DEVICE-TO-DEVICE MULTICAST IN UNDERLAY CELLULAR NETWORKS

A Thesis

submitted by

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in partial fulfillment of the

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DECLARATION

I hereby certify that the work which is being presented in the thesis titled **"Device-to-Device Multicast in Underlay Cellular Networks"** in the requirement for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the School of Computing and Electrical Engineering, Indian Institute of Technology Mandi, is an authentic record of my own work carried with the guidance of Dr. Samar Agnihotri, Indian Institute of Technology Mandi, India. Due acknowledgment has been made wherever the work described is based on the findings of the other investigators. The work presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

Mandi, 175 005

Ajay

THESIS CERTIFICATE

This is to certify that the thesis titled **Device-to-Device Multicasts in Underlay Cellular Networks**, submitted by **Ajay**, to the **Indian Institute of Technology, Mandi**, for the award of the degree of **Doctor of Philosophy**, is a bonafide record of the research work done by him with my guidance. The contents of this thesis, in full or in parts, have not been submitted to any other institute or university for the award of any degree or diploma.

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Dr. Samar Agnihotri
(Advisor)

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- *Ajay Bhardwaj*

Dedicated to my parents

ABSTRACT

Supporting ever increasing number of mobile users with data-hungry applications, running on battery limited devices, is a daunting challenge for telecommunications community. Underlay device-to-device (D2D) communication, which allows physically proximate mobile users to directly communicate with each other by reusing the spectrum, without going through the base station, holds promise to help us tackle this challenge. In a cellular network, underlay D2D communication offers opportunities for spectrum reuse and spatial diversity which may lead to enhanced coverage, higher throughput, and robust communication in the network. Further, for applications such as weather forecasting and live streaming, which may require the same chunks of data distributed to geographically proximate users, D2D multicasting may provide better utilization of network resources compared to D2D unicast or Base Station (BS) based multicast, such as LTE eMBMS. However, extensive deployment of underlay D2D multicast in a network may cause severe co-channel interference due to spectrum reuse and rapid battery depletion of the multicasting D2D nodes as they may have to expend more power to fight co-channel interference and to relay data. Therefore, in this thesis, we focus on some of the challenges in supporting D2D multicast communication in underlay cellular networks, propose novel approaches to address these challenges without compromising on the promise of D2D multicast in cellular networks, and evaluate their performances.

In the first part of the thesis, we study the resource allocation schemes where multiple D2D multicast groups may share cellular users' uplink channels. We formulate an optimization problem that maximizes the achievable system throughput while fulfilling the maximum power constraint of every cellular user and multicast group transmitter, and ensuring a certain level of quality of service (QoS) to every cellular user and D2D multicast group. The formulated optimization problem is an instance of mixed integer non-linear programming (MINLP) problem, which is computationally intractable, in general. Therefore, to find a feasible solution, we propose a pragmatic two-step process of channel allocation and power allocation. In the first-step, we propose a channel sharing algorithm, which determines the subset of multicast groups that

may share a channel. Then, we propose a power allocation algorithm that maximizes the system throughput, while satisfying transmit power and interference constraints. We demonstrate impact of the QoS requirements of CUs and the maximum available transmission power on achievable system throughput. Further, we also explore the problem of sum rate maximization over general fading environments. In particular, we provide an exact calculation of outage probability experienced by a D2D receiver in a multicast group and a scheme to optimally share channels among D2D MGs and CUs by minimizing these probabilities.

In the second part of the thesis, we address the problem of mutual interference minimization between cellular users and D2D multicast groups by adopting a realistic and pragmatic approach to effectively reduce the co-channel interference of cellular transmission on D2D multicast reception. We consider the cellular users as the primary users in a cell, having exclusion zones around them, where no receiver of any multicast group can exist. We use a stochastic geometry based approach to model this scenario and formulate the corresponding network sum throughput maximization problem. Specifically, we model the locations of cellular users and D2D multicast groups receivers with two different spatial distributions, namely homogeneous Poisson Point Process (PPP), and Poisson Hole Process (PHP), respectively. The D2D multicast groups are enabled only when their receivers are outside cellular users' exclusion regions. In this setting, we formulate a network sum throughput maximization problem in terms of joint multicast group channel and power allocation problem with constraints on the maximum power of D2D transmitters and acceptable quality of service of cellular users and multicast group receivers. We prove that the channel allocation problem has computational complexity at least exponential in both, the number of cellular users and the number of multicast groups. However, after numerically analyzing the nature of the optimal solution in a wide variety of scenarios, we observe that though theoretically any number of multicast groups can be assigned to any cellular channel, the optimal performance is invariably achieved when small and almost equal number of multicast groups are assigned to all channels. Based on this observation, we propose schemes that achieve almost optimal performance with reducing computational complexity in the number of multicast groups. We also provide a novel scheme to reduce the complexity with respect to the number of cellular channels. We further compare the performance of the proposed schemes with the performance of the optimal scheme with respect to variation of different system parameters and show that the proposed schemes achieve almost optimal performance in computationally efficient manner.

In the third part of the thesis, we introduce an approach based on stochastic geometry to derive the relation between average sum-rate and energy consumption. In particular, we explore spectral efficiency (SE) and energy efficiency (EE) trade-off for this problem by formulating the EE maximization problem with constraint on SE and maximum available transmission power. The formulated problem is non-convex, and is solved using a proposed heuristic gradient power allocation algorithm. It is shown that energy efficiency has a non-trivial behavior due to complex interplay among various system parameters, such as available power, spectral requirements, and D2D multicast groups density. There is an optimal value of SE that can be supported, which results in the corresponding maximal value of EE for each value of multicast group transmitter power.

Concluding, in this work, we highlight various aspects of D2D multicast in underlay cellular networks through analytical and numerical frameworks, and provide insights into the practical system design.

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