Energy Efficiency Analysis of Cellular Downlink Transmission with Network Coding over Rayleigh Fading Channels

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Received January 4, 2013; revised January 17, 2013; accepted January 23, 2013; published March 29, 2013

Abstract

Recently, energy-efficient cellular transmission has received considerable research attention to improve the energy efficiency of wireless communication. In this paper, we consider a cellular network consisting of one base station (BS) and multiple user terminals and explore the network coding for enhancing the energy efficiency of cellular downlink transmission from BS to users. We propose the network coded cellular transmission scheme and conduct its energy consumption analysis with target outage probability and data rate requirements in Rayleigh fading environments. Then, the energy efficiency in Bits-per-Joule is further defined and analyzed to evaluate the number of bits delivered per Joule of energy cost. Numerical results show that the network coded cellular transmission significantly outperforms the traditional cellular transmission in terms of energy efficiency, implying that given a Joule of energy cost, the network coded cellular transmission scheme can deliver more bits than the traditional cellular transmission.

Keywords: Energy efficiency, network coding, cellular networks, outage probability

This research was supported in part by the Natural Science Foundation of China (NSFC) grant (No. 61271240).

http://dx.doi.org/10.3837/tiis.2013.03.002

1. Introduction

With the development of society and economy, there is an explosive growth in cellular communication services, which results in a continuous increase of the electric energy consumption. Nowadays, in order to provide users with better service experience, today's mobile terminals (e.g., smart phones) are generally equipped with multiple network access interfaces to support both the short-range communication (e.g., Bluetooth and Wi-Fi) and long-range communication (e.g., cellular networks) [1], which, however, cost considerable energy for connecting multiple networks. Moreover, the fast growth of wireless multimedia services (e.g., video game, video-on-demand) would further drain the battery energy of mobile terminals. Notice that the advances in battery technology are very slow and the battery capacity has been improved by eighty percent only in the past decades [2]. In contrast, the energy consumed by mobile terminals keeps fast growth. More specifically, the first-generation mobile devices have low power consumption at 1-2 Watts around and the third-generation (referred to as 3G) terminals double this figure. Moreover, the fourth-generation (known as 4G) terminals are expected to further double the 3G devices' power consumption [3], which may lead 4G mobile phones to be limited to work in certain places, even bound to a single place where power charging outlets are available, which is called "energy trap" [4]. It is therefore extremely important to investigate energy-efficient wireless communication to reduce the energy consumption of cellular transmission to avoid so-called "energy trap" effect.

Network coding was initially introduced for satellite communication [5] and then examined for wired networks [6], which was further developed for wireless networks [7], [8], especially for cooperative wireless networks [9]. In [5], the authors proposed a distributed source coding scheme for satellite communication and characterized the inner and outer bounds on admissible coding rate region of the distributed source coding. The network information flow with so-called network coding was then studied in [6] for wired networks, in which the admissible coding rate region was developed by exploiting so-called max-flow min-cut theorem. In [7], the authors investigated the use of network coding to reduce the number of retransmissions in a broadcast network and showed that the proposed network coding scheme performs better than the traditional automatic repeat-request (ARQ) scheme in terms of bandwidth efficiency. A noisy network coding scheme was further proposed in [8] for a general noisy network consisting of multiple sources and destinations, which reduces the performance gap to the cutset bound as compared with the conventional network coding approaches. In addition, a practical physical-layer network coding scheme was presented in [9] for two-way relay networks, where the relay nodes are used to assist the message exchange between two network nodes. It is pointed out that the aforementioned work is focused on the use of network coding for improving the transmission throughput and reliability. However, the energy efficiency of network coding for wireless communication is yet to be investigated.

In this paper, we explore the network coding in a cellular network consisting of one base station (BS) and multiple users, aiming at enhancing the energy efficiency of cellular transmission. The main contributions of this paper are summarized as follows. First, we propose a network coding scheme for cellular downlink transmission from BS to multiple users and derive a closed-form energy consumption expression of the network coded cellular transmission with target outage probability and data rate requirements. Second, we provide the definition of energy efficiency in Bits-per-Joule, which is used to evaluate the number of bits delivered per Joule of energy cost. For the comparison purpose, we also analyze the energy efficiency of traditional cellular transmission as a benchmark scheme. Finally, numerical results on energy efficiency are presented to show the advantage of proposed network coded cellular transmission over traditional cellular transmission.

