as the Okumura model and Hata model.

Once a user successfully received a packet, it will send an acknowledgement to the sender of that packet. All the acknowledgement channels are assumed to be reliable channels without error and delay. BS_1 and BS_2 are also assumed to be connected via a wired cable and they can share the acknowledgement information with each other.

All the packets transmitted by the base stations are coded packets based on linear network coding. We assume that the coding is operated over a finite field with *q* elements, *GF*(*q*), where $q \geq K$. We use the network coding method proposed in [8]. Since $q \geq K$, it is guaranteed that each broadcast packet is innovative to all users. In other words, a user can recover the original file as long as it has successfully received any *N* broadcast packets. An example of network coding is given in **Example 1**. For more details about the network coding method, we refer the reader to [8]. We say that U_i is *complete* if it has received *N* broadcast packets. Otherwise, we say that U_i is *incomplete*.

Example 1: Let $q = 3$, $K = 3$ and $N = 3$. We assume that each encoding vector is a 1×3 row vector. For example, an encoding vector [1 0 1] means that the corresponding encoded packet is obtained by taking linear combinations of the first and the third uncoded packets

with coefficients being 1.

Let $\mathbf{C}_i$ be the encoding matrix of user U_i, where its rows represent the encoding vectors U_i has received so far. At a particular time slot, consider

$$\mathbf{C}_1 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}, \mathbf{C}_2 = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix} \text{ and } \mathbf{C}_3 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \end{bmatrix}$$

Each user needs to receive at least one more packet for successfully decoding the original file. If the network coding method proposed in [8] is used, we can broadcast an encoding vector $\mathbf{v}^* = [0\ 1\ 2]$ to all users in one time slot. For each U_i, $\mathbf{v}^*$ is not in the row space of $\mathbf{C}_i$, i.e. $\mathbf{v}^*$ cannot be obtained by taking linear combinations of row vectors in $\mathbf{C}_i$ over $GF(3)$. Therefore, $\mathbf{v}^*$ is innovative to all the three users. As long as U_i can successfully receive $\mathbf{v}^*$, it can get a full rank matrix by appending $\mathbf{v}^*$ to the end of $\mathbf{C}_i$. Then, U_i can successfully decode the original file by using Gaussian elimination to solve the matrix equations.

However, if XOR network coding is used, it cannot find such an encoding vector that is innovative to all the three users simultaneously. It requires at least two transmissions. For example, the base station may transmit the encoding vector [0 1 1] to U_1 and U_2 in the first slot and the encoding vector [0 1 0] to U_3 in the second slot. The network coding method proposed in [8] outweighs XOR in this case.

Given a scheduling scheme $\mathbf{B}$, we use an integer random variable $T_\mathbf{B}$ to denote the required number of transmissions for $\mathbf{B}$ to complete the broadcast. We define the broadcast schedule of $\mathbf{B}$ as a binary sequence, $\Phi_\mathbf{B} = \{\varphi_1, \varphi_2, \ldots, \varphi_{T\mathbf{B}}\}$. If $\varphi_t = 0$, BS_1 is selected to transmit at the t-th time slot. Otherwise, if $\varphi_t = 1$, BS_2 is selected. We define the sequence of transmit power $\Lambda_\mathbf{B}$ as $\{\lambda_1, \lambda_2, \ldots, \lambda_{T\mathbf{B}}\}$, where $\lambda_t \in \Theta$ is the transmit power level used at the t-th time slot.

