Coordinated Paradigm for D2D Communications

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***Abstract*—Interference management is an important subject in Device to Device (D2D) communication when underlying a LTE-A cellular band. By default, in LTE-A there is negligible intra-cell interference due to the orthogonality of the subcarriers but this orthogonality will be lost when D2D communication takes place under cellular users (CU). Therefore, the purpose of this paper is to propose a novel scenario with the help of coordinated multipoint (CoMP) technology to remove inter and intra interference between D2D and CU. So far no works have been done on coexistence analysis of CoMP and D2D. This paper is the first effort on coexistence analysis of these two technologies. It is clear that the combination of D2D and CoMP can offer a palette of interesting colors that can paint new business opportunities for mobile stakeholders promoting its candidacy for 5G wireless communication system. To this end, we present numerical results, which prove that this novel scenario will increase the spectral and energy efficiency of whole system and offloaded the traffic from core network.**

***Index Terms*—D2D Communication; CoMP; Energy-efficiency;LTE-Advanced**

I. Introduction

The world is becoming an energy conscious society having a profound impact on today's digital revolution. One of the biggest impediments of future wireless communications systems is the need to limit the energy consumption of battery-driven devices so as to prolong the operational times and to avoid active cooling. In fact, without new approaches for energy saving, there is a significant threat that 4G mobile users will be searching for power outlets rather than network access, and becoming once again bound to the pre-historic world of fixed line communications. If we are to maintain market sustainability, then there is a clear need for prolonged battery lifetime: the word mobile is taken as de facto, in that users have the freedom to roam around and be connected to the best available technology at any time; however, if preventive measures are not taken to conserve energy, then users could be restricted to the nearest power supply falling victim to the so called "Energy Trap".

To that end, it is extremely important to explore energy-efficient or so-called "green" wireless communication technologies to reduce the energy consumption of both base stations and user terminals. Presently, coordination and device to device communication (D2D) over licensed band are envisioned as key enabling technologies to achieve the green wireless communications. Coordination and D2D are well recognized as an enhanced technology for 5G wireless networks and becomes a hot research topic in wireless communications. Coordination communication allows the distributed eNB to assist each other for maximizing their respective interests and D2D has potential to offload the traffic from operator core network by transferring the data directly between devices, which poses a new angle on the wireless network optimization.

A. Coordinated Multi-Point (CoMP) Transmission

Recently 3GPP LTE-Advanced has adopted Coordinated Multi-Point (CoMP) transmission/reception due to its ability to mitigate and/or coordinate inter-cell interference (ICI). However, there is room for reducing energy consumption further by exploiting the inherent flexibility of dynamic resource allocation protocols. The Third Generation Partnership Project (3GPP) community has already taken steps towards reducing the energy consumption in future emerging networking technologies (e.g. Long Term Evolution (LTE)-Advanced) by proposing new energy efficient networking topologies, deployment strategies and modulation technologies. Todays wireless technologies are mostly based on orthogonal frequency division multiplexing (OFDM) system. OFDM can effectively eliminate the intra-cell interference (same cell) due to orthogonal subcarrier modulation; and therefore the only major source of interference to handle is inter-cell interference (ICI) (i.e. between different cells). ICI significantly decreases the achievable throughput of each user as well negatively impacts on cell average throughput. Especially, users at the cell-edge areas suffer from serious ICI leading to poor cell-edge throughput. ICI has a large effect on system capacity, particularly when the frequency reuse factor is equal to one. As cell sizes decrease in the future, inter-cell interferences will become more of a problem. In the framework of 3GPP, many solutions are proposed for LTE to cope with ICI and achieve overall increased cell edge throughout. Relay and Coordinated multipoint (CoMP) [1] are examples of solutions proposed by 3GPP for the LTE-Advanced standard. Although CoMP has added advantages over Relay technologies, as CoMP uses coordination in transmission and reception of signals among different base stations, which helps to further reduce ICI [2]. CoMP transmission and reception techniques utilize multiple transmit and receive antennas from multiple antenna site locations, which may or may not belong to the same physical cell, to enhance the received signal quality as well as decrease the received spatial interference [3]. Using CoMP the cell average and cell edge throughput are boosted, unlike with Relay, which only increases the cell edge throughput [4]. CoMP has been an active area of research, both in academia as well as in industry. For example, an ongoing work item in 3GPP targets support of CoMP in future releases of LTE [5].