The rest of this paper is organized as follows. Section II presents the system model of a cellular network and proposes a network coding scheme for cellular downlink transmission. In Section III, given target outage probability and data rate requirements, we conduct the energy efficiency analysis of proposed network coded cellular transmission over Rayleigh fading channels. Next, in Section IV, numerical energy efficiency results are presented to show the energy saving benefits of using network coding. Finally, we provide some concluding remarks in Section V.

2. Proposed Network Coding Scheme for Cellular Downlink Transmission

In this section, we first present the system model of a cellular network consisting of one BS and multiple users, where BS transmits downlink packets to the multiple users, respectively. Then, we propose the network coding scheme for cellular downlink transmission as well as the traditional cellular transmission as a benchmark scheme for comparison.

2.1 System Model

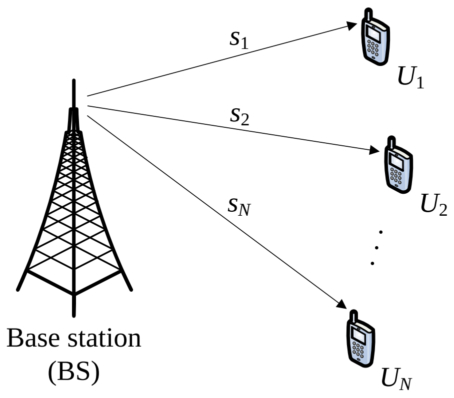

Fig. 1. A cellular network consists of one base station (BS) and N users.

Fig. 1 shows the system model of a cellular network consisting of one base station (BS) and N users denoted by $\boldsymbol{U} = \{U_1, U_2, \cdots, U_N\}$. As shown in Fig. 1, the signal to be transmitted from BS to U_i is denoted by s_i, where $i = 1, 2, \cdots, N$. In the cellular network, BS is regarded as a centralized controller and communicates with N users using an orthogonal multiplexing method such as the time division multiplexing (TDM) and orthogonal frequency division multiplexing (OFDM). It needs to be pointed out that different orthogonal multiplexing techniques achieve the same Shannon capacity performance in an information-theoretical sense. Without loss of generality, the TDM approach is assumed at BS for transmitting $s_1, s_2, \cdots, s_N$ to $U_1, U_2, \cdots, U_N$, respectively. More specifically, $s_1, s_2, \cdots, s_N$ are transmitted by BS over different orthogonal time slots to avoid interfering with each other. Notice that this paper is focused on the cellular downlink transmission from BS to N users and similar performance analysis can be obtained for the cellular uplink transmission from users to BS.

Generally speaking, wireless transmission experiences the path loss and fading, i.e., the received signal at destination is a faded version of transmit signal. Assuming the transmit power P_T, the received signal power P_R is given by

$$P_R = \frac{P_T |h|^2}{d^n},$$

where d is the transmission distance, n is the path loss exponent, and h is a fading co-efficient of the channel from transmitter to receiver. Notice that the path loss exponent is typically in the range of 2 to 4, i.e., $2 \le n \le 4$, where $n = 2$ is used to characterize the propagation loss in free space. The channel coefficient h is modeled as Rayleigh fading, i.e., random variable $|h|^2$ follows exponential distribution with mean σ_h^2. Although only the Rayleigh fading is considered in this paper, similar performance analysis and results can be obtained for other fading models (e.g., Nakagami fading). In addition, the additive white Gaussian noise (AWGN) at receiver is modeled as a zero-mean circularly symmetric complex Gaussian (CSCG) random variable with variance σ_n^2. As discussed in [1], the noise variance σ_n^2 is given by

$$\sigma_n^2 = \kappa TB,$$

where κ denotes the Boltzmann constant (i.e., $\kappa = 1.38 \times 10^{-23}$ $Joule/K$), T denotes the system temperature in Kelvin (K), and B denotes the channel bandwidth. Letting $N_0 = \kappa T$ and considering room temperature $T = 290K$, we easily obtain $N_0 = -174\text{dBm/Hz}$, which is referred as the noise power spectral density.

