# Improving performance of Full Duplex Device to Device Communication Underlaying Cellular Networks

Dr.M.Baritha begum[1], K.sharmila[2]
[1]*Assistant Professor, Department of ECE, Saranathan College of Engineering, Trichy, India*
[2]*PG Student, Department of ECE, Saranathan College of Engineering, Trichy, India*

***Abstract* - In this project two novel cooperative modes are developed for full-duplex D2D communication underlying cellular networks. The network MU-MIMO based mostly mode (N-mode) and therefore the successive forwarding mode (S-mode).within the N-mode, two-D2D users work as network MIMO to forward the info to cellular users and so influence the channel diversity within the S-mode, the spatial distribution of D2D users and cellular users is explored to boost the transmission rate. Reinforced these modes, two D2D users share the downlink resources with two close cellular users at the same time to attain each proximity gain and employ gain. Moreover, these modes are analogous temperament for edge cellular users. To optimize the performance of the two modes, the top power allocation is conducted by considering the influence of residual self-interference at full duplex radios and therefore the necessities of the minimum transmission rate for each cellular users and D2D users.**

***Index Terms* - MIMO, Full duplex, D2D Communication**

## I.INTRODUCTION

In few years ago, the proliferation of smart phones, tablets, and other wireless devices has stimulated in wide spreading of social networking and multimedia content sharing, which leads to an explosive growth of wireless data traffic. As a result, the bottom station (BS) suffers an important burden. To meet the enormously increasing demands of knowledge traffic, device to device (D2D) communication underlaying cellular networks has been proposed as a key technology in 4G and 5G networks. D2D communication cannot only alleviate the burden of a BS, but it also can improve the spectrum efficiency.

So far, three modes have been designed for D2D communication underlaying cellular networks. cellular mode, dedicated mode, and another one reuse mode. In the cellular mode, the BS is acting as a relay for D2D users. In the dedicated mode and the reuse mode, the D2D users share orthogonal and non-orthogonal resources with a cellular user, respectively

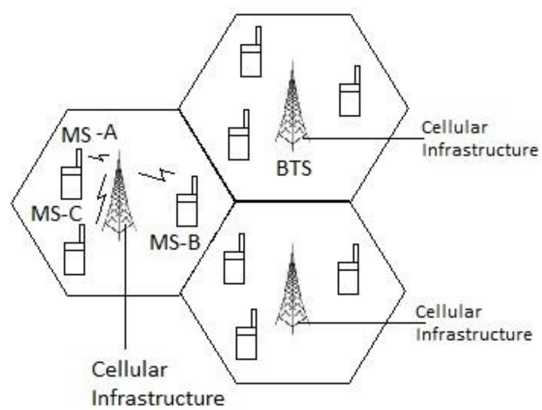


Fig 1: Cellular Network Model

A cellular network or mobile network could even be a communication network where the last link is wireless. The network is distributed over land areas called "cells", each served by a minimum of 1 fixed-location transceiver, but countless commonly, three cell sites or base transceiver stations .These base stations supply the cell with the network coverage which may be used for transmission of voice, data, and totally differing types of content.. A cell sometimes uses a certain set of frequencies from near cells, to avoid interference and supply secure service quality at intervals each cell

DEVICE-TO-DEVICE

Device to device communication in cellular networks is defined as the direct communication between two mobile users without traversing the Antenna. D2D communication is usually non-transparent to the cellular network and it can occur on the cellular frequencies or unlicensed spectrum.

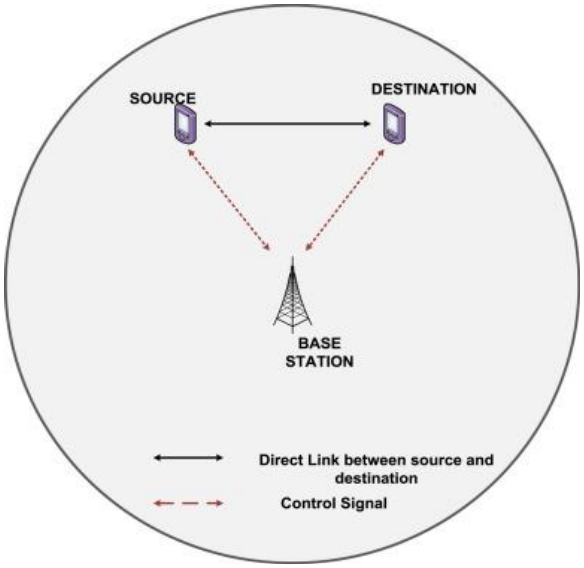


Fig 2: D2D Communication Network

In an ancient cellular network, all communications should undergo the bachelor's degree though human activity revelries are in vary for proximity based D2D communication. The benefits of D2D communications transcend spectral efficiency they will doubtless improve output, energy potency, delay, and fairness. Communication through bachelor's degree suits standard low rate mobile services like voice decision and text electronic communication within which users are rarely shut enough for direct communication. Hence, D2D communications in such situations will greatly increase the spectral potency of the network.

In this project, we investigate new cooperative D2D modes by combining full duplex and D2D communication. The existing modes consider independent transmissions of D2D users and cellular user so that they must avoid the interference to each other. More specifically, orthogonal resources are allocated to D2D users and nearby cellular user by the dedicated mode because of the strong interference, e.g., cellular user U and D2D users However, if the cellular user and D2D users can work cooperatively to share the same resources, the reuse gain can also be achieved in this situation. In addition, the cooperative transmissions can still keep the spatial efficiency. For example, if the cellular user U and D2D users D1 can work cooperatively as shown in Fig., the D2D users D2 can reuse the same resources since they To this end, we explore new cooperative modes for the situation that the D2D users are close to cellular users.

