Performance Measurement and Relay Selection for Device to Device Communication

***Abstract*— The ever increasing demand for higher data rate, has led to the development of Device to Device Cooperative Communication. The diversity techniques will have restrictions to the multiple antenna hardware to be fabricated into a small mobile device. To overcome that we use a virtual diversity system, wherein the relay will be helpful in transmitting the data and thus giving us the desired diversity gain. This consists the network for D2D Cooperative Communication. The D2D communication will help in increasing the data rate and also the spectral efficiency of the network. Various methods are used for the relay selection and resource sharing in D2D communication, amongst which we will be discussing about the bandwidth exchange model of cooperative communication. The advantage of using bandwidth exchange model is the exclusion of a centralized base station. We have proposed an algorithm for bandwidth exchange and relay selection for an *'MxN'* Network of sources and relays. We have defined a utility function based on the data rate of source and relay, which will be helpful in relay selection. The results show a considerable increase in data rate. Also the spectral efficiency is increased along with the reduction in power consumption.**

Keywords— D2D, utility, bandwidth, co-operation

I. INTRODUCTION

The recent advancement in the field of Wireless Communication, the performance of the channel connectivity and mobile access has improved drastically. But a lot restrictions are to be resolved because of shadowing effect, multi-path fading and other path loss component. This causes variations in the channel parameters in time and frequency domains, which can't be modeled easily as compared to the traditional hard wired communication. The implementation of diversity techniques; which includes time, frequency and space domain, has further helped in improving the performance of the wireless communication networks. The diversity gain can be obtained through the usage of multiple antennas at the transmitter as well as the receiver and hence creating a SIMO, MISO or MIMO depending on the application. Considering the scenario of cellular communication or mobile communication network, the installation of multiple antennas in a single mobile unit or node will have lot of restrictions, considering the weight and size of device, hardware cost and complex maintenance. Hence it is not feasible to implement the multiple antenna diversity technique in this case. But the need for better channel performance and detection led to the concept of cooperative communication. A lot of research has been done in the field of D2D cooperative communication, and is still demanding more for the commercial application. This research proved to be very useful for laying the foundation of D2D cooperative communication and gave further scope for exploring it. We will be discussing about all the literature that we have referred from the very basic introductory aspect to the advanced algorithms and results.

The work of M. N. Tehrani, M. Uysal, and H. Yanikomeroglu, gave us the basic idea about the D2D cooperative communication [3]. Also they have discussed about the various challenges faced for the same, typically in the pricing model of cooperative communication. In our project, in order to remove the complexities of pricing model we have implemented the bandwidth exchange model, whose advantages will be discussed later on.

We have also referred the work done by M. Islam, N. Mandayam and S. Kompella, on optimal resource allocation through bandwidth exchange [4]. They have considered the maximum summation of utility model for exchanging the bandwidth but in a centralised network scenario having a base station. But in our work we have considered a distributed approach in order to avoid the maintenance complexity in the network. Nevertheless we have taken into consideration centralised algorithm for relay assignment for a comparative study with distributed algorithm.

The research of D. Zhang, R. Shinkuma and N. D. Mandayam is based on the energy conserving incentive mechanism for the resource allocation through bandwidth exchange with the help of data rate [5]. We took the approach of them of using the individual data rate of source and relay instead of the utility as a whole for relay assignment, thus making the algorithm equally dependent on source as well as relay. They have implemented a game theoretic nash bargaining model, while we have used the data rates as weights for selecting the relay link instead of game theory.

The time exchange model for distributed cooperative forwarding as suggested by M. N. Islam, S. Balasubramanian, N. B. Mandayam, I. Seskar and S. Kompella gives insights on using the time division technique for cooperative communication, thereby increasing the overall goodput of the network [6]. In our project we have used their concept of resource exchange but in terms of bandwidth and power, as we have assumed that the relay does not have a licenced bandwidth.

