DOI: 10.3969/j. issn. 1673-5188. 2017. 02. 007
http://kns.cnki.net/kcms/detail/34.1294.TN.20170505.1054.002.html, published online May 5, 2017

# Network Coding-Based Interference Management Scheme in D2D Communications

**WANG Shuang and HOU Ronghui**
(Xidian University, Xi'an 710071, China)

**Abstract**

In this paper, we propose an interference management scheme for device-to-device (D2D) communications in cellular networks. Considering the underlay D2D communications, the signal quality of cellular users would be affected by D2D users. To solve this problem, we explore the application of network coding and relay-assistance to mitigate interference. In the proposed scheme, helper nodes overhear the signal from cellular users, encode the received packets, and send the encoded packets to the base station. We design the helper node selection scheme and the transmission policy of helper nodes. The performance of the proposed scheme for different positions of the cellular user and D2D users is then evaluated. The results suggest that the cellular transmission scheme should be adjusted dynamically when underlay D2D communications are active. Compared with the existing solutions, the proposed scheme can effectively increase system throughput.

**Keywords**

D2D; interference management; network coding; relay

## 1 Introduction

As an underlay to cellular network, device-to-device (D2D) technology has being intensively studied for fifth generation (5G) system. Resource reuse technology for D2D communications provides high data rate and improves spectrum efficiency [1], [2]. However, it also makes interference management more complicated. Therefore, interference mitigation becomes a key problem for further development of D2D technology.

Power control and resource allocation are extensively discussed to guarantee the link quality of cellular users while D2D communications exist. On the other hand, network coding technology is a promising technique for improving network capacity. Applying network coding for multi-hop D2D communications is considered in [3] and [4]. Exploiting the inherent broadcasting nature of wireless medium, network coding can deliver multiple packets in a single transmission, and thus yield higher throughput.

Considering the situation where one cellular user device and two D2D pairs exploit the same resources, an interference coordination mechanism is proposed to enhance system capacity in [5], which can select proper D2D users without causing intensive interference. Channel allocation in a single cell system with D2D pairs is modeled in [6], and a scheme aiming to maximize the number of D2D pairs is proposed. An interference coordination scheme that does not allow different D2D pairs to share the same radio resources in a limited interference area is proposed in [7], and a power control scheme to obtain an upper bound of D2D transmitter power is also included to mitigate interference. In order to control the interference on cellular users, an algorithm for obtaining the upper bound of the number of D2D pairs is proposed in [8], which reuses the uplink resource under the conditions that the D2D users' location and channel state information (CSI) are unknown. With the channel state information, the transmission mode selection for maximizing the spectrum reusing ratio is studiedin [9], and a lower bound of interference distance is derived according to the transmitter density and QoS requirement of a D2D pair. By using this distance, two resource allocation schemes are proposed, namely the dual metric scheme and the tolerant interference degree (TID) scheme. These schemes achieve more uniform resource allocation to avoid the excess interference of some resources.

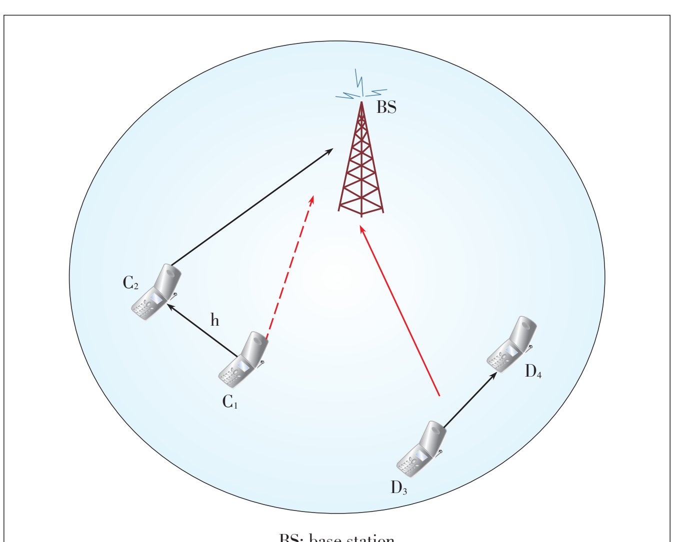
There are some investigations on joint applications of network coding and D2D communications. In [10], the integration of D2D and network coding (NWC) technologies in cellular network is considered. The performance of two-time-slot and three-time-slot network coding technologies are studied from the perspectives of end-to-end signal to interference plus noise ratio (SINR) and spectral efficiency. In [11], three-time-slot network coding is further investigated to assist D2D transmission. In addition, the average power consumption is also evaluated. The issues studied in [10] and [11] are further discussed in [12]. An adaptive mode selection scheme and a resource allocation algorithm are proposed in [12] to further improve the end-to-end SINR and spectral efficiency. A routing protocol for network coding is designed in [13], and each individual link quality is enhanced by using relay-based network coding. CSI is a critical factor for network design, however, each node usually only has its own CSI, and lacks the CSI of other D2D pairs. To