## II. LITERATURE SURVEY

L. Song [1], introduces the key components of D2D-LAN, and provides an overview of the technical challenges as well as possible solutions for deploying multi-hop D2D communications and networks. Since interference is the main limitation in the deployment of undelaying networks, special attention will be given to those problems in relation to resource allocation and interference avoidance management. The use of D2D communication can introduce another communication dimension, that is, the handset freedom in a less strict way.

Zhang[2] make a case for associate adaptation multiple access (AMA) theme, that dynamically switches between the planned cooperative ulcer, standard ulcer, and OMA schemes, per the extent of residual self- interference.

The [3] implement a joint beam former vogue draw back to maximize total rate, i.e., a joint transmit variance matrix vogue draw back, demonstrating the coupled effects between SI and CCI. However, the advance drawback is non-convex and tasking to hunt out the simplest transmit variance conditions owed to the coupled SI and CCI to bypass this problem, we incline to incline to use the duality between broadcast channel (BC) and multiple access channel (MAC) and formulate the entire rate maximization drawback The projected algorithms guarantee fast convergence and low machine quality. The [4] projected a different approach of equivalent self-interference cancellation is developed throughout this paper. plenty of specifically, a balanced RF frond-end circuit is supposed to allow a symbol to propagate through symmetrical ways that such that: (1) transmit signals taking fully different completely different ways that to achieve the receiver is cancelled; (2) receive signals from other ways square measure simply at the receiver.

Chung, el, at [5] presents a fundamental measure full duplex radio system for 5G wireless networks. This vogue combines a dual-polarization antenna-based analog distribute with a digital self-interference cancellation that operates in real time. Full duplex radios unit capable of gap new prospects in contexts of high traffic demand where their unit restricted radio resources. An essential issue, however, in implementing full duplex radios in real wireless environments has the flexibility to cancel self-interference.to beat the self-interference challenge, we've got an inclination to pattern our vogue on a software-defined radio platform Wang [6], discuss full duplex for heterogeneous networks that accommodate the bigness of device-to-device communications. The short link distance and lower transmit power of device-to-device communications create them glorious candidates to use full duplex in band transmission. By incorporating power allocation for self-interference cancellation reinforced antenna isolation, analog cancellation, and digital cancellation, full-duplex device-to-device, FD-D2D, nodes will doubtless improve spectrum potency in Het Nets. In multi hop D2D communications, the supply node (S) and destination node (D) will communicate via direct link likewise as totally different relay hops, that demonstrates a typical state of affairs wherever each S and D square measure in HD, whereas relay nodes (Rs) square measure in FD.

## III. EXISTING SYSTEM

Full duplex communication has become practical in recent years, which is also considered as a hopeful technology in 5G networks. The conventional balanced RF circuit is designed to conduct equivalent self-interference cancellation at the frontend, which can achieve 60dB self-interference cancellation.

Moreover, their experimental results show:

- The received signal suffers negligible SNR loss regardless of the received SNR.
- Their prototype supports all WiFi modulation schemes and bandwidths with low SNR loss.

An existing real-time full duplex prototype is executed for LTE systems, which can achieve 1.9 times higher throughput than half duplex system. Thus, it is necessary to consider how to successfully syndicate full duplex and D2D communication for 5G networks. So far, a few papers have considered the combination of full duplex and D2D communication.

More specifically, orthogonal resources are allocated to D2D users and nearby cellular user by the dedicated mode because of the strong interference, e.g., cellular user U and D2D users D1 in Fig. However, if the cellular user and D2D users can work cooperatively to share the same resources, the reuse gain can also be accomplished in this situation.

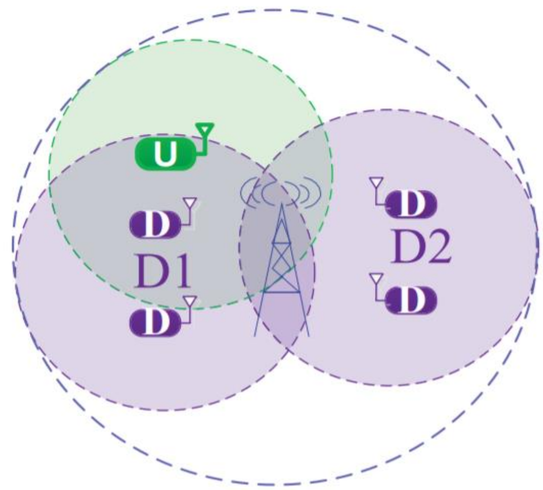


Fig 3: The BS with two pairs of D2D users and one cellular user

In addition, the cooperative shows can still keep the spatial efficiency. For example, if the cellular user U and D2D users D1 can work accommodatingly as shown in Fig., the D2D users D2 can reuse the same resources since they are far away from both U and D1. To this end, we explore new cooperative modes for the situation that the D2D users are close to cellular users.

