Range-Difference Based Resource Allocation Scheme for D2D-Aided Heterogeneous Networks

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Abstract. In this paper, the resource allocation issues in Device-to-Device (D2D) aided heterogeneous networks are investigated, with successive interference cancellation (SIC) capabilities enabled in base stations (BSs). The problem of maximizing the sum throughput of whole network by considering real-time transmissions is formulated. After that, the globally optimal power control is carried out relying on both the *enumeration* and *Kuhn-Munkres* methods. To both guarantee the successful transmission probability (STP) of cellular users (CUEs) and reduce the system's management overhead, a range-difference based resource allocation scheme is proposed. Numerical results show that the average throughput of CUEs can be substantially improved without sacrificing the performance of CUEs by invoking the proposed resource allocation scheme.

Keywords: Heterogeneous network · Device-to-Device (D2D) Resource allocation · Successive Interference Cancellation (SIC) Range-difference

1 Introduction

With the rapid development of mobile communication technologies, the telecom operators are struggling to meet the customers' exponentially increasing demand of mobile data traffic, thus requiring both spectral efficiency and throughput of the wireless networks to be substantially improved [1–3]. Furthermore, the existing wireless access networks (WANs) architecture is based on the centralized control of base stations (BSs), which have often been operating at overload state, it is highly required to offload the mobile traffics from the BS side to the mobile terminal side [4,5].

Device-to-Device (D2D) communications mode, which enables the geographically close-by user equipments (UEs) to form D2D pairs by creating a direct wireless link between them (i.e. without relying on the intervention of BSs),

K. Long et al. (Eds.): 5GWN 2017, LNICST 211, pp. 506–516, 2018.
https://doi.org/10.1007/978-3-319-72823-0_47

has been regarded as a promising traffic-offloading technique [6,7]. Note that either half-duplex mode or full-duplex [8–10] mode can be implemented in D2D devices. Meanwhile, in light of the fact that the negative effect of large-scale power loss due to the relatively longer BS-to-UE distance in conventional cellular networks can be effectively relieved by implementing D2D mode, the power efficiency as well as spectral efficiency of the wireless networks can be substantially improved [11]. Thus, the underlaying cellular networks that support both the conventional cellular communications and the D2D mode can be implemented for both substantially improving the network throughput and effectively enhancing the load balance capability of the whole networks.

Despite of the promising benefits in terms of spectral/power efficiencies offered by D2D-aided heterogeneous networks, the potential performance gains may still be degraded due to the frequency reuse between these two tiers. Thus, a reasonable resource allocation strategy must be implemented for effectively mitigating the impact of D2D induced interference [12].

A variety of works associated with intelligent power control and resource allocation strategies have been carried out for facilitating the D2D-induced interference coordination and management [13–16]. For instance, in [13], a pricing-based mechanism is proposed for managing the interference imposed on the cellular users (CUEs) by D2D users (DUEs) through controlling the prices on the corresponding sub-channels. Combining with a non-cooperative Nash game among D2D pairs, the quality of service (QoS) of both CUEs and DUEs can be guaranteed in the pricing-based mechanism. Furthermore, in [16], a centralized power control strategy is proposed to guarantee a sufficiently high coverage probability of CUEs by limiting the D2D-induced interference (while scheduling as many D2D links as possible). In addition, advanced signal processing techniques can also be employed for performing interference cancellation in D2D-aided heterogeneous networks [17,18]. Relying on the successive interference cancellation (SIC) capabilities [19,20] of both BSs and DUEs, authors in [18] attempted to adjust both transmit power and data rate for managing the interference between cellular and D2D tiers, whereas the authors in [17] mainly analyzed the successful transmission probability (STP) of the multi-cell networks by using stochastic geometry method.