The publication of W. Zhou, B. Xie, and C. Hao, on "A Novel Bargaining Based Power Allocation for Coordinated Multiple Point Transmission/Reception" [7] helped us to understand about the bargaining theory approach with the concept of patience factor. This model can be used for real time relay assignment where the benefits of both source and relay are taken into consideration.

II. WHY CO-OPERATION.

D2D communication is expected to be a key feature in next generation cellular network system. They possess various advantages such as: offloading the cellular system, reduced battery consumption, increased bit-rate, and robustness to infrastructure failures. Comparing to other competing D2D technologies like Bluetooth and Wi-Fi, cellular D2D communication can give local service providers access to licensed spectrum with a controlled interference environment to avoid the uncertainties of the license exempt band when making investment decisions. The design of an efficient device-to-device communication mode as underlay to a cellular network is a key problem to be solved.

To prove that co-operation provides the above stated benefits we have simulated scenario shown in Fig 1.1. The data rate for different percentage of power shared by relay and propionate bandwidth shared by source is shown in Fig 2.1. Similarly the data rate achieved by relay through this trade-off can be seen in Fig 2.2. Since both must benefit from this power-bandwidth trade-off equally we calculated the utility of source and relay as can be seen from Fig 2.3 and 2.4. To get equilibrium point we calculated the product utility where both relay and source agree to share their resources as seen in Fig 2.5.

III. System Model

To understand the system model, let us consider a simplified scenario of only one source, one relay and the destination of the source as shown in figure 1.1. In order a have a mathematical model for the various links we have used the path loss experimental model instead of the statistical Gaussian model, so that the results are almost similar to the practical scenario. Also in order to calculate the data rate available with the relay for its own data transmission, we have included a destination for the relay as well. It will also be helpful in calculating the utility of the system.

In the bandwidth exchange model, the source will share certain part of its bandwidth with the relay. And the relay will send the data to the destination of source with the help of that shared bandwidth. Also as an incentive for using the power for transmitting the data of source, the relay can further send its own data to its destination, i.e. destination of relay.

A. Mathematical Modelling

- SNR for Source to Source-Destination

$$\gamma_{sd1} = \left(\frac{P_{s1}}{N_0 * W_{s1}}\right) * \left(\frac{d_0}{d_{sd}}\right)^a \dots\dots\dots (1)$$

- Data Rate for Source to Source-Destination

$$R_{sd1} = W_{s1} * \log_2(1 + \gamma_{sd1}) \dots\dots\dots (2)$$

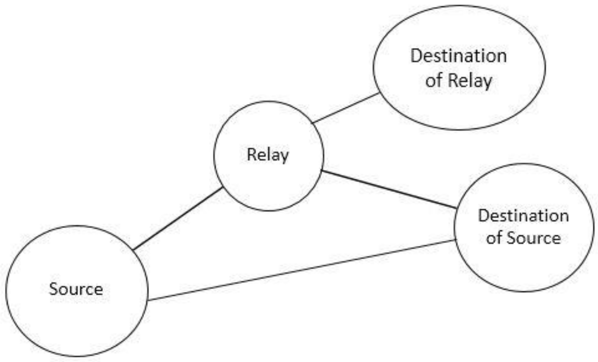

Fig. 1.1: Illustration of a pair-wise cooperative communication system

Also for the comperative evaluation of the data rate achieved by relay, the maximum data rate achieved by relay (entire bandwidth from source is available) will be

- Maximum SNR for Relay to Relay-Destination

$$\gamma_{rrdm} = \left(\frac{P_{s1}}{N_0 * W_{s1}}\right) * \left(\frac{d_0}{d_{rrd}}\right)^a \dots\dots\dots (3)$$

- Maximum data rate for Relay to Relay-Destination

$$R_{rrdm} = W_{s1} * \log_2(1 + \gamma_{rrdm}) \dots\dots\dots (4)$$

Here for simplicity purpose we have taken the normalized value of power and bandwidth, i.e. $P_{s1} = 1$ and $W_{s1} = 1$.