## IV. PROPOSED SYSTEM

The proposed full duplex communications and the terminated capacity of D2D links, two innovative cooperative modes are designed in this project. The network MU-MIMO based mode (N-mode) and also the sequential forwarding mode (S-mode). Both the modes follow the same idea. In first one, the data for a cellular user is sent to a D2D user. While a D2D user receives its own data, it utilizes the terminated capacity to receive the cellular data. In second one, two D2D users leverage the terminated capacity to relay the cellular data to cellular users. At the same time, the D2D users also send their own data. Different power levels are used by the D2D users to send their own D2D data and forward the cellular data. When the D2D users and cellular users decode the received data, succeeding interference cancellation (SIC) technology is utilized in both phases. However, the procedures for the N-mode and the S-mode are different in phase two. In the N-mode, two D2D users first exchange the received cellular data in a slot so that D2D users have the cellular data for two cellular users. In the next slot, these two D2D users conduct multi-user network

MIMO to forward the cellular data to the two cellular users in order to exploit channel diversity, which is similar to the multicell MIMO cooperative networks. In the S-mode, two D2D users forward the received cellular data to two cellular users sequentially in two slots in order to force the spatial distribution of D2D users and cellular users. Since the N mode and the S-mode reconnoitre different capabilities, given a certain situation we need to select a better mode between the N-mode and the S-mode.

## PROPOSED COOPERATIVE D2D MODE DESIGN

For example, if the cellular user U and D2D users D1 can work cooperatively as shown in Fig. 1, in the existing, D2D users D2 can reuse the same resources since they are far away from both U and D1. To this end, we reconnoiter new cooperative modes for the situation that the D2D users are close to cellular users. More specifically, a pair of full duplex D2D users is considered to share the downlink resources with cellular users in this project.

The cooperative mode design is based on the following two intuitions to improve the spectrum efficiency.

- Firstly, the full duplex D2D users can transmit and receive simultaneously. To fully force the capability of the two full duplex D2D users, each D2D user can be used to cooperate with a cellular user as shown in Fig.
- Thus, the D2D users are considered to share the resources with two cellular users at the same time, which makes the proposed cooperative modes distinct from the existing modes.
- Secondly, regulated by practical modulation and coding schemes, the transmission rate of each link cannot exceed the maximum rate that is determined by the highest modulation and coding scheme.
- Thus, even though the channel excellence of D2D link is very high, the capacity of D2D link cannot be fully utilized. We define this unused channel capacity as terminated capacity.
- To utilize these terminated capacity, an idea similar non-orthogonal multiple access (NOMA) is used in our cooperative mode design, i.e., different power levels are leveraged to send D2D data and cellular data.
- However, NOMA is usually used at the BS, while our cooperative mode design forces this idea at D2D users. Although NOMA is applied to D2D users in where one of them is assumed to be a full duplex radio, cooperation between D2D and cellular users is not studied.

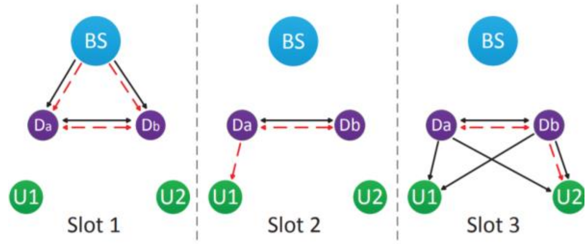


Fig 4: The Black Solid line is N-Mode; The Red dash line is S-Mode

Thus, although the channel quality of D2D link is very high, the capacity of D2D link cannot be fully utilized. We define this unused channel capacity as redundant capacity.

## SYSTEM MODEL

The system model is shown in Fig. one BS, a pair of D2D users, and two cellular users. We consider the D2D users sharing the downlink resources with two nearby cellular users. Both the D2D users and cellular users are considered with one antenna. The BS is armed with two antennas. In additionally, the D2D users are full duplex nodes. The broadcasts between the BS and cellular users are half duplex communications. The self-interference cancellation capability of the full duplex radio is characterized by a factor α, i.e., if the transmit power is *P*, then the residual self-interference is α*P*. α = 0 means perfect cancellation.

Both the N-mode and the S-mode need three equal slots to finish the cooperative process. The data from the BS to $U_1$ and $U_2$ is denoted by $x_1$ and $x_2$, respectively. The transmit power for $x_1$ and $x_2$ in each slot t is denoted by $P_{1t}$ and $P_{2t}$, t = 1, 2, 3. The D2D users send different data in each slot, and the data sent from Da and Db in each slot is denoted by $x_{abt}$ and $x_{bat}$, t = 1, 2, 3. The corresponding transmit power is denoted by $P_{at}$ and $P_{bt}$, t = 1, 2, 3.

## THE NETWORK MU-MIMO BASED MODE

In the N-mode, Da and Db first get both data $x_1$ and $x_2$ and then work as network MIMO to forward $x_1$ to $U_1$ and $x_2$ to $U_2$. Since Da and Db work as network MU-

MIMO to forward data $x_1$ and $x_2$, the channel diversity can be utilized in this mode. To do so, three slots are needed.