While most of the existing resource allocation algorithms are carried out by solving complicated optimization or game problems, both of which generally require accurate channel state information (CSI), the system's management overhead will thus be significantly increased. Besides the above-mentioned algorithms, guard zone based interference management schemes have also been widely investigated [21,22] for offering innovated resource allocation strategies. In this paper, we mainly focus our attention on maximizing the (real-time) sum throughput, with a range-difference based scheme proposed for the D2D-aided heterogeneous networks. The main contributions of this paper are reflected in the following aspects:

1. The resource allocation problem for D2D-aided underlaying cellular networks is formulated, with SIC capabilities considered in terminals.

2. The optimization model of maximizing the (real-time) sum throughput of the whole network is provided.
3. The globally optimal solution of the proposed algorithm is derived relying on the *enumeration* and *Kuhn-Munkres* methods.
4. A range-difference based resource allocation scheme is proposed for simultaneously improving the average STP of CUEs and reducing the system's management overhead.

The remainder of this paper is organized as follows. Section 2 describes the system model for D2D-aided heterogeneous networks, together with the formulation of the problem of sum throughput maximization. In Sect. 3, a range-difference based resources allocation scheme is proposed. After that, the numerical results are given out in Sect. 4. Finally, Sect. 5 concludes this paper.

2 System Model and Problem Formulation

In this section, we first describe the system model for the proposed D2D aided heterogeneous networks, followed by formulating the resource allocation problem of the proposed system, with SIC capabilities enabled in the devices. After that, we derive the globally optimal solution of the above-mentioned optimization problem relying on the *enumeration* and *Kuhn-Munkres* methods.

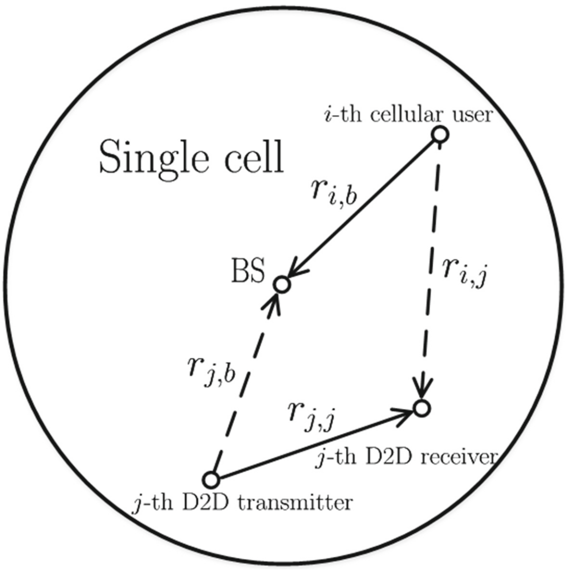

Fig. 1. D2D aided heterogeneous network, in which the uplink licensed spectrum is assumed to be reused by DUEs.

2.1 System Model for D2D-Aided Heterogeneous Networks

In this paper, we consider the D2D-aided underlaying cellular networks, in which the uplink licensed spectrum is allowed to be reused by D2D pairs, as illustrated in Fig. 1. To ease our analysis, we consider the scenario in which a total of N CUEs share spectrum resources with N D2D pairs simultaneously. Meanwhile, we assume that the i-th CUE operates at transmit power P_i^c, where $i \in \{1, 2, \cdots, N\}$. Without loss of generality, the transmit power of j-th DT is assumed to be $P_j^d = \beta_{i,j} P_i^c$, where the coefficient $\beta_{i,j}$ is no less than 0 for any $i, j \in \{1, 2, \cdots, N\}$. Furthermore, the radius of the cell is denoted by R. Distances associated with the i-th CUE-to-BS link and the j-th DT-to-BS link are represented by $r_{i,b}$ and $r_{j,b}$, respectively. Meanwhile, the distance between i-th CUE and j-th D2D receiver (DR) is denoted by $r_{i,j}$. Similarly, r_{jj} denotes the distance between the peers of the j-th D2D pair. In addition, both CUEs and DTs are assumed to be distributed randomly and uniformly within the cellular coverage, with DRs uniformly located within the radius-50 m circle area that is centered by the corresponding DTs.