B. Device-to-Device (D2D) Communication

A key motivation for D2D connectivity is its potential for operators to offload traffic from the core network, and the

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framework for a new communication paradigm to support social networking through localization. The current adhoc mode communication does not support this well due to its configuration complexity. In D2D communication, devices are communicating with each other without intermediate nodes. D2D communication uses cellular spectrum (license band) supported by a cellular infrastructure and promises three types of gain: a) the proximity of user equipments (UE) may allow for extremely high bit rates, low delays and low energy consumption [6, 7]; b) the reuse gain implies that radio resources may be simultaneously used by cellular as well as D2D links, tightening the reuse factor so that the same spectral resource can be used more than once within the same cell [7]; c) finally, there is a gain from not having to use both an uplink and a downlink resource, as is the case when communicating via the access point in the cellular mode. Moreover, D2D communication may extend the cellular coverage and facilitate new types of wireless peer-to-peer services. D2D is also economical communication because it uses the same pre-existing cellular infrastructure which increases network efficiency. This increased network efficiency supports more services and improves current services and applications.

The rest of the paper is organized as follows: section II presents related work, section III and IV present the system model and the interference coordination respectively, section V presents deployment scenario and numerical results, followed by conclusion in section VI.

II. Related Work

Current technologies that address energy efficient resource management for cooperative and competitive heterogeneous networks (HetNet) systems under a variety of network objectives and constraints is not yet fully developed [8]. Although much work on energy efficient network deployment strategies has been done, current results are still quite rudimentary and some important challenges remain to be investigated [9]. In [10] the authors investigated the energy efficiency of heterogeneous network and also took into account the effects of cell size on cell energy efficiency by introducing a new concept of area energy efficiency. For example: interference management with respect to energy saving and the trade-off between the capacity and energy efficiency in HetNet is worth investigating. In [10], the performance of a conventional heterogeneous network in terms of EE is first introduced, although, only pico cell is considered as a LPN and no coordination or cooperation is present as well. Moreover, a Multi-RAT HetNet energy optimization is also provided this work [11]. In the research work [12], the design of energy efficient cellular networks through the employment of base station sleep mode strategies as well as small cells, and the trade-off issues associated with these techniques, is investigated. The work in [13] which looks into energy efficient way of operating dense small cell networks by applying concept from cognitive radio.

Similarly, current works on D2D mainly focus on device discovery including discovery signal design, resource allocation and scheduling, synchronization mechanism, etc. There are also several recent papers which address the multihop D2D communications as an underlay of an LTE-A network [14, 15]. The feasibility and the range of D2D communication and its impact on the power margins of cellular communications are studied in [16] and references there in. For a scenario with D2D multicast communication integrated into a cellular network, a clustering concept is introduced in [17] and references there in.

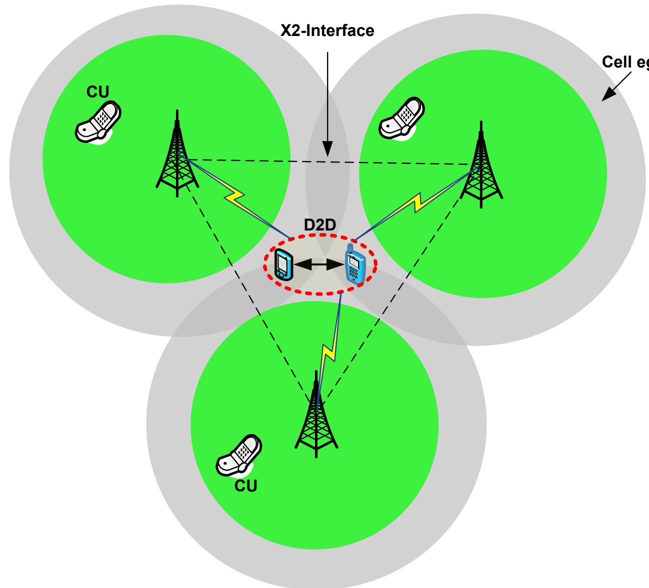

Fig. 1. Cooperative paradigm for D2D communication

A. Contribution

So far no works have been done on coexistence analysis of CoMP and D2D. This paper is the first effort on coexistence analysis of these two technologies. CoMP will help us to remove the inter cell interference by using the coordination between the eNB and intra cell interference between CU and D2D will be removed by using well-known zero forcing algorithm. After removing the interference, D2D technology help us to offload the traffic from the core network and transfer data directly between the device at very high speed which eventually reduces the delay and increase the spectral and energy efficiency of whole system. Moreover this scenario will also improve the reliability i.e. there is several channel/radio pipes at the cell edge from D2D to eNB. The probability that all the channels are deteriorated at the same time is quite small.

