Efficient Resource Allocation Algorithm for D2D Communication in 5G Wireless Networks

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Efficient Resource Allocation Algorithm for D2D Communication in 5G Wireless Networks

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ABSTRACT: Device-to-device (D2D) communication is a leading technology to improve spectral efficiency and needed data rates in 5G networks. It brings down the offload traffic rate too in advanced network communications that employ wireless techniques. In this work, a novel Hungarian-based joint uplink-downlink resource allocating method is explained for realizing optimized network throughput. It considers the Quality of Service of the D2D clients and cellular users (CUs). Specifically, the proposed technique allows the device clients to reuse the resource provisions of CUs at the instant of either downlink or uplink. Formulation of optimizing problems is done as a mixed integer non-linear programming language generally called NP-hard (non-polynomial time hardness). The issue is addressed in a couple of different stages. The first stage is assigning Sub Channel (SC) and the second stage is Power Allocation (PA). This verifies the performance of the SC assignment and PA with network throughput, the maximum transmission power of CUs, D2D, BS as well as distancing from one to another to be the parameters of prime concern. The Hungarian method in the proposal is a converging optimizing answer in polynomial time. Finally, the results are compared with the existing joint uplink-downlink resource allocation (JUDRA) techniques.

Index terms: Subchannel assignment, Optimal Power allocation, Spectrum sharing, energy efficiency, optimization.

1. Introduction

The industry for wireless communication is gaining popularity due to adoption of the emerging technologies like the Internet of Things, Machine Learning, Robotics, Artificial Intelligence and D2D communication, [1], etc. Communicating in the wireless domain requires small power dissipation, high rates of data, low latency, a wide area of coverage [2] and efficient spectrum sparing. These needs are on a rapid increase every day [3]. All such issues are addressed for providing as well as supporting the demands of the 5G as well as even beyond 5G [4]. Many technologies and techniques have been implemented for increasing the demand for network capacity. According to the present expected requirements of communication networks, an emerging technology called D2D [5] communication serves well. The concept of D2D communication as an underlay to a cellular network, operating on the same network via the base stations is called evolved node (eNB) in the LTEA [6]. User Equipment (UE) may directly communicate with each other over the D2D links without (UEs are usually controlled by BS) involvement of the BS [7]. This increases the efficiency of the spectrum. It also enables the network for acquiring additional clients of D2D. But, communicating in D2D will cause interference to the network of cellular type if their design is improper [8]. The popularity of D2D is ever-increasing rapidly for its unique features. Advanced technologies provide better QoS [9]. The next-generation networks improve the system performance and additionally provide a variety of services. Direct communication with a limited range of distance could be a valid candidate to satisfy the demand for increased data rate, spectral efficiency, and reduced
delay [10]. D2D permits higher throughput, spectral and energy efficiency with reduced latency & transmitted power for direct communication [11].

Interference management is a critical issue for D2D underlay networks of cellular type in which D2D and cellular communications [12] are existing in networks at the same time. For limiting the interferences to the existing cellular users (CUs), restricting the D2D links’ transmitting energy as well as the distancing of the D2D pair clients is [13] suggested. D2D communication is introduced as a promising technique [14]. The D2D communication is allowing the UEs in the neighborhood to do communication with one another with no routing facility, or even traffic via the cellular BS. Such communication reduces the transmitting power, as well as end-to-end delay as transmitting distances,[15] Communicating with the use of D2D in cellular situations provides significant performance gain in terms of offloading data as it is communicating in a direct way. [16] Added to that, spectrum efficiency is better as cellular resources are reused, extended coverage (there is a provision of extra connections among UE) as well as there is sharing of contents between the users.

The energy consumption of the overall system varies with [17] the D2D pairs’ count. As the D2D users count got increased, energy consumption also increased. Spectrum sharing is a way of reusing spectrum resources and improving the performance of wireless networks. It has significant benefits [18] on spectral efficiency and power consumption. Such a method of communication requires a sensible style of radio traffic management [19]. For improved overall performance, D2D links and cellular links can share an equivalent radio resource [20]. The priority of the interference caused by D2D communication in underlying cellular uplink transmission networks [21] has been the target of many research scholars.

The comprehensive analysis of D2D communications is using either only uplink resource sharing or only downlink resource sharing [22]. Last decade such research works are already done. Now the joint resource allocation has the emerging scope to resolve the [23] 5G requirements. The joint uplink and downlink method for sharing resources between cellular users and D2D users [24] is of concern now. The method to maximize the throughput of the network is brought in for D2D communicating situations for reusing uplink and downlink resources provided [25] for CUs. It is a generalized situation, in which interferences [26-27] between D2D of multiple types also are included. Communicating in a D2D way might utilize the spectrum of a licensed or unlicensed kind for forming direct links known as in-band as well as out-band communication [28-29] respectively.

Fig.1. D2D Communication based on the spectrum utilization.
Fig. 1. D2D, we have three major important modes. 1. cellular mode, 2. dedicated mode and 3. reuse mode. The reuse mode is considered for our joint resource allocation [30-31] in D2D. Joint resource and power control allocation in a multi-cell scenario is considered in [32-35].

Simulation results for checking the effectiveness of the method in the proposal: The performance network’s throughput for the method in the proposal namely Hungarian is weighed against only JUDRA [12]. Results show the effectiveness of the novel Hungarian method in the proposal on various performance matrices like D2D link distance, SC Assignment, transmission energy allocation, etc. Simulation results showed higher performance than the existing resource allocation schemes’ performance in terms of network throughput. The Hungarian assignment rule is considered to assign SC first. After that utilizing the SC values for power allocation (PA) is performed. It maximizes the system’s performance. At the same time it guarantees minimum QoS.