**This work is supported in part by the National Natural Science Foundation of China (Grant Nos. 61571351 and 61231008), and ZTE Industry-Academia-Research Cooperation Funds.**

enable all the nodes to get global CSI, a network-coded information exchange scheme with an emphasis on minimizing the total transmission cost for exchanging CSI between nodes is proposed in [14]. Then, a transmission scheme with the object of load balancing is proposed to achieve the minimum transmission cost. The performance of cell range extension in relay-based D2D is studied in [15]. Then, a scheme integrating mode selection, resource allocation and power control is proposed, and the performance evaluation results show that the performance of decode-and-forward with network coding is superior to both the traditional cellular and the amplify-and-forward schemes.

Existing works focus on utilization of network coding to assist D2D transmission or routing protocols. To our best knowledge, this is the first paper which uses network coding technology to solve D2D uplink interference issue, as illustrated in **Fig. 1**. D2D communication pairs reuse the resource assigned to cellular user $C_1$. The quality of cellular link is degraded due to D2D interference. The helper node $C_2$ overhears the packets on the cellular link and decodes these packets. After being motivated, the helper node transmits the recoded packets to BS. With our proposed scheme, the total number of packets sent by the source node is less than that under the traditional scheme.

First of all, we use random linear network coding (RLNC) for the transmission of cellular nodes. In this way, the base station (BS) only concerns the total number of received packets with no need to care about what packets it received. Some helpers, which may be idle cellular users, would overhear the packets sent from the source node. The helpers would forward the received packets when they are predicted to be helpful. In this work, the selection of helpers and the transmission scheme are the two key issues. We propose the helper selection method. Moreover, we analyze the performance of the network capacity with helper nodes, which facilitates us to design an efficient transmission scheme for the helpers.




▲Figure 1. A cellular user communicates with BS via a helper node.

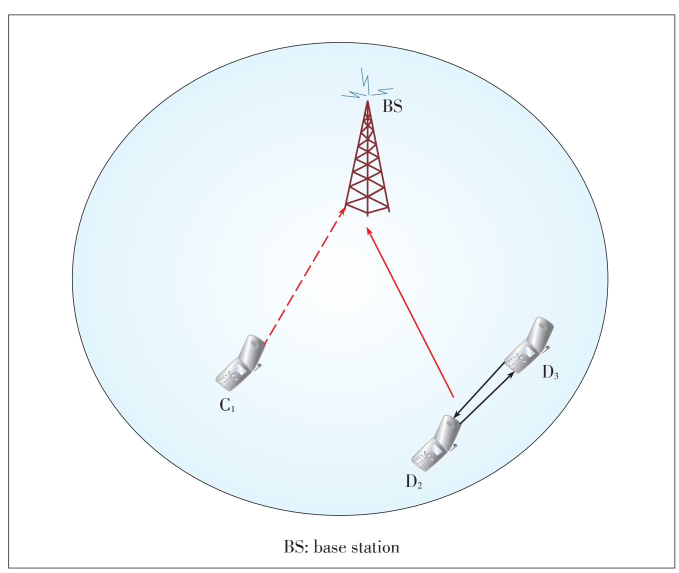
It is obvious that the performance gain provided by using helper nodes are different from that by different locations of cellular nodes. We analyze the performance gain as the function of the location of cellular users and D2D users respectively. We also conduct the simulations to demonstrate the performance gain of the proposed method.

The remainder of this paper is organized as follows. Section 2 describes the system model and presents some preliminaries. In section 3, a method for cellular users to transmit data with the assistance of helper nodes and network coding technology is stated. In section 4, we theoretically analyze the performance gain of our proposed scheme. Our simulation scenario and results are showed in section 5. Finally, we conclude the paper in section 6.

## 2 System Model

We consider a single-cell cellular network scenario with one cellular user communicating with BS. D2D users reuse the uplink period of network as depicted in **Fig. 2**. Since D2D users reuse the uplink resource block assigned to the cellular user, the quality of cellular user communications will be degraded. Inactive users are distributed randomly in the system, which may be selected as helpers.

