

Chapter 2

Literature Survey on Cooperative Device-to-Device Communication

Abstract In this chapter, we review some important work related with cooperative device-to-device communication. We first present recent advances in cellular network offloading technologies, followed by existing efforts on device-to-device communication. Then, we present the related work of cooperative communication, focusing on energy efficiency, relay assignment, and time-spectrum allocation.

2.1 Device-to-Device Communication

In the past a few years, there has been lots of research [26, 39] on network traffic offloading that focuses on offloading cellular traffic to WiFi or other networks to save bandwidth or energy. A quantitative survey of mobile data traffic surge and a strategic solution to traffic offloading has been presented in [7]. Korhonen et al. [24] have discussed existing traffic offloading solutions, and presented and evaluated three different IP traffic offloading solutions that aim to work on the internet layer and rely only on the standard IETF2 defined TCP/IP protocol suite, not requiring any access-technology-specific knowledge. Lee et al. [26] have presented a quantitative study on the performance of 3G mobile data offloading through WiFi networks. Their trace-driven simulation using the acquired whole-day traces indicates that WiFi already offloads about 65 % of the total mobile data traffic and saves 55 % of battery power without using any delayed transmission. Rstanovic et al. [39] have designed two algorithms for delay-tolerant offloading of bulky, socially recommended content from 3G networks. They find that both solutions succeed in offloading a significant amount of traffic with a positive impact on user battery lifetime.

Device-to-device (D2D) communication becomes a hot research topic recently due to its benefits of offloading data traffic at base station in cellular networks. In their early work, Janis et al. [19] propose to facilitate local peer-to-peer communication by a D2D radio that operates as an underlay network to an IMT-Advanced cellular network. Later, they have studied D2D communication in three modes, i.e., reuse mode (D2D links share common channels with cellular links), dedicated mode (D2D links use dedicated channels), and cellular mode (all communication is relayed by base station), and designed mode selection algorithm for a three-user (one D2D pair and a cellular user) cellular network [9]. Based on a similar network model, Yu et al. [51] have investigated the throughput optimization problem over shared resources

while fulfilling prioritized cellular service constraints. For more general models, D2D communications have been extensively investigated from aspects such as interference management, power control, spectrum sharing, and so on. For example, Janis et al. [18] have proposed a practical and efficient scheme for generating local awareness of the interference between cellular and D2D users at the base station, which then exploits the multiuser diversity inherent in the cellular network to minimize the interference. Kaufman et al. [22] have developed a distributed dynamic spectrum protocol, in which ad-hoc D2D users opportunistically access the spectrum actively in use by cellular users. A new interference management scheme is proposed to improve the reliability of D2D communication in [36]. They derive outage probability in close form and design a mode selection algorithm to minimize outage probability. Lee et al. [27] have proposed a two-stage semi-distributed resource management framework for the D2D communication. At the first stage of the framework, the base station (BS) allocates resource blocks (RBs) to BS-to-user device (B2D) links and D2D links, in a centralized manner. At the second stage, the BS schedules the transmission using the RBs allocated to B2D links, while the primary user device of each D2D link carries out link adaptation on the RBs allocated to the D2D link, in a distributed fashion. A two-tier 5G cellular network that involves a macrocell tier (i.e., BS-to-device communications) and a device tier (i.e., device-to-device communications) has been discussed in [46]. Li et al. [34] have investigated the fundamental problems of how D2D communication improves the system performance of cellular networks and what is the potential effect of D2D communication, with the aid of the optimal solutions for the system resource allocation and mode selection obtained under the realistic user and mobility conditions. Specifically, by formulating a max-flow optimization problem that maximizes the content downloading flows from all the cellular base stations to the content downloaders through any possible ways of transmission, they obtain the theoretical upper bound to system content-downloading performance.

2.2 Cooperative Communication

The basic idea of CC is proposed in the pioneering paper [47]. Later, Laneman et al. [25] have studied the mutual information and outage probability between a pair of nodes using CC under both AF (amplify-and-forward) and DF (decode-and-forward) mode. Based on their fundamental work, CC has been extensively studied from the perspectives of both physical layer and network layer. We summarize the most relevant work in the following categories: energy efficiency, relay assignment, and time-spectrum allocation in cooperative communications.

In [45], Simic et al. compare the energy-efficiency of two major cooperative diversity schemes, virtual-MISO (multiple-input-single-output) and decode-and-forward, in wireless sensor networks. They show that decode-and-forward outperforms virtual-MISO since it avoids explicit local communication among cooperating nodes. The energy efficiency of CC in wireless body area networks is investigated in [17]. To minimize the energy consumption, the problem of optimal power allocation is

studied with the constraint of targeted outage probability. In [20], the energy consumption is optimized by taking amplifier power and circuit power into consideration in cooperative wireless sensor networks. An energy-efficient relay selection scheme integrated with a routing protocol is proposed in [10] for wireless sensor networks. All above work focuses on the total energy consumption of nodes involved in CC, which is significantly different from the lifetime maximization problem studied in this paper.