At the BS side, the received signal power from CUE and DT can be denoted by $P_{i,b}^c = h_{i,b} r_{i,b}^{-\alpha} P_i^c$ and $P_{j,b}^d = h_{j,b} r_{j,b}^{-\alpha} P_i^d$, respectively, under assumption of Rayleigh fading channels with small scale fading coefficients $h_{i,b}, h_{j,b} \sim \exp(1)$, where $h_{i,b}$ and $h_{j,b}$ denote the corresponding channel attenuations, and $\alpha > 2$ denotes the path-loss exponent. According to the aforementioned uniform-distribution properties of both CUEs and DTs, the probability density function (pdf) of $r_{i,b}$ and $r_{j,b}$ can be represented by $f(r_{i,b}) = 2r_{i,b}/R^2$ and $f(r_{j,b}) = 2r_{j,b}/R^2$, respectively. Furthermore, through sample variable substitutions, we can readily derive both $P_{i,b}^c \sim \exp(r_{i,b}^{\alpha}/P_i^c)$ and $P_{j,b}^d \sim \exp(r_{j,b}^{\alpha}/\beta_{i,j}/P_i^c)$.

2.2 Problem Formulation

In this paper, we aim to maximize the network's sum throughput relying an appropriately designed resource allocation algorithm as

$$\mathbf{P1:} \max \sum_{i \in \mathcal{C}, j \in \mathcal{D}} \alpha_{i,j} R_{i,j} \tag{1}$$

$$\text{s.t.} \quad \sum_{i \in \mathcal{C}} \alpha_{i,j} = 1, \tag{1a}$$

$$\sum_{j \in \mathcal{D}} \alpha_{i,j} = 1, \tag{1b}$$

$$\alpha_{i,j} = \{0, 1\}, \quad \forall i \in \mathcal{C}, j \in \mathcal{D}, \tag{1c}$$

where $\mathcal{C}$ and $\mathcal{D}$ denote the index sets of CUEs and D2D paris, respectively, $R_{i,j}$ is the aggregative rates of i-th CUE (i.e. R_i^c) and j-th D2D pairs (i.e. R_j^d), i.e. $R_{i,j} = R_i^c + R_j^d$, $\alpha_{i,j}$ denotes the resource sharing relationship between i-th CUE and j-th D2D pair, and $\alpha_{i,j} = 1$ when the i-th CUE and j-th D2D pair share the same spectrum resource (otherwise $\alpha_{i,j} = 0$). On one hand, constraints in (1a) and (1b) guarantee the one-to-one correspondence between CUEs and D2D pairs, requiring that any single D2D pair must reuse the spectrum of one and only one CUE. On the other hand, any individual CUE must coexist with one and only one D2D pair. We can readily show that **P1** is identical to a maximum weighted bipartite matching problem that can be faultlessly solved out via *Kuhn-Munkres* method [23], where CUE and D2D pair are the bipartite vertexes, $R_{i,j}$ stands for the weight.

In the following, we will focus on mitigating the D2D-induced interference, thus enhancing the sum throughput of the network. Without loss of generality, we assume that the BSs are capable of implementing SIC. From information theory, the desired signal from CUE in the SIC-enabled BS receiver side will not be deteriorated by the DT-induced interference, and consequently we have $R_i^c = \log_2\left(1 + \frac{P_i^c g_{i,b}}{\Gamma N_0}\right)$ if $R_j^d \le \log_2\left(1 + \frac{P_j^d g_{j,b}}{\Gamma\left(P_i^c g_{i,b} + N_0\right)}\right)$ can be satisfied[1]. Otherwise, the interference caused by DT cannot be totally eliminated, thus leading to $R_i^c = \log_2\left(1 + \frac{P_i^c g_{i,b}}{\Gamma\left(P_j^d g_{j,b} + N_0\right)}\right)$, where Γ denotes the signal-to-interference-plus-noise ratio (SINR) gap [24] that is set to be $\Gamma = 8.8$ dB in this paper. The problem of $R_{i,j}$-maximization can thus be rewritten as