We assume that the CSI of all involved links is known by the BS and that the CSI of the link between nodes can be acquired by the receiver. For each communication pair in system, we label the transmitter as $i$, the receiver as $j$ and the interference node as $k$ [15]. The large-scale fading is determined by the Euclidian distance $d_{ij}$ between two users, and $\alpha$ represents for the path-loss exponent. A Rayleigh random variable $f_{ij}$ determines the small-scale fading. The SINR at




▲Figure 2. D2D users communicate by reusing the uplink resource of cellular users in cellular network.

the receiver can be calculate as

$$SINR_j = \frac{P_{T_i} d_{i,j}^{-\alpha} h_{i,j}}{\sum_k P_{T_k} d_{k,j}^{-\alpha} h_{k,j} + \sigma^2}. \quad (1)$$

The relative bit error rate (BER) and packet error rate (PER) can be further obtained. The PER of a link is represented by $e$.

In this paper, RLNC technology is used for packet transmission. The helper node can simply send out a linear combination of their received packets. As shown in **Fig. 3**, the user $C_1$ sends out two packets $P_1$ and $P_2$, we assume that the helper node overhears both the packets although one of the packets is lost at the BS. The helper then sends the coded packet $P_1+P_2$ to the BS. With $P_1+P_2$, the BS can always obtain all the packets no matter which one is lost.

The BS chooses helper nodes according to link condition information. As illustrated in Fig. 1, the BS estimates the number of packets that each helper node should store before transmitting and informs relevant helpers. Helpers overhear the packets from the cellular user and encode these packets. Traffic generated by cellular users is divided into data blocks, and each data block is called a generation. Each generation is composed of a certain number of packets. The BS needs to receive enough linearly independent packets to decode a generation. If the field size of RLNC is large enough, the probability of receiving linearly dependent coded packets is low. We consider one generation transmitting process.

## 3 The Proposed Interference Management Scheme

To mitigate the interference caused by D2D users, the proposed method selects helper nodes to assist transmission of cellular users, and network coding technology is also applied (Fig. 1). In the proposed scheme, the specific frequency resource is assigned to one cellular user and only one D2D communication pair is assumed to reuse it.

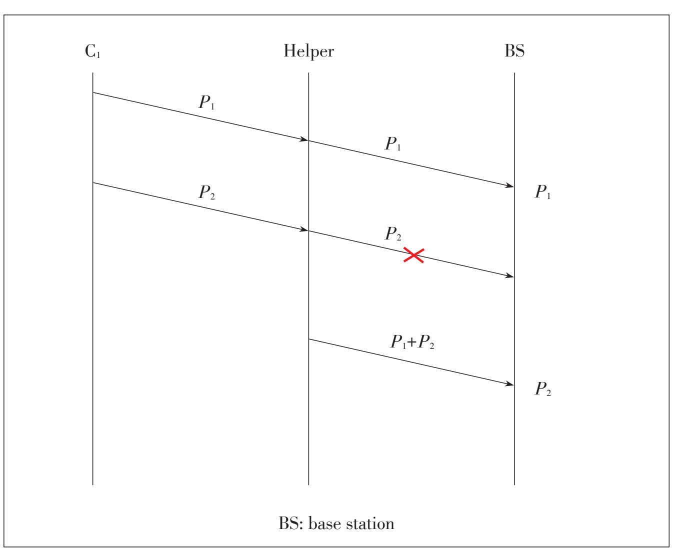
We also assume that the BS knows link conditions of all the involved links. According to the method described in section 2, the link PER between the cellular user and BS $e_{U\_B}$ can be obtained. When the value of $e_{U\_B}$ is inferior to a specific level $E$, that is, the cellular user is severe influenced, the cellular user will be authorized for application of helper nodes. The value of $E$ is associated with the traffic type.

### 3.1 Helper Selection

The geographical locations of users are different, which leads to complex link conditions between nodes. We assume that all idle nodes in coverage can be chosen as a helper node. The users can be divided into two categories according to their relative link conditions. **Fig. 4** shows the link conditions of a helper in the system, and $e_i$ represents PER.

Quality of each individual link is also a critical factor for helper selection. We assume that $e_0$ is the upper bound of PER to be borne by the system. For a candidate helper node $i$, $e_{\max} = \max\{e_{i1}, e_{i2}\}$; if the link condition of node $i$ satisfies the condition $e_0 \geqslant e_{\max}$, node $i$ would be chosen as a candidate. The link condition of helpers are described in **Fig. 5**.