2.2 Traditional Cellular Transmission

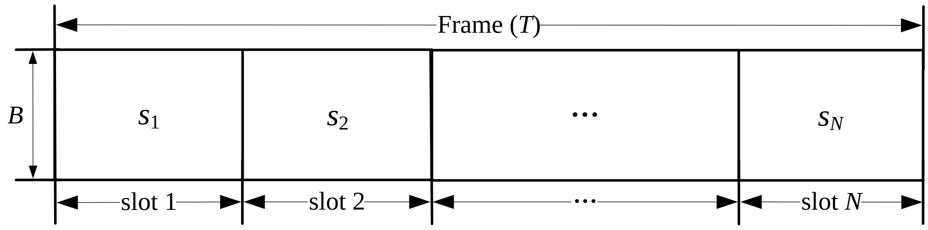

Fig. 2. Frame structure of the traditional cellular downlink transmission from BS to N users employing time division multiplexing (TDM), where B and T represent the spectrum bandwidth and frame duration, respectively.

For the comparison purpose, let us first consider the traditional cellular downlink transmission without network coding. Fig. 2 shows the frame structure of traditional cellular downlink transmission by considering the time division multiplexing (TDM), where B and T represent the spectrum bandwidth and frame duration, respectively. As shown in Fig. 2, each frame is divided into N time slots and BS transmits s_i to U_i in time slot i with power P_i and data rate R in bits per second. Thus, the received signal at U_i from BS is given by

$$y_i(i) = d_{bi}^{-n} h_{bi}(i)\sqrt{P_i}s_i + n_i, \tag{1}$$

where d_{bi} is the transmission distance from BS to U_i, n is the path loss exponent, $h_{bi}(i)$ is a fading coefficient of the channel from BS to U_i in time slot i, and n_i is the zero-mean AWGN with noise power $\sigma_n^2 = N_0 B$. From Eq. (1), the received signal-to-noise ratio (SNR) at U_i with the traditional cellular transmission in time slot i is obtained as

$$\gamma_i^T(i) = \frac{|h_{bi}(i)|^2 P_i}{d_{bi}^n N_0 B}, \tag{2}$$

where the superscript T denotes "traditional" and N_0 is the noise power spectral density.

2.3 Proposed Network Coding Scheme

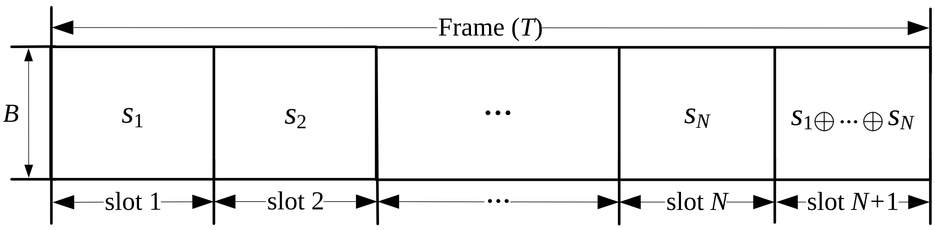

Fig. 3. Frame structure of the proposed network coding scheme for cellular downlink transmissions from BS to N users, where B and T represent the spectrum bandwidth and frame duration, respectively.

In this subsection, we propose the network coding scheme for cellular downlink transmission from BS to N users. Fig. 3 shows the frame structure of proposed network coded cellular downlink transmission, where B and T represent the spectrum bandwidth and frame duration, respectively. One can see from Fig. 3 that the whole frame is divided into $N+1$ time slots, where the first N slots are utilized to transmit $s_1, s_2, \cdots, s_N$ and the modulo-2 addition among $s_1, s_2, \cdots, s_N$ (i.e., $s_1 \oplus s_2 \oplus \cdots \oplus s_N$) is transmitted in time slot $N+1$. As a consequence, U_i is able to obtain s_i in two possible ways: 1) by decoding the received signal in time slot i; and 2) by performing the modulo-2 addition among the decoded outcomes of received signals in remaining N slots. We assume that in the network coded cellular downlink transmission, the same transmit power P is adopted by BS in different time slots. Moreover, BS transmits at data rate $\frac{N+1}{N}R$ in bits per second in order to send the same amount of effective information as the traditional cellular transmission. Considering that BS transmits s_i with power P in time slot i, the received signal at U_i is expressed as

$$r_i(i) = d_{bi}^{-n} h_{bi}(i)\sqrt{P} s_i + n_i, \tag{3}$$

from which the received SNR is given by

$$\gamma_i^P(i) = \frac{|h_{bi}(i)|^2 P}{d_{bi}^n N_0 B}, \tag{4}$$

where the superscript P stands for "proposed". Similarly to Eq. (4), the received SNR at U_i in other time slots, e.g., slot j, can be given by