$$\mathbf{P2:} \max R_i^c + R_j^d \tag{2}$$

$$\text{s.t.} \quad R_i^c = A\log_2\left(1 + \frac{P_i^c g_{i,b}}{\Gamma\left(P_j^d g_{j,b} + N_0\right)}\right) + (1-A)\log_2\left(1 + \frac{P_i^c g_{i,b}}{\Gamma N_0}\right), \tag{2a}$$

$$R_j^d = \log_2\left(1 + \frac{P_j^d g_{j,j}}{\Gamma\left(P_i^c g_{i,j} + N_0\right)}\right), \tag{2b}$$

$$A = \mathbb{1}\left\{R_j^d > \log_2\left(1 + \frac{P_j^d g_{j,b}}{\Gamma\left(P_i^c g_{i,b} + N_0\right)}\right)\right\}, \tag{2c}$$

$$P_c^{th} \le P_i^c \le P_c^{max}, \tag{2d}$$

[1] In other words, the transmission rate of DT is not beyond its channel capacity, therefore the interference caused by DT can be cancelled completely in theory.

$$P_d^{th} \leq P_j^d \leq P_d^{max}, \tag{2e}$$

where (P_c^{th}, P_c^{max}) and (P_d^{th}, P_d^{max}) are the minimum and maximum values of transmit power of CUE and DT, respectively. Denoting $f\left(P_i^c, P_j^d\right) = R_{i,j} = R_i^c + R_j^d$, it has been shown in [25], $f(\lambda P_i^c, \lambda P_j^d) > f(P_i^c, P_j^d)$ will always hold that in the interior of the feasible space when $\lambda > 1$. Thus, $f(P_i^c, P_j^d)$ would reach its maximum if either of the following conditions, i.e. $P_i^c = P_c^{max}$ and $P_j^d = P_d^{max}$, can be satisfied. Furthermore, it has also been proved in [25] that $f\left(P_i^c, P_j^d\right)$ would be a convex function of P_i^c (or P_j^d) if $P_j^d = P_d^{max}$ (or $P_i^c = P_c^{max}$) is satisfied. Evidently, the maximum of $f\left(P_i^c, P_j^d\right)$ must be reachable at one of the extreme points of the feasible space.

By substituting (2b) into (2c), we can readily derive that $A = 0$ if

$$\frac{g_{j,j}}{P_i^c g_{i,j} + N_0} \leq \frac{g_{j,b}}{P_i^c g_{i,b} + N_0} \tag{3}$$

is satisfied. Otherwise, we have $A = 1$ when

$$\frac{g_{j,j}}{P_i^c g_{i,j} + N_0} > \frac{g_{j,b}}{P_i^c g_{i,b} + N_0}. \tag{4}$$

If $A = 0$ is met, we can readily conclude that the extreme points of P_i^c (denoted by $P_{i,0}^c$) are just happened at the apexes of the intersection of (2d) and (3). Similarly, when $A = 1$ is met, we can obtain the extreme points $P_{i,1}^c$, which correspond to the apexes of the intersection of (2d) and (4). In addition, we will get the optimal solution of problem **P2** relying on the *enumeration* method, with the optimal power pair (P_i^{c*}, P_j^{d*}) represented by

$$(P_i^{c*}, P_j^{d*}) = \underset{(P_i^c, P_j^d) \in U_0 \cup U_1 \cup U}{\arg\max} R_{i,j}, \tag{5}$$

where $U_0 = (P_i^c \in P_{i,0}^c, P_d^{max})$, $U_1 = (P_i^c \in P_{i,1}^c, P_d^{max})$, and $U = (P_c^{max}, P_d^{th}) \cup (P_c^{max}, P_d^{max})$.

Following the above-mentioned derivations, we can always derive the maximum $R_{i,j}$ for any $i \in \mathcal{C}$ and $j \in \mathcal{D}$ settings, which will be saved as the weight of the edges between bipartite vertexes $\mathcal{C}$ and $\mathcal{D}$. Eventually, the maximum sum throughput can be obtained.