Based on Fig. 4, the type of candidate helpers can be distin-




▲Figure 3. Network coding technology.

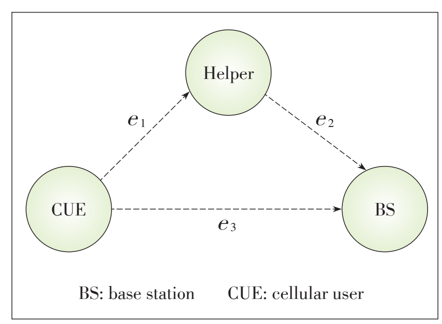



Figure 4. ▶ Packet error rate of the link related to a helper.

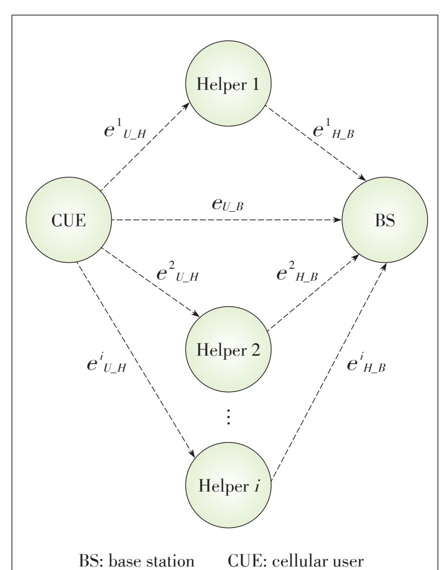



Figure 5.▶ Link condition of multiple helpers.

guished by (2) and (3).

1) CSI of users satisfies:

$$(1-e_1)\cdot e_3 \geqslant 1-e_2 \text{ ,} \tag{2}$$

2) CSI of users satisfies:

$$(1-e_1)\cdot e_3 \leqslant 1-e_2 \text{ ,} \tag{3}$$

where ( $1-e_1$ ) represents the probability that a helper receives a packet from the cellular user successfully. $e_3$ is the probability of transmission failure on cellular link to the BS. In the proposed scheme, helpers overhear the packets that the cellular user transmits to the BS. A packet received by helpers but not received by the BS is defined as an innovative packet. The product of ( $1-e_1$ ) and $e_3$ is the probability that a helper receives an innovative packet.

Eq. (2) means that the probability of receiving an innovative packet is higher than transmitting one. From the perspective of packet number, a helper receives more innovative packets than it transmits. This kind of helper is able to transmit an innovative packet upon receiving it, since the link condition is able to support for continuous transmitting of innovative packets. Helper nodes delivering more packets means that the retransmission of the cellular user can be reduced. Therefore, this type of helpers is the prior choice.

### 3.2 Transmission Mode

Helper nodes overhear packets transmitted by the cellular user. Two types of helpers are motivated when enough packets are stored. Helpers transmit packets to the BS in turn after being motivated. It is obvious that this process can be divided into two parts: before and after helpers are motivated. During the period before helpers are motivated, all helpers are regarded as a whole unit of system. The packets that fail to transmit on the cellular link are innovative packets for the helper unit. If an innovative packet is received by at least one helper, we consider this packet is received by the helper unit. Helpers store packets and recode them before being motivated. Repeated transmissions can be decreased and even avoided since innovative packets are most likely coded. Each transmission from helper nodes contains new content so that the transmission efficiency is high, and that is the reason why network coding is applied. After receiving enough packets, the BS can decode all the packets and obtain the content. As stated above, the field size of linear network coding is large enough. Therefore, we consider that all the coded packets are linearly independent. The BS can decode a generation once receiving enough number of packets. The content of packets is not being concerned. Based on the theory, we study the problem from the perspective of packet number.