III. System Model

Cooperative paradigm system model is shown in Fig. 1. In our system we have two kinds of users' cellular users (CU) and D2D users. CUs are allocated in the green region (cell center) of each coordinated eNB. D2D users are allocated at cell edge in gray region. We also assume that, if any user in the green region it is term as CU and if it in gray region it term as D2D users. D2D in the gray region received signal from all cooperative base station to enhance the signal quality.

A. SINR Calculation

While calculating the SINR, we consider that D2D pair are in close vicinity at cell edge and there is direct LOS between them and CU are in the cell center and there can be NLOS between D2D receiver and CU. Therefore, for D2D receiver ($D2D^R$), we consider only pathloss models [7, 18] and for CU we also consider shadowing and fast fading effect in the channel calculation $\left(P_{eNB_{i,u}}^{RB_m}\right)$.

$$PL_{D2D^R_{i,j,h}} = 40\log_{10}d[m] + 30\log_{10}(f_c) + 49. \quad (1)$$

where, $PL_{D2D^R_{i,j,h}}$ is the link between j^{th} $D2D^S$ (D2D sender) and h^{th} $D2D^R$ in the coverage of eNB_i; d represents the distance between a sender and a receiver in meters and f_c is the carrier frequency in GHz.

Now we assume $P_{eNB_{i,u}}^{RB_m}$ and $P_{D2D^S_{i,j,h}}^{RB_m}$ are the strengths of the received signal for m^{th} RB from the i^{th} eNB to the u^{th} CU and from j^{th} $D2D^S$ to the h^{th} $D2D^R$ in the j^{th} $D2D^S$ coverage in eNB_i. Then, the SINR of $CU_{i,u}$ for RB_m is

$$\gamma_{CU_{i,u}}^{RB_m} = \frac{P_{eNB_{i,u}}^{RB_m}}{N_o + \sum I_{eNB}^{RB} + \sum I_{D2D^s}^{RB_m}}, \quad (2)$$

and the SINR of $\mathrm{D2D}^R_{i,j,h}$ for RB_m is

$$\gamma_{D2D^R_{i,j,h}}^{RB_m} = \frac{P_{D2D^S_{i,j,h}}^{RB_m}}{N_o + \sum I_{eNB}^{RB} + \sum I_{D2D^s}^{RB_b}}. \quad (3)$$

N_o is the white noise. I_{eNB}^{RB} and $I_{D2D^s}^{RB_m}$ are the strengths of the interfering signal from the other eNBs and from D2D senders in the macrocell coverage to the users. We can also analyze the throughputs for $CU_{i,u}$ and $D2D^R_{i,j,h}$, $T_{UE_{i,u}}$ and $T_{D2D^R_{i,j,h}}$ by using Shannon theorem as:

$$T_{CU_{i,u}} = \sum_{m=1}^{M} (RB_m).\log\left(1 + \gamma_{CU_{i,u}}^{RB_m}\right) \ , \quad (4)$$

$$T_{D2D^R_{i.j,h}} = \sum_{m=1}^{M} (RB_m).\log\left(1 + \gamma_{D2D^R_{i,j,h}}^{RB_m}\right) \ , \quad (5)$$

and total system throughput for eNB and for all D2D senders T_{eNB_i} and $T_{D2D^s_i}$ in the i^{th} macrocell are calculated using (6) and (7)

$$T_{eNB,i} = \sum_{i=0}^{CU} T_{UE_{i,u}}, \quad (6)$$

$$T_{D2D^S_i} = \sum_{i=0}^{D2D} T_{D2D^R_{i.j,h}}. \quad (7)$$

IV. Interference Coordination Technique

This cooperative D2D system can be seen as a network MIMO system using BSs as a distributed antenna array [19]. For the cooperative CoMP system, two types of interference is occurred – intra-cell and inter-cell interference (ICI). More specifically intra-cell interference termed as intra-cell interference (IntraCI) and inter-cell interference (ICI). There are two types of interference we come across in the transmission methods. Those are the IntraCI and the ICI.