- In the first slot, the BS leverages MU-MIMO technology to transmit data $x_1$ and $x_2$ to Da and Db, respectively. To make sure Da (Db) only receives $x_1$ ($x_2$), Zero-Forcing (ZF) precoding is used at the BS. The ZF transmit precoding over transmitters (2-antenna BS or two D2D users) be can be used to conquer interference when there are two one-antenna receivers. At the same time, D2D users altercation data with each other. The receiving power of D2D data should be higher than that of cellular data, which is achieved by proper transmit power allocation. Thus, the D2D users can first decode the D2D data and then use SIC to decode the cellular data. For example, Da first decodes $x_{ba1}$ and then decodes $x_1$ by SIC. Note that in the SIC processing, the enduring self-interference is dried as noise.
- In the second slot, Da (Db) needs to get data $x_2$ ($x_1$) such that Da and Db both have $x_1$ and $x_2$. The D2D users use different power to send their own data and cellular data. For example, Da sends $x_{ab2}$ and $x_1$ to Db instantaneously, the power level of $x_{ab2}$ is higher than $x_1$. Thus, Db can use SIC to decode both $x_{ab2}$ and $x_1$. After this slot, both D2D users have $x_1$ and $x_2$.
- In the third slot, the two D2D users work as network MU-MIMO to forward the cellular data to U1 and U2. ZF precoding is used at D2D users so that $U_1$ ($U_2$) does not receive data $x_2$ ($x_1$). At the same time, D2D users also send their own data xab3 and $x_{ba3}$. The D2D users use higher power to send $x_1$ and $x_2$. Thus, when $U_1$ and $U_2$ decode the cellular data, they treat the D2D data as noise. Since the D2D users already know $x_1$ and $x_2$ from the previous slots, they can use SIC to decode their own data.

The procedure of the N-mode is shown in Fig. with black solid line. The detailed process in each slot is studied as follows.

First slot: The BS uses ZF precoding to send $x_1$ and $x_2$ so that $U_1$ only gets $x_1$ and $U_2$ only gets $x_2$. The precoding vectors for $x_1$ and $x_2$ are denoted as $u_1$ and $u_2$. The transmit power for $x_1$ and $x_2$ is $P_{11}$ and $P_{21}$, respectively. Thus, the signal transmitted from the BS is

$$X = \sqrt{P_{11}}u_1x_1 + \sqrt{P_{21}}u_2x_2$$

At the same time, $D_a$ ($D_b$) sends data $x_{ab1}$ ($x_{ba1}$). The transmit power for $x_{ab1}$ and $x_{ba1}$ is $P_{a1}$ and $P_{b1}$, respectively. Thus, the signals received at $D_a$ and $D_b$ at the first slot are

$$\begin{aligned} y_{\alpha 1} &= h_1 x + \sqrt{P_{b1}}h_d x_{ba1} + \sqrt{\alpha P_{a1}}x_{ab1} + n \\ &= \sqrt{P_{11}}h_1u_1x_1 + \sqrt{P_{21}}h_1u_2x_2 + \sqrt{P_{b1}}h_d x_{ba1} \\ &\quad + \sqrt{\alpha P_{a1}}x_{ab1} + n \\ &= \sqrt{P_{11}}h_1u_1x_1 + \sqrt{P_{b1}}h_d x_{ba1} + \sqrt{\alpha P_{a1}}x_{ab1} + n \end{aligned}$$

$$\begin{aligned} y_{b1} &= h_2 x + \sqrt{P_{a1}}h_d x_{ab1} + \sqrt{\alpha P_{b1}}x_{ba1} + n \\ &= \sqrt{P_{11}}h_2u_1x_1 + \sqrt{P_{21}}h_2u_2x_2 + \sqrt{P_{a1}}h_d x_{ab1} \\ &\quad + \sqrt{\alpha P_{b1}}x_{ba1} + n \\ &= \sqrt{P_{21}}h_2u_2x_2 + \sqrt{P_{a1}}h_d x_{ab1} + \sqrt{\alpha P_{b1}}x_{ba1} + n \end{aligned}$$

Where $\sqrt{\alpha Pa1}$ ($\sqrt{\alpha Pb1}$) is residual self-interference at Da (Db) and n represents the noise. By proper transmit power allocation; the received signal from the D2D user can be tougher than the signal from the BS.

Second slot: We assume Da ($D_b$) sends $x_1$ ($x_2$) with power $P_{12}$ ($P_{22}$). The transmit power of $x_{ab2}$ ($x_{ba2}$) is $P_{a2}$ ($P_{b2}$). Thus, the transmitting signals of Da and Db are

$$x_{a2} = \sqrt{P_{12}}x_1 + \sqrt{P_{a2}}x_{ab2}$$
$$x_{b2} = \sqrt{P_{22}}x_2 + \sqrt{P_{b2}}x_{ba2}$$

Third slot: After the second slot, Da and Db both have the data x1 and x2. Thus, we can utilize Da and Db as network MIMO to forward x1 and x2 to U1 and U2. We also use ZF precoding for x1 and x2 so that U1 and U2 only receive x1 and x2, respectively. We assume that the transmit power for x1 and x2 is P13 and P23, respectively. The precoding vectors for x1 and x2 are denoted as w1 = [w11, w12] T and w2 = [w21, w22] T, respectively. At the same time, the D2D users also use lower power to send their own data xab3 and xba3. Thus, the signals transmitted by Da and Db are

$$x_{a3} = \sqrt{P_{13}}w_{11}x_1 + \sqrt{P_{23}}w_{21}x_2 + \sqrt{P_{a3}}x_{ab3}$$
$$x_{b3} = \sqrt{P_{13}}w_{12}x_1 + \sqrt{P_{23}}w_{22}x_2 + \sqrt{P_{b3}}x_{ba3}$$

THE SEQUENTIAL FORWARDING MODE

In the S-mode, the BS first uses MU-MIMO technology to send $x_1$ and $x_2$ to Da and Db, respectively. Then, Da and Db forward the data $x_1$ and

$x_2$ to U1 and U2 in different slots. Thus, the S-mode also needs three slots to finish the cooperative procedure. The first slot is the same with the N mode. After this slot, Da (Db) gets the cellular data $x_1$ ($x_2$). In the second slot, Da uses higher power to forward x1 to $U_1$ and lower power to send its own data xab2 to Db. At the same time, Db sends data $x_{ba2}$ to Da. $U_1$ treats $x_{ab2}$ and $x_{ba2}$ as noise when decoding $x_1$. Db first decodes the stronger data x1 and then uses SIC to decode xab2. In the third slot, Db uses higher power to forward $x_2$ to $U_2$ and lower power to send its own data xba3 to Da. At the same time, Da sends data $x_{ab3}$ to Db. $U_2$ treats $x_{ab3}$ and xba3 as noise when decoding $x_2$. Da first decodes the tougher data $x_2$ and then uses SIC to decode $x_{ba3}$.