Assuming that BS needs to receive $g$ packets to decode a generation. After being motivated, a helper and the cellular transmit $k$ packets. For the whole transmission process, the number of total packets transmitted by the cellular user is represented by $X$, and then we get:

$$X \cdot e_{U\_B} \cdot \left(1-\prod_{i=1}^{n} e^{i}_{U\_H}\right) = \sum_{j=1}^{n} k\left\{1-e^{i}_{H\_B}\right\} \text{ ,} \tag{4}$$

and

$$X \cdot (1-e_{U\_B}) + \sum_{j=1}^{n} k\left\{1-\prod_{i=1}^{n}\left(1-e^{i}_{U\_H}\right)\right\} \cdot (1-e^{j}_{H\_B}) = g \text{ ,} \tag{5}$$

where $n$ is the total number of helpers. PER of each link is constant. The value of $k$ and $X$ can be solved from (4) and (5). $\sum_{i=1}^{n} k \cdot (1-e^{i}_{H\_B})$ denotes the total number of packets that the BS receives from all helpers, and $X \cdot (1-e_{U\_B})$ denotes the packet number from the cellular user. The left side of (4) represents the innovative packets the helper unit receives. Here we assume that new content is included in each packet, which means that the packets from the helper unit are innovative packets. Eq. (5) means that the packets the BS receives are from the helpers and the cellular user respectively.

## 4 Performance Evaluations

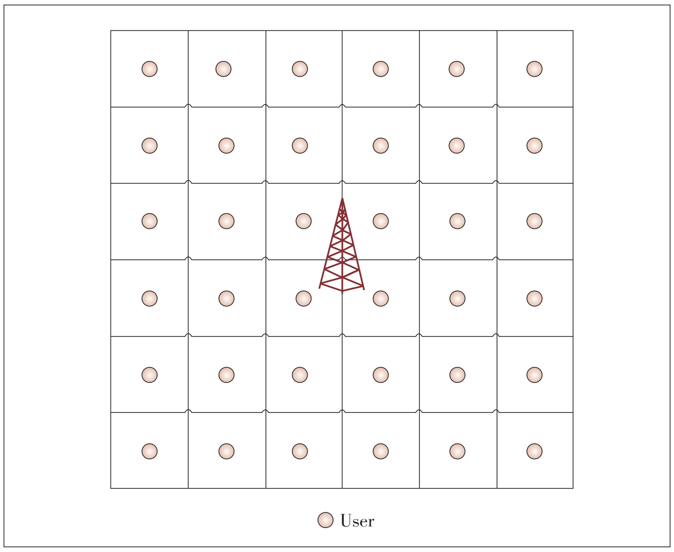
In this section, we give numerical simulation results to justify our analysis and to evaluate the performance of the proposed scheme. In conventional direct transmission schemes, a cellular user transmits packets to a BS continuously. When the BS receives enough packets for decoding, it sends a terminating signal to the cellular user to terminate the process.

The performance of the proposed system varies with different cellular user positions and different D2D positions. We assume that the interference sources are only D2D communications and Gaussian noise. The performance is evaluated from the perspective of packet number, and the receiving signal strength is only related with the distance. The simulation scenario and calculations of PER are described in section 2. **Table 1** shows the simulation parameters.

The cellular coverage is divided into many subareas (clusters) as illustrated in **Fig. 6**. The user performance at the center of the subarea is discussed to represent the users within the subarea. Cellular users and D2D users are located in different

**▼Table 1. Simulation parameters**

| Simulation parameters | Value |
|---|---|
| Side length of cellular coverage | 3000 m |
| Side length of subarea | 200 m |
| BS coordinate | (1500, 1500) |
| Cellular transmit power | 15 dBm |
| D2D transmit power | 10 dBm |
| Target number of packets $g$ | 200 |
| Pass-loss exponent $\alpha$ | 2 |
| Gaussian noise | −100 dBm |




▲Figure 6. Clusters and user locations in the cellular coverage.

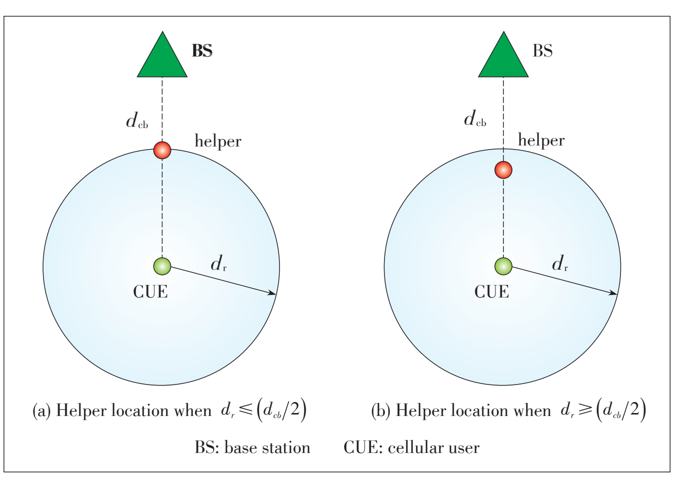
locations to evaluate the performance of the proposed scheme. These locations are represented by the red points in Fig. 6.