At time t, $\mathbf{B}$ specifies a function f_t to determine φ_t and λ_t:

$$(\phi_t, \lambda_t) = f_t(\phi_1, \lambda_1, \mathbf{e}_1, \phi_2, \lambda_2, \mathbf{e}_2, \ldots, \phi_{t-1}, \lambda_{t-1}, \mathbf{e}_{t-1})$$

where $\mathbf{e}_t$ is the channel status at the t-th time slot. It is a binary random vector of length K. If $\mathbf{e}_t(i) = 1$, it means that the channel between the transmitter and U_i is too bad and U_i cannot receive the broadcast packet. Otherwise, U_i can receive that packet. Note that the probability distribution of $\mathbf{e}_t$ depends on whether BS_1 or BS_2 is chosen as the transmitter at time t. We call a realization of the sequence $\{\mathbf{e}_1, \mathbf{e}_2, \ldots, \mathbf{e}_{T\mathbf{B}}\}$ a channel realization under $\mathbf{B}$, denoted by $\Omega_\mathbf{B}$.

For a transmission with transmit power λ_t, the energy consumption is λ_t times the duration of a time slot. To simplify notations, we assume that the duration is one unit and will be ignored throughout this paper. Therefore, the total energy consumption of a particular channel re-

alization $\Omega_\mathbf{B}$ is denoted by $X_\mathbf{B}$ and can be computed as

$$X_\mathbf{B} = \sum_{t=1}^{T_\mathbf{B}} \lambda_t.$$

The expected energy consumption of $\mathbf{B}$ is denoted by $E[X_\mathbf{B}]$, where the expectation is taken with respect to the probability distribution of $\mathbf{e}_t$, which depends on φ_t. Our objective is to minimize $E[X_\mathbf{B}]$ by determining an optimal scheduling scheme $\mathbf{B}$ which requires to determine $\Phi_\mathbf{B}$ and $\Lambda_\mathbf{B}$ as well.

3. Optimal Scheme

The joint power control and scheduling problem can be formulated as a dynamic programming problem with the following parameters.

• **State** We define the state of all users as a $1 \times K$ state vector $\mathbf{s} = [s_1\ s_2\ \ldots\ s_K]$, where s_i, $0 < i \leq K$, denotes the number of packets that U_i has received. The state space is denoted by $\mathbf{S} = [s_1\ s_2\ \ldots\ s_K]$, where $0 \leq s_i \leq N$ and $0 < i \leq K$. The goal state is defined as $\mathbf{s}_g = [N\ N\ \ldots\ N]$, which means every user has received N packets and can be considered as a complete user.

• **Action** At each time step, we need to determine both the transmitter and the transmit power. We define the action set as $\mathbf{A} = \{0, 1\} \times \Theta$. At each time slot, an action $a = (b, \theta)$ is selected from $\mathbf{A}$. Action $a = (b, \theta_m)$ means that BS_b is selected to transmit with transmit power θ_m.

• **State Transition Probability** Given a state $\mathbf{s}$, let $p(\mathbf{s}'|\mathbf{s}, a)$ denote the state transition probability that transfers from $\mathbf{s}$ to $\mathbf{s}'$ under action a. Now, we are going to introduce how to compute the state transition probability $p(\mathbf{s}'|\mathbf{s}, a)$.

For a given action $a = (b, \theta_m)$ and given states $\mathbf{s} = [s_1\ s_2\ \ldots\ s_K]$ and $\mathbf{s}' = [s_1'\ s_2'\ \ldots\ s_K']$, we use $p(s_i'|s_i, a)$ to denote the probability that the number of packets received by U_i changes from s_i to s_i' under action a. Since all the downlink channels are assumed to be mutually independent across users, the state transition probability $p(\mathbf{s}'|\mathbf{s}, a)$ is the product of $p(s_i'|s_i, a)$ for all users. Hence,

$$p(\mathbf{s}'|\mathbf{s}, a) = \prod_{i=1}^{K} p(s_i'|s_i, a)$$

We define $Q_i(a)$ as the success probability of taking action a to transmit to user U_i. Based on the previous discussion, $Q_i(a)$ equals the reliability $R_{bi}(\theta_m)$ and $Q_i(a)$ can be obtained by Equation (1). Based on the given states $\mathbf{s}$, $\mathbf{s}'$ and the number of packets that U_i has received, the state transition for U_i can be classified into five different cases. The transition probability of each case can be obtained by the following equation.