The S-mode is well suitable for the case that the two cellular users are distinctly close to two D2D users. For example, U1 is close to Da and U2 is close to Db. In such a case, in the second (third) slot the interference from Db (Da) to $U_1$ ($U_2$) is small. The procedure of the S-mode is shown in Fig. with red - dash line. The detailed process in each slot is analyzed as follows.

First slot: In the first slot, the BS uses ZF precoding to send x1 and x2 to Da and Db, respectively. At the same time, Da and Db argument their own data. This slot is same with the N-mode. Thus, the SINR value of each link is also the same with the N-mode.

Second slot: Da uses different power levels to send x1 and xab2. Thus, the signal sent by Da at the second slot is

$$x_{a2} = \sqrt{P_{12}}x_1 + \sqrt{P_{a2}}x_{ab2}$$

Db just sends data xba2. Thus, the signal sent by Db is

$$x_{b2} = \sqrt{P_{b2}}x_{ba2}$$

When U1 decodes the data x1, it treats other signals as noise. Thus, the SINR of signal x1 in the second slot is

$$\gamma_{12} = \frac{P_{12}|g_{11}|^2}{P_{a2}|g_{11}|^2 + P_{b2}|g_{12}|^2 + \sigma^2}$$

Db will first decode x1 and then use SIC to decode xab2. The self-interference is treated as noise. Thus, the SINR of signal xab2 in the second slot is

$$\gamma_{ab2} = \frac{P_{a2}|h_d|^2}{\alpha P_{b2} + \sigma^2}$$

The SINR of signal xba2 in the second slot is

$$\gamma_{ba2} = \frac{P_{b2}|h_d|^2}{\alpha(P_{12} + P_{a2}) + \sigma^2}$$

Third slot: In this slot, Db uses different power levels to send data x2 and xba3. Da just sends data xab3. Thus, the procedure is symmetric with the second slot. We get the SINR of xab3, xba3, and x2 in the same way as the second slot:

$$\gamma_{ba3} = \frac{P_{b3}|h_d|^2}{\alpha P_{a3} + \sigma^2}$$

$$\gamma_{ab3} = \frac{P_{a3}|h_d|^2}{\alpha(P_{23} + P_{b3}) + \sigma^2}$$

$$\gamma_{23} = \frac{P_{23}|g_{22}|^2}{P_{b3}|g_{22}|^2 + P_{a3}|g_{21}|^2 + \sigma^2}$$

From the scrutiny of N-mode and S-mode we know that the performance of both modes depends on power allocation for each link. Besides, we need to select a better mode between N-mode and S-mode for a precise situation based on the maximum sum rate of D2D transmissions and cellular transmissions. Thus, optimal power allocation to maximize the total transmission rate is critical for both N-mode and S-mode.

## OPTIMAL POWER ALLOCATION

To optimize the performance of the two cooperative modes, optimal power allocation is conducted to maximize the sum rate of D2D and cellular transmissions. Shannon capacity is used to characterize the transmission rate, i.e., the transmission rate of each link is given by R = log2 (1 + γ), where γ is the SINR. Three types of restraints are considered in the optimization.

Firstly, we use the minimum transmission rate as the QoS requirement for both cellular users and D2D users. More specifically, the minimum SNR requirement for each link is used to represent the QoS requirement. In the cooperative modes, all users share the same frequency resources in each slot. To avoid undernourishment in frequency sharing, we set the minimum transmission rate for each link to provide QoS requirement. Different QoS requirements for cellular users and D2D users are studied, i.e.,γd for each D2D link and γc for cellular users. Note that three slots are needed to send one copy of cellular data. Thus, the minimum SINR requirement γc means that the minimum rate for cellular user in a slot is 13 log(1+γc).

Secondly, the constraint of practical modulation and coding scheme is considered. The minimum SINR of each link needs to be higher than the requirement for the lowest modulation and coding scheme (γl). We set γd and γc larger than γl . Thus, the link SINR needs to be larger than the QoS requirement γd or γc. In addition, the maximum required SINR depends on the highest modulation and coding scheme (γh). Finally, the maximum transmit power constraint of each node is considered. Different maximum power restrictions are set for the BS and users, i.e., P m for the BS and Pm for users.