In [4], Bletsas et al. develop and analyze a distributed method to select the “best” relay based on local measurements of the instantaneous channel condition such that it can achieve the same diversity-multiplexing tradeoff as the protocols that require coordination and distributed space-time coding for multiple relays. Zhao et al. [53] show that it is sufficient to choose one “best” relay node instead of multiple ones for a single unicast session under AF mode. Moreover, they propose an optimal power allocation algorithm based on the best relay selection to minimize the outage probability. For multiple unicast sessions, Sharma et al. [40] consider the relay node assignment with the goal of maximizing the minimum data rate among all concurrent sessions. With the restriction that any relay node can be assigned to at most one source-destination pair, an optimal algorithm called ORA (Optimal Relay Assignment) is developed. By relaxing this constraint to allow multiple source-destination pairs to share one relay node, Yang et al. [50] prove that the total capacity maximization problem can be solved with an optimal solution within polynomial time. The benefit of CC in multi-hop wireless networks is exploited in [41] by a joint optimization of relay assignment and flow routing. When user mobility is considered, Li et al. [28] propose a dynamic relay selection scheme. With the objective of minimizing the long-term average cost while satisfying the QoS requirement. They formulate it by an optimization model based on the constrained Markov decision process and solve it using linear programming techniques.

CC in channel-constrained wireless networks is investigated in the following literatures. In [14], Gong et al. propose a cooperative relay scheme that increases the SINR at secondary receivers in cognitive radio networks. They only focus on the spectrum sharing at relay nodes under the assumption that all relay nodes are deployed at the same location. A joint optimization problem of channel pairing, channel-user assignment and power allocation is studied [15] for a dual-hop relaying network with multiple channels. It deals with a simple scenario that a source communicates with multiple users via a fixed relay. He et al. [16] optimize the resource allocation in a cognitive relay network, where a base station provides services to a set of secondary users that can assist each other using cooperative communication. A cooperative cognitive radio framework is studied in [23, 52] focusing on the interaction between the secondary and primary users. The idea is that primary users select some of secondary users to be the cooperative relays and in turn lease portion of the channel access time to them for their own data transmission. Shih et al. [44] have proposed a cooperative, multi-channel MAC protocol that incorporates the concept of cooperative communication into multi-channel MAC protocols, enabling a single transceiver to carry out the work of multiple transceivers. Recently, Li et al. [33] have studied the problem of joint relay assignment and channel allocation for cooperative communications in CRNs.