$$p(s_i'|s_i, a) = \begin{cases} 0, & \textbf{if } s_i' < s_i, \\ 1, & \textbf{if } s_i' = s_i = N, \\ 1 - Q_i(a), & \textbf{if } s_i' = s_i < N, \\ Q_i(a), & \textbf{if } s_i' - s_i = 1, \\ 0, & \textbf{if } s_i' - s_i \geq 2. \end{cases}$$

Now we are going to discuss how to find the optimal action for each state. For $\mathbf{s} \in \mathbf{S}$, we define $V(\mathbf{s})$ as the expected energy consumption for the system to evolve from $\mathbf{s}$ to $\mathbf{s}_g$ given that optimal actions are chosen in every state, and define $\pi(\mathbf{s})$ as the optimal action at state $\mathbf{s}$. It is clear that $V(\mathbf{s})$ is non-zero except when $\mathbf{s} = \mathbf{s}_g$. For $\mathbf{s} \in \mathbf{S} \setminus \{\mathbf{s}_g\}$, we define $V(\mathbf{s}, a)$ as the expected energy consumption for the system to evolve from $\mathbf{s}$ to $\mathbf{s}_g$ given that action a is chosen for state $\mathbf{s}$ and optimal actions are chosen for the other states. For a given action $a = (b, \theta_m) \in \mathbf{A}$, $V(\mathbf{s}, a)$ can be computed by solving the following equation:

$$V(\mathbf{s}, a) = \theta_m + \sum_{\mathbf{s}' \in \mathbf{S} \setminus \{\mathbf{s}\}} p(\mathbf{s}'|\mathbf{s}, a)V(\mathbf{s}') + p(\mathbf{s}|\mathbf{s}, a)V(\mathbf{s}, a), \quad (2)$$

where θ_m means that each state transition takes one transmission and θ_m is the energy consumption of that transmission. Note that the summation only involves those states that can be immediately reached from $\mathbf{s}$. In other words, state $\mathbf{s}'$ is involved only when $p(\mathbf{s}'|\mathbf{s}, a)$ is non-zero. Equation (2) can be written as:

$$V(\mathbf{s}, a) = [\theta_m + \sum_{\mathbf{s}' \in \mathbf{S} \setminus \{\mathbf{s}\}} p(\mathbf{s}'|\mathbf{s}, a)V(\mathbf{s}')] / [1 - p(\mathbf{s}|\mathbf{s}, a)] \quad (3)$$

Note that our problem has the property that the state-transition graph is a directed acyclic graph. It mea-ns that given two distinct states, $\mathbf{s}$ and $\mathbf{s}'$, if $\mathbf{s}'$ can be reached from $\mathbf{s}$ after a certain number of state transitions, then $\mathbf{s}$ cannot be reached from $\mathbf{s}'$. **Figure 2** shows an example of the state transition graph for $K = 2$ and $N = 2$. For directed acyclic graph, it is well known that there is a topological ordering of vertices, which means that if there is a state transition from $\mathbf{s}$ to $\mathbf{s}'$, then $\mathbf{s}$ comes before $\mathbf{s}'$ in the ordering. Due to this property, $V(\mathbf{s})$ can be computed backward from $V(\mathbf{s}_g)$. To compute $V(\mathbf{s})$, we apply the formula in (3) to find $V(\mathbf{s}, a)$. $V(\mathbf{s})$ and the optimal action at $\mathbf{s}$ can then be obtained by
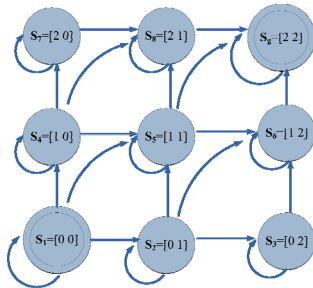
Figure 2. State-transition graph for *K*=2 and *N*=2.

