On Energy Efficiency of the Nearest-Neighbor Cooperative Communication in Heterogeneous Networks

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Abstract—In this paper, we consider a two-dimensional heterogeneous cellular network scenario consisting of one base station (BS) and some mobile stations (MSs) whose locations follow a Poisson point process (PPP). The MSs are equipped with multiple radio access interfaces including a cellular access interface and at least one short-range communication interface. We propose a nearest-neighbor cooperation communication (NNCC) scheme by exploiting the short-range communication between a MS and its nearest neighbor to collaborate on their uplink transmissions. In the proposed cooperation scheme, a MS and its nearest neighbor first exchange data by the short-range communication. Upon successful decoding of the data from each other, they proceed to send their own data, as well as the data received from the other to the BS respectively in orthogonal time slots. The energy efficiency analysis for the proposed scheme is presented based on the characteristics of the PPP and the Rayleigh fading channel. Numerical results show that the NNCC scheme significantly improves the energy efficiency compared to the conventional non-cooperative uplink transmissions.

Index Terms—Cooperative communication; Poisson point process; heterogeneous cellular network

I. INTRODUCTION

Nowadays many of mobile stations (MSs), e.g., smart cellular phones, tablets and PDAs, are equipped with multiple radio access interfaces, e.g., cellular radio access, wireless local area network (WLAN), Bluetooth interfaces and etc.. As multi-mode MSs, they can constitute heterogeneous cellular networks (HCNs) and make it possible to improve the performance of cellular uplinks by serving as a relay to their neighboring MSs. By some of short-range communication methods provided by the multi-mode MSs, they can communicate with each other with significantly high efficiency and quite low cost. Then the MSs can exploit the short-range communication links among them along with the uplinks to the base station (BS) to form the cooperative communication, which can improve the performance of the HCNs with regard to rate, outage probability, coverage, energy efficiency and etc.. This paper focuses on the improvement of the energy efficiency of uplink cellular communications based on cooperation between neighboring MSs in HCNs.

Cooperative diversity has already emerged as a new and effective technique to combat fading and to decrease energy consumption in wireless networks. The nearest neighbor relay scheme that relay is chosen to be the nearest-neighbor to the user towards the BS (access-point) always has been applied in [1], [2]. [1] proposes and analyzes the performance of two schemes: a distributed nearest-neighbor relay assignment in which users can act as relays, and an infrastructure-based relay assignment in which fixed relay nodes are deployed in the network to help the users forward their data. [2] explores the balance between cooperation through relay nodes and aggregated interference generation in large decentralized wireless networks using decode-and-forward by the nearest neighbor relay scheme. [3] proposes an energy-efficient cooperative multicasting scheme by properly selecting relay agents (RAs) based on their location, channel condition and coverage. [4] studies the relay selection schemes to reduce energy consumption, and the optimal number of cooperative is also given. Besides, [5] is based on coded cooperation, which combines cooperation and channel coding together. To save bandwidth and improve the information transmission rate, network coding [6] is often used after the MSs receive each other’s information successfully. But based on some criteria, [7] finds more scenarios where network coding has no gain on throughput or energy saving. Further more, many existing works concentrate on the resource allocation in cooperative networks. [8] presents both a centralized and a distributed power allocation schemes to optimize the BER performance of cooperative networks. To maximize the overall throughput, [9] proposes an optimal power allocation. An adaptive coded

∗The corresponding author is Lijun Wang. The authors would like to acknowledge the support from the International Science and Technology Cooperation Program of China (Grant No. 2014DA11640, 2012DFG12250 and 0903), the National Natural Science Foundation of China (NSFC) (Grant No. 61471180, 61271224 and 61301128), the NSFC Major International Joint Research Project (Grant No. 61210002), the Ministry of Science and Technology 863 program (Grant No. 2014AA01A707), the Hubei Provincial Science and Technology Department (Grant No. 2013CFB188), the Fundamental Research Funds for the Central Universities (Grant No. 2013ZZGH009 2013Q1N155), and Special Research Fund for the Doctoral Program of Higher Education (Grant No. 20130142120044), and EU FP7-PEOPLE-IRSES (Contract/Grant No. 247083, 318992 and 610524)
cooperative protocol based on incremental redundancy by a
ACK/NACK feedback is proposed in [10].