Using the path loss model the SNR values for the various links in cooperative communication are as follows:

- Source to Source-Destination

$$\gamma_{sd} = \left(\frac{P_{s1}}{N_0 * W_s}\right) * \left(\frac{d_0}{d_{sd}}\right)^a \dots\dots\dots (5)$$

- Source to Relay

$$\gamma_{sr} = \left(\frac{P_{s1}}{N_0 * W_s}\right) * \left(\frac{d_0}{d_{sr}}\right)^a \dots\dots\dots (6)$$

- Relay to Source-Destination

$$\gamma_{rd} = \left(\frac{P_r}{N_0 * W_r}\right) * \left(\frac{d_0}{d_{rd}}\right)^a \dots\dots\dots (7)$$

- Relay to Relay-Destination

$$\gamma_{rrd} = \left(\frac{P_{rd}}{N_0 * W_{rd}}\right) * \left(\frac{d_0}{d_{rrd}}\right)^a \dots\dots\dots (8)$$

The SNR and data rates available in cooperative communication for various protocols and data rate for relay node is represented in the below equations:

- SNR (Source to Source-Destination) for DF Protocol

$$\gamma_{df} = \min(\gamma_{sr}, \gamma_{rd}) \dots\dots\dots (9)$$

- Data Rate (Source to Source-Destination) for DF Protocol

$$R_{srd} = W_s * \min(\log_2(1 + \gamma_{sr}), \log_2(1 + \gamma_{sd} + \gamma_{rd})) \dots\dots\dots (10)$$