Algorithm 1: Dynamic Programming (DP) Algorithm

Input: The initial state $\mathbf{s} = \mathbf{0}_{1 \times K}$
Output: $V(\mathbf{s})$ and $\pi(\mathbf{s})$ for all $\mathbf{s} \in \mathbf{S}$
set $V(\mathbf{s}) := 0$ and $\pi(\mathbf{s}) := 0$ for all $\mathbf{s} \in \mathbf{S}$ //global variables
do OptimalAction(s)
return $V(\mathbf{s})$ and $\pi(\mathbf{s})$ for all $\mathbf{s} \in \mathbf{S}$
Function: OptimalAction(s)
for $\mathbf{s}' \in \mathbf{S} \setminus \{\mathbf{s}_g, \mathbf{s}\}$ **do**
if $p(\mathbf{s}'|\mathbf{s}, a) > 0$ for any $a \in \mathbf{A}$ and $V(\mathbf{s}') = 0$
do OptimalAction(s')
end if
end for
for $a = (b, \theta_m) \in \mathbf{A}$ **do**
$V(\mathbf{s}, a) := [\theta_m + \sum_{\mathbf{s}' \in \mathbf{S} \setminus \{\mathbf{s}\}} p(\mathbf{s}'|\mathbf{s}, a)V(\mathbf{s}')] / [1 - p(\mathbf{s}|\mathbf{s}, a)]$
end for
$V(\mathbf{s}) := \min_{a \in \mathbf{A}} V(\mathbf{s}, a)$
$\pi(\mathbf{s}) := \arg \min_{a \in \mathbf{A}} V(\mathbf{s}, a)$
end function

$$V(\mathbf{s}) = \min_{a \in \mathbf{A}} V(\mathbf{s}, a) \textbf{ and } \pi(\mathbf{s}) = \arg \min_{a \in \mathbf{A}} V(\mathbf{s}, a),$$

respectively. To implement this idea, recursion may be used, and we state the recursive algorithm in Algorithm (1). We call it Dynamic Programming (DP) scheme.

By the principle of optimality [12], DP is optimal in terms of minimizing expected energy consumption.

4. Heuristic Schemes

While DP is optimal, its time complexity grows exponentially with K. To reduce complexity, we propose two fast heuristic algorithms for large networks. When the number of users is relatively small, we propose a greedy algorithm which dynamically changes the transmit power. When the number of users is very large, we propose an algorithm which uses fixed transmit power.

4.1. Greedy Algorithm

The greedy algorithm has the following three steps.

Step 1: At the beginning of a time slot, let s_j, where $0 < j \leq K$, denote the number of packets that U_j has received. We first choose the user U_i which has received the least number of packets. If there are multiple qualified users, we will randomly pick one of them.

Step 2: Select the base station BS_b^* that is closer to U_i as the sender. If both BS_1 and BS_2 have the same distance from U_i, randomly pick one of them as the sender in the current slot.

Step 3: We define a parameter $E_{bi}(\theta_m)$ for each trans-

mit power level θ_m. At a particular slot, $E_{bi}(\theta_m)$ is defined as the expected energy consumption required to make user U_i successfully receive a packet, assuming that BS_b is selected to transmit with power θ_m. $E_{bi}(\theta_m)$ can be computed as follows.

$$E_{bi}(\theta_m) = \frac{1}{R_{bi}(\theta_m)}\theta_m, \qquad (4)$$

where $R_{bi}(\theta_m)$ is the reliability of the channel from BS_b to U_i with transmit power θ_m.

After computing the $E_{bi}(\theta_m)$ value for each θ_m, choose the transmit power $\theta_m{*}$ that corresponds to the minimal $E_{bi}(\theta_m)$ as the transmit power of current slot. If there exists more than one $E_{bi}(\theta_m)$ which has the minimal value, just randomly pick one of them. Then $BS_b{*}$ will broadcast a packet to all users with transmit power $\theta_m{*}$.