Many of the above works have presented valuable theories,
methods and technologies of cooperative communication. But
there are still some improvements left to perform. Zou et al.
in [11] investigate user terminals cooperating with each other
in transmitting their data packets to the BS, by exploiting
the multiple network access interfaces, which is called inter-
network cooperation. Given a target outage probability and
data rate requirements, they analyze the energy consumption
of conventional schemes as compared to the proposed inter-
network cooperation. The results show that the inter-network
cooperation can significantly improve the energy efficiency
of the uplink cellular communications. However in practical
view there are some limits of this scheme work. In [11],
it is required that the cooperative MSs have the same distances
to the BS and know the instantaneous fading coefficients
of both the short-range communication channel and each cellular
channel to form an orthogonal matrix used in cooperative.
In contrast, our paper intends to propose a more general
and yet efficient cooperative scheme for HCNs, in which the
cooperative MSs do not need to locate at the same distance
away from the BS and are able to perform the cooperative
communication without knowing the channel status.

The main contributions of this paper are summarized as
follows. At first, we present a nearest-neighbor cooperative
communication (NNCC) scheme in a HCN consisting of
different radio access networks, i.e., a short-range commu-
nication network and a cellular network. Then we compare
the proposed NNCC scheme to conventional schemes without
user cooperation under target outage probability and data rate
requirements. Secondly, we derive the energy efficiency of
NNCC scheme in a Rayleigh fading environment. Further
more, given a target outage probability, data rate requirements
and distances between MSs and the BS, we derive the cumu-
lative distribution function (CDF) and the probability density
function (PDF) of energy consumption by considering the MSs
that follow a Poisson point process (PPP).

The remainder of this paper is organized as follows. Section
II presents the network model and the NNCC scheme. In Sec-
tion III we present the desired power consumption analysis,
then we derive the CDF and the PDF of the system desired
power consumption by considering stochastic spatial distri-
bution of cooperative MSs. Section IV gives the numerical
results. Finally, Section V concludes the paper.

II. SYSTEM MODEL

In this section, we first present a two-dimensional network
model of a HCN environment. Then, we propose a NNCC
scheme by exploiting the short-range network to assist cellular
uplink transmissions.

A. Network Model

Consider a HCN consisting of a BS and some MSs whose
locations follow a homogeneous Poisson point process (PPP)
with density \( \rho \). The MSs are assumed to equip with multiple
radio access interfaces including at least a short-range commu-
nication interface and a cellular access interface. The MSs can
communicate with their neighboring MSs by the short-range
communication. The packet size of data is assumed to be the
same across cellular communication link and all short-range
communication links between MSs. Without loss of generality,
we consider the BS is located at the origin of coordinate,
and a specific MS U1 located at coordinate \( (r_0, 0) \) intends
to communicate with the BS. Our model is shown in Fig. 1.
U1 will choose its nearest neighboring MS, denoted by U2,
to cooperatively communicate with the BS. According to the
properties of the homogeneous PPP, the distance \( r \) between
U1 and U2 satisfies the following PDF [12]

\[
f_r(r) = 2\pi\rho r \exp \left(-\pi\rho r^2 \right),
\]

then the coordinate of U2 can be obtained as \( (r_0 + r \cos \theta, r \sin \theta) \), where \( \theta \) follows a uniform distribution
between \(-\frac{\pi}{2}\) and \(\frac{\pi}{2}\). Denote the distance between U1 and
the BS by \( r_1 \). The distance \( r_2 \) between the MS U2 and BS
can be obtained as

\[
r_2^2 = r^2 + r_1^2 + 2r_1 r \cos (-\theta) = r^2 + r_1^2 + 2r_1 r \cos \theta.
\]