## 4.1 Location of Helper Nodes

To simplify the calculation, we assume that the location of the help node is optimal such that the network capacity is maximized. The distance between the BS and cellular user is $d_{cb}$, the range of helper selection is $d_r$. If $d_r \leqslant (d_{cb}/2)$, the helper node is placed at the boundary of the cluster, and located on the straight line between the BS and cellular user (**Fig. 7a**). If $d_r \geqslant (d_{cb}/2)$, the helper is placed on the straight line between the BS ad cellular user (**Fig. 7b**). The distance between helper and cellular user is $d_{cb}/2$.

## 4.2 Performance Analysis of Different Cellular User Positions

We first consider that the locations of the BS and D2D users




▲Figure 7. Helper locations.

are fixed. The coordinate of D2D is (2200, 400). **Fig. 8** compares the total packet numbers for two different methods. Fig. 8a represents the performance of the method of direct transmission, while Fig. 8b represents the method with helper nodes. It is known that the farther the cellular user is from the BS, the severer the influence caused by D2D is. Our simulation results show that the proposed method decreases the packet number, especially when the cellular user is at the margin of coverage.

The performance gain of each subarea is illustrated in **Fig. 9**, in which the y-axis denotes the number of packets to be reduced by the proposed scheme. From the simulation result, we observe that the performance gain is related with the distance of the cellular user and BS. The farther the cellular user is from the BS, the larger the performance gain achieved by the proposed scheme is. With the increase of the distance between the cellular user and BS, the cellular link PER increases. Prob-

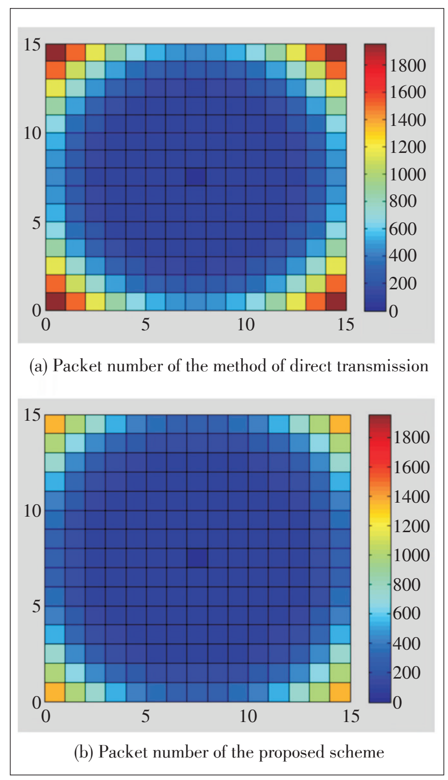



Figure 8.▶ Comparison of the total packet numbers for direct transmission and the proposed scheme.

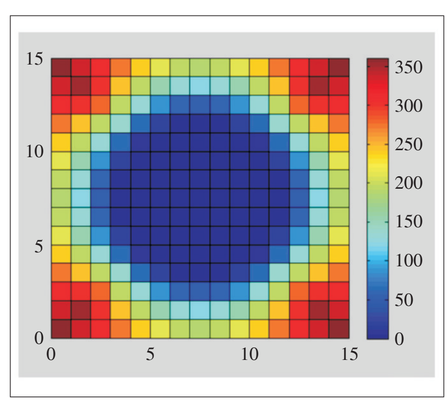


Figure 9.▶ Promotion of packet number proposed scheme comparing with direct transmission.

ability of successful transmission for direct transmission decreases significantly, so that the cellular user has to transmit more packets to ensure enough packets received by BS. In the proposed scheme, the probability that a packet is received by at least one helper is high. With the increase of the number of helpers, the packet number would be reduced.

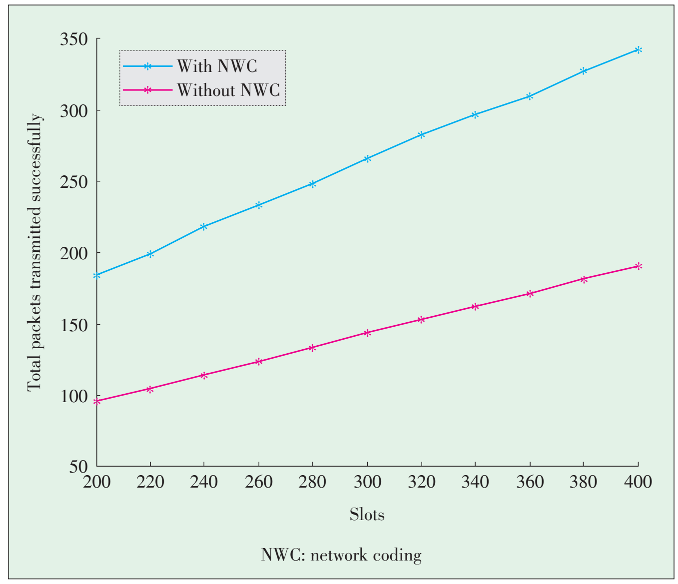
### 4.3 Performance Analysis of Different D2D Positions