The rest of the paper is summarized as follows:

Section 2 explains the model of the system as well as the narration of the problem. Section 3 discusses the Hungarian scheme in the proposal for allocating resources in a couple of steps i.e., assigning of SC as well as PA. Section 4 presents the results expressed numerically. Finally, Section 5 contains the Conclusion as well as its scope in the future.

2. System Model

The joint resource allocation for D2D communication in a fully loaded single cell [12] is illustrated in Figure 2. Here clients who are active are identified as the CUs or DUs. The set of cellular users (S_{cu}) and set of D2D users are denoted as (S_{d2d}). They are uniformly distributed in the circular cell coverage area. The D2D coverage is very low if the users go far away from the CU users. The set of cellular users is represented as S_{cu} = [C_1, C_2, ..., C_C]. The D2D clients set is represented to be S_{d2d} = [D_1, D_2, ..., D_C]. The rest of the parameters are represented as given below:

The transmitted power with maximal value for CUs is P_{c, max}.
The transmitted power of BS with maximal value is shown as P_{b, max}.
The transmitted power of D2D with maximal value is shown as P_{d, max}.
The key symbolisations’ listings with corresponding significance are presented in Table 1. The gain of the channel at a specific instance to link transmitting as well as receiving is taken into account. The Fast-fading coefficient is represented by (X_{x,y}) and the slow-fading coefficient by (Y_{x,y}). For the efficient sub-channel (SC) assignment, mention may be made that the CUs present in the SCs may be used again by DTx of multiple types. But every pair of D2D is permitted to use again one uplink or downlink SC only once.
The paper contains a novel Hungarian-based method. It is made as a proposal for maximizing the whole network’s throughput. The problem of optimizing consists of achieving the need for a minimum data rate for DUs as well as CUs. Sharing of resources is created for the network that is spectrum efficient. Now, the problem tends to be mixed-integer non-linear programming (MINLP) rather NP-hard. The proposal is made for solving the problem in a couple of stages. Obtaining parameters that are nearly optimal may be done in polynomial time. The notations and symbols used in this paper are tabulated in Table 1.
Table 1 Notations and Symbols used.

<table>
<thead>
<tr>
<th>Symbols/Notation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{cu}$</td>
<td>Set of CCU</td>
</tr>
<tr>
<td>$S_{d2d}$</td>
<td>Set of DTx</td>
</tr>
<tr>
<td>$N_{ch}$</td>
<td>Number of SCs</td>
</tr>
<tr>
<td>$D_{tx,rx}$</td>
<td>D2D link distance</td>
</tr>
<tr>
<td>$r_c$</td>
<td>Cell radius</td>
</tr>
<tr>
<td>$B_w$</td>
<td>SC Bandwidth</td>
</tr>
<tr>
<td>$K$</td>
<td>Path loss constant</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>Path loss exponent</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>Noise power</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>Tolerance</td>
</tr>
<tr>
<td>$p_b^{max}$</td>
<td>Maximum BS transmission power</td>
</tr>
<tr>
<td>$p_c^{max}$</td>
<td>Maximum CU transmission power</td>
</tr>
<tr>
<td>$p_d^{max}$</td>
<td>Maximum Tx transmission power</td>
</tr>
<tr>
<td>$T^u_c$</td>
<td>Minimum uplink rate requirement</td>
</tr>
<tr>
<td>$T^d_c$</td>
<td>Minimum downlink rate requirement</td>
</tr>
<tr>
<td>$T^u_{c,d}$</td>
<td>Minimum D2D rate requirement</td>
</tr>
<tr>
<td>$\mu_{d2d,cu}$</td>
<td>Interference indicator</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Optimization variable</td>
</tr>
<tr>
<td>$L_1, L_2, L_3...$</td>
<td>Constraints</td>
</tr>
<tr>
<td>$\alpha_1, \alpha_2, \alpha_3$</td>
<td>Optimization Problem</td>
</tr>
<tr>
<td>$\frac{u}{dl}$</td>
<td>Total Throughput</td>
</tr>
<tr>
<td>$\frac{u}{dl}$</td>
<td>uplink/downlink</td>
</tr>
<tr>
<td>$Y_b$</td>
<td>Received signal at BS</td>
</tr>
<tr>
<td>$Y_c$</td>
<td>Received signal at CU</td>
</tr>
<tr>
<td>$Y_r$</td>
<td>Received signal at SC</td>
</tr>
<tr>
<td>$P_b$</td>
<td>Transmission power of BS</td>
</tr>
<tr>
<td>$P_t$</td>
<td>Transmission power of BS to CU.</td>
</tr>
<tr>
<td>$P_c$</td>
<td>Transmission power of CU</td>
</tr>
<tr>
<td>$P_t$</td>
<td>Transmission power of DTx.</td>
</tr>
<tr>
<td>BS</td>
<td>Base station</td>
</tr>
<tr>
<td>SINR</td>
<td>Signal to noise interference ratio</td>
</tr>
</tbody>
</table>

To improve the network’s throughput, a channel reuse mechanism is used to allocate resources. For any specific instance, the cell resource utilized by SC could be reutilized by one of the existing D2D pairs. This analyzing task is carried out taking into account utilizing the resource of either uplink or downlink.