Then go back to Step 1 and repeat the procedure until all the users are complete. The greedy algorithm can be summarized as Algorithm (2), which is called Greedy Transmission (GT) algorithm.

4.2. Fixed Power Algorithm

When the number of users is very large, the users with worst channels locate at the boundaries of the cells with high probabilities. For such scenarios, we propose the following algorithm with fixed transmit power.

BS_1 transmits at odd time slots and BS_2 transmits at even slots. The transmit power is always set to a fixed power level $\theta{*}$. BS_1 and BS_2 take turns to transmit until all users are complete.

The transmit power $\theta{*}$ is determined as follows. Consider a wireless system which consists of BS_1 and only one user U_1. Suppose U_1 is located at the border of the cell, i.e. the distance between U_1 and BS_1 is the radius r. For each θ_m, we calculate the expected energy consumption $E_{11}(\theta_m)$ defined by Equation (4). Then select the power level with minimal $E_{11}(\theta_m)$ as $\theta{*}$, which means $\theta{*}$ is the optimal power level for U_1, a user locating at the boundary.

Algorithm 2: Greedy Transmission (GT) Algorithm

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while $\mathbf{s} \neq \mathbf{s}_g$ **do**

Set $i = \arg \min_{0 < i \leq K}\{s_i\}$,

Set $b = \arg \min_{b \in \{1,2\}}\{d_{bi}\}$,

for m=1 **to** $|\Theta|$ **do**

Compute $E_{bi}(\theta_m)$ by using Equation (4).

end for

Set $m = \arg \min_{0 < m \leq |\Theta|}\{E_{bi}(\theta_m)\}$.

Let BS_b transmit a coded packet with power θ_m.

Update $\mathbf{s}$.

end while

Note that this algorithm has such a feature that it does not require any channel state information of users. We call this algorithm the Fixed Power (FP) algorithm.

5. Numerical Results

We evaluate the performance of proposed algorithms via simulations. The downlink channels are modeled containing combined effects of path loss and Rayleigh fading. The minimal transmit power $\theta_{\min}$ and maximal transmit power $\theta_{\max}$ are set to 100mW (20 dBm) and 20W (about 43 dBm), respectively. Θ includes 20 ordered power levels which are linearly spaced between and including $\theta_{\min}$ and $\theta_{\max}$. The SINR threshold Γ is set to 3 dB. δ is set to different values to evaluate the performances under different cell locations. Other parameters are shown in **Table 1** [13]. For each set of parameters, the results are averaged over 10,000 repetitions.

We compare the proposed algorithms with the scheme named NCPC in [5] and an ARQ scheme. For NCPC, we set the parameter, the extension radius of the center cell, to $1.15r$, which is the same as the simulation in [5]. We refer the reader to [5] for details of NCPC. In the ARQ scheme, BS_1 transmits at odd slots and BS_2 transmits at even slots. Note that if all the users in a cell are complete, only the base station of the other cell will transmit at the remaining time slots. In each cell, the base station retransmits each uncoded packet until all the users in its cell has received it. The transmit power is determined as follows. At a particular slot, the base station BS_b first selects a target user U_i which requires the packet to be broadcast while has the longest distance from the base station. Then, use Equation (4) to calculate the expected energy consumption $E_{bi}(\theta_m)$ for each θ_m. Finally, select the power level with minimal $E_{bi}(\theta_m)$ as the transmit power in that slot.

For small scale networks, we compare the performances of DP, GT and FP with NCPC and ARQ. In **Figure 3**, we first evaluate the performances of different cell locations with $N = 4$ and $K = 4$ and δ varies from 0.3 to 1.9. When $\delta = 0.3$, the two cells are almost totally overlapped with each other. When $\delta = 1.9$, the two cells are almost separated. We can find that both DP and GT always perform better than NCPC and ARQ. In particular,

Table 1. Simulation parameters[13].