We consider a general channel model that incorporates the
radio frequency, path loss and fading effects in characterizing
wireless transmissions, i.e.,

\[
P_R = P_T \left( \frac{\lambda}{4\pi d} \right)^2 G_T G_R |h|^2,
\]

where \( P_R \) is the received power, \( P_T \) is the transmitted power,
\( \lambda \) is the carrier wavelength, \( d \) is the transmission distance,
\( G_T \) is the transmit antenna gain, \( G_R \) is the receive antenna
gain, and \( h \) is the channel fading coefficient. In this paper,
we consider a Rayleigh fading model to characterize the channel
fading, i.e., \( |h|^2 \) is modeled as an exponential random variable.

B. The NNCC Scheme

In the NNCC scheme, when MS U1 and its nearest neighbor
MS U2 intend to send data \( D_1 \) and \( D_2 \) to the BS, respectively,
they cooperate with each other according to the following steps:

1) U1 and U2 exchange their data over the short-range communication network in time slot 1.

2) If both U1 and U2 succeed in decoding the data from each other, defined as the case $\delta = 0$, both of them will send their own data as well as the data received from the other side to the BS in time slot 2 and time slot 3, respectively, i.e., they send both $D_1$ and $D_2$ to the BS over two orthogonal cellular uplink channels. Otherwise, defined as the case $\delta = 1$, U1 and U2 will send only their own data to the BS separately in time slot 2, just like a conventional non-cooperation communication.

Assuming that the short-range channels among MSs and the cellular channels to the BS are orthotropic and there is no interference at the BS among the MSs’ signals, we only consider the channel noise when analyzing the performance of the scheme. Considering that U1 transmits $D_i$ to Uj with the signal power $P_{ij}^{NC}$, we can obtain the received signal-to-noise-ratio (SNR) between MSs by NNCC scheme as

$$\gamma_{ij}^{NC} = \frac{P_{ij}^{NC}}{N_0 B_s} \left( \frac{\lambda_s}{4\pi r} \right)^2 G_U G_{U2} |h_{ij}|^2,$$  \hspace{1cm} (4)

where $i = 1 \text{ or } 2$, $j = 2 \text{ or } 1$, $i \neq j$, $\lambda_s$ is the carrier wavelength of the short-range communication, $G_U$ is the antenna gain at U1, $G_{U2}$ is the antenna gain at U2, and $h_{ij}$ is the fading coefficient of the channel from U1 to Uj. The noise is modeled as $N_0 B_s$, where $N_0$ is the noise power spectral density and $B_s$ is the channel bandwidth.

In step 2, MSs will transmit the data to the BS, and the received SNR at the BS from MS U1 or U2 over the cellular channel can be obtained as

$$\gamma_{ib} = \frac{P_{ib}}{N_0 B_c} \left( \frac{\lambda_c}{4\pi r_i} \right)^2 G_{U1} G_{BS} |h_{ib}|^2,$$  \hspace{1cm} (5)

where $i = 1 \text{ or } 2$, $\lambda_c$ is the cellular carrier wavelength, $B_c$ is the cellular spectrum bandwidth, $G_{BS}$ is the receive antenna gain at BS, and $h_{ib}$ is the fading coefficient of channel from U1 to BS.

### III. ENERGY EFFICIENCY ANALYSIS OF NNCC SCHEME

In this section, we analyze the energy efficiency of the proposed NNCC scheme compared to the conventional scheme without cooperation, under the requirements of target outage probability $P_{\text{out}}$ and data rate $R$.