D2D communications is not allowed if the interference on the cellular user is very severe. The interference factor W, which is defined as a constant, indicates the interference level that a transmission link can tolerate. The specific value of interference factor is determined by traffic type and the level of quality of service (QoS). The total packet number that the cellular transmits without D2D users is represented by $S_1$, and the total packet number need to be delivered with the interference from D2D users is represented by $S_2$. D2D users are allowed when the factors satisfy the condition: $[(S_1-S_2)/S_1]\leqslant W$. Here we consider the interference factor W as 2.

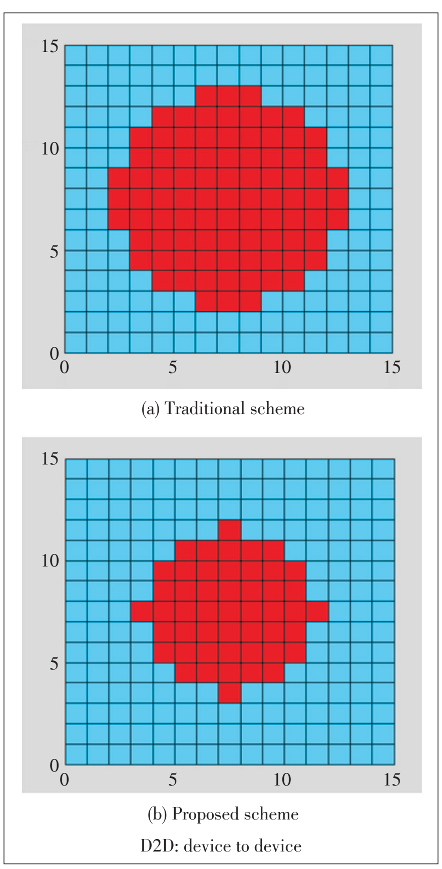
**Fig. 10** shows the simulation results. The subareas are colored blue when D2D communications are allowed. It is obvious that the area that D2D communications is allowed is extended when the proposed scheme is applied.

### 4.4 Application of Network Coding

**Fig. 11** shows the comparison of whether the network coding technology is applied. For the relay scheme without any helper node, the relay node overhears the packets from the source and delivers these packets to the BS directly. It can be seen that better performance can be achieved by network coding since the packets transmitted by the helper node are useful and unnecessarily repeated packets are mostly avoided.




**▲Figure 11. Comparison of methods with or without NWC.**




**◀Figure 10. D2D communication regions in different schemes.**

## 5 Conclusions

In this paper, a relay-based interference management framework with network coding technology is proposed to mitigate the interference from D2D users. We design the helper node selection scheme and the transmission policy of helper nodes. Performance evaluation verifies that the proposed scheme extends the region of D2D communication and improves the system throughput.


### Acknowledgements

We would like to extend our sincere gratitude to XIE Yutang from ZTE Corporation for his instructive advice and useful suggestions on this paper.



**References**

[1] G. Fodor and N. Reider, "A distributed power control scheme for cellular network assisted D2D communications," in *2011 IEEE Global Telecommunications Conference (GLOBECOM 2011)*, Houston, USA, Dec. 2011, pp. 1-6. doi: 10.1109/GLOCOM.2011.6133537.

[2] G. Fodor, E. Dahlman, S. Parkvall, et al., "Design aspects of cellular network assisted device-to-device communications," *IEEE Communication Magazine*, vol. 50, no.3, pp. 170-177, Mar. 2012. doi: 10.1109/MCOM.2012.6163598.

[3] L. Wei, R. Q. Hu, Y. Qian, and G. Wu, "Enable device-to-device communications underlaying cellular networks: challenges and research aspects," *IEEE Communication Magazine*, vol. 52, no. 6, pp. 90-96, Jun. 2014. doi: 10.1109/MCOM.2014.6829950.