$$\gamma_i^P(j) = \frac{|h_{bi}(j)|^2 P}{d_{bi}^n N_0 B}, \tag{5}$$

where $j \in \{1, 2, \cdots, N+1\} - \{i\}$ and $-$ denotes the set difference. For notational convenience, let Ω_i denote set $\{1, 2, \cdots, N+1\} - \{i\}$, i.e., $\Omega_i = \{1, 2, \cdots, N+1\} - \{i\}$. It can be observed that the cardinality of set Ω_i is given by N. So far, we have completed the signal modeling of proposed network coded cellular downlink transmission scheme. The following presents the energy efficiency analysis of the traditional and proposed cellular transmission schemes.

3. Energy Efficiency Analysis with Target Outage and Rate Requirements

In this section, we analyze the energy efficiency of traditional and proposed cellular transmission schemes over Rayleigh fading channels. Under the target outage probability and data rate requirements, we first characterize the energy consumption of cellular transmission and then present an energy efficiency definition to evaluate the number of bits delivered per Joule of energy cost.

3.1 Traditional Cellular Transmission

This subsection presents the energy efficiency analysis of traditional cellular transmission. Throughout this paper, we consider that different users (i.e., $U_1, U_2, \cdots U_N$) have the same outage probability and data rate requirements. Without loss of generality, the target outage probability and data rate for different users are denoted by $\overline{\text{Pout}}$ and $\overline{R}$ (in bits/s), respectively. Using Eq. (2) and the Shannon capacity formula, we can obtain the channel capacity from BS to U_i in time slot i as

$$C_{bi}^T(i) = B\log_2\left(1 + \frac{|h_{bi}(i)|^2 P_i}{d_{bi}^n N_0 B}\right). \tag{6}$$

As discussed in [13], an outage event occurs when the channel capacity drops below the target data rate $\overline{R}$. Thus, an outage probability of the transmission from BS to U_i with the traditional scheme can be obtained from Eq. (6) as

$$\text{Pout}_i^T = \Pr\left(C_{bi}^T(i) < \overline{R}\right). \tag{7}$$

Substituting Eq. (6) into Eq. (7) gives

$$\mathrm{Pout}_i^T = \Pr\left(|h_{bi}(i)|^2 < \frac{(2^{\bar{R}/B}-1)d_{bi}^n N_0 B}{P_i} \right). \tag{8}$$

Note that random variable $|h_{bi}(i)|^2$ follows exponential distribution with mean σ_{bi}^2. Thus, we can further compute Eq. (8) as

$$\mathrm{Pout}_i^T = 1 - \exp\left(-\frac{(2^{\bar{R}/B}-1)d_{bi}^n N_0 B}{P_i \sigma_{bi}^2} \right). \tag{9}$$

Given the target outage probability, i.e., $\mathrm{Pout}_i^T = \overline{\mathrm{Pout}}$, we can obtain the power consumption of BS in time slot i from Eq. (9) as

$$P_i = -\frac{(2^{\bar{R}/B}-1)d_{bi}^n N_0 B}{\sigma_{bi}^2 \ln(1-\overline{\mathrm{Pout}})}, \tag{10}$$

where $0 < \overline{\mathrm{Pout}} < 1$. Considering that the duration of time slot is T/N, the energy consumption of BS in time slot i denoted by E_i is given by

$$E_i = -\frac{T}{N} P_i . \tag{11}$$

Thus, the total energy consumption of BS over N time slots with the traditional cellular transmission scheme is obtained as

$$E_T = \frac{T}{N} \sum_{i=1}^{N} P_i . \tag{12}$$

Since BS transmits at data rate $\bar{R}$ during N time slots, the total number of bits transmitted can be given by

$$\mathrm{Nbits} = \bar{R}T . \tag{13}$$

Using Eqs. (12) and (13), the energy efficiency in Bits-per-Joule is defined as

$$\eta_T = \frac{\mathrm{Nbits}}{E_T} = \frac{N}{\sum_{i=1}^{N} P_i} \bar{R}, \tag{14}$$

which is used to quantify the number of bits delivered per Joule of energy cost.