#### A. Energy Consumption in the NNCC scheme

**Theorem 1.** Under the situation that the BS succeeds in receiving the complete data from both MSs, the power consumption for the NNCC scheme can be obtained as

$$P^{NC} = P_{12}^{NC} + P_{21}^{NC} + (1 + (1 - P_{\text{out}})^2)(P_{1b}^{NC} + P_{2b}^{NC}),$$  \hspace{1cm} (6)

where $P_{\text{out}}$ is the target outage probability, and to meet the target outage probability, where $P_{12}^{NC}$, $P_{21}^{NC}$, $P_{1b}^{NC}$ and $P_{2b}^{NC}$ are the desired transmission power from U1 to U2, U2 to U1, U1 to the BS and U2 to the BS, respectively, which are given by (9) and (13).

**Proof:** Due to the limited error correction capability in practical communication systems, both the short-range and cellular communications cannot achieve the Shannon capacity. Therefore, let $\Delta_s > 1$ and $\Delta_c > 1$ denote the performance gaps for the short-range communication and the cellular communication from their respective capacity limits, respectively. Using (3) and considering the performance gap $\Delta_s$ away from Shannon capacity, we obtain the maximum achievable rate from U1 to U2 of the short-range communication of the NNCC scheme as

$$C_{12}^{NC} = B_s \log_2 \left( 1 + \frac{P_{12}^{NC} G_{U1} G_{U2} |h_{12}|^2}{\Delta_s N_0 B_s} \left( \frac{\lambda_s}{4\pi r} \right)^2 \right).$$  \hspace{1cm} (7)

In a Rayleigh fading channel, all random variables $|h_{12}|^2$, $|h_{21}|^2$, $|h_{1b}|^2$ and $|h_{2b}|^2$ follow independent exponential distributions with means $\sigma_{12}^2$, $\sigma_{21}^2$, $\sigma_{1b}^2$ and $\sigma_{2b}^2$, respectively. As we know, an outage event occurs when the channel capacity falls below the required data rate. Using (3) and considering the performance gap $\Delta_s$ away from Shannon capacity, we can obtain the outage probability of the short-range transmission from U1 to U2 as

$$P_{\text{out}12} = \Pr \left( C_{12}^{NC} < R \right) = 1 - \exp \left( -\frac{16\pi^2 \Delta_s N_0 B_s r^2 \left( 2 \frac{\lambda_c}{\lambda_s} - 1 \right)}{P_{12}^{NC} \sigma_{12}^2 G_{U1} G_{U2} \lambda_s^2} \right).$$  \hspace{1cm} (8)
Assuming $P_{\text{out}}^{\text{NC}} = P_{\text{out}}$, we can obtain the desired power consumption of MSs for short-range communication $P_{ij}^{\text{NC}}$ from (5) as

$$P_{ij}^{\text{NC}} = -\frac{16\pi^2 \Delta s N_0 B_\theta}{\sigma^2_{ij} G_{U_1} G_{U_2} \lambda^2_{\text{NC}}} \ln (1 - P_{\text{out}}^{\text{NC}}) r^2. \quad (9)$$

Given $\sigma^2_{12} = \sigma^2_{21}$, we can obtain $P_{21}^{\text{NC}} = P_{21}^{\text{NC}} = \zeta r^2$, where

$$\zeta = -\frac{16 \pi \Delta_{\text{nc}} N_0 B_\theta}{\sigma^2_{12} G_{U_1} G_{U_2} \lambda^2_{\text{NC}}} \ln (1 - P_{\text{out}}^{\text{NC}}).$$

As discussed before, case $\delta = 0$ implies that both U1 and U2 succeed in decoding each other’s signals through short range communications, and $\delta = 1$ means that either U1 or U2 fails to decode in the short-range transmissions. We can describe $\delta = 0$ and $\delta = 1$ as follows.