A. Intra-cell interference (IntraCI) coordination

The intra-CoMP-cell interferences are originated in D2D mode. It is created by the D2D receiver (cell edge UE) to CU (cell center UE) when they are assigned by same resource from the CoMP. Specifically, upon utilizing users' CSI, the eNB can design dedicated precoder to sufficiently suppress MUI based on a range of principles, such as zero-forcing (ZF), minimum mean-square-error (MMSE) [20, 21].

In this paper, only ZF precoding is considered, which steers a beam towards CU UEs direction and nulls in the direction of the D2D UEs, thus eliminating intra-cell interference [22] and vice versa also. For example, CU with channel matrix $\mathbf{H}$, while precoding vectors $\mathbf{f}_{CU}$ building the precoding matrix $\mathbf{F}$ are initially given by

$$\mathbf{f}_{CU} = \frac{\mathbf{h}_{CU}^H}{\left\|\mathbf{h}_{CU}^H\right\|_2} \quad (8)$$

Where, $\mathbf{h}_{CU}^H$ represents the corresponding CU UE's column of the pseudo-inverse $\mathbf{H} = \mathbf{H}^H\left(\mathbf{H}\mathbf{H}^H\right)^{-1}$ of the total channel matrix $\mathbf{H}$ of the total UEs.

B. Inter-Cell interference (ICI) coordination

The latter type of interference is originated for both CU and D2D UE mode. The ICI interferences is occurred when the interferences originates from BSs (for 3GPP BS termed as eNB) of other cells. For example, the interference between two eNBs such as eNB1 and eNB2 is ICI or inter-cell interference. This interference is managed, estimated and coordinated by the proposed algorithm. Indeed, using the backhaul, this type of coordinated system becomes able to exchange data, control information with the all eNBs under the management of a central joint unit and, consequently, coordinate interference.

Specifically, in comparison with CU UEs, D2D (cell-edge) UEs tend to have lower received signal strength and are therefore more vulnerable to ICI. For our scenario, to minimize the ICI we devise ICI reduction technique using coordination through feedback [23, 24]. The feedback process is done by the backhaul where the power consumption model for the backhaul must be considered for a realistic coordinated scenario. The algorithm of the envisioned scenario for interference coordination is listed as follows in Algorithm 1.

V. Deployment Scenario and Numerical Results

A C++ based LTE-A system level simulator (SLS) is used in order to evaluate the performance of the proposed scenario. There are two ways to deploy CoMP technology–autonomous distributed control based on an independent eNB configuration which processes every signaling of its own, or centralized control based on centrally controlled -eNB configuration connected via fiber through joint processing unit (JPU) [25]. The obvious question is whether coordination between cells can be distributed or centralized [26]. There is no impact on any radio-interface for independent eNB coordination. In autonomous eNB configuration, coordination is used between eNB. This method is more complex than the other since signaling delay and overhead between eNB is still an open

Algorithm 1 ICI Coordination Algorithm

1: Each UE estimates the channel from the serving eNB.
2: Each UE estimates the channel from the interfering eNB.
3: Each UE receives the feedback information. The feedback information contains given in the following:
   a. Rank indicator (RI), Precoding matrix indicator (PMI) and channel quality indicator (CQI) for the serving cell.
   b. Reference PMI from the interfering eNBs.
4: Information exchange between the eNBs operated by the eNBs.
5: Each UE receives the PMI which is used for performance enhancement:
   a. That means improvement of SINR while using the recommended set of PMIs at the interfering eNBs.
6: Each UE sent back the information which is fed back to serving eNB as well as interfering eNBs.
   (We should keep in mind that in this way of process, the UE can send all the feedback information to the serving eNB depending on the serving eNB to pass all the related information to the interfering eNBs. Besides, the UE can choose to feedback the information to the specified destination straightway. As a result, the reference PMI together can be sent back to the interfering eNBs from the UE directly.)
7: Finally, Serving eNB and the interfering eNBs select respective PMI to serve their aimed users.
   (Interfering eNBs are evoked to choose the PMI which maximizes the capacity of its own serving UE within the preferable set while no central scheduler is present. On the other hand, the PMI for the serving UE are decided jointly across all the serving eNBs by the central scheduler if central scheduler is available.)

challenge. Therefore in our analysis, we deploy CoMP with the centralized control where coordination of eNBs is done on JPU.