References

1. V. Asghari, S. Aissa, End-to-end performance of cooperative relaying in spectrum-sharing systems with quality of service requirements. *IEEE Trans. Veh. Technol.* **60**(6), 2656–2668 (2011)
2. A. Beck, A. Ben-Tal, L. Tetruashvili, A sequential parametric convex approximation method with applications to nonconvex truss topology design problems. *J. Glob. Optim.* **47**(1), 29–51 (2010)
3. E. Beres, R. Adve, On selection cooperation in distributed networks, in *IEEE CISS*, pp. 1056–1061, 2006
4. A. Bletsas, A. Khisti, D. Reed, A. Lippman, A simple cooperative diversity method based on network path selection. *IEEE J. Sel. Area. Commun.* **24**(3), 659–672 (2006)
5. D. Cabric, S. Mishra, R. Brodersen, Implementation issues in spectrum sensing for cognitive radios, in *IEEE Asilomar Conference on Signals, Systems and Computers*, pp. 772–776, 2004
6. A. Cacciapuoti, I. Akyildiz, L. Paura, Correlation-aware user selection for cooperative spectrum sensing in cognitive radio ad hoc networks. *IEEE J. Sel. Area. Commun.* **30**(2), 297–306 (2012)
7. Y. Choi, H.W. Ji, J. Yoon Park, H. Chul Kim, J. Silvester, A 3w network strategy for mobile data traffic offloading. *IEEE Commun. Mag.* **49**(10), 118–123 (2011)
8. X. Deng, A. Haimovich, Power allocation for cooperative relaying in wireless networks. *IEEE Commun. Lett.* **9**(11), 994–996 (2005)
9. K. Doppler, C.-H. Yu, C. Ribeiro, P. Janis, Mode selection for device-to-device communication underlaying an lte-advanced network, in *IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 1–6, 2010
10. W. Fang, F. Liu, F. Yang, L. Shu, S. Nishio, Energy-efficient cooperative communication for data transmission in wireless sensor networks. *IEEE Trans. Consum. Electron.* **56**(4), 2185–2192 (2010)
11. M. Felegyhazi, M. Cagalj, S. Bidokhti, J.-P. Hubaux, Non-cooperative multi-radio channel allocation in wireless networks, in *Proceeding IEEE INFOCOM*, pp. 1442–1450, May 2007
12. L. Gao, X. Wang, A game approach for multi-channel allocation in multi-hop wireless networks. in *Proceeding ACM MobiHoc*, pp. 303–312, 2008
13. C. Gao, Y. Shi, Y. Hou, H. Sherali, H. Zhou, Multicast communications in multi-hop cognitive radio networks. *IEEE J. Sel. Area. Commun.* **29**, 784–793 (2011)
14. X. Gong, W. Yuan, W. Liu, W. Cheng, S. Wang, A cooperative relay scheme for secondary communication in cognitive radio networks, in *IEEE GLOBECOM*, pp. 1–6, 2008
15. M. Hajiaghayi, M. Dong, B. Liang, Optimal channel assignment and power allocation for dual-hop multi-channel multi-user relaying, in *IEEE INFOCOM*, pp. 76–80, April 2011
16. C. He, Z. Feng, Q. Zhang, Z. Zhang, H. Xiao, A joint relay selection, spectrum allocation and rate control scheme in relay-assisted cognitive radio system, in *IEEE VTC*, pp. 1–5, 2010
17. X. Huang, H. Shan, X. Shen, On energy efficiency of cooperative communications in wireless body area network, in *IEEE WCNC*, pp. 1097–1101, March 2011
18. P. Janis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler, K. Hugl, Interference-aware resource allocation for device-to-device radio underlaying cellular networks, in *Proceeding IEEE Vehicular Technology Conference*, pp. 1–5, 2009
19. P. Jänis, C.-H. Yu, K. Doppler, C. Ribeiro, C. Wijting, K. Hugl, O. Tirkkonen, V. Koivunen, Device-to-device communication underlaying cellular communications systems. *Int. J. Commun. Netw. Syst. Sci.* **2**(3), 169–178 (2009)
20. W. Ji, B. Zheng, Energy efficiency based cooperative communication in wireless sensor networks, in *IEEE ICCT*, pp. 938–941, Nov 2010
21. C. Jiang, Y. Shi, Y. Hou, W. Lou, Cherish every joule: maximizing throughput with an eye on network-wide energy consumption, in *Proceedings of IEEE INFOCOM*, pp. 1934–1941, March 2012
22. B. Kaufman, J. Lilleberg, B. Aazhang, Spectrum sharing scheme between cellular users and ad-hoc device-to-device users. *IEEE Trans. Wirel. Commun.* **12**(3), 1038–1049 (2013)