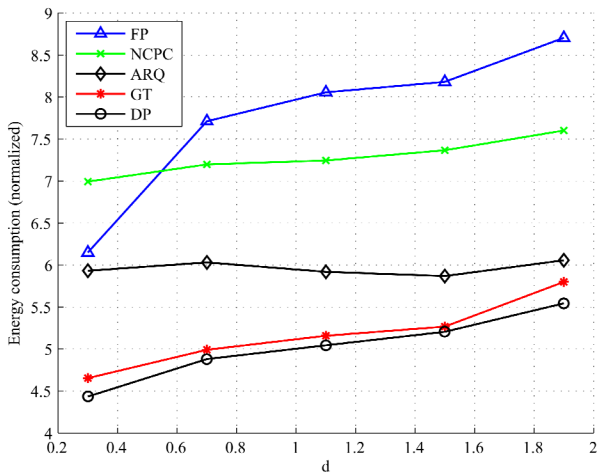| Parameter	Value
Cell radius r	1 Km
Bandwidth	20 MHz
No. of resource blocks	100
BS antenna gain	11 dBi
MS antenna gain	0 dBi
Minimum coupling loss	53 dB
Path loss	$128.1 + 37.6\log_{10}(d_{bi})$, d_{bi} in Km
Noise density	-165 dBm/Hz
Noise figure	9 dB

Figure 3. Energy consumption for *N*=4, *K*=4 and various *δ*.

compared with NCPC when *δ* = 0.3, DP and GT can reduce energy consumption by 37% and 34%, respectively. Compared with ARQ, when *δ* = 0.3, DP and GT can reduce energy consumption by 26% and 22%, respectively. To investigate the effects of number of users, we run simulations with *N* = 4, *δ* = 1.0 and *K* varies from 2 to 4. The simulation results are shown in **Figure 4**. DP and GT also outweigh NCPC and ARQ in all the scenarios. Especially, compared with NCPC, both DP and GT can reduce energy consumption by about 50% when *K* = 2. Compared with ARQ, when *K* = 4, DP and GT can reduce energy consumption by 17% and 16%, respectively. In both **Figure 3** and **Figure 4**, the performance gap between DP and GT is less than 6%, which means the GT performs very well and is close to the optimal scheme. In both **Figure 3** and **Figure 4**, FP performs worse than other schemes. The reason is that, when the number of users is small, the "worst" user is not located near the cell boundary with high probabilities, where the worst user means it has the longest distance from base station. That means the transmit power of FP is too large and FP is energy inefficient.

For large scale networks, we evaluate the performance of GT, FT, NCPC and ARQ with changing *K* and *δ*. Considering the computational complexity of DP, it is not taken into comparison. In **Figure 5**, the parameters are set to *N* = 60, *K* = 50 and *δ* varies from 0.3 to 1.9. Both GT and FP perform better than NCPC and ARQ, no matter how the cells are located. In particular, compared with NCPC, when *δ* = 0.3, GT and FP can reduce energy consumption by 19% and 15%, respectively. Compared with ARQ, when *δ* = 1.9, GT and FP can reduce energy consumption by 50% and 47%, respectively. We also evaluate the performances with *N* = 60, *δ* = 1 and *K* varies from 20 to 100. The simulation results are shown in **Figure 6**. Both GT and FP also require less transmit energy. In particular, compared with NCPC, when *K* = 100,

GT and FP can reduce energy consumption by 18% and 14%, respectively. Compared with ARQ, when *K* = 100, GT and FP can reduce energy consumption by 57% and 55%, respectively. In both **Figure 5** and **Figure 6**, the performance of FP is comparable to that of GT. In **Figure 6**, the gap is less than 5% when *K* ≥ 40. As the number of users increases, the gap between GT and FP becomes smaller and smaller. The reason is that, when number of users is large, the users with worst channels are located near the cell boundary. In that case, the transmit power selected by GT is close, or even equal, to that selected by FP. Therefore, their performances are very close.