Optimal Power Allocation for the N-mode

Both the N-mode and the S-mode need three slots. We average the total transmission rate to each slot so that the D2D transmission rate is given by

$$R_D = \frac{1}{3}(R_{ab1} + R_{ab2} + R_{ba1} + R_{ba2} + R_{ba3})$$

For each cellular user, the data is promoted by the D2D users. Thus, the transmission rate of each cellular user is unwavering by the minimum rate of the three slots. We also average the cellular transmission rate to unit slot so that we have

$$R_{u1} = \frac{1}{3}\min\{R_{11}, R_{12}, R_{13}\}$$

$$R_{u2} = \frac{1}{3}\min\{R_{21}, R_{22}, R_{23}\}$$

Where Ru1 and Ru2 are the final transmission rates for U1 and U2, respectively. The sum rate Rs of D2D users and cellular users is represented as: Rs = RD + Ru1 + Ru2. Our goal of using power allocation control is to achieve the maximum sum rate of cellular feasts and D2D transmissions.

However, the augmented rate of cellular user does not improve the final cellular rate since it depends on the minimum rate among the three slots. Thus, the two sum rates are the same. As a result, there are multiple solutions that achieve the maximum sum rate. However, the power feastings are different.

Optimal Power Allocation for the S-mode

For the S-mode, we also have the manacles for SINR and power. For each cellular user, the cellular transmission rate is the minimum rate in the associated two slots. Thus, we have

$$R_{u1} = \frac{1}{3}\min\{R_{11}, R_{12}\}$$

$$R_{u2} = \frac{1}{3}\min\{R_{21}, R_{23}\}$$

In the S-mode, the data x1 and x2 are sent by the BS with MU-MIMO in the first slot. Then the data to U1 and U2 are distinctly forwarded by Da and Db in the second and third slot. According to the procedure of the S-mode, the power allocation can be divided into two sovereign processes:

1. The power allocation for P11 and Pb1 in the first slot and Pa2, Pb2, and P12 in the second slot.
2. The power allocation for P21 and Pa1 in the first slot and Pa3, Pb3, and P23 in the third slot.

MODE SELECTION

Both the N-mode and the S-mode utilize the passionate D2D capacity to help transmissions of cellular users. However, the N-mode and the S-mode are suitable for different situations. In the N-mode, the D2D users work as network MU-MIMO for cellular users with ZF precoding. Thus, the N-mode can leverage channel diversity. However, the performance of ZF precoding highly depends on the channel orthogonality between the D2D users to U1 and U2. If the channel orthogonality is not sufficient, Da and Db need to use much higher power to send x1 and x2, which is not efficient. From the procedure of the S-mode we know that the channel orthogonality between g1 and g2 has no impact on the S-mode. It is suitable for the case that two D2D users are close to two cellular users separately. Given a situation, we need to select a better one between the N-mode and the S-mode

In addition, in both the N-mode and the S-mode, there is a cellular data obligation problem for the BS in the first slot. In the N-mode, the BS has two choices to assign the cellular data:

1. Sending x1 to Da and x2 to Db.
2. Sending x2 to Da and x1 to Db.

These two choices may result in different sum rates. The same two choices are also applied to the S-mode. If the BS sends x1 to Da, Da will forward x1 for U1. However, if the BS sends x2 to Da, Da will forward x2 for U2. These two choices will also result in different sum rates. Thus, in fact the BS needs to consider four cases for the cooperative modes.

V. SIMULATION SETUP

In this section, we assess the performance of the N-mode and the S-mode in the condition that the D2D users are close to each other and also close to the cellular users. In this situation, only the cooperative modes and the dedicated modes can be applied. Thus, we compare the performance of the N-mode and the S-mode with the dedicated mode. Two kinds of self-interference cancellation capabilities are considered: 1) perfect self-interference cancellation ($\alpha = 0$); 2) non-perfect self-interference cancellation with 110 dB cancellation as realized in [13] ($\alpha = 10-11$). Firstly, two typical deterministic cases are studied to show the advantages of the N-mode and the S mode in selection section, in which the channel conditions for all users are fixed.

In the general scenario, we model the channel as the Log-distance path loss model plus Rayleigh fading to reflect large scale attenuation and small-scale fading, respectively. The Log-distance path loss is determined by $PL(d) = PL(d0) + 10 \times n \times \log(d/d0)$, where we set $PL(1) = 30$ and $n = 2.7$. By this setup, the user at 800 m and 1100 m distance from the BS will get 10 dB and 6 dB SNR, respectively, if only path loss is considered.

One major problem of downlink resources sharing is that the intrusion at a cellular user in the reuse mode is much harder to control than the case of uplink resource sharing. Thus, the existing modes target to avoid the interference between D2D users and cellular users, i.e., reuse mode is used only if the D2D users are far away from the cellular users. Instead of avoiding the interference, however, the cooperative modes exploit the short distance between the D2D users and cellular user to conduct cooperative transmissions. By proper power allocation, not only higher spectrum efficacy is achieved, but also the intrusion at the cellular user is well controlled. In addition, the cooperative modes can be applied in both FDD and TDD systems; the downlink occurrence band and the downlink slots are used in FDD systems and TDD systems, respectively.

## SIMULATION RESULTS AND DISCUSSION

The performance of the N-mode and the S-mode in the situation that the D2D users are close to each other and also close to the cellular users. In this situation, only the cooperative modes and the dedicated modes can be applied. Thus, we compare the performance of the N-mode and the S-mode with the dedicated mode. Two kinds of self-interference cancellation capabilities are considered: 1) perfect self-interference cancellation ($\alpha = 0$); 2) non-perfect self-interference cancellation with 110 dB cancellation as realized ($\alpha = 10-11$).

