Mode Selection in Underlay Device to Device Communication

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***Abstract*—**Device to device communication (D2D) refers to a technology that enables the communication between multiple devices or users without having base station. It holds a great promise in improving energy efficiency, throughput and spectral efficiency and thus regarded as a key technology component in LTE-Advanced. Also D2D transmission reduces transmission delay and power consumption taking the advantages of short transmission distance. The objective of this paper is to investigate the fundamental problem in D2D communication underlaying cellular network, that is either establishing D2D communication or make a traditional cellular communication. For this a mode selection mechanism is proposed to control the number of user equipments (UEs) performing D2D communications to achieve maximum spectral efficiency. In this paper a distance-based D2D mode selection procedure is considered that can simply switch the direct D2D link and normal cellular link. By this mode selection, a suitable mode selection threshold that achieves maximum data rate has been found out. Stochastic geometry is used to analyze the performance of this mode selection mechanism. The impact of number of D2D pairs in the mode selection threshold is also evaluated in the paper. From the simulation results, mode selection threshold for different D2D user pairs has been found out.

Keywords: *Device to device communication, LTE-Advanced, mode selection, stochastic geometry.*

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I. INTRODUCTION

The telecommunication operators are now struggling to accommodate the huge demands of mobile users. Moreover, 4G cellular technologies (WiMAX and LTE-A), which have extremely efficient physical and MAC layer performance, are still lagging behind mobile users booming data demand [1]. Therefore, researchers are seeking new paradigms to revolutionize the traditional methods of cellular networks. Device-to-Device (D2D) communication is one of such paradigms that appear to be a promising component in next generation cellular technologies. Considering the current 4G technologies cannot fulfill the huge gap between the actual communication performances and the forthcoming user expectations, Third Generation Partnership Project (3GPP) has been developing an enhanced Long- Term Evolution (LTE) radio interface called LTE Advanced (LTE-A). LTE-A radio interface is designed with a lot of advanced communication techniques such as carrier aggregation, massive multiple-input multiple-output (MIMO), millimeter waves, low-power nodes (LPNs, e.g., picoeNBs, femtoeNBs, and relays), as well as D2D communication, which are believed to be able to significantly enhance the current 4G cellular technologies in terms of system capacity, coverage, peak rates, throughput, latency and user experience.

Device-to-device (D2D) communications was initially proposed in cellular networks as a new paradigm for enhancing network performance. Device-to-Device (D2D) communication is defined to directly route data traffic between spatially closely located mobile user equipments (UEs) [2]. The appearance of new applications such as content distribution, location-aware advertisement and v2x communication introduced new use cases for D2D communications in cellular networks. The initial studies showed that D2D communications has advantages such as increased spectral efficiency and reduced communication delay [3, 4]. Taking the advantages of short transmission distance, D2D transmission increases resource utilization as well as reduce transmission delay and power consumption.

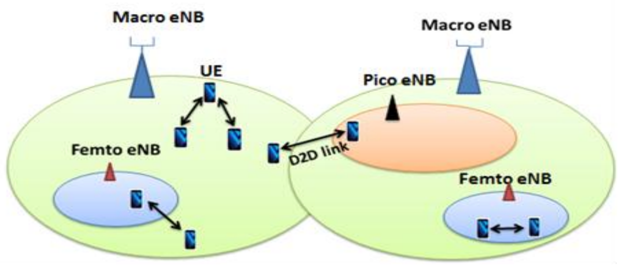

Fig 1. Illustration of D2D communications among multi-tier cells in LTE-A HetNets.

Fig 1 illustrates an example of D2D communications among multi-tier cells in Long Term Evolution – Advanced (LTE-A) network. Here the user equipments (UEs) are distributed in macro cells, pico cells and femto cells. For controlling each of these cells, there are macro eNB (evolved Node B), femtoeNBand picoeNB. The UEs which are in close proximity communicate directly via D2D link is also shown in figure.

The remaining of this paper is organized as follows. Section II discusses the related works on D2D communication. In section III, we describe the mode selection procedures for D2D communication underlying cellular networks and the impact of number of users in mode selection threshold.. Section IV concludes this work.