At the time of reuse of uplink, from [12] CU transmits one signal to BS utilizing a particular frequency. This frequency is made use of by the device transmitter DTx. That signal received at the BS end has the expression for $Y_b$ as follows:

$$Y_b = \sqrt{(p_c d_{c,b}^{-\beta_1}) h_{c,b} x_c + \sum_{t \in s_{d2d}} \mu_t x_t + \eta_b}$$

Here $\mu_t = \begin{cases} 1 & \text{if the identical SC link is made use of from CU to BS as well as for D2D's communicating needs} \\ 0 & \text{if not the case.} \end{cases}$

$d_{c,b}, d_{t,b}$ = components denoting Distance.

$h_{c,b}, h_{t,b}$ = channel Coefficients (instantaneous values)

$x_c =$ CU’s Transmission power.

$x_t =$ DTx’s Transmission power

$\eta_b =$Gaussian noise in the BS region and the mean is 0 while the variance is $\sigma^2$

Pathloss exponent is considered as $\beta_1$ and it is the same for every communication link.

The SINR received from Eqn. (1) in the BS uplink for reusing can now be stated as

$$SINR_{c,ul}^u = \frac{p_c|h_{c,b}|^2 d_{c,b}^{-\beta_1}}{I_{t,b} + \beta_2^2},$$

Here $I_{t,b} = \sum_{t \in s_{d2d}} \mu_t x_t + \eta_b$ is the Device Tx’s interference.

$\beta_2 =$ power due to Noise expressed in dbm.

In the same manner, while the reuse of a downlink, BS transmits one signal to CU with a particular frequency. This frequency is made use of by the device transmitter DTx. The signal’s formula in the CUs is stated for $Y_c$ as

$$Y_c = \sqrt{(p_t d_{t,b}^{-\beta_1}) h_{t,b} x_t + \sum_{t \in s_{d2d}} \mu_t x_t + \eta_b}$$
\[ Y_c = \sqrt{(p_b d_{b,c}^{-\beta_1}) h_{b,c,x_b}} + \sum_{t \in S_{d2d}} \mu_{t,c} d_{t,c}^{-\beta_1} h_{t,c,x_{t+\eta_c}}. \]  

(3)

Where as
\[ \mu_{t,c} = \begin{cases} \in [0,1] & \forall t \in S_{d2d}; \\
1 & \text{if the identical SC link is made use of from CU to BS as well as for D2D’s communicating needs} \\
0 & \text{if not the case.} \\
\end{cases} \]

\[ d_{b,c}, d_{t,c} \] components denoting Distance
\[ h_{b,c} \] = channel Coefficients (instantaneous values)
\[ h_{t,c,} \] = channel Coefficients (instantaneous values)
\[ x_b \] = BS’ Transmission power.
\[ x_t \] = Transmitting power of DTx.
\[ \eta_b \] = Gaussian noise in the BS region and the mean is 0 while the variance is \( \sigma^2 \)

Using Eqn. (3) the SINR in the CU, in the situation of reusing downlink can be stated as
\[ \text{SINR}_{c}^{dl} = \frac{p_b |h_{b,c}|^2 d_{b,c}^{-\beta_1}}{1_{ul}^{t,c} + \beta_2^2}, \]

(4)

Here
\[ 1_{ul}^{t,c} = \sum_{t \in S_{d2d}} \mu_{t,c} p_t h_{c,b}^2 d_{t,b}^{-\beta_1} \]
\[ \text{is the Device T}_{x} \text{’s interference} \]
\[ \beta_2 = \text{power due to Noise expressed in dbm.} \]

In specific situations, D2D has permission to reuse a downlink or uplink sharing of resources based on available SCs. Therefore, the signal received in the DRs for downlink-uplink SC is written to be \( Y_r \)

\[ Y_r = \sqrt{(p_t d_{t,r}^{-\beta_1}) h_{t,r,x_t}} + \sum_{c \in S_{c,u}} \mu_{c} d_{c,r}^{-\beta_1} h_{c,r,x_c} + \mu_{d,c} d_{t,c}^{-\beta_1} (p_b d_{b,r}^{-\beta_1}) h_{b,r,x_b} + \sum_{k \in S_{d2d}} \mu_{k,c} d_{k,r}^{-\beta_1} h_{k,r,x_{t+\eta_r}}, \]

(5)
Here \( \mu_{k,c} = \in [0,1] \forall k \in d2d; \)

\[ \mu_{k,c} = 1; \text{if the identical link SC is made to reuse for communicating needs of D2D,} \]

\[ = 0; \text{if not the case.} \]

\( d_{t,r}, d_{b,r}, d_{c,r}, d_{k,r}, \) Components denoting the distance.

\( h_{t,r}, h_{b,r}, h_{c,r}, h_{k,r} \) are the channel coefficients (instantaneous values).

\( \eta_r \) =Gaussian noise

\[ \text{SINR}_{d}^{ul/dl} = \frac{p_b |h_{t,r}|^2 d_{t,r}^{-\beta_1}}{I_{c,r}^{cu} + I_{b,r}^{d2d} + \mu_{k,c}^{ul/dl} + \beta_2^2}, \] (6)

Where \( I_{c,r}^{cu}, I_{b,r}^{d2d}, \mu_{k,c}^{ul/dl} \) are the interference components from the CU, D2D, BS.

\( \beta_2 \) = Power due to noise expressed in dbm.

### 3.1 Formulating the Problem

The uplink transmitting rate for channel capacity according to Shannon- Heartly theorem for the \( c^{th} \) CU is

\[ T^{ul}_{c} = \frac{B_w \log_2 (1 + \text{SINR}^{ul}_{c})}{} \] (7)

Here \( B_w \) is SCs Bandwidth.