We consider a centrally controlled CoMP. In this approach, a processing unit located centrally uses a diverse set of information – Channel State Information (CSI) which includes CQI, Pre-coding Matrix Index (PMI) and Rank Indicator (RI) informed by the UE (D2D or CU) – to decide which sets of eNB are best suited for serving the user. Since the processing is centrally controlled, the central processor, in this case the JPU, will handle all the digital signal processing. The phase components of the waveforms for transmission are pre-computed at the central processing units and extracted into the set of eNBs that are best suited to serve the UE. The data to and from the eNB is sent via a common backhaul interface typically carried over an optical network, and the bandwidth requirement to handle waveforms in either direction can be in gigabits per second depending on the capacity the eNB is dimensioned to provide.

For SLS purposes, we consider a LTE-A cellular system consisting of 19 CoMP cell sites, with six CoMP cell sites in the first tier and twelve CoMP cell sites in the second tier, surrounding the central CoMP cell. Each CoMP cell site includes three 120-degree hexagonal sectors, i.e., 57 sectors in total are simulated. All the simulation results are collected from the three central hexagonal sectors in the central CoMP cell site, with the other 54 sectors serving as interferers.

CU and D2D sender (D2DSs) are randomly deployed in the cellular network coverage and are stationary. The decision on whether a user is D2D or CU is made on For example, a user is in a cell-edge if

$$\Gamma_u^m \leq \Gamma_{\text{threshold}} \tag{9}$$

where, $\Gamma_{\text{threshold}}$ is a predetermined threshold in dB. In this paper we put $\Gamma_{\text{threshold}} = 3$dB. In the case of cell-edge user joint transmission of signal occurred to increase signal strength. At cell edge D2D sender $(D2D^S)$ and D2D receiver $(D2D^R)$) are separated from their corresponding D2D sender with uniform random distance which is uniform random variable between [1, 20] meters. Simulation result shows (Fig. 2) that after 20m distance, the throughput of both links, direct and cellular are almost equal. Other simulation parameters are shown in Table I.

TABLE I
KEY SIMULATION PARAMETERS

Parameter Name	Value
Carrier Frequency	2.6 GHz
Bandwidth	10MHz
Number of Resource Block	50
Number of CU	10 90
Number of $D2D^S$	10 100
Number of $D2D^R$	1 (every $D2D^S$ has only one $D2D^R$)
Traffic Model	Full Buffer
Scheduler	Proportional fairnes
Channel Model	D2D: Pathloss [7, 18]
	CU: SCM [27]

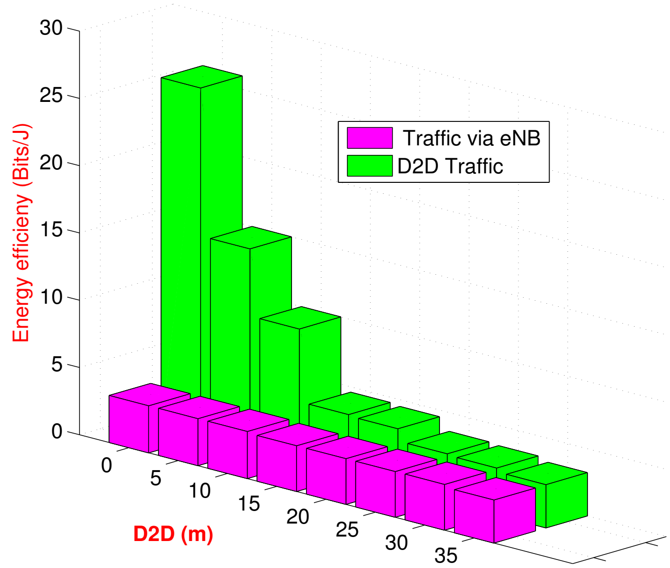

Fig. 2. D2D Throuhput

Figure 2 shows the D2D throughput as a function of the distance between the communicating D2D devices. For short distance, the throughput of the direct D2D greatly exceeds the throughput when solely relaying D2D traffic through the eNB. For 5 m link distance, the average D2D throughput is 15Mbps compared to 3.5Mbps when all D2D traffic is relayed by the eNB. This means, that D2D communication improves the energy efficiency of the system as compared to the relayed link due to high throughput and lower transmission power. As the distance between D2D pair increases the energy efficiency decreases. Energy metrics [28] for maximizing energy efficiency (EE) are defined as the ratio of the total transmitted bits per unit energy consumption (unit: bits/Joule), as shown in equation (10).

$$EE = \frac{Data\,rate}{Power}\left[\begin{array}{l}\frac{bits/Second}{Watt} \\ = \frac{bits}{Second \times Watt} = bits/Joule\end{array}\right] \quad (10)$$

Simply, the goal is to increase the number of bits in a given transmitted power. This means, the higher the throughput, the higher the energy efficiency.