II. LITERATURE SURVEY

Liu et al. in [1] described that D2D communication holds great promise in improving energy efficiency, throughput, delay, as well as spectrum efficiency. As a combination of ad-hoc and centralized communication mechanisms, D2D communication enables researchers to merge together the long-term development achievements in previously disjoint domains of ad-hoc networking and centralized networking. In order to help researchers to have a systematic understanding of the emerging D2D communication, they have provided a comprehensive survey of available D2D related research works ranging from technical papers to experimental prototypes to standard activities, and outline some open research problems which deserve further studies.

Asadi et al. in [2] described that D2D communications was initially proposed in cellular networks as a new paradigm for enhancing network performance. The emergence of new applications such as content distribution and location-aware advertisement introduced new user cases for D2D communications in cellular networks.In this paper, they provided a taxonomy based on the D2D communicating spectrum and review the available literature extensively under the proposed taxonomy. Moreover, they provide new insights into the over-explored and under-explored areas that lead us to identify open research problems of D2D communications in cellular networks.

Zhang et al. in [3] described that D2D is an attractive add-on component in 5G system to improve spectrum efficiency and user experience by reusing licensed cellular spectrum. In this paper, they proposed to enable D2D communication in unlicensed spectrum (D2D-U) as an underlay of the uplink LTE network for further booming the network capacity. A sensing-based protocol is designed to support the unlicensed channel access for both LTE and D2D users. They further investigated the subchannel allocation problem to maximize the sum rate of LTE and D2D users while considering their interference to the existing Wi-Fi systems. Specifically, they developed an iterative user-subchannel swap algorithm.

Lili Wei et al. in [4] presented a survey on device-to-device communication underlaying a cellular network. They explained that D2D communication has great potential to improve wireless system spectral and energy efficiency due to the proximity of communication parties and higher spectrum reuse gain. They also discussed technical challenges and researches of D2D communication underlying cellular networks. The key research areas addressed in this paper include interference management, multihop D2D communications, and D2D communications in hetNets.

Guo et al. in paper [5] focus on the intra-cell interference and propose a D2D mode selection scheme to manage it inside a finite cellular network region. They studied the outage probability experienced at the BS and a D2D receiver using stochastic geometry.

Gamage et al. in paper [6] investigated how to leverage D2D communication to further improve the performance of a converged network which consists of an LTE-A cellular network and IEEE 802.11n WLANs. They identified three main technical challenges that complicated resource allocation.. To address these challenges, They proposed a resource allocation scheme that performs mode selection and allocation of LTE-A network resources in three different timescales.

Andrews et al. in [7], Minming et al. in [8], Elsawy et al. in [9] presents a tutorial on stochastic geometry (SG) based analysis for cellular networks. The paper [7] described that wireless networks are fundamentally limited by the intensity of the received signals and by their interference. So mathematical techniques have been developed to provide geometrical configuration of network. The location of the nodes in the wireless network can be modeled as random Poisson point process. So different techniques based on stochastic geometry and the theory of random geometric graphs such as point process theory and probabilistic combinatorics can be applied, which gives results on the connectivity, capacity, outage probability, and other fundamental limits of wireless networks. In paper [8], The authors proposed a geometrical method to obtain the guard distances from D2D user equipment (DUE) to the base station (BS), to the transmitting cellular user equipment (CUE), and to other communicating D2D pairs respectively considering the SIR requirements for macro -cell and D2D communications.

Zhi-Yu Yang et al. in [10] investigated the very beginning and fundamental problem in D2D communications underlaying cellular network that is, either establishing local D2D communications or make a traditional communication with BS. They proposed a novel mode selection mechanism to control the number of UEs performing D2D communications to achieve maximum average transmit data rate. They applied the recent innovation, stochastic geometry, to analyze the performance of the proposed mode selection mechanism and included the realistic features in cellular network.As a result, this work served as a powerful and efficient tool for analyzing the effects of D2D mode selection

Zhang et al. in [11] investigated CR-assisted D2D communications in a cellular network and found that it is a viable solution for D2D communications, in which devices access the network with mixed overlay–underlay spectrum sharing. Their comprehensive analysis reveals several engineering insights useful to system design.

Jeffrey G. Andrews et al. in paper [12] addressed two fundamental and interrelated issues in device-to-device (D2D) enhanced cellular networks. The first issue was how D2D users should access spectrum and they consider two choices: overlay (orthogonal spectrum between D2D and cellular UEs) and underlay (non- orthogonal). The next issue the authors considered was how D2D users can choose the two communication modes i.e., direct communication mode and communication through base station. It depends on distance between the potential D2D transmitter and receiver. They considered a hybrid network model where the positions of mobiles are modeled by random spatial Poisson point process (PPP). They found that, as the proportion of potential D2D mobiles increases, the optimal spectrum access factor in the underlay decreases.