23. K. Khalil, M. Karaca, O. Ercetin, E. Ekici, Optimal scheduling in cooperate-to-join cognitive radio networks, in *IEEE INFOCOM*, pp. 3002–3010, April 2011
24. J. Korhonen, T. Savolainen, A. Ding, M. Kojo, Toward network controlled ip traffic offloading. *IEEE Commun. Mag.* **51**(3), 96–102 (2013)
25. J. Laneman, D. Tse, G. Wornell, Cooperative diversity in wireless networks: efficient protocols and outage behavior. *IEEE Trans. Inf. Theory* **50**(12), 3062–3080 (2004)
26. K. Lee, J. Lee, Y. Yi, I. Rhee, S. Chong, Mobile data offloading: how much can wifi deliver? *IEEE/ACM Trans. Netw.* **21**(2), 536–550 (2013)
27. D.H. Lee, K.W. Choi, W.S. Jeon, D.G. Jeong, Two-stage semi-distributed resource management for device-to-device communication in cellular networks. *IEEE Trans. Wirel. Commun.* **13**(4), 1908–1920, (2014)
28. Y. Li, P. Wang, D. Niyato, W. Zhuang, A dynamic relay selection scheme for mobile users in wireless relay networks, in *IEEE INFOCOM*, pp. 256–260, April 2011
29. P. Li, S. Guo, Z. Cheng, A.V. Vasilakos, Joint relay assignment and channel allocation for energy-efficient cooperative communications, in *IEEE WCNC*, pp. 5740–5744, 2012
30. P. Li, S. Guo, V. Leung, Improving throughput by fine-grained channel allocation in cooperative wireless networks, in *IEEE GLOBECOM*, pp. 5740–5744, 2012
31. P. Li, S. Guo, Y. Xiang, H. Jin, Unicast and broadcast throughput maximization in amplify-and-forward relay networks. *IEEE Trans. Veh. Technol.* **61**(6), 2768–2776 (2012)
32. P. Li, S. Guo, W. Zhuang, B. Ye, Capacity maximization in cooperative crns: joint relay assignment and channel allocation, in *IEEE ICC*, pp. 6619–6623, March 2012
33. P. Li, S. Guo, W. Zhuang, B. Ye, On efficient resource allocation for cognitive and cooperative communications. *Accept. IEEE J. Sel. Areas Commun.* (2013)
34. Y. Li, Z. Wang, D. Jin, S. Chen, Optimal mobile content downloading in device-to-device communication underlying cellular networks. *IEEE Trans. Wirel. Commun.* **13**(7), 3596–3608 (2014)
35. G. Liu, L. Huang, H. Xu, W. Liu, Y. Zhang, Maximal lifetime scheduling for cooperative communications in wireless networks, in *Proceeding International Conference on Computer Communications and Networks (ICCCN)*, pp. 1–6, 2010
36. H. Min, W. Seo, J. Lee, S. Park, D. Hong, Reliability improvement using receive mode selection in the device-to-device uplink period underlying cellular networks. *IEEE Trans. Wirel. Commun.* **10**(2), 413–418 (2011)
37. S. Mishra, A. Sahai, R. Brodersen, Cooperative sensing among cognitive radios, in *IEEE ICC*, vol. 4, pp. 1658–1663, June 2006
38. C.H. Papadimitriou, K. Steiglitz, in *Combinatorial Optimization: Algorithms and Complexity* (Prentice-Hall, Inc., Upper Saddle River, 1982)
39. N. Ristanovic, J.-Y. Le Boudec, A. Chaintreau, V. Erramilli, Energy efficient offloading of 3g networks, in *Proceeding of IEEE Conference on Mobile Ad-Hoc and Sensor Systems (MASS)*, pp. 202–211, 2011
40. S. Sharma, Y. Shi, Y.T. Hou, S. Kompella, An optimal algorithm for relay node assignment in cooperative ad hoc networks. *IEEE/ACM Transactions on Networking*, pp. 879–892, 2010
41. S. Sharma, Y. Shi, Y.T. Hou, H.D. Sherali, S. Kompella, Cooperative communications in multi-hop wireless networks: joint flow routing and relay node assignment, in *IEEE INFOCOM*, pp. 1–9, 2010
42. S. Sharma, Y. Shi, J. Liu, Y. Hou, S. Kompella, Is network coding always good for cooperative communications? in *IEEE INFOCOM*, pp. 1–9, March 2010
43. S. Sharma, Y. Shi, Y. Hou, H. Sherali, S. Kompella, Optimizing network-coded cooperative communications via joint session grouping and relay node selection, in *IEEE INFOCOM*, pp. 1898–1906, April 2011
44. T.-C. Shih, C.-C. Kao, S.-R. Yang, A cooperative mac protocol in multi-channel wireless ad hoc networks, in *Proceeding Wireless Communications and Mobile Computing Conference (IWCMC), 2011 7th International*, pp. 1831–1836, 2011
45. L. Simic, S. Berber, K. Sowerby, Energy-efficiency of cooperative diversity techniques in wireless sensor networks, in *IEEE PIMRC*, pp. 1–5, Sept 2007

46. M. Tehrani, M. Uysal, H. Yanikomeroglu, Device-to-device communication in 5g cellular networks: challenges, solutions, and future directions. *IEEE Commun. Mag.* **52**(5), 86–92 (2014)
47. E.C. van der Meulen, Three-terminal communication channels. *Adv. Appl. Probab.* **3**, 120–154 (1971)
48. F. Wu, S. Zhong, C. Qiao, Globally optimal channel assignment for non-cooperative wireless networks, in *Proceeding IEEE INFOCOM*, pp. 1543–1551, April 2008
49. F. Wu, N. Singh, N. Vaidya, G. Chen, On adaptive-width channel allocation in non-cooperative, multi-radio wireless networks, in *Proceeding IEEE INFOCOM*, pp. 2804–2812, April 2011
50. D. Yang, X. Fang, G. Xue, Hera: an optimal relay assignment scheme for cooperative networks. *IEEE J. Select. Area. Commun.* **30**(2), 245–253 (2012)
51. C.-H. Yu, K. Doppler, C. Ribeiro, O. Tirkkonen, Resource sharing optimization for device-to-device communication underlaying cellular networks. *IEEE Trans. Wirel. Commun.* **10**(8), 2752–2763 (2011)
52. J. Zhang, Q. Zhang, Stackelberg game for utility-based cooperative cognitive radio networks, in *ACM MobiHoc*, pp. 23–32, 2009
53. Y. Zhao, R. Adve, T. Lim, Improving amplify-and-forward relay networks: optimal power allocation versus selection. *IEEE Trans. Wirel. Commun.* **6**(8), 3114–3123 (2007)

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