6. Conclusions

In this paper, we consider the problem of minimizing the expected transmit energy consumption for a two-cell broadcasting system. On one hand, we apply the innovative network coding to reduce the number of retransmissions. On the other hand, we use power control to control
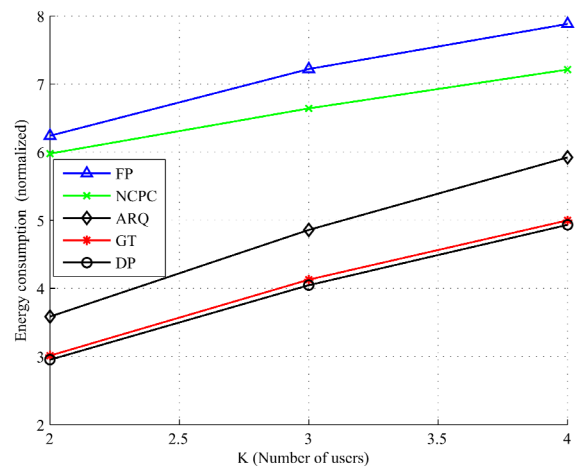

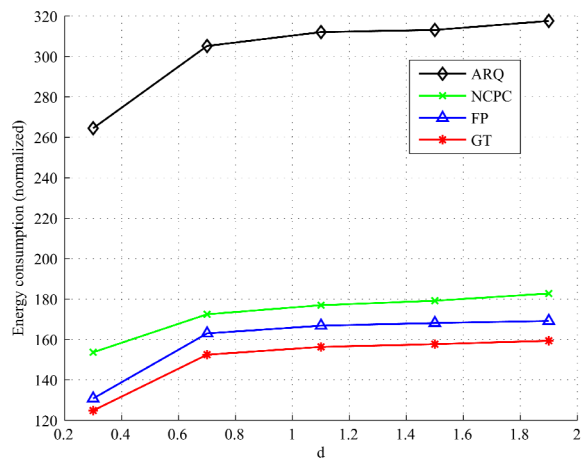**Figure 4. Energy consumption for *N*=4, *δ*=1 and various *K*.**

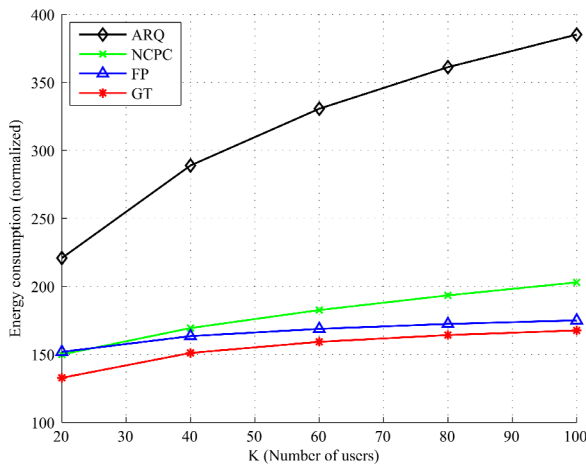**Figure 5. Energy consumption for *N*= 60, *K*= 50 and various *δ*.**

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Figure 6. Energy consumption for *N*=60, *δ*=1 and various *K*.

the received SINR such that the transmit efficiency can be improved. Besides, we also consider the scheduling problem of the two base stations. We first propose an optimal algorithm called DP, in the sense of minimizing expected energy consumption, which uses dynamic programming to choose the optimal action for each state. To reduce complexity, we also propose two sub-optimal greedy algorithms, called GT and FP, respectively, for large scale networks. Simulation shows that GT has a very close performance to that of the optimal DP when the network is small. When the number of users is very large, both FP and GT outweigh NCPC and ARQ. Although the algorithms are designed for two-cell systems in this paper, they can be extended to multiple-cell systems.

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