3.2 Proposed Network Coding Scheme

In this subsection, we present the energy efficiency analysis of proposed network coded cellular downlink transmission. As aforementioned, in the network coded transmission, a user U_i can obtain s_i from BS in two possible ways: 1) by decoding its received signal from BS in time slot i; and 2) by performing the modulo-2 addition among the decoded outcomes of its received signals from BS in other N slots. Hence, an outage event occurs at U_i in decoding s_i only when U_i fails to decode its received signal in time slot i and is unable to succeed in decoding all the received signals in other N time slots. Therefore, an outage probability of the transmission from BS to U_i with the proposed network coding scheme can be given by

$$\mathrm{Pout}_i^P = \Pr\left(C_{bi}^P(i) < \frac{(N+1)\bar{R}}{N}, \min_{j\in\Omega_i} C_{bi}^P(j) < \frac{(N+1)\bar{R}}{N} \right), \tag{15}$$

where $\Omega_i = \{1,2,\cdots,N+1\}-\{i\}$, $C_{bi}^P(i)$ and $C_{bi}^P(j)$ represent the channel capacities of transmission from BS to U_i in time slots i and j, respectively. Using the Shannon capacity formula, we can obtain $C_{bi}^P(i)$ from Eq. (4) as

$$C_{bi}^P(i) = B\log_2\left(1 + \frac{|h_{bi}(i)|^2 P}{d_{bi}^n N_0 B} \right). \tag{16}$$

Similarly, we can also obtain $C_{bi}^P(j)$ from Eq. (5) as

$$C_{bi}^P(j) = B\log_2\left(1 + \frac{|h_{bi}(j)|^2 P}{d_{bi}^n N_0 B} \right). \tag{17}$$

Substituting Eqs. (16) and (17) into Eq. (15) and assuming that the wireless fading varies independently from slot to slot (i.e., $|h_{bi}(i)|^2$ and $|h_{bi}(j)|^2$ are independent of each other), we can obtain Eq. (18) at the top of following page.

$$\begin{aligned} \mathrm{Pout}_i^P &= \Pr\left(|h_{bi}(i)|^2 < \frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{P} \right) \\ &\times \Pr\left(|\min_{j\in\Omega_i} h_{bi}(j)|^2 < \frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{P} \right) \end{aligned}. \tag{18}$$

It is pointed out that both random variables $|h_{bi}(i)|^2$ and $|h_{bi}(j)|^2$ follow independent exponential distribution with the same mean σ_{bi}^2. As a consequence, we can obtain term $\Pr\left(|h_{bi}(i)|^2 < \frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{P} \right)$ as

$$\Pr\left(|h_{bi}(i)|^2 < \frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{P} \right) = 1 - \exp\left(-\frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{\sigma_{bi}^2 P} \right). \tag{19}$$

Also, we can similarly obtain

$$\begin{aligned} &\Pr\left(|\min_{j\in\Omega_i} h_{bi}(j)|^2 < \frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{P} \right) \\ &= 1 - \Pr\left(|\min_{j\in\Omega_i} h_{bi}(j)|^2 > \frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{P} \right) \\ &= 1 - \prod_{j\in\Omega_i} \Pr\left(|h_{bi}(j)|^2 > \frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{P} \right) \\ &= 1 - \exp\left(-\frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 BN}{\sigma_{bi}^2 P} \right) \end{aligned}. \tag{20}$$

Substituting Eq. (19) and (20) into Eq. (18) gives

$$\begin{aligned}\mathrm{Pout}_i^P = 1 &- \exp\left(-\frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{\sigma_{bi}^2 P}\right) \\ &- \exp\left(-\frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 BN}{\sigma_{bi}^2 P}\right) \\ &+ \exp\left(-\frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B(N+1)}{\sigma_{bi}^2 P}\right)\end{aligned} \quad . \tag{21}$$