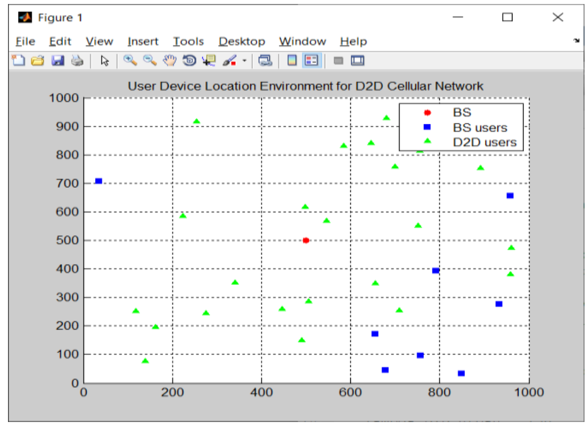


Fig 5: Typical System Implementation BS, D2D and Users

The channel parameters between D2D users and U1 and U2 s are considered to share the resources with two cellular users at the same time, which makes the proposed cooperative modes distinct from the existing modes. Secondly, restricted by practical modulation and coding schemes, the transmission rate of each link cannot exceed the maximum rate that is determined by the highest modulation and coding scheme.

Next Fig. In the S-mode, the BS first uses MU-MIMO technology to send x1 and x2 to Da and Db, respectively. Then, Da and Db forward the data x1 and x2 to U1 and U2 in different slots. The channel as the Log-distance path loss model plus Rayleigh fading to reflect large scale attenuation and small-scale fading, respectively. The Log-distance path loss is determined by $PL(d) = PL(d0) + 10 \times n \times \log(d/d0)$, where we set $PL(1) = 30$ and $n = 2.7$.

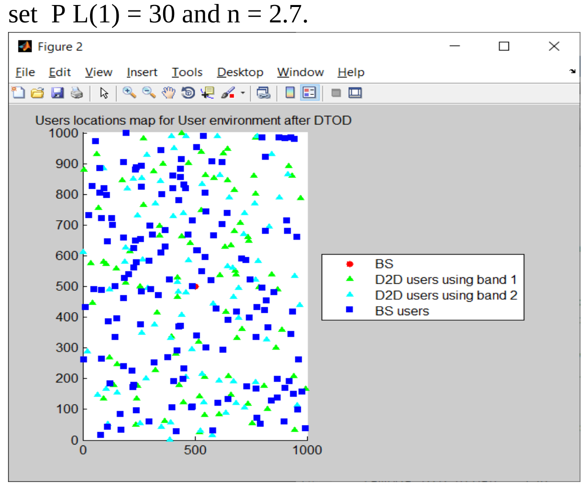


Fig 6: D2D and Full Duplex Communication for Users (S-Mode)

Given a distance, the channel parameter h is created as follows. Firstly, the attenuation is calculated based on Log-distance path loss and a Rayleigh fading value. Secondly, based on the transmission power, the noise floor, and the attenuation, the modulus of h (i.e., |h|) is resolute, and then the phase θ of h is consistently selected from [0, 2π]. In the N-mode, Da and Db first get both data x1 and x2 and then work as network MIMO to forward x1 to U1 and x2 to U2. Since Da and Db work as network MU-MIMO to forward data x1 and x2, the channel diversity can be utilized in this mode.

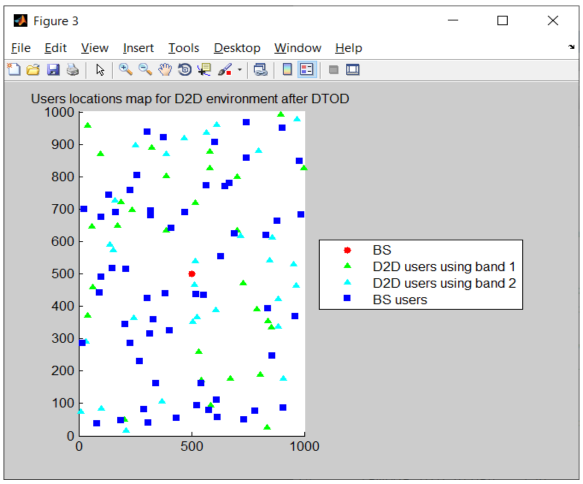


Fig 7: D2D and Full Duplex Communication for D2D (N-Mode)

For both the N-mode and the S-mode, there are two choices for the BS to assign the cellular data:

1. The BS sends x1 to Da and x2 to Db.
2. The BS sends x2 to Da and x1 to Db.

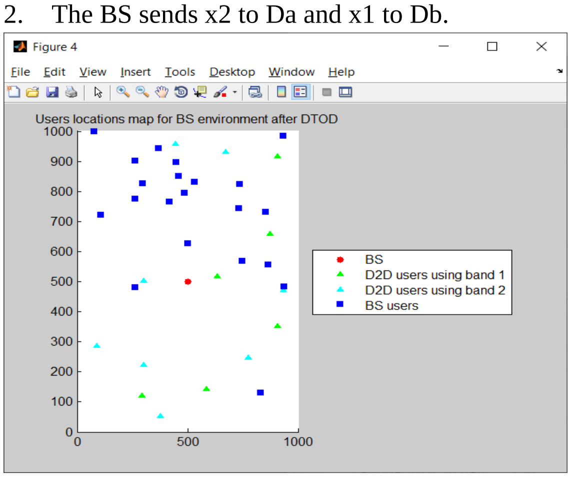


Fig 8: D2D and Full Duplex Communication (N-Mode and S-Mode)

The transmission rate of D2D users keeps stable when the QoS requirements of cellular users are small, which means the D2D users just use their fired capacity to help the cellular users. When the QoS requirements of cellular users' further increase, the transmission rate of D2D users decreases since the D2D users need to share some capacities to support the cellular transmissions.