3 Range-Difference Based Resource Allocation

In this section, a heuristic range-difference based resource allocation strategy is proposed for reducing the system complexity. At the SIC-enabled BS side, the desired signal from CUE will be decoded correctly, if $P_{i,b}^c > P_{j,b}^d$ is satisfied. Otherwise, if $P_{j,b}^d > P_{i,b}^c$ is met, the signal of interfering DT will be firstly decoded and eliminated from the received superposition signal, followed by decoding the

CUE's message from the interference-free signal. For a given decoding threshold η, the CUE's STP as a function of (η, $r_{i,b}$, $r_{j,b}$) can be expressed as

$$\begin{aligned} \mathrm{P_{STP}}(\eta, r_{i,b}, r_{j,b}) = & \Pr\left[\frac{P_{i,b}^c}{N_0} \geq \eta, \frac{P_{j,b}^d}{P_{i,b}^c + N_0} \geq \eta, P_{j,b}^d > P_{i,b}^c\right] \\ & + \Pr\left[\frac{P_{i,b}^c}{P_{j,b}^d + N_0} \geq \eta, P_{i,b}^c \geq P_{j,b}^d\right]. \end{aligned} \tag{6}$$

It has been shown in [21] that $\mathrm{P_{SIC}}(\eta, r_{i,b}, r_{j,b}) = \Pr\left(P_{j,b}^d > P_{i,b}^c\right) + \Pr\left(P_{j,b}^d \leq P_{i,b}^c\right) = 1$ will be met in interference-limited networks (i.e. $N_0 \to 0$), if $\eta < 1$ is satisfied. Otherwise, when $\eta \geq 1$, $\mathrm{P_{SIC}}(\eta, r_{i,b}, r_{j,b})$ is shown to be a convex function of $r_{j,b}$, with its minimum value attainable at $r_{j,b} = r_{i,b}\beta_{i,j}^{1/\alpha}$.

As inspired by the aforementioned results, we should try to prevent CUE and D2D pair with special properties (i.e. $r_{j,b} \approxeq r_{i,b}\beta_{i,j}^{1/\alpha}$) from sharing the same spectrum, when we perform resource allocation. Heuristically speaking, we aim to maximize the distance between CUEs and DTs, thus proposing the range-difference based resource allocation optimization model as

$$\mathbf{P3:} \max \sum_{i\in\mathcal{C}, j\in\mathcal{D}} \alpha_{i,j} d_{i,j} \tag{7}$$
$$\text{s.t.}(2a) - (2c),$$

$$P_i^c = P_c^{max}, \tag{7a}$$

$$P_j^d = \beta P_i^c = P_d^{max}, \tag{7b}$$

where $d_{i,j} = |r_{j,b} - r_{i,b}\beta^{1/\alpha}|$. Similarly, **P3** can also be viewed as a maximum weighted bipartite matching problem, which can be successfully solved by using *Kuhn-Munkres* algorithm. Compared with the power control strategy in **P1**, scheme in **P3** does not require accurate channel state information (CSI) and has ah lower computational complexity.

4 Numerical Results

In this section, we will numerically validate the proposed analysis as well as evaluate the performance of the proposed scheme. We consider the scenario comprising 100 geographically randomly and uniformly distributed CUEs that coexist with 100 D2D pairs inside a single-cell coverage having a radius of 500 m. The distributions of both DTs and DRs are shown in Sect. 2. Furthermore, the maximum distance between a D2D pair is assumed to be 100 m. The path loss exponent α is set to be 4, with rayleigh fading channels assumed in each link. Meanwhile, the SINR gap is set to 8.8 dB. In addition, the maximum transmit powers of CUEs and DTs are assumed to be $P_c^{max} = 30$ dBm and $P_d^{max} = 21$ dBm, respectively, corresponding to twice the minimum transmit powers, i.e. $P_c^{th} = 1/2P_c^{max}$ and $P_d^{th} = 1/2P_d^{max}$. Finally, the noise power density is assumed to be -174 dBm/Hz.

