Selective Overlay Mode Operation for D2D Communication in Dense 5G Cellular Networks

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Selective Overlay Mode Operation for D2D Communication in Dense 5G Cellular Networks

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***Abstract*—Fifth generation (5G) cellular networks would include millimeter wave (mmWave) for communication which gains the advantage of extensive frequency reuse and directive propagation. The recent trends in device-to-device (D2D) communication have escalated the importance of proximity based services for next generation cellular systems. The integration of mmWave and D2D technology will improve the performance and spectral efficiency greatly. In areas with high call traffic density, D2D communication can operate in overlay mode giving the advantage of low complexity interference avoidance technique. The complexity is decreased as the resources to overlay mode are dedicated resulting in no interference from cellular user unlike in underlay mode. Such a scenario is considered in this paper where interference management between D2D devices sharing same radio resources plays a key role in system performance. Thus, the inband resources for D2D operation selectively switch to overlay mode in based on the call traffic. Two problems are addressed in this paper. Firstly, assigning the resources for overlay mode which is solved using quadratic programming. Next, the problem is formulated to maximize system capacity in overlay mode which is solved using a heuristic algorithm which is simulated. The proposed scheme has optimal performance for dense network in controlled overlay operation for 5G networks. The scheme also overcomes the problem of spectrum wastage in overlay mode by its selective operation.**

I. Introduction

The recent innovations and technological developments in the field of communication focus on serving the ever growing demand for bandwidth. Along with the advancement in bandwidth intensive applications, the number of devices per unit area is also increasing drastically. The current fourth generation (4G) cellular systems using the technologies like OFDM, MIMO, massive small cell deployment, heterogeneous network (HetNet) and relays could improve the spectral efficiency but would not be able to serve the increasing demand for higher bandwidth. Therefore, the fifth generation (5G) cellular technology would be developed to overcome the spectrum shortage and serve more number of users, beyond 4G. The 5G technology would exploit mmWave spectrum for communication, where the spectrum is unparalleled compared to the cellular systems operating in microwave frequencies [1]. The mmWave carrier has poor propagation because of oxygen absorption effect, more free space path loss, decreased signal penetration through obstacles, high gain antenna requirements for directional communication and ISI due to many reflective paths over massive operating bandwidths. These propagation characteristics are advantageous for short range communication where a loss of 20 dBm/km is negligible for communication within 100 m distance [2]. This enables aggressive spatial reuse with simultaneously operating networks with interference avoidance, highly directional antennas and beam forming techniques which are used to mitigate path loss. The outdoor propagation at and above 28 GHz is realizable when taken the advantage of rich multipath propagation to improve the received signal strength [3].

In 4G networks, device-to-device (D2D) communication is admitted to be a feasible solution to overcome the spectrum scarcity [4]. In D2D communication, two cellular users in proximity communicate with each other directly without traversing the base station. The next generation cellular systems employing D2D communication can support the huge demand for bandwidth and improve the spectrum efficiency to a great extent. In [5], [6] D2D communication is discussed as a disruptive technology direction for 5G. D2D communication can be centralized by base station control or can be decentralized [7]. D2D communication in licensed spectrum is termed as inband operation and using unlicensed spectrum as outband operation. Inband operation can reuse the resources of cellular user called the underlay mode or may operate on dedicated resources from licensed band called the overlay mode [4]. In underlay mode, interference management and resource management of the licensed spectrum plays a key role. Recent innovations focus on addressing these problems in underlay mode [8], [9]. Underlay mode provides good spectral efficiency and QoS when the interference is managed well along with an efficient resource allocation scheme [10]. In overlay mode, some part of the licensed spectrum resources are dedicated for D2D communication. Overlay mode simplifies the resource allocation procedure as interference from the cellular user is absent but the spectrum resources are wasted in the absence of D2D users. However, overlay mode can achieve better throughput performance [11].

In this paper, we try to gain the advantage of both the underlay and overlay mode of operation for inband D2D communication. Overlay mode is selected by the base station in case of dense traffic scenario. Most research simplifies the interference management scheme by allocating a cellular user resource to at most two D2D pairs in underlay operation [8], [12]. The uplink performance metrics for underlay D2D are discussed in [13] which focus on the effect of interference from adjacent D2D user. This work emphasizes to improve

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the spectrum utility, when large number of devices are in proximity D2D can switch to overlay mode with efficient method of power control with distance while managing the interference below the threshold level. For instance, consider a scenario inside a multi-storey building where the call rate is high per unit area. In such a case, overlay resources can be used by the devices in proximity. However, overlay resources for D2D operation are not limited to these areas but can be reused by the base station after the minimum reuse distance. This helps to decrease the complex computations at the base station and also avoids causing uplink interference to the base station. For example, a building with $10,000m^2$ area may fall into a sector of a cell with 500m coverage radius (3 sector cell model) and can be provided extensive connectivity with overlay resources. The dense area may not necessarily include indoor propagation for communication and may have call requests from an outdoor areas as well. We selected mmWave for communication because of its advantage of frequency reuse and more number of available resources compared to LTE-A in 4G. The main problem to be addressed in overlay mode is the underutilization of spectrum resources in the absence of D2D users. Hence to improve the spectrum utility and reduce the spectrum wastage, some amount of resources are assigned to overlay mode which can be reassigned based on traffic demand. The amount of spectrum dedicated for overlay operation depends on the historical data of call traffic. We provide a prediction based model for resource assignment in overlay mode.

The rest of the paper is organized as follows. Firstly, we describe the system with suitable assumptions. Next, the problem of resource assignment to overlay mode is addressed and solved using quadratic programming with suitable result. Later, a resource management scheme for D2D in overlay mode is proposed and simulated. Finally, the work is summarized providing key conclusion remarks.