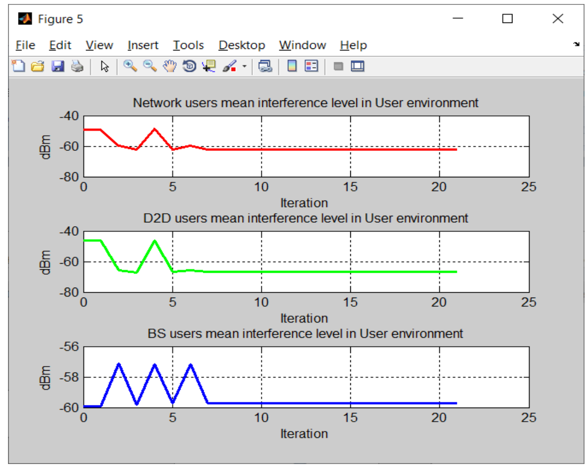


Fig 9: SNR between D2D

Fig. The sum rate of cooperative modes increases with the increasing SNR of D2D link, since the D2D users have more terminated capacity with the increasing SNR of D2D link. However, the dedicated mode keeps the same sum rate with the increasing SNR of D2D link. The reason is that the maximum rate is limited by the modulation and coding scheme and the terminated capacity cannot be utilized. The advantage of the S-mode, we consider another typical case where the two cellular users are close to the two D2D the advantage of the S-mode, we consider another typical case where the two cellular users are close to the two D2D.

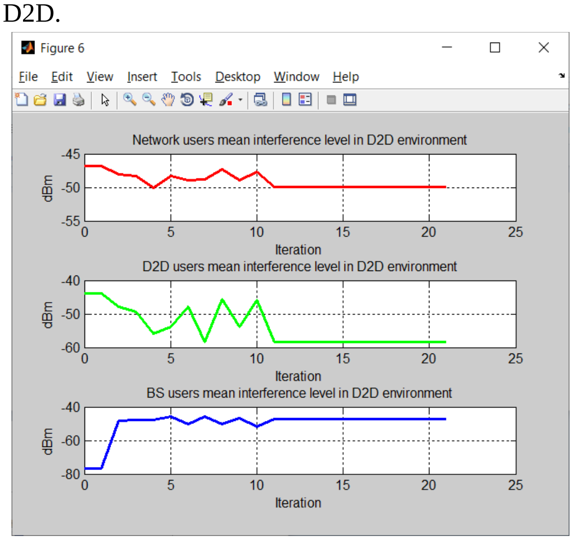


Fig 10: SNR between both modes

As shown in Fig, the S-mode achieves better performance than the N-mode. Same with case 1, the cooperative modes with perfect cancellation achieve higher recital than nonperfect cancellation case. The reason why some points are missing for the N-mode is that the N-mode cannot satisfy these QoS requirements of cellular users.

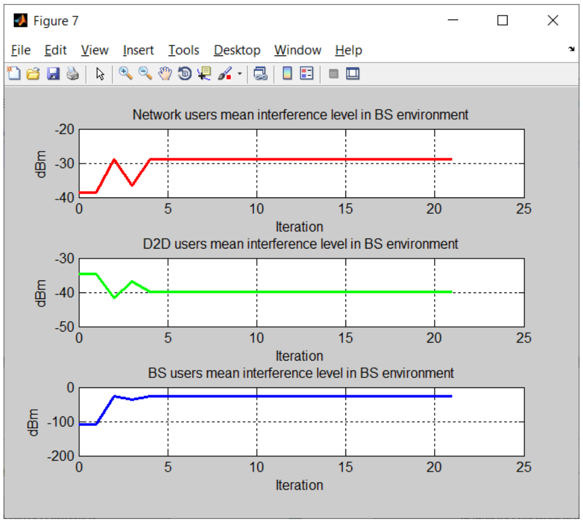


Fig 11: The transmission rate of both mode

The sum rate since cooperative modes increases as the SNR of D2D link increases since more D2D terminated capacity can be used for cellular transmissions. However, if only the dedicated mode is considered, the sum rate retains the same as the SNR of D2D link increases since the terminated of the D2D link cannot be utilized. On the other hand, with the increasing QoS requirements of cellular users, the sum rate decreases for both situations since more resources are needed by cellular users.

## VI. CONCLUSION

In this project, two cooperative modes, i.e., the N-mode and the S-mode were considered for full duplex D2D communication underlaying cellular networks. By leveraging the redundant capacity of D2D links, the cooperative modes realized both imminence gain and reuse gain when D2D users are close to the cellular users. Optimal power allocation was conducted to maximize the sum rate in both modes under perfect and non-perfect self-interference cancellation. Two typical cases and five general scenarios were evaluated to authenticate the advantages of the cooperative modes. Simulation results showed that the cooperative modes achieved overall sum rate enhancement over the dedicated mode in perfect and non-perfect (110 dB) cancellation cases, respectively.

With the cooperative modes, the D2D users and the nearby cellular users can share the same resources. Besides, the D2D users act as transport for cellular users. Thus, the cooperative modes can expand the network ability in two aspects: 1) They can simply replace the dedicated mode to achieve a higher sum rate; 2) A BS can force the D2D users as lively relays to improve the recital of edge users so that the BS has more relay choices for edge users also fixed relay.

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