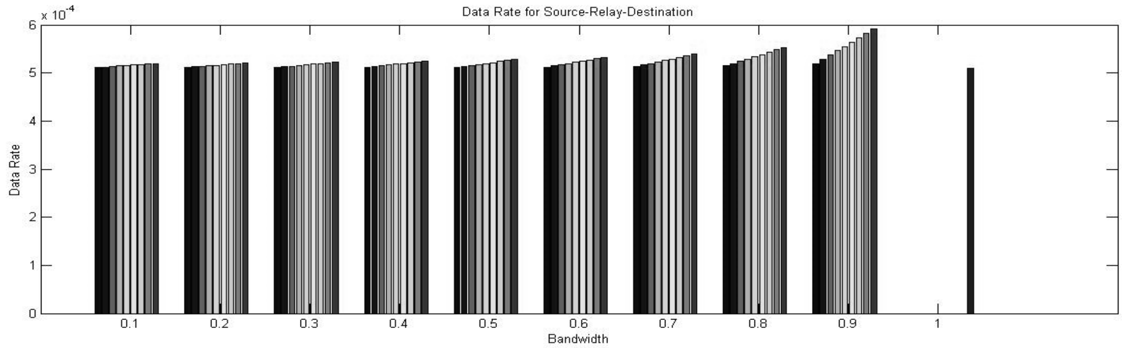

Fig 2.1 Data Rate for Source-Relay-Destination

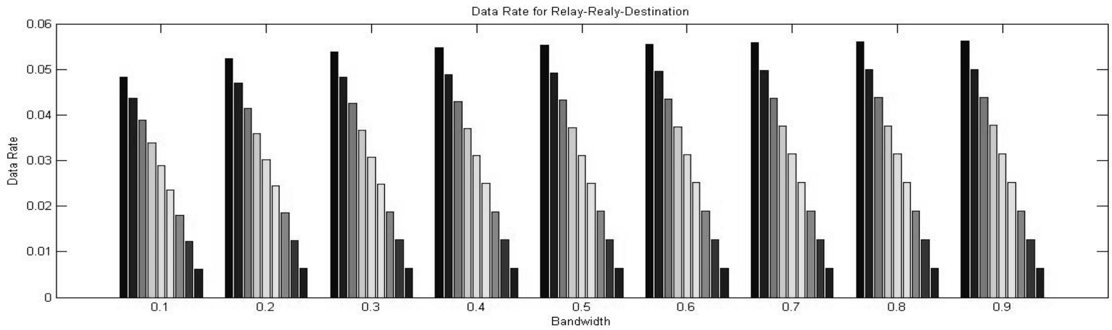

Fig 2.2 Data Rate for Relay-Relay-Destination

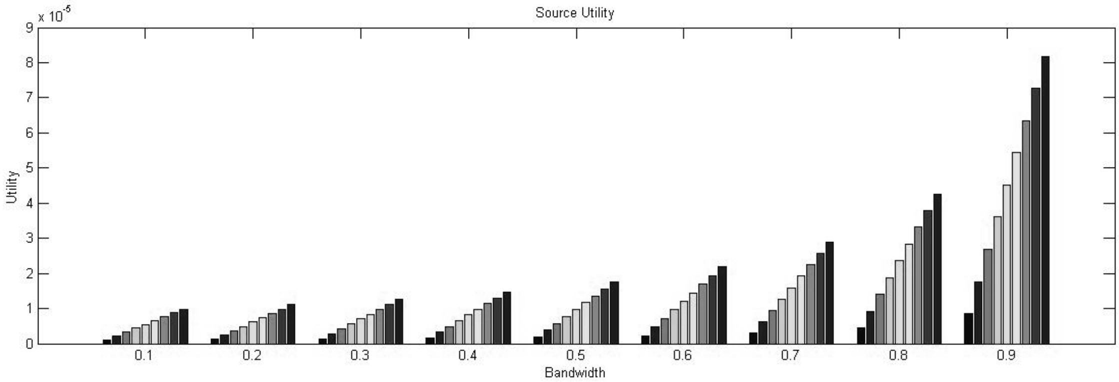

Fig 2.3 Source Utility

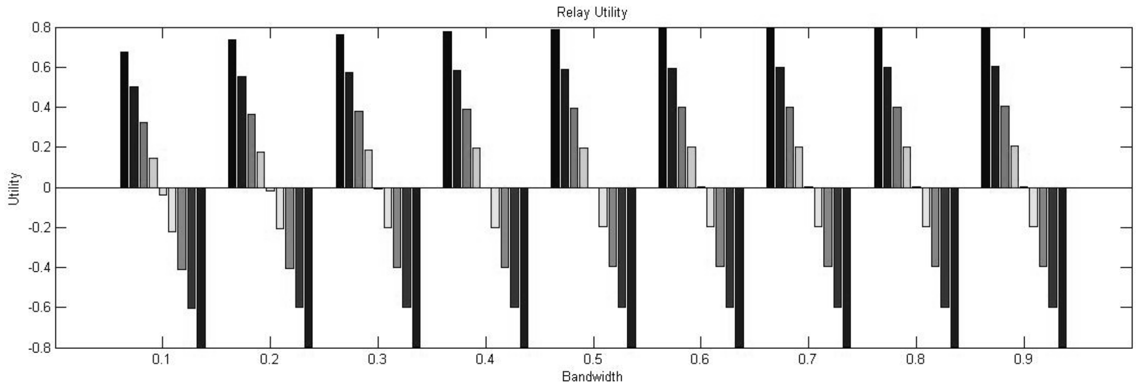

Fig 2.4 Relay Utility

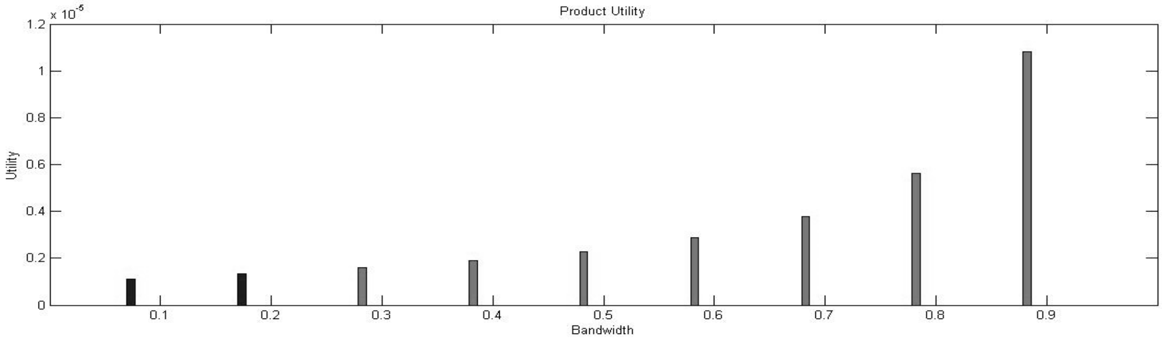

Fig 2.5 Product Utility

- SNR (Source to Source-Destination) for AF Protocol

$$\gamma_{af} = \left(\frac{\gamma_{rd} * \gamma_{sr}}{\gamma_{rd} + \gamma_{sr} + 1}\right) \dots \dots \dots (11)$$

- Data Rate (Source to Source-Destination) for AF Protocol

$$R_{srd} = W_s * log_2\left(1 + \gamma_{sd} + \gamma_{af}\right) \dots \dots \dots (12)$$

- Data Rate for Relay to Relay-Destination

$$R_{rrd} = W_{rd} * log_2\left(1 + \gamma_{rrd}\right) \dots \dots \dots (13)$$

The utility, which will be helpful in selecting the relay and the value of bandwidth shared, can be defined as below:

- Utility of Source

$$U_s = (R_{srd} - R_{sd1}) \dots \dots \dots (14)$$

- Utility of Relay

$$U_r = \frac{R_{rrd}}{R_{rrdm}} - P_r \dots \dots \dots (15)$$

- Product Utility

$$U_p = (U_s * U_r) \dots \dots \dots (16)$$

B. **'***MxN'* Source-Relay Network

Having understood the model of a simplified cooperative communication network having only one source and one relay, along with their respective destinations, we can further extend the model having *'M'* sources and *'N'* relays. This will be similar to the practical network scenario having numerable sources and relays, and we have to select an optimized link for the same. The figure 3.2 below explains the network structure. Here we have assumed that all the sources have a single destination, and similarly all the relays will also have a single destination.

It is clear that not in all scenarios we will be having equal number of sources or relays and hence we have design the relay assignment algorithm such that we can get optimized allocation in terms of data rate and also bandwidth.