III. MODE SELECTION IN DEVICE TO DEVICE COMMUNICATION UNDERLYING CELLULAR NETWORK

Fundamental problem in D2D communication underlying cellular network is either establishing local D2D communications or make a traditional communication with BS. We consider distance-based D2D mode selection and use a mode selection threshold to determine D2D or cellular communication is desired. The user equipment whose perform D2D communications (known as DeUEs) and who make the traditional cellular connection with BS (known as CeUEs) share the same spectrum. The following sessions deal with the features of underlay D2D and different aspects for mode selection in D2D. In underlay D2D communication, cellular and D2D communications share the same spectrum. Inband D2D can improve the spectrum efficiency of cellular networks by reusing spectrum resources (i.e., underlay) [5, 6]

A. Stochastic geometry and voronoi tessellation

Stochastic geometry (SG) is a rich branch of applied probability which allows the study of random phenomena on the plane or in higher dimensions [7-9].

It is intrinsically related to the theory of point processes. It has succeeded to provide a unified mathematical paradigm to model different types of wireless networks, characterize their operation, and understand their behavior. The main strength of the analysis based on SG, hereafter denoted as SG analysis, can be attributed to its ability to capture the spatial randomness inherent in wireless networks. Furthermore, SG models can be naturally extended to account for other sources of uncertainties such as fading, shadowing, and power control. In some special cases, SG analysis can lead to closed-form expressions that govern system behavior. These expressions enable the understanding of network operation and provide insightful design guidelines, which are often difficult to get from computationally intensive simulations.Voronoi tessellation is an important tool that comes under stochastic geometry.

B. *Network model*

We consider a hybrid network model [10]. The co-channel deployment and underlay sharing between CeUEs and potential DeUEs are assumed, that is, both CeUEs and potential DeUEs can utilize all the resources if interference constrained.

The spatial distribution of BSs and UEs are assumed to follow a homogeneous Poisson Point Process (PPP) with density and , respectively. The network model is shown in fig 2. DeUE pair transmits its data by direct D2D link if the distance between transmitter and receiver is closed enough; otherwise the potential DeUE transmitter will connect to the closest BS to transmit the data by using the uplink spectrum just like a normal CeUE do. The effects of path loss attenuation, Rayleigh fading with unit average power G and background noise power N0 are in channel model [11, 12].

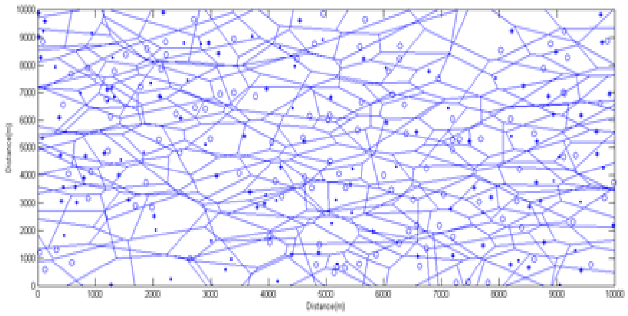

Fig 2. A hybrid network model. Cross, dot and circle denote, uplink cellular transmitters, D2D transmitters and base stations respectively

IV. SIMULATION RESULTS & DISCUSSIONS

The distance based mode selection procedure in underlay D2D communication is simulated to find out the mode selection threshold.

A. *Cellular & D2D Link spectral efficiency*

The cellular and D2D link spectral efficiencies are given by equations in [10, 12].

The spectral efficiency RC of cellular links is given by:

$$R_C = E[\frac{1}{N}\log(1+SINR_C)] =$$

$$\frac{\lambda_B}{\lambda_C} * \left(1-\exp\left(\frac{-\lambda_C}{\lambda_B}\right)\right) * \int_0^\infty \frac{1}{1+x}[L_{ICC}(Bx)+L_{IDC}(Bx)]dx$$

Here$\lambda_B$is the intensity of base station, λ_C is intensity of cellular user equipments and D2D user equipments in D2D mode, $L_{ICC}(Bx)$ is the laplace transform of interference from CeUE transmitter to CeUE transmitter, $L_{ICD}(Bx)$ is the laplace transform of interference from DeUE transmitter to DeUE receiver and is B is Bandwidth.