Considering the target outage probability $\mathrm{Pout}_i^P = \overline{\mathrm{Pout}}$ and denoting $x_i = \exp\left(-\frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{\sigma_{bi}^2 P}\right)$, we can obtain from Eq. (21) as

$$1 - x_i - x_i^N + x_i^{N+1} = \overline{\mathrm{Pout}}, \tag{22}$$

from which the solution $0 < x_i^* < 1$ can be easily determined. Thus, given $\mathrm{Pout}_i^P = \overline{\mathrm{Pout}}$, the power consumption P is obtained as

$$P = -\frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{d_{bi}^2 \ln(x_i^*)}, \tag{23}$$

where x_i^* is in the range of 0 to 1 and satisfies Eq. (22). Considering the fact that for all N users, the corresponding outage probabilities of transmissions from BS to different users should be guaranteed to be less than $\overline{\mathrm{Pout}}$, we can obtain the power consumption P as

$$P = -\min_{i \in \boldsymbol{U}} \frac{[2^{(N+1)\bar{R}/(NB)}-1]d_{bi}^n N_0 B}{d_{bi}^2 \ln(x_i^*)}, \tag{24}$$

where $\boldsymbol{U}$ represents the set of N users. Therefore, the total energy consumption of BS over the frame duration T with the proposed network coded cellular transmission scheme is given by

$$E_P = PT\ . \tag{25}$$

Meanwhile, in the network coded cellular transmission, the total number of effective bits transmitted over the frame duration T can be given by

$$\mathrm{Nbits} = \frac{(N+1)\bar{R}}{N}\frac{NT}{N+1} = \bar{R}T\ . \tag{26}$$

Using Eqs. (25) and (26), the energy efficiency of proposed network coded cellular transmission is given by

$$\eta_P = \frac{\mathrm{Nbits}}{E_P} = \frac{\bar{R}}{P}, \tag{27}$$

where P is given by Eq. (24).

4. Numerical Results and Discussions

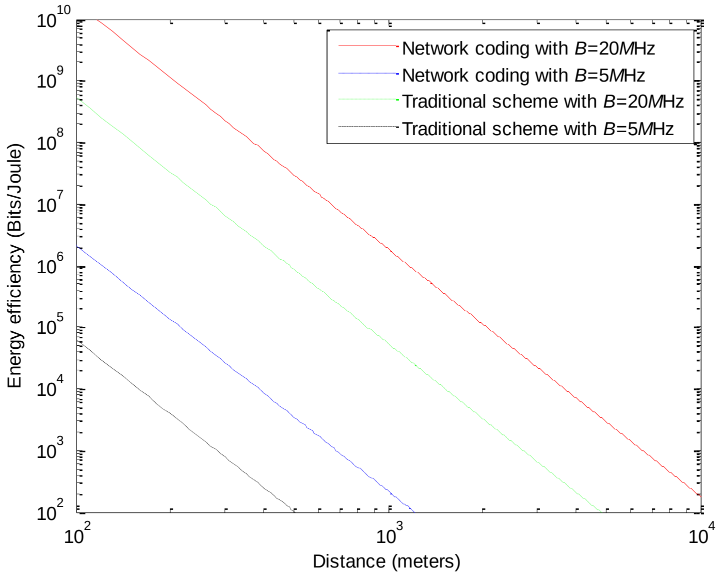

Fig. 4. Energy efficiency versus transmission distance from BS to N users ($d_{b1} = d_{b2} = \cdots = d_{bN}$) of the traditional and proposed cellular transmission schemes with target outage probability $\overline{\text{Pout}} = 10^{-3}$, data rate $\overline{R} = 10M\text{bits/s}$, $N_0 = -174\text{dBm/Hz}$, $N = 2$, $n = 4$, $\sigma_{b1}^2 = 1$ and $\sigma_{b2}^2 = 2$.

In this section, we present the numerical energy efficiency results to show the advantage of proposed network coded cellular transmission scheme over the traditional cellular transmission. Fig. 4 shows the energy efficiency of traditional and proposed cellular transmission schemes with target outage probability $\overline{\text{Pout}} = 10^{-3}$ and data rate $\overline{R} = 100M\text{bits/s}$ by plotting Eqs. (14) and (27) as a function of transmission distance from BS to N users ($d_{b1} = d_{b2} = \cdots = d_{bN}$), in which two different spectrum bandwidths (i.e., $B = 5M\text{Hz}$ and $B = 20M\text{Hz}$) are considered. One can observe from Fig. 4 that the energy efficiencies of traditional and proposed cellular transmission schemes corresponding to $B = 20M\text{Hz}$ are higher than these corresponding to $B = 5M\text{Hz}$, respectively. This means that increasing the spectrum bandwidth can improve the energy efficiency of cellular transmission. In addition, Fig. 4 also shows that for both cases of $B = 5M\text{Hz}$ and $B = 20M\text{Hz}$, the proposed network coding scheme always outperforms the traditional cellular transmission in term of energy efficiency, implying the energy saving benefits of using network coding for the cellular transmission.