Here we have taken two approaches into consideration, the distributed assignment and the centralized assignment and depending on the application we can easily decide which approach will suite the best.

IV. SIMULATION

A. Relay Selection for an 'MxN' Network

Having established the method for the bandwidth exchange in a simplified scenario, we can now further extend the algorithm for relay selection in an 'MxN' network. We will be using DF protocol in this case, nonetheless similar steps are to be followed for AF protocol. We have taken two approaches for this example, a distributed and a centralized method of relay selection.

- Distributed Selection

The algorithm, for the same is as described below:

1. Decide the locations of M sources and N relays. (N≤M)
2. Calculate the amount of bandwidth which needs to be shared to achieve maximum possible data rate
3. Create two matrices of the size MxN, one showing the data rate achievable for the source (for all the possible source to relay combinations, here N) and the data rate for the relay. Name them R_srd and R_rrd respectively.
4. In R_srd, find out the relay for each source which gives the maximum data rate and in R_rrd find out the source for each relay which gives maximum data rate.
5. If the selection of relay by the source and the selection of source by the relay matches, assign that source and relay pair as link and jump to step 7, else go to step 6.
6. Since the selection does not match, create a utility matrix, which is sum of the two data rates, and assign a link which gives the maximum utility out of all the values.
7. Discard the values of the source and relay which are linked together, and hence the matrix dimensions for both R_srd and R_rrd will be reduced.
8. Repeat from step 4, until all the relays are allocated a source.