As shown in the Fig. 3, coordinated system achieves more throughputs then the non-coordinated system. This is because the inter and/or intra interference is well managed in the proposed scenario. Inter cell interference (ICI) is mitigated using the coordination between the eNB and intra cell (IntraCI) interference is removed using zero forcing algorithm.

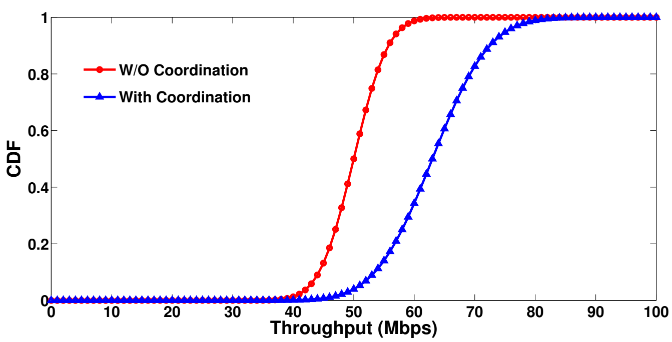

Fig. 3. Coordination Analysis

Fig. 4 demonstrates that there is a clear increase in cellular network throughput when offloading is enabled, and the more we offload, the higher is the gain.

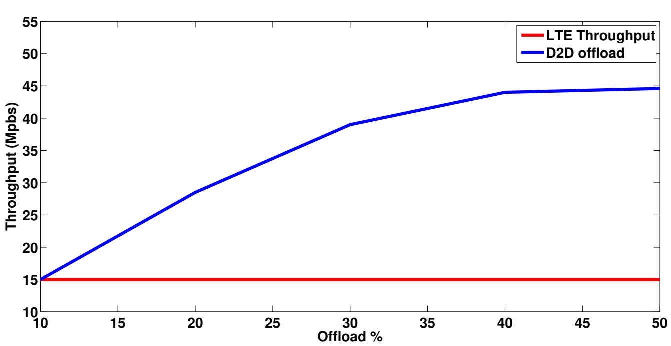

Fig. 4. Offload traffic

Figure 5 shows the impact of the power consumption of the backhaul segment on the overall network power consumption of CoMP. The value of the total network power consumption [29, 30] is shown as a function of the area throughput requirements. Both technology options, i.e., fiber, microwave are considered. The figure confirms the intuition that the impact of the backhaul power consumption is larger for a heterogeneous network scenario compared to without backhaul. This is true regardless of the technology choice for the backhaul. This means that technology and topology considerations for the backhaul will be increasingly important for optimizing the total network power in a CoMP scenario.

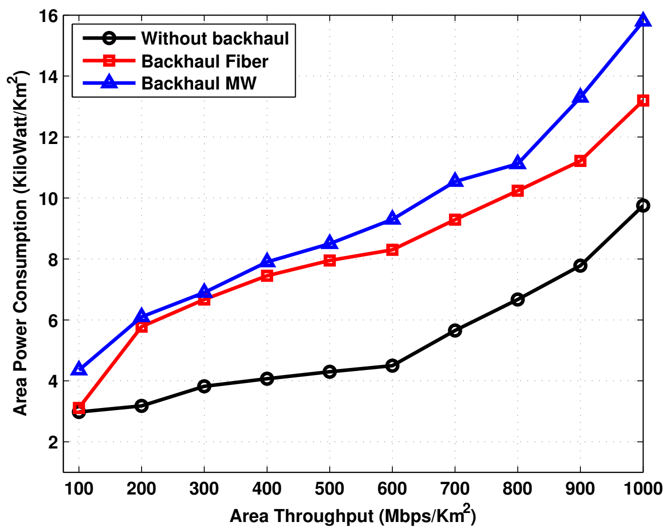

Fig. 5. Backhaul Comparison

VI. Concluding Remarks

In this paper we presented the novel scenario which is based on the coexistence of coordinated system (CoMP) and D2D. This novel scenario brings the benefit in term of system throughput and energy efficiency. Furthermore, our scenario removed inter and intra cell interference using coordination and zero forcing algorithm. D2D helped in offload the traffic from the eNB which increases the overall system throughput. In the end we gave the comparison of between backhaul technologies for the CoMP. In future, we have planned to optimize this scenario for energy and spectral efficiency while considering the backhaul power consumption.

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