In Fig. 2, the CUE's STP as a function of $r_{j,b}$ is evaluated under variant $r_{i,b}$ and decoding thresholds η. For a given set of parameters, the CUE's STP will first decrease and then increase as $r_{j,b}$ increases, implying that there always exists an attainable minimum value.

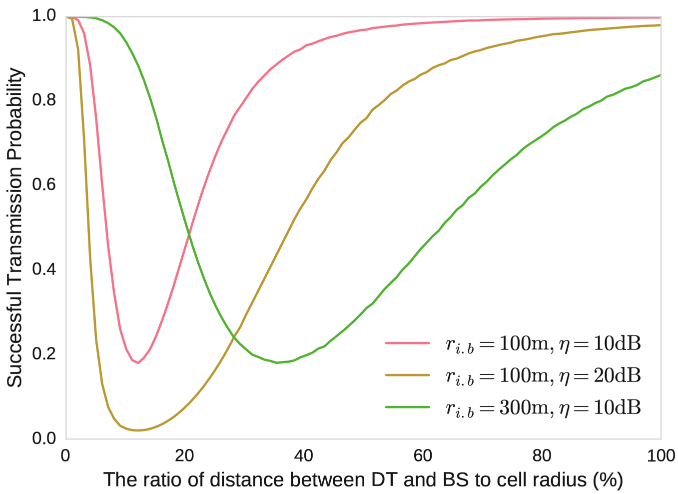

Fig. 2. Successful transmission probability of CUE as a function of the distance between DT and BS $r_{j,b}$ under variant CUE-to-BS distances $r_{i,b}$ and decoding thresholds η.

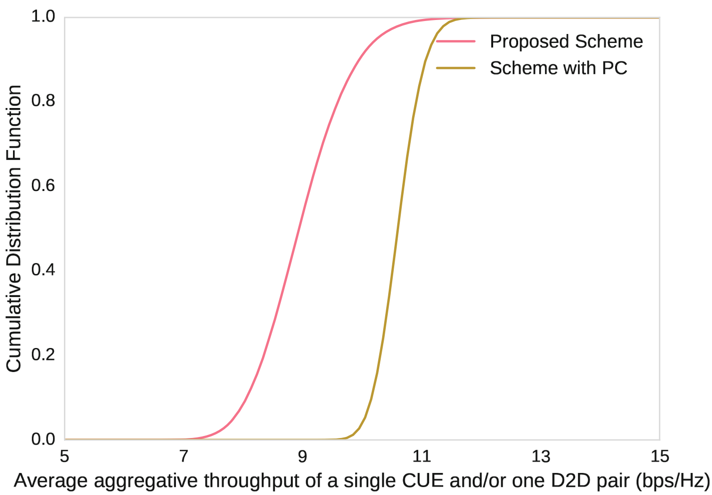

Fig. 3. Performance comparisons of the proposed scheme and scheme with power control in terms of CDF of the average aggregative throughput of a single CUE and/or D2D pair.

In Fig. 3, the cumulative distribution function (CDF) of the average aggregative throughput of one CUE/D2D pair is evaluated. As a performance benchmark, numerical results associated with scheme using power control are also provided. It is obvious that the maximum possible throughput of the two schemes are reasonably identical. Furthermore, it is shown that the sum throughput of the proposed scheme is slightly lower than that using power control aided scheme.

In Fig. 4, the CDF of the average throughput of CUE is evaluated. For comparing and analyzing the impact of the proposed scheme, numerical results associated with the scheme using power control are also presented. It is observed that the CUE's average throughput will be improved by using the proposed scheme, since the range-difference based technique will successfully prevent the geographically specific UEs from sharing the same spectrum, thus guaranteeing the QoS of CUEs.