In the same way, the transmitting rate of downlink for channel capacity is

\[ T^{dl}_{c} = \frac{B_w \log_2 (1 + \text{SINR}^{dl}_{c})}{} \] (8)

The transmitting rate for the \( D^{th} \) D2D pair is

\[ T^{ul/dl}_{d} = B_w \log_2 \left( 1 + \text{SINR}^{ul/dl}_{d} \right). \] (9)

The System Throughput on the whole may be expressed as

\[ T^{ul/dl}_{\text{sum}} = \sum_{c \in cu} \left( T^{ul}_{c} + T^{dl}_{c} + \sum_{c \in d2d} \mu_{c}^{ul/dl} T^{ul/dl}_{t} \right). \] (10)

For getting the optimum solution for allocating sub-channel as well as transmitting power- rather the joint resource allocation (the JRA approach), which will lead to improved maximizing of throughput of the network by the use of the joint allocation technique as

\[ \alpha_{1}: \max_{\mu, p} T^{ul/dl}_{\text{sum}} \] (11)
Subjected to the following constraints

\[ L_1: T_{c_{ul}} \geq \beta_{c_{ul}}, T_{c_{dl}} \geq \beta_{c_{dl}}, \forall c \in s_{cu} \]  

\[ L_2: T_{d_{ul/dl}} \geq \beta_{d_{ul/dl}}, \forall d \in s_{d2d}, \]  

\[ L_3: 0 \leq p_c \leq p_{c_{max}}, \forall c \in s_{cu}, \]  

\[ L_4: 0 \leq p_d \leq p_{d_{max}}, \forall d \in s_{d2d}, \]  

\[ L_5: \mu_{d,c_{ul}}, \mu_{d,c_{dl}} \in (0,1), \forall c \in s_{cu}, \forall d \in s_{d2d} \]  

\[ L_6: \left( \sum_{c \in s_{cu}} \mu_{d,c_{ul}} \right) \left( \sum_{c \in s_{cu}} \mu_{d,c_{dl}} \right) = 0, \forall d \in s_{d2d}. \]  

In the optimization problem for \( \alpha_1 \), \( \mu \) is the binary variables’ set which indicates assigning SCs for pairs of D2D; \( P \) stands for the transmitting power set for CU as well as DTx., \( L_1 \) is the constraint stand for the minimal transmission rate needed for CUs (reusing downlink as well as uplink situations). \( L_2 \) is the constraint ensuring the required minimum rate of transmitting for D2D pair in downlink-uplink reusing cases. \( L_3 \) as well as \( L_4 \) are the constraints controlling the maximal transmitting power for both CUs as well as DTx. This is due to the fact that practically speaking the levels of maximal power of amplifiers are limited. \( L_5 \) is the constraint ensuring the reusing of binary parameters. \( L_6 \) is the constraint indicating that DTx has permission to reuse downlink or uplink CU resources in a simultaneous way. One may presume that any one of the sub-channels of CUs can be reused by multiple DTx.

From (11) to (17), \( \alpha_1 \) tends to be the MINLP optimization problem that poses tough work to solve directly. This is due to having differing variables. Also, it is in a continuous way [12]. The \( L_1 \) as well as \( L_2 \) constraints are continuous. But, they are non-convex [30]. Apart from that, the optimizing problem variable \( \mu \) reuse parameters have values that are discrete. In such a situation, the Hungarian algorithm is proposed for getting an improved solution that is near-optimal. The stated tough NP-hard optimizing problem is subdivided into two sub-problems for bringing down the complexity. To begin with, assigning sub-channels is done. Then allocation of power are done. Hence, a dual iterating technique is brought in, to sequentially perform the SCs assigning and then power allocation.

### 3.2 SC Assignment Stage

A dual optimizing technique is ushered in by [24-25], [29-30] and it is given to find the optimal solution for Hungarian in \( \alpha_2 \) with computational complexities which can be solved. It begins doing SC assignment in 3-A. Subsequently, the power allocation issue is handled in 3-B. It is carried out using the SC assigning outcomes.
To arrive at an improved solution for the issue of assigning SC, yet another technique is identified. That is, relax the constraint L5 in a position the integer variables $\mu$ could get changed to a continuous form as shown below:

\[
L_7: 0 \leq \mu_{d,c}^{ul} \leq 1, 0 \leq \mu_{d,c}^{dl} \leq 1, \forall c \in s_{cu}, \forall d \in s_{d2d}.
\]  

(18)

Then, L5, the constraint in (16) would be modified as a replacement utilizing constraint L7 in (18). Next, algebraically a few manipulating steps are carried out on the constraints L1 and also L2. The optimization problem can be modified as

\[
\alpha_2: \max_{\mu, p} T_{\text{sum}}^{ul/dl} (\mu, p) \quad (19)
\]

Subjecting to

\[
L_9: 2 \beta_{c, u} B (\text{SINR}_{c}^{ul}(\mu, p)) \leq 1, 2 \beta_{c, d} B (\text{SINR}_{c}^{dl}(\mu, p)) \leq 1, \forall c \in s_{cu} \quad (20)
\]

\[
L_{10}: 2 \beta_{d, u} B (\text{SINR}_{d}^{ul}(\mu, p)) \leq 1, \forall d \in s_{d2d} \quad (21)
\]

Yet, $\alpha_2$ is a non-convex optimizing problem. There is difficulty in finding out an optimal solution to $\alpha_2$. Hence a [12] JUDRA is used for obtaining the solution. Hence, the optimized solution in the proposal follows the identical JUDRA method utilizing the assigning algorithm of Hungarian type for finding the optimized solution.

The scheme in the proposal is a combination-type optimizing algorithm for solving the problem that is used for assigning; it is in polynomial time.

