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 IETF 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.
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