Fig. 5 shows the energy efficiency comparison between the traditional and proposed cellular transmission schemes by plotting Eqs. (14) and (27) as a function of outage probability requirement $\overline{\text{Pout}}$ with target data rate $\overline{R} = 100M\text{bits/s}$, $N_0 = -174\text{dBm/Hz}$, $N = 2$, $n = 4$, $d_{b1} = d_{b2} = 500\text{m}$, $\sigma_{b1}^2 = 1$ and $\sigma_{b2}^2 = 2$. As shown in Fig. 5, the energy efficiencies of both traditional and proposed cellular transmission schemes increase as the outage probability becomes larger, implying that increasing the target outage probability will result in an increase of energy efficiency. It is seen from Fig. 5 that for both the traditional and proposed cellular transmission schemes, the energy efficiency corresponding to $B = 20M\text{Hz}$ is strictly higher than that corresponding to $B = 5M\text{Hz}$, showing the energy efficiency improvement by increasing the spectrum bandwidth. Fig. 5 also shows that for both cases of $B = 5M\text{Hz}$ and $B = 20M\text{Hz}$, the proposed network coding scheme performs better than the traditional cellular transmission in term of energy efficiency. This means that given a Joule of energy cost, the network coded cellular transmission scheme can deliver more bits than the traditional cellular transmission.

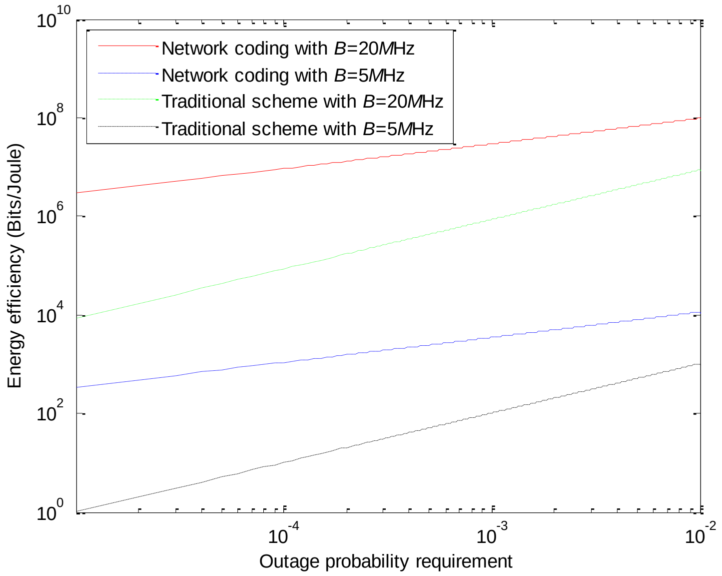

Fig. 5. Energy efficiency versus target outage probability $\overline{\text{Pout}}$ of the traditional and proposed cellular transmission schemes with target data rate $\overline{R} = 100M\text{bits/s}$, $N_0 = -174\text{dBm/Hz}$, $N = 2$, $n = 4$, $d_{b1} = d_{b2} = 500\text{m}$, $\sigma_{b1}^2 = 1$ and $\sigma_{b2}^2 = 2$.

5. Conclusion

In this paper, we investigated the network coding for improving energy efficiency in cellular networks and proposed the network coded cellular transmission scheme. Under target outage probability and data rate requirements, we derived the energy consumption of proposed network coded cellular transmission over Rayleigh fading channels and conducted its energy efficiency analysis to evaluate the number of bits delivered per Joule of energy cost. For the comparison purpose, we also analyzed the energy efficiency of the conventional cellular transmission. Numerical results showed that the proposed network coded cellular transmission strictly outperforms the traditional cellular transmission in terms of energy efficiency, which verifies the energy saving benefits of exploiting network coding for cellular transmission.

In this paper, we only investigated the single antenna at both BS and users. However, exploiting multiple antennas can further improve the energy efficiency performance of cellular transmissions under target quality of service (QoS) requirement. It is thus of high practical interest to extend the results of this paper to the general case with multiple antennas. We leave this interesting extension for our future work.

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