Now, the optimization problem which gets modified to the nth iteration is expressed as

\[
\alpha_3: \max_{\mu, p} T_{\text{sum}}^{ul/dl(n)} (\mu, p) \quad (22)
\]

Subjected to

\[
L_{10}: 2 \beta_{c, u} B (\text{SINR}_{c}^{ul(n)}(\mu, p)) \leq 1, 2 \beta_{c, d} B (\text{SINR}_{c}^{dl(n)}(\mu, p)) \leq 1, \forall c \in s_{cu} \quad (23)
\]

\[
L_{11}: 2 \beta_{d, u} B (\text{SINR}_{d}^{ul(n)}(\mu, p)) \leq 1, \forall d \in s_{d2d} \quad (24)
\]
The optimizing Problem $\alpha_3$ still remains a non-convex kind. [12] By utilizing the main geometric programming principles it can be stated that it is in the equivalent form of $\alpha_3$ and it is in convex form.

The convex form equivalent to the optimization problem can be expressed as

$$\alpha_4: \max_{\bar{\mu}, \bar{p}} \sum_{S_{\text{sum}}} (\text{exp}(\bar{\mu}), \text{exp}(\bar{p}))$$  \hspace{1cm} (25)

Subjected to

$$L_{12}: 2 \frac{\bar{\beta}_{c}}{B} \left( \text{SINR}_{c}^{u} \text{exp}(\bar{\mu}), \text{exp}(\bar{p}) \right) \leq 1, 2 \frac{\bar{\beta}_{c}}{B} \left( \text{SINR}_{c}^{d} \text{exp}(\bar{\mu}), \text{exp}(\bar{p}) \right) \leq 1, \forall c \in S_{\text{cu}}  \hspace{1cm} (26)$$

$$L_{13}: 2 \frac{\bar{\beta}_{d}}{B} \left( \text{SINR}_{c}^{u} \text{exp}(\bar{\mu}), \text{exp}(\bar{p}) \right) \leq 1, \forall d \in S_{d2d}  \hspace{1cm} (27)$$

$$L_{14}: 0 \leq \text{exp}(\bar{p}_c) \leq p_{c}^{\text{max}}, \forall c \in S_{\text{cu}},$$  \hspace{1cm} (28)

$$L_{15}: 0 \leq \text{exp}(\bar{p}_d) \leq p_{d}^{\text{max}}, \forall d \in S_{d2d},$$  \hspace{1cm} (29)

$$L_{16}: \bar{\mu}_{d,c}^{ul}, \bar{\mu}_{d,c}^{dl}, \bar{\mu}_{d,c}^{ul/dl} \in \{0,1\}, \forall c \in S_{\text{cu}}, \forall d \in S_{d2d}. \hspace{1cm} (30)$$

$$L_{17}: \left( \sum_{c \in S_{\text{cu}}} \bar{\mu}_{d,c}^{ul} \right) \left( \sum_{c \in S_{\text{cu}}} \bar{\mu}_{d,c}^{dl} \right) = 0, \forall d \in S_{d2d}. \hspace{1cm} (31)$$

The equation (25) is a convex type optimizing problem $\alpha_4$. Hence, it may be improved to the near-optimal solution utilizing the Hungarian method in the proposal. It can be seen from the analysis mentioned above, the SCs assignment is carried out utilizing the assigning algorithm of the Hungarian type.

Algorithm 1. Hungarian Resource Allocation Algorithm

1. Initialize the parameters $S_{\text{cu}}$: The set of CU users $S_{d2d}$: The set of D2D pairs

2. Function [Assignment Channel, Power]: Hungarian (rszie, cszie)

3. Assignment data (Channel, Power) = Assign (rszie, cszie [0,1])

   // Subtracting row minima from in each row wise…

4. While (1)

5. Find minimum value Among rows then Row result= Assignment data-min value of row
//Repeat the same process for column section
//Subtracting column minima from each column wise.

6. Assignment [row, column] = Size (Assignment)
7. count=0
8. for S_{cu}, S_{d2d} = 1: row.
9. If (Throughput = 0: condition)
10. count=count+1
11. end
12. end
13. count c=0
14. for S_{cu}, S_{d2d} = 1: column
15. If (condition)
16. end
17. end
18. if (count row= row && count column=column)
19. Break the loop if condition is not satisfied
20. end
21. end
22. Get Final Assignment data = Resultant Optimal solution.
23. // Complete the resources using Hungarian algorithm until the number of total channels is 0
24. // Complete the joint downlink and uplink subchannel allocation.
25. // The System throughput capacity depends on the sum function.

3.3 Power Allocation

In the Hungarian second stage, the power allocation utilizes the optimization solution for SC assignment
is obtained from 3-2. Now, CUs set could be defined and DTx after SC assigning task as s_{cu} and s_{d2d}.
It is in such a way that the forming of a problem with power allocation could be expressed as

\[ \alpha_5: \max_p T_{sum}^{ul/dl} \]  

Subject to constraints

\[ L_{18}: T_{c}^{ul} \geq \beta_{c}^{ul}, T_{c}^{dl} \geq \beta_{c}^{dl}, \forall_c \in s_{cu} \]  

\[ L_{19}: T_{d}^{ul/dl} \geq \beta_{d}^{ul/dl}, \forall_d \in s_{d2d}, \]  

(32)  

(33)  

(34)
\[ L_{20}: 0 \leq p_c \leq p_c^{\text{max}}, \forall c \in s_{cu}, \]  
\[ L_{21}: 0 \leq p_d \leq p_d^{\text{max}}, \forall d \in s_{d2d}, \]  