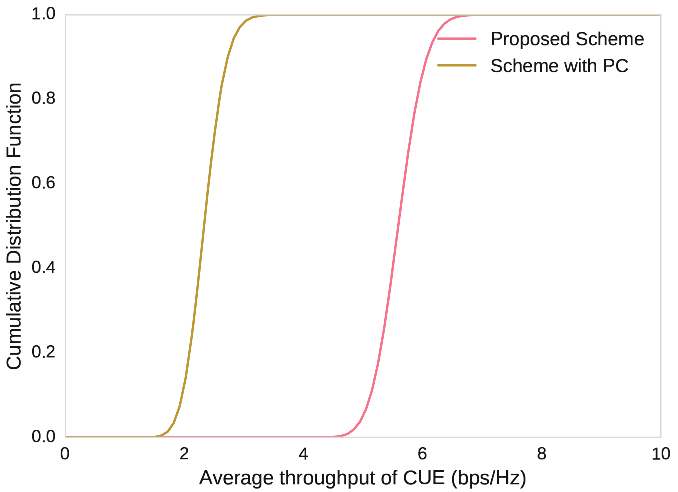

Fig. 4. Performance comparisons of the proposed scheme and scheme with power control in terms of CDF of the average throughput of CUE.

5 Conclusion

In this paper, a range-difference based resource allocation scheme was proposed for D2D-aided heterogeneous networks. We first formulated the resource allocation problem by enabling the SIC capabilities in terminals. After that, the system model associated with maximizing the sum throughput was provided, followed by deriving the globally optimal solution relying on the *enumeration* and *Kuhn-Munkres* methods. Furthermore, by analyzing the impacting factors of CUEs' STP, a range-difference based resource allocation scheme was proposed for both guaranteeing the QoS of CUEs and reducing the system's management overhead. Numerical results validated the proposed analysis, showing that the average throughput of CUEs can be substantially improved by invoking the proposed range-difference based resource allocation scheme.

Acknowledgement. This work was supported by the key project of the National Natural Science Foundation of China (No. 61431001), the open research fund of National Mobile Communications Research Laboratory Southeast University (No. 2017D02), Key Laboratory of Cognitive Radio and Information Processing, Ministry of Education (Guilin University of Electronic Technology), and the Foundation of Beijing Engineering and Technology Center for Convergence Networks and Ubiquitous Services. (Corresponding author: Zhongshan Zhang).

References

1. Chen, S., Zhao, J.: The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication. IEEE Commun. Mag. **52**(5), 36–43 (2014)
2. Zhang, Z., Long, K., Wang, J., Dressler, F.: On swarm intelligence inspired self-organized networking: its bionic mechanisms, designing principles and optimization approaches. IEEE Commun. Surv. Tuts. **16**(1), 513–537 (2014). First Quarter
3. Zhang, Z., Long, K., Wang, J.: Self-organization paradigms and optimization approaches for cognitive radio technologies: a survey. IEEE Wirel. Commun. Mag. **20**(2), 36–42 (2013)
4. Zhang, H., Jiang, C., Beaulieu, N.C., Chu, X., Wen, X., Tao, M.: Resource allocation in spectrum-sharing OFDMA femtocells with heterogeneous services. IEEE Trans. Commun. **62**(7), 2366–2377 (2014)
5. Zhang, H., Jiang, C., Mao, X., Chen, H.-H.: Interference-limited resource optimization in cognitive femtocells with fairness and imperfect spectrum sensing. IEEE Trans. Veh. Technol **65**(3), 1761–1771 (2016)
6. Doppler, K., Rinne, M., Wijting, C., Ribeiro, C.B., Hugl, K.: Device-to-device communication as an underlay to LTE-advanced networks. IEEE Commun. Mag. **47**(12), 42–49 (2009)
7. Feng, D., Lu, L., Yuan-Wu, Y., Li, G., Li, S., Feng, G.: Device-to-device communications in cellular networks. IEEE Commun. Mag. **52**(4), 49–55 (2014)
8. Zhang, Z., Chai, X., Long, K., Vasilakos, A.V., Hanzo, L.: Full duplex techniques for 5G networks: self-interference cancellation, protocol design, and relay selection. IEEE Commun. Mag. **53**(5), 128–137 (2015)
9. Zhang, Z., Long, K., Vasilakos, A.V., Hanzo, L.: Full-duplex wireless communications: challenges, solutions and future research directions. Proc. IEEE **104**(7), 1369–1409 (2016)
10. Chai, X., Liu, T., Xing, C., Xiao, H., Zhang, Z.: Throughput improvement in cellular networks via full-duplex based device-to-device communications. IEEE Access **4**, 7645–7657 (2016)
11. Asadi, A., Wang, Q., Mancuso, V.: A survey on device-to-device communication in cellular networks. IEEE Commun. Surv. Tuts. **16**(4), 1801–1819 (2014)
12. Phunchongharn, P., Hossain, E., Kim, D.I.: Resource allocation for device-to-device communications underlaying LTE-advanced networks. IEEE Wirel. Commun. **20**(4), 91–100 (2013)
13. Yin, R., Yu, G., Zhang, H., Zhang, Z., Li, G.Y.: Pricing-based interference coordination for D2D communications in cellular networks. IEEE Trans. Wirel. Commun. **14**(3), 1519–1532 (2015)