D:\EMAG\2017-04-56/VOL15\RP2.VFT——7PPS/P6

[4] T. V. Vu, T. M. T. Nguyen, and G. Pujolle, "Distributed opportunistic and diffused coding in multihop wireless networks," in *IEEE International Communication Conference*, Ottawa, Canada, Nov. 2012, pp. 5583–5587. doi: 10.1109/ICC.2012.6364712.
[5] X. W. Liao, J. G. Deng, and W. Wang, "Interference coordination mechanism for device-to-device communication in uplink period underlaying cellular networks," in *International Conference on Wireless Communications & Signal Processing*, Huangshan, China, Oct. 2012, pp. 1–5. doi: 10.1109/WC SP.2012.6542914.
[6] R. Yin, T. Han, and G. D. Yu, "Interference-aware channel allocation for device-to-device communication underlaying cellular networks," in *IEEE International Conference on Communications in China*, Beijing, China, Aug. 2012, pp. 422–427. doi: 10.1109/ICCChina.2012.6356919.
[7] D. Y. WANG, X. Wang, and Z. Yuan, "An interference coordination scheme for device-to-device multicast in cellular networks," in *IEEE Vehicular Tehnology Conference*, Yokohama, Japan, Sept. 2012, pp. 1–5. doi: 10.1109/VTCFall.2012.6398945.
[8] S. Shalmashi, G. W. Miao, and S. S. Ben, "Interference constrained device-to-device communications," in *IEEE International Conference on Communications*, Sydney, Australia, Jun. 2014, pp. 5245–5250. doi: 10.1109/ICC.2014.6884154.
[9] Y. L. Xu, Y. Liu, and D. Li, "Resource management for interference mitigation in device-to-device communication, " *IET Communications*, vol. 9, no. 9, pp. 1199–1207, Jun. 2015. doi: 10.1049/iet-com.2014.0976.
[10] G. Fodor, A. Gattami, and A. Pradini, "Device-to-Device communications and network coding: friends or foes?" *IEEE COMSOC MMTC E-Letter*, vol. 9, no. 1, pp. 33–35, Jan. 2014.
[11] A. Pradini and G. Fodor. (2014, Jun. 23–26). *Performance analysis of network coding schemes in network assisted D2D communications* [Online]. Available: https://www.metis2020.com/wp-content/uploads/publications/EuCNC_2014_Pradini_etal__D2D_NWC.pdf
[12] G. Fodor, A. Pradini, and A. Gattami, "On applying network coding in network assisted D2D communications," in *20th European Wireless Conference*, Barcelona, Spain, 2014.
[13] D. E. Lucani, M. V. Pedersen, and F. H. P. Fitzek, "Network coding to enhance standard routing protocols in wireless mesh networks," in *IEEE Globecom Workshops*, Georgia, USA, Dec. 2013, pp. 610–616. doi: 10.1109/GLOCOMW.2013.6825055.
[14] X. M. Wang, C. Yuen, T. J. Li, W. T. Song, and Y. L. Xu, "Minimizing transmission cost for third-party information exchange with network coding," *IEEE Transactions on Mobile Computing*, vol. 14, no. 6, pp. 1218–1230, Aug. 2014. doi: 10.1109/TMC.2014.2350989.
[15] A. Abrardo, G. Fodor, and B. Tola, "Network coding schemes for device-to-device communications based relaying for cellular coverage extension, " in *IEEE International Workshop on Signal Processing Advances in Wireless Communications*, Stockholm, Sweden, Jun. 2015, pp. 670–674. doi: 10.1109/SPAWC.2015.7227122.

Manuscript received: 2015-12-03

## Biographies

**WANG Shuang** (wangshuangv086@163.com) received the B.Eng. and M.Eng. degrees in communication engineering from Xidian University in 2013 and 2016, respectively. Her research interests include D2D communication and wireless networks. Since 2016, she has been with State Grid Corporation of China, where she is currently an engineer.

**HOU Ronghui** (rhhou@xidian.edu.cn) received the B.Eng., M.Eng., and Ph.D. degrees in communication engineering from Northwestern Polytechnical University, China in 2002, 2005, and 2007, respectively. She was a post-doctoral fellow with the Department of Electrical and Electronic Engineering, The University of Hong Kong, China, from 2007 to 2009. Since 2009, she has been with Xidian University, China, where she is currently a professor with the Department of Telecommunication Engineering. Her research interests include network quality of service issues, routing algorithm design, and wireless networks.