Where,

\[ T_{\text{sum}}^{ul/dl} = \sum_{c \in s_{cu}} (T_c^{ul} + T_c^{dl} + \sum_{c \in s_{d2d}} T_t^{ul/dl}). \]  

\[ T_c^{ul} = B \log_2(1 + \text{SINR}_c^{ul}), \]  
\[ T_c^{dl} = B \log_2(1 + \text{SINR}_c^{dl}), \]  

And

\[ T_d^{ul/dl} = B \log_2\left(1 + \text{SINR}_d^{ul/dl}\right). \]  

From the above equations, SINR later to assigning SCs could be expressed as follows:

\[ \text{SINR}_c^{ul} = \frac{p_c |h_{c,b}|^2 a_{c,b}^{-\beta_1}}{I_{t,b}^{ul} + \beta_2^2}, \]  
\[ \text{SINR}_c^{dl} = \frac{p_b |h_{b,c}|^2 a_{b,c}^{-\beta_1}}{I_{t,c}^{ul} + \beta_2^2}, \]  

And

\[ \text{SINR}_d^{ul/dl} = \frac{p_b |h_{t,r}|^2 a_{t,r}^{-\beta_1}}{I_{c,r}^{cu} + I_{p,r}^{d2d} + I_{k,r}^{ul/dl} + \beta_2^2}. \]  

The problem of optimizing in \( \alpha_5 \) is non-convex in nature. The problem \( \alpha_5 \) resembles the problem defined in \( \alpha_1 \) with the exception that \( \alpha_5 \) is including the solution of the assignment of SCs. Hence, algorithm 1 is applied directly to the power allocation to obtain the solution. The solutions realized are the optimized solutions for the components of power for CUs as well as DTx. To make it brief, the lengthy derivations to allocate power are not shown.

4. Results and Discussion

The simulation is compared with the existing joint resource allocation technique, and it is given in [12] and that multiple D2D link pairs residing in a cell region will recycle the transmission cellular resources at the same time. However, each cellular user and D2D pair in the same region of a cell causes interference. During the stage of assignment of SC, the prime complexity of computation will be in observation in every iterative step and the solution that is optimized for problem 4 has arrived. The solution for the problem of convex optimization is obtained; its complexity in computation can be the number of inequality constraints as well as variables. Hence, there is complexity in computation. It is to be solved in every iterative step. The stage of allocating power is utilized for solving the updated problem L5.
At the time of the stages of assignment of SC as well as allocating power, the number of iterative steps needed depends on the precision of convergence, i.e., the value of $\beta_3$. The results section contains the analysis of the level of tolerance. The simulation parameters used in this proposed research are given in Table 2.

**Table. 2 Simulation Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius of the cell</td>
<td>500m</td>
</tr>
<tr>
<td>D2D link distance</td>
<td>50m</td>
</tr>
<tr>
<td>Set of Cellular users</td>
<td>C=50</td>
</tr>
<tr>
<td>Set of Device (DTx) users</td>
<td>D=50</td>
</tr>
<tr>
<td>Sub channel bandwidth</td>
<td>312.5 kHz</td>
</tr>
<tr>
<td>Pathloss Constant</td>
<td>0.01</td>
</tr>
<tr>
<td>Maximum eNB Transmission Power</td>
<td>43 dBm</td>
</tr>
<tr>
<td>Maximum CU Transmitted Power</td>
<td>23 dBm</td>
</tr>
<tr>
<td>Maximum Device Transmitted Power</td>
<td>21 dBm</td>
</tr>
<tr>
<td>Maximum D2D Transmitted Power</td>
<td>15 dBm</td>
</tr>
<tr>
<td>Minimum Downlink rate requirement</td>
<td>2bps/Hz</td>
</tr>
<tr>
<td>Minimum Uplink rate requirement</td>
<td>2bps/Hz</td>
</tr>
<tr>
<td>Minimum D2D rate requirement</td>
<td>2bps/Hz</td>
</tr>
<tr>
<td>Pathloss exponent</td>
<td>4</td>
</tr>
<tr>
<td>Tolerance factor</td>
<td>0.01,0.001</td>
</tr>
<tr>
<td>Noise Power</td>
<td>-174 dBm per Hz</td>
</tr>
<tr>
<td>Simulation Type</td>
<td>MATLAB</td>
</tr>
</tbody>
</table>

This part of the report is containing simulated outcomes to verify the proposed Hungarian technique’s performance metrics. The simulated results obtained from [1] and [20] are taken into consideration. They are depicted in Table 2. MATLAB is employed for obtaining the simulated outputs utilizing the Manto Carlo technique. The corresponding average is depicted as a plot centered on the corresponding results. The simulated outcomes of the proposed Hungarian technique are weighed against the existing JUDRA [12] method. Based on the only uplink resource allocation (OURA), D2D clients could use again only uplink CU resources. If not, only the downlink resource allocation (ODRA) could use again the CUs downlink resources via communication of D2D.

The method in the proposal is allowing the D2D clients for sharing the existing either uplink or downlink cellular resources to be reused by D2D communication effectively.
Fig. 3. Convergence speed of Objective Function ($\alpha_2$) at Sub-channel Assignment.

Fig. 3 shows the convergence speed of the objective function ($\alpha_2$) value at the sub-channel assigning stage. In Fig. 3 the two-difference tolerance ($\beta_3$) levels i.e., $\beta_3=0.01$ and 0.001 for SC assignment with various cellular (C) users and D2D users (D) are considered. The first situation is $\beta_3=0.01$, C=30 & D=10, $\beta_3=0.01$, C=50 & D=30. A smaller number of C and D users provides maximum throughput utilization. We know that the capacity of a wireless network is determined by three important factors: the tolerance factor, the number of users who consumed energy, and bandwidth channel utilization.