14. Yin, R., Zhong, C., Yu, G., Zhang, Z., Wong, K.K., Chen, X.: Joint spectrum and power allocation for D2D communications underlaying cellular networks. IEEE Trans. Veh. Technol. **65**(4), 2182–2195 (2016)
15. Sun, J., Liu, T., Wang, X., Xing, C., Xiao, H., Vasilakos, A.V., Zhang, Z.: Optimal mode selection with uplink data rate maximization for D2D-aided underlaying cellular networks. IEEE Access **4**, 8844–8856 (2016)
16. Lee, N., Lin, X., Andrews, J.G., Heath, R.: Power control for D2D underlaid cellular networks: modeling, algorithms, and analysis. IEEE J. Sel. Areas Commun. **33**(1), 1–13 (2015)
17. Ma, C., Wu, W., Cui, Y., Wang, X.: On the performance of successive interference cancellation in D2D-enabled cellular networks. In: 2015 IEEE Conference on Computer Communications (INFOCOM), pp. 37–45, April 2015
18. Song, H., Ryu, J.Y., Choi, W., Schober, R.: Joint power and rate control for device-to-device communications in cellular systems. IEEE Trans. Wirel. Commun. **14**(10), 5750–5762 (2015)
19. Saito, Y., Kishiyama, Y., Benjebbour, A., Nakamura, T., Li, A., Higuchi, K.: Non-orthogonal multiple access (NOMA) for cellular future radio access. In: Proceedings of IEEE Vehicular Technology Conference (VTC Spring), pp. 1–5, June 2013
20. Sen, S., Santhapuri, N., Choudhury, R.R., Nelakuditi, S.: Successive interference cancellation: carving out MAC layer opportunities. IEEE Trans. Mob. Comput. **12**(2), 346–357 (2013)
21. Lv, S., Xing, C., Zhang, Z., Long, K.: Guard zone based interference management for D2D-aided underlaying cellular networks. IEEE Trans. Veh. Technol. **66**(6), 5466–5471 (2016)
22. Chen, Z., Kountouris, M.: Guard zone based D2D underlaid cellular networks with two-tier dependence. In: IEEE International Conference on Communication Workshop (ICCW), pp. 222–227 (2015)
23. Kuhn, H.W.: The Hungarian method for the assignment problem. Naval Res. Logistics Q. **2**(1–2), 83–97 (1955)
24. Garcia-Armada, A.: SNR gap approximation for M-PSK-based bit loading. IEEE Trans. Wirel. Commun. **5**(1), 57–60 (2006)
25. Gjendemsjo, A., Gesbert, D., Oien, G.E., Kiani, S.G.: Optimal power allocation and scheduling for two-cell capacity maximization. In: Proceedings of 2006 IEEE International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks, pp. 1–6 (2006)