The spectral efficiency RD of D2D links is derived as follow.

$$R_D = E[\frac{1}{N}\log(1+SINR_D)] =$$

$$e^{-\xi\pi\mu^2} * R_C + (1-e^{-\xi\pi\mu^2}) * \int_0^\infty \frac{1}{1+x}[L_{IDD}(Bx)+L_{IDC}(Bx)]dx$$

whereξispotential D2D parameter., $\mu$is mode selection threshold, $L_{IDD}(Bx)$is laplace transform of interference from CeUE transmitter to CeUE transmitter, $L_{IDC}(Bx)$ is the laplacetransform of interference from DeUE transmitter to DeUE receiver and B is Bandwidth.

Based on these the average rates of cellular and potential D2D UEs, D2D mode selection threshold was simulated in Matlab. Fig 5 shows the average rates of CeUEs and potential DeUEs as a function μ in the underlying scenario. The average rate of CeUEs almost constant as μ increases. This is because the CeUEs suffer from the interference caused by the underlaidDeUE transmitters. The average rate of DeUE first increases and then become constant as increases. That is due to the average rate of potential DeUE is co-determined by its cellular-mode rate and D2D-mode rate.

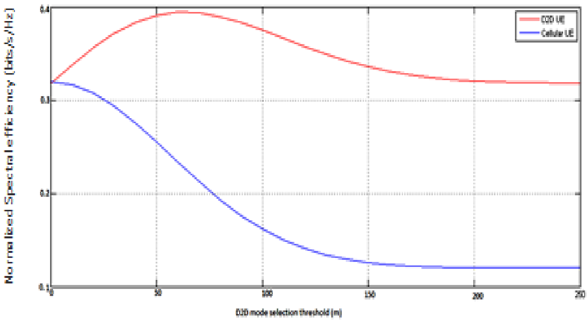

Fig 3..Average rate of cellular and D2D user equipment

In Fig 3, the average rate of CeUEs obtained is 0.05 and average rate of DeUEs obtained is 0.28. The average rate of DeUEs first increases and then become constant as μ increases. The result shows that if distance threshold is about 250 m or 300 m, D2D communication can provide high data rate. Within a distance of 250-300 m, if a user chooses D2D mode, then it can provide data rate greater than cellular communication. The mode selection threshold is obtained as 80 m if there are 3o D2D UEs.

B. *Impact of number of user pairs in D2D mode selection threshold*

In this subsection we are evaluating the impact of number of users in mode selection threshold. For this equation of RD is simulated for different density of user equipments

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Fig 4 is the result obtained through the simulation done in matlab. From the result it is clear that there is a shift in mode selection threshold with respect to user density. As the number of D2D pairs increases, the mode selection threshold decreases. But upto a distance of 50 m, the impact of increase in D2D pairs is not seen.

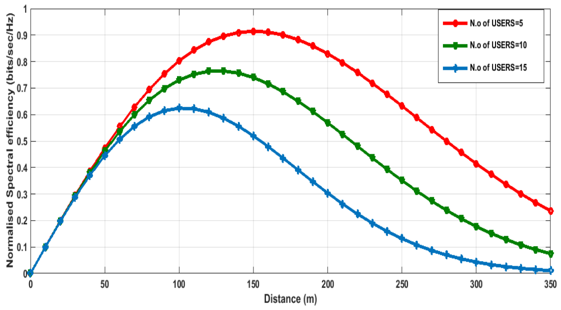

Fig 4. D2D mode selection threshold with different number of user pairs

This result conveys that D2D communication within a distance of 50 m can support massive number of users. The values of threshold obtained from graph are tabulated in table 1 given below.

TABLE 1: Comparison of D2D mode selection threshold with number of D2D users

Number of D2D Users	D2D Mode Selection Threshold
5	150
10	130
15	100

V. CONCLUSION

A hybrid network model was created to analyse the performance of D2D communication. Since underlay D2D communication, both intra-tier and inter-tier interference are considered in this work. We showed that in the underlay case there should be a tradeoff between the underlay D2D spectrum access and mode selection. Weconsidered a distance-based D2D mode selection that can simply switch D2D mode and cellular mode. By this mode selection strategy, we derived the close form expressions of spectral efficiency of D2D links and cellular links and applied them to find a reliable D2D mode selection threshold. The mode selection threshold is obtained as 80 m for 30 D2D pairs. But it is seen that the threshold decreases when number of users increases.

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