$\delta = 0$:

$$B_s \log_2 \left( 1 + \frac{\gamma_{\text{NC}}^{\text{NC}}}{\Delta s} \right) \geq R \text{ and } B_s \log_2 \left( 1 + \frac{\gamma_{\text{NC}}^{\text{NC}}}{\Delta s} \right) \geq R. \quad (10)$$

$\delta = 1$:

$$B_s \log_2 \left( 1 + \frac{\gamma_{\text{NC}}^{\text{NC}}}{\Delta s} \right) < R \text{ or } B_s \log_2 \left( 1 + \frac{\gamma_{\text{NC}}^{\text{NC}}}{\Delta s} \right) < R. \quad (11)$$

Denote the target outage probability for short-range communication between U1 and U2 by $P_{\text{out}}$, given $P_{\text{out}}^{\text{NC}} = P_{\text{out}21} = P_{\text{out}}$, we have

$$\Pr (\delta = 0) = (1 - P_{\text{out}})^2,$$

and

$$\Pr (\delta = 1) = 1 - (1 - P_{\text{out}})^2.$$

Moreover, denote the target outage probability for cellular communication from U1, U2 to the BS by $P_{\text{out}}^{\text{NC}}$, and given $P_{\text{out}1b}^{\text{NC}} = P_{\text{out}2b}^{\text{NC}} = P_{\text{out}}^{\text{NC}}$, we have $\Pr (C_{1b} < R) = \Pr (C_{2b} < R)$, then we obtain the outage probability of the NNCC scheme by from (10) and (11) as

$$P_{\text{out}} = (1 - P_{\text{out}})^2 * \left( P_{\text{out}1b}^{\text{NC}} + (1 - (1 - P_{\text{out}})^2) \right) * \left( 1 - (1 - P_{\text{out}})^2 \right).$$

Then, we obtain

$$P_{\text{out}}^{\text{NC}} = \sqrt{(1 - \epsilon)^2 + P_{\text{out}} (2\epsilon - 1) - (1 - \epsilon)}, \quad (12)$$

where $\epsilon = (1 - P_{\text{out}})^2$.

We can obtain the power consumption of U1 for cellular communication from (12) as

$$P_{(1b)}^{\text{NC}} = -\frac{16\pi^2 \Delta_{\text{e}} N_0 B_c}{\sigma^2_{(1b)} G_{U_1} G_{BS} \lambda^2_{\text{NC}}} \ln (1 - P_{\text{out}}^{\text{NC}})^2. \quad (13)$$

Given $\sigma^2_{1b} = \sigma^2_{2b}$, we can obtain $P_{(1b)}^{\text{NC}} = \eta r^2$ and $P_{(2b)}^{\text{NC}} = \eta r^2$, where

$$\eta = -\frac{16 \pi \Delta_{\text{e}} N_0 B_c}{\sigma^2_{1b} G_{U_2} G_{BS} \lambda^2_{\text{NC}}} \ln (1 - P_{\text{out}}^{\text{NC}}).$$

Notice that in case of $\delta = 0$, cooperation communication is employed and there are energy consumption at both time slot 2 and time slot 3, resulting in that a total power consumption of $2(P_{(1b)}^{\text{NC}} + P_{(2b)}^{\text{NC}})$ is consumed by U1 and U2 in transmitting to BS. In case of $\delta = 1$, U1 and U2 consume a total power consumption of $(P_{(1b)}^{\text{NC}} + P_{(2b)}^{\text{NC}})$ for transmitting to BS. Therefore, considering both the short-range communication and cellular transmissions, the total power consumption by the NNCC scheme is given by

$$P_{\text{NC}} = P_{(1b)}^{\text{NC}} + P_{(2b)}^{\text{NC}} + (2 \Pr (\delta = 0) + \Pr (\delta = 1)) (P_{(1b)}^{\text{NC}} + P_{(2b)}^{\text{NC}}) = P_{(1b)}^{\text{NC}} + P_{(2b)}^{\text{NC}} + (1 + (1 - P_{\text{out}}^2)) (P_{(1b)}^{\text{NC}} + P_{(2b)}^{\text{NC}}).$$