In the second situation $\beta_3=0.001$, C=30 & D=10, $\beta_3=0.001$, C=50 & D=30. The simulated outcomes infer that the convergence speed is exceedingly dependent upon the tolerance factor $\beta_3$ level. It is achieving improved outcomes with minimum convergence speed with equivalent tolerance levels [3]. As it is observed, if the convergence speed is increased, power consumption is also increased, which tends to make efficient resource allocation impossible. The JUDRA approach [12] clearly takes a faster convergence speed into account than the proposed Hung scheme, and the maximum convergence speed will also consume more power. Hungarian takes only a minimum speed of 2750 dBm into account to achieve comparable results (even better for various tolerance levels of 0.01 and 0.001).
Fig. 4 illustrates the objective function’s ($\alpha_2$) convergence speed value updated at the time of allocating power. In Fig. 4, the tolerance ($\beta_3$) levels are considered i.e., $\beta_3=0.01$ and 0.001 for allocating power with differing Cellular as well as D2D clients. Starting with the situation $\beta_3=0.01$, C=30 & D=10, $\beta_3=0.01$, C=50 & D=30. According to Fig. 4, if the number of cellular and D2D users increased linearly, throughput would degrade, which makes it challenging to obtain efficient resource allocation. The tolerance factor is a variable parameter used to improve network throughput. We can observe that the updated power allocation stage required fewer iterations to achieve the same results because it utilized the results of the SC assignment stage.

Next situation is $\beta_3=0.001$, C=30 & D=10, $\beta_3=0.001$, C=50 & D=30. The simulated outcomes infer that the speed of convergence exceedingly depends on the tolerance factor $\beta_3$ level. One can conclude that the convergence speed completely depends on the tolerance factor, $\beta_3$. The iterations’ count needed is small for the stage at allocating power when compared with the assignment of SC. This is because allocating power utilized the results gathered during the stage of assignment of SC. It is nearer to the better-optimized solution. The proposed Hungarian method achieved better results with a minimum convergence and a maximum speed of 5000 dBm, compared to JUDRA with the same scenario [12].
Fig. 5 depicts the network’s throughput bits per second (bps) with various D2D link distances. The proposed scheme allows a greater number of D2D candidates to reuse the resources either downlink or uplink available cellular user CU sub-channels. So, it performs only uplink or only downlink resource sharing at a time. The proposed Hungarian scheme performs better throughput up to a maximum of 4000 bps than the existing JUDRA [12] which performs less network throughput bps for the same D2D link distance of 100 meters maximum. The only Uplink resource allocation (OURA) provides better throughput than only downlink resource allocation (ODRA). It is because the evolved node (eNB) or BS in ODRA is transmitting larger energy than the CUs (in OURA). It causes interference at the receiving end. The transmitted power DTx possesses limited transmitting power having more d2d link distance which is why D2D communication prefers to underlay sharing for longer link distance. Fig. 5 concludes that network or system throughput degradation with the larger link distances. Lastly, Fig. 5 shows that the best throughput is achieved with the BS as close as possible.
Fig. 6 is indicating the throughput of the network with changing maximal DTx transmission power. Looking at Fig. 6 it could be confirmed that larger D2D underlay communication could be made with increased transmission power (DTx). JUDRA is performing with improvement with increased throughput compared with OURA or ODRA [12]. Also, it can be weighed with the proposed JUDRA scheme in Hungarian. It is the proposed method yielding better throughput (1200-2200) bps/Hz. As the maximum power transmission increases the network throughput also increases in a linear manner depending on the number of D2D users. At $P_{d_{\text{max}}}=15$ dbm, At $P_{d_{\text{max}}}=21$ dbm and At $P_{d_{\text{max}}}=27$ dbm, the throughput performance is different because maximum power transmission provides better network throughput for the same number of D2D users.
Fig. 7 indicates the network’s throughputs in bps/Hz with the various number of potential transmission power in dBm. The maximum number of D2D users having this ability allows more SCs to be re-used, resulting in higher network capacity gains. Fig. 7 depicts that as the potential D2D transmissions count is increased to 50 dbm, the throughput increases by 2500 bps/Hz. Therefore it is leading to a larger gain in network capacity. This is due to the fact that increased SCs are used again by more D2D clients. One can see that the D2D communication throughput ratio depends on how much power is sent from the base station. It is noticed that network throughput is having better growth with the number of potential DTx increments. The proposed Hungarian approach clearly outperforms compared to JUDRA [12], while at the same time, JUDRA is better than OURA or ODRA.
Figure 8 indicates the network’s throughput in bits per second comparison of the proposed Hungarian joint uplink-downlink resource allocation method with differing CUs’ counts which are active. So that only active CUs can share the reused resources to improve the network throughput. The network’s throughput is increased with a greater CUs’ count which is active. So that D2D underlay communications have a good chance of reusing the resources of CUs that are there. This is the reason that the system throughput is increasing rapidly. In the Hungarian scheme in the proposal, D2D candidates may reuse available downlinks or uplink CUs resources dynamically. It is observed that as the number of active CUs increased, the related network throughput also increased. The proposed approach provides up to 875 bps/Hz of throughput improvement over 30 active CUs. In [12], the existing JUDRA approach achieved lower network throughputs (bps/Hz) across 30 active CUs than the proposed Hung algorithm.
Figure 9 shows the network's throughput for different Radius of Cell RC= 300 meters, 500 meters and 800 meters with differing maximum transmitting power values of $P_{\text{d,max}}$, when maintaining the density of users as constant. The maximum transmitting power DTX received from the BS. The cell radius also plays an important role in achieving the maximum network throughput because interference will degrade the network throughput if the distance of D2D users from the BS is low and, in that case, the impact of the interference is also low. Such active D2D users are uniformly distributed in the cell coverage. Hence, farther the distancing from the BS or CUs amongst active clients drastically brings down the impact of interference. Comparing the network throughput it is found to depend upon the differing values of the radius of the cell for differing transmitting power. One can observe from Fig. 9 that the larger cell radius (RC = 800 m) provides maximum throughput over the smaller cell radius (RC = 500 m and RC = 300 m) cases. So, in the case where RC = 800 meters, the maximum distance, system, or network throughput gets better. Hence the system throughput or throughput of network performances is better. Figure 9 depicts it.
The results of Fig. 10 show various transmission powers that are \( P_d \text{max} = 15 \) dBm, 21 dBm and 27 dBm with different D2D link distances in meters. The comparison of the network’s throughput with differing D2D link distances is provided based on \( P_d \text{max} \) values. We noticed that the \( P_d \) maximum of 15 dBm provided maximum network throughput, i.e., 2350 bps/Hz, over the \( P_d \) maximum of 21 dBm and the \( P_d \) maximum of 27 dBm because of the link distance away from the BS. We have compared the results of the [12] JUDRA scheme, where network throughput is bps/Hz for 100 meters of link distance for different transmitting power levels (\( P_d \text{max} = 15, 21, \) and 27 dBm values). Clearly, the proposed-hung approach provides better results than the existing JUDRA, and from [12], JUDRA is much better than OURA or ODRA.
Fig. 11. Network Throughput (bps/Hz) for different Cell Radius with different link distances (meters).