Based on this algorithm we will discuss an example for relay selection. Consider 6 sources, 3 relays, one source-destination and one relay-destination. The locations of all of them are indicated as below.

Source 1: (0,0) Source 2: (0,2) Source 3: (0,3)
Source 4: (0,5) Source 5: (0,7) Source 6: (3,0)
Relay 1: (6,4) Relay 2: (3,3) Relay 3: (1,2)
Source-Destination: (8,8) Relay-Destination: (10,10)

Also the values for various parameters used for calculating data rate are: No = 0.01 do = 1 a = 3 Ws = 10

Based on the above model the matrix for R_srd and R_rrd are obtained as:

R_srd	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
Relay 1	0.1863	0.2745	0.3079	0.3079	**0.2308**	0.5453
Relay 2	**0.2477**	0.2690	0.2822	0.3105	0.3314	0.2822
Relay 3	0.1399	**0.1616**	0.1751	0.2039	0.2252	0.1751

Table 4.4: R_srd for Distributed Selection

R_rrd	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
Relay 1	0.3762	0.3746	0.3740	0.3740	**0.3754**	0.3697
Relay 2	**0.1461**	0.1460	0.1459	0.1457	0.1455	0.1459
Relay 3	0.0818	**0.0817**	0.0816	0.0815	0.0814	0.0816

Table 4.5: R_rrd for Distributed Selection

Utility	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
Relay 1	0.5527	0.6349	0.6649	0.6590	0.5790	0.8980
Relay 2	0.3839	0.4007	0.4110	0.4333	0.4497	0.4111
Relay 3	0.2118	0.2290	0.2397	0.2625	0.2794	0.2397

Table 4.6: Utility for Centralized Selection

- CENTRALIZED SELECTION.

In case of centralized selection, a base station or a central access point will be present. The selection parameter will be utility, which is the sum total of R_srd and R_rrd. By using the maximum summation algorithm we will decide the links to be established between the source and the relay. The algorithm is described as below:

1. Decide the locations of M sources and N relays. ($N \leq M$)
2. Calculate the amount of bandwidth which needs to be shared to achieve maximum possible data rate
3. Create two matrices of the size MxN, one showing the data rate achievable for the source (for all the possible source to relay combinations, here N) and the data rate for the relay. Name them R_srd and R_rrd respectively.
4. Create a new matrix named utility having value: Utility = R_srd + R_rrd
5. In Utility, find out the source and relay combination which gives the maximum value of Utility and assign that source and relay pair as a link.
6. Discard the values of the source and relay which are linked together, and hence the matrix dimensions for Utility will be reduced.
7. Repeat from step 5, until all the relays are allocated a source.

We will be using the same example as used in the distributed selection algorithm. The resultant Utility matrix is given below.

From the bold and underlined numerals we can identify the source and relay link which is as given below:

Source 6 Ξ Relay 1
Source 5 Ξ Relay 2
Source 4 Ξ Relay 3

Here in this method the overall efficiency of the network is maximized. The source-relay links obtained through this method is different from that of distributed selection, but it totally depends on the application whether which method is to be used.

V. CONCLUSION

The results obtained clearly indicates the advantages of cooperative communication over conventional wireless communication. The resource allocation results obtained with the help of utility shows that the shared bandwidth will increase the data rate and also the overall spectral efficiency. The results of the relay selection of *'MxN'* network, indicates that the performance of the network as a whole can be improved. The power required by the source in cooperative communication is less as compared to without cooperation. Having selected the bandwidth exchange model over the pricing or the auctioning model, has an advantage that the bandwidth exchange model will not require any base station for initiating the communication. Also the computational and hardware cost of base station will be saved and at the same time power consumption will also be reduced. Hence we can conclude that in all aspects, cooperative communication will always be advantageous over non-cooperative communication.

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