In order to compare our method and the traditional method, we give the same target interrupt probability definition about two schemes, and then we will derive the power consumption for the conventional scheme without user cooperation, in which both U1 and U2 succeed in transmitting their data to the BS separately. Similarly to the power consumption analysis of the NNCC scheme, assuming that $P_{\text{out}1b}^{\text{NC}} = P_{\text{out}2b}^{\text{NC}} = P_{\text{out}}$, the total power consumption of U1 and U2 under conventional non-cooperative communication can be obtained by

$$P_{\text{C}} = \sum_{i=1}^{2} P_{(i)}^{\text{C}}, \quad (14)$$

where

$$P_{(i)}^{\text{C}} = -\frac{16\pi^2 \Delta_{\text{e}} N_0 B_c \eta^2}{\sigma^2_{(i)} G_{U_1} G_{BS} \lambda^2_{\text{NC}}} \ln (1 - P_{\text{out}}^{\text{C}})^2, \quad (15)$$

and

$$P_{\text{out}}^{\text{C}} = 1 - \sqrt{1 - P_{\text{out}}}. \quad (16)$$

As (12) and (16) show, the NNCC scheme can save more energy than the conventional scheme because it can work under larger target outage probability. Theorem 1 and (14) give the relations between the desired transmission powers and the target outage probabilities as well as other impact factors, e.g., path loss, fading, and thermal noise, under the NNCC scheme and the conventional non-cooperative scheme, respectively. Based on them, some further performance analysis, such as the energy efficiency analysis in Section III-B, can be presented.

B. Energy Efficiency Analysis based on PPP

In order to get more performance analysis about the NNCC scheme, we put the NNCC scheme on a more general environment, we will consider MSs satisfy Poisson point process, which meet actual situation. The result is more practical and performance analysis is more accurate. Moreover, considering the stochastic spatial distribution of the MSs, we can derive the CDF and PDF of the desired transmission power which meet the target outage probability and rate requirement.

**Theorem 2.** When the spatial distribution of the MSs follows a homogeneous PPP with density $\rho$, the PDF of $P_{\text{NC}}^{\text{NC}}$ is

$$f_{P_{\text{NC}}^{\text{NC}}} = \begin{cases} \int_{\Delta R}^{\pi/2} \rho R_{\text{e}}(\alpha_{\text{nc}}^2)^2 \sin(\alpha_{\text{nc}}^2) d\alpha, & Q_1 \\ \int_{\Delta R}^{\pi/2} \rho R_{\text{e}}(\alpha_{\text{nc}}^2)^2 \sin(\alpha_{\text{nc}}^2) d\alpha, & Q_2 \end{cases}.$$
and the CDF of $P_{\text{NC}}$ is
\[
F_{P_{\text{NC}}} (P_{\text{NC}}) = \begin{cases} 
\frac{3\pi}{2} e^{-\frac{\pi}{2} \varepsilon (\pi - \theta)} d\theta, & \text{if } Q_1 \\
\frac{3\pi}{2} e^{-\frac{\pi}{2} \varepsilon (\pi - \theta)} d\theta + F_{P_{\text{NC}}} (2\varepsilon \eta r_1^2), & \text{if } Q_2,
\end{cases}
\]
where
\[
\varepsilon = 1 + (1 - P_{\text{out}})^2, \quad (17)
\]
\[
\Delta_R = \sqrt{(\varepsilon r_1 \cos \theta)^2 - (2\zeta + \varepsilon \eta)(2\varepsilon \eta r_1^2 - P_{\text{NC}})}, \quad (18)
\]
\[
R_2 = \frac{-\varepsilon r_1 \cos \theta + \Delta_R}{2\zeta + \varepsilon \eta}, \quad (19)
\]
and
\[
R_1 = \frac{-\varepsilon r_1 \cos \theta - \Delta_R}{2\zeta + \varepsilon \eta}. \quad (20)
\]

$Q_1$ stands for $2\varepsilon \eta r_1^2 - \frac{(\varepsilon r_1 \cos \theta)^2}{2\zeta + \varepsilon \eta} < P_{\text{NC}} \leq 2\varepsilon \eta r_1^2$ and $Q_2$ stands for $P_{\text{NC}} > 2\varepsilon \eta r_1^2$.