Fig. 11 shows that the throughput of the network depends on different cell radius values at RC=300 meters, 500 meters and 800 meters for different D2D link distances in meters. Fig. 11 depicts that for a link distance of 50 m, the Hungarian method in the proposal is offering throughput of the network: 1650 bps/Hz, 2030 bps/Hz, 2150 bps/Hz, for RC=300 meters, 500 meters and 800 meters respectively. These are much higher than the existing ones in the same scenario JUDRA [12]. It is observed that for small cell radius values, the throughput of the network decreases. With a higher radius of cell values like RC=800 meters, the throughput of the network is increasing as compared to the RC=300 meters. So, it can be concluded that in Fig. 10 and Fig. 11, the network throughput completely depends on the maximum transmission in dbm and cell radius values in meters. And notice that as the link distance for D2D increases, the network throughput decreases drastically.
Figure 12 shows the throughput of the network for differing CUs maximal transmitting power. It is noticed that the proposed Hungarian approach uplink network throughput is increasing, and at the same time, the proposed downlink network throughput is decreasing with the increased CUs transmission power $P_c^{\text{max}}$. The first reason may be CUs utilize extra resources for transmitting with larger $P_c^{\text{max}}$. The second reason is that the downlink-transmitting task experiences more interferences. At any one stage, both uplink and downlink resources will meet at a point in the joint resource allocation approach. The proposed scheme gives a maximum network throughput of 630 bps/Hz over 30 active CUs at maximum transmission power. This is clearly better than the current JUDRA [12].
Fig. 13 indicates the throughput of the network for the different maximum BS transmitting powers. In Fig. 13 uplink network throughput is decreasing due to the interferences at the CUs increasing with transmission power $P_b$ max. On the other hand, downlink network throughput increases while CUs may be served because of increasing $P_b$ max value. Hence throughput increases. We can see that [12] the JUDRA has a lower network throughput, whereas the proposed scheme has the highest downlink and uplink network throughputs (450 bps/Hz and 490 bps/Hz, respectively).
Fig. 14 depicts the network throughput for various transmitting power. In Fig. 14, as the transmitting power is increased for D2D, the throughput of the network too increased. The network throughput achieved (2150 bps/Hz) is better than the JUDRA for a similar number of D2D DTx maximum power transmissions in dBm. The performance of the Hungarian approach is compared with the existing JUDRA [12]. The method in the proposal yielded improved results overall as far as network throughput of CUs as well as DTx and QoS is concerned. The throughput obtained from the method of Hungarian is nearer to the optimized solution. The proposed method produced better overall results in terms of CU network throughput and DTx, and the quality of service and network throughput bps/Hz obtained from the proposed scheme are closer to the optimal solution.

5. Conclusion

The Hungarian scheme in the proposal is utilizing the uplink or downlink CU channels present in an efficient manner. Maximizing the throughput of the system is resolved by considering the constraints of power for transmitting as well as reuse gain factors. These render the problem of optimization very hard to find a solution for. So, a couple of subproblems are formed. Then a solution is found. First Sub-channel Assignment is performed using the Hungarian algorithm. Next, the results found are utilized to realize a better-optimized solution for allocating power. The set of D2D users and cellular users at the same time can share the constant transmission of cellular resources. The network throughput and overall system performance are mathematically evaluated and simulated using Monte Carlo simulation. It is shown that the proposed technique maintains higher network throughput. The analytical and simulation results showed a
promising resolution for accommodating demands for network throughput services. We can conclude that the network throughput depends on so many factors, like the number of active CUs, the link distance between cellular users and D2D users, the cell radius, the maximum transmitting power of BS, CUs, and D2D, etc. In the future, this work can be extended to a multi-cell scenario for a D2D communication environment.

-Ethical Approval and Consent to participate: Not applicable
- Human and Animal Ethics: Not applicable
- Consent for publication: I, the undersigned, give my consent for the publication of identifiable details, which can include photograph(s) and/or videos and/or case history and/or details within the text ("Material") to be published in the above Journal and Article.
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