Proof: Due to independence of random variables $r$ and $\theta$, considering $\theta$ follows the uniform distribution between $-\frac{\pi}{2}$ and $\frac{3\pi}{2}$, $r$ satisfies (1), the PDF of $r$ and $\theta$ can be obtained as
\[
f(r; \theta) = r \exp \left(-\pi r^2 \right). \quad (21)
\]

Substituting (6) into (2), we obtain
\[
P_{\text{NC}} = (2\zeta + \varepsilon \eta) r^2 + 2\varepsilon \eta r_1 \cos \theta r + 2\varepsilon \eta r_1^2. \quad (22)
\]

So the the CDF of $P_{\text{NC}}$ is

\[
F_{P_{\text{NC}}} (P_{\text{NC}}) = \text{Pr} \left( P_{\text{NC}} \leq P_{\text{NC}} \right) = \text{Pr} \left( (2\zeta + \varepsilon \eta) r^2 + 2\varepsilon \eta r_1 \cos \theta r + 2\varepsilon \eta r_1^2 \leq P_{\text{NC}} \right). \quad (23)
\]

Based on (21) and (23), we can acquire the PDF of desired power for NNCC scheme as Theorem 2 expresses.

From Theorem 2 we will know the PDF and CDF of $P_{\text{NC}}$, and can easily obtain its expectation. It can help us to find the energy efficiency. Based on Theorem 2, it is easy to derive the relations between desired transmission power of the NNCC scheme and the target outage probability as well as other impact factors. Considering a successful transmission delivering both data of U1 and U2 by the total power consumption $P_{\text{NC}}$, the energy efficiency of the NNCC scheme can be derived by
\[
EE_{\text{NC}} = \frac{2R}{E(P_{\text{NC}})} \quad (24)
\]

In Section IV some numerical results about the desired transmission power and the energy efficiency of the NNCC scheme are given.
cooperative MSs tends to be smaller when the density of the MSs increases, and thus less power consumption is required in step 1. Fig. 5 demonstrates that the energy consumptions of the NNCC scheme decreases as the target outage probability increases with various densities of the MSs.

Fig. 5. Relation between the desired the transmission power and the density of MSs, with target outage probability $P_{out} = 10^{-3}$, effective rate $R = 1000000$ bits/s, and inter-user distance $r_1 = 2000$ m.

Fig. 4. Energy efficiency by various transmission schemes with target outage probability $P_{out} = 10^{-3}$, effective rate $R = 1000000$ bits/s, and inter-user distance $r_1 = 2000$ m.

Fig. 6. Desired transmission power with regard to the target outage probability with effective rate $R = 1000000$ bits/s, and U1-BS distance $r_1 = 150$ m.

**V. CONCLUSIONS**

In this paper, we propose a cooperative communication scheme, namely the NNCC scheme, in which a MS in HCN and its nearest neighbor MS exploit a short-range communication network to assist the cellular transmissions. The energy efficiency of the NNCC scheme is analyzed and derived in closed-form expressions, which provide insights into the relations between energy efficiency and many important factors, e.g., MS density, the distance between the MSs and the BS, the target outage probability and etc.. Numerical results show that the NNCC scheme is simple, yet efficient compared to the existing schemes. Although this article studies collaboration between two MSs only, it’s obvious that there are vast energy saving comparing with the traditional scheme, no matter from the aspects of the distance between BS and MSs or expectation. In this paper, we have only considered the scenario of a single BS and allow only two MSs cooperate with each other. In the future, we will extend the work to the multicell scenario with multi-MS cooperative communications.

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