II. System Description and Assumptions

Millimeter wave channel is considered for communication through the base station. The instantaneous channel state information (CSI) is available at the base station to have the knowledge of gain between the links established. The base station (BS) coordinates all the communication within the cell.

A. Network Model

A single cell environment in 5G cellular network covering two areas with dense call traffic is considered in this paper. Let K number of D2D users be served in the dense areas. After the minimum reuse distance devices can operate in cellular mode or in underlay mode if in proximity. We emphasize the case when a single resource block is shared by K number of users in overlay mode and after minimum reuse distance, used by other user equipment. In such a scenario, where the radio resources are shared between D2D users in overlay mode, interference must be maintained below a threshold level by controlling the transmit power of D2D users. Figure 1 shows such a network model. The total D2D connections

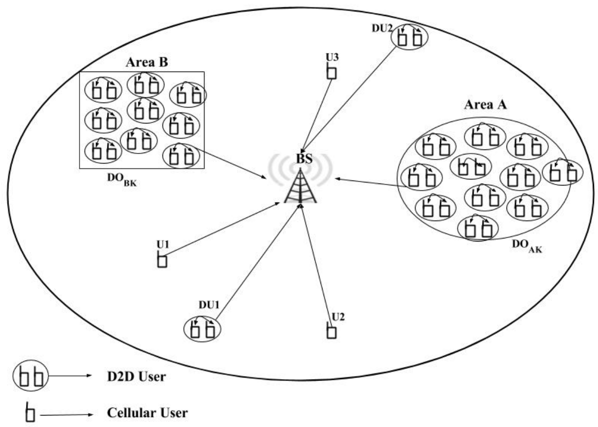

Fig. 1: System model for multiple D2D connections in a cell illustrating interference between D2D users in Area A and Area B

in Area A are DO_{AK} and in Area B are DO_{BK} sharing a single resource block. U_1, U_2 and U_3 are user equipment operating in cellular mode after the minimum reuse distance. DU_1 and DU_2 are D2D users operating in underlay mode by maintaining their interference below the threshold of cellular mode users. The Area A and Area B are densely populated which use dedicated resources in overlay mode. During indoor propagation of mmWave in overlay operation, the radio wave experiences high path loss when it encounters an obstacle. This also turns to be an advantage of decreasing interference to adjacent D2D pair. Interference can not only be managed by the transmit powers but also can be managed by the distance of separation spatially between two D2D pairs. In this paper, we assume the maximum distance of separation between devices D2D communication to be 20m [14], as an increase in this distance trades off with the degrade in system performance. It is also assumed that instantaneous CSI is available for communication. In [15], an approach for resource allocation in underlay mode is proposed with statistical CSI. However, this increases complexity in the implementation algorithm. In 4G systems, instantaneous CSI can be obtained using reference signals. In this paper, the resource allocation procedure is carried out with an assumption of availability of instantaneous CSI.

B. Channel Model and Achievable Data Rate

In a 5G cellular network, all the D2D connections use the same air interface and the licensed band for operation. The base station serves a set of $B = \{b_1, b_2, ..., b_B\}$ resource blocks (RB) in total which are available for allocation. Each RB corresponding to a bandwidth of bw_n. The RB available for overlay mode is a set of $M = \{m_1, m_2, ..., m_k\}$, which serves K number of D2D users in overlay mode. Each resource block allocated is separately denoted as rb_n, where the index n varies. Then, the bandwidth of a single resource block will be a product of rb_n and bw_n. With such a high user density and high amount of interference, the transmission is affected by multi-path fading and path loss shadowing. The licensed bands for mmWave are 28GHz, 38GHz and 72GHz which are selected to provide better QoS [1]. The densely populated areas operating in overlay mode need not necessarily be indoor. The signal experiences path loss with both line of sight and non-line of sight components which correspond to their log-normal shadow fading [3]. Multi-path fading in mmWave systems is a Rician channel [1]. The received signal at a D2D receiver is,

$$y_d = \sqrt{P_d} H_{dd} D_d + \sum_{d'=1} [x_{dd'} \sqrt{P_{d'}} H_{dd'} D_{d'}] + N_n \quad (1)$$

where, P_d and $P_{d'}$ corresponds to the D2D equipment transmit power and transmit power of another D2D equipment sharing the same RB respectively. H_{dd} is the channel gain of D2D pair link and $H_{dd'}$ is the channel gain between one D2D pair and another D2D pair. D_d and $D_{d'}$ is the transmit data from the devices. $x_{dd'}$ is a binary variable which is set to 1 if another D2D pair, d' is allocated the same RB as that used by D2D pair d. N_n is the thermal noise in the channel. In order to take the advantage of spectrum utility, the D2D users (DU) are allowed to reuse the resources until the signal to interference and noise ratio (SINR) requirement is fulfilled. The SINR must be maintained above a threshold level, γ_d^{th}.

$$\begin{aligned} \gamma_d =& \frac{P_d H_{dd}}{\sum_{d'=1}^{K} [x_{dd'} P_{d'} H_{dd'}] + N_n} \\ &\geq \gamma_d^{th}, \end{aligned} \quad (2)$$

where, $d = 1, 2, ..., K$. Here, unlike in underlay mode, the interference to cellular user will not exist. This decreases the complexity in SINR calculation to a great extent, thereby decreasing the computation burden to the base station and facilitating short scheduling time. The achievable data rate can be defined by Shannon capacity model, which assumes the D2D transmitter attain near channel coding capacity. Hence the data rate achievable is a close approximate to capacity, and is as follows:

$$R = \sum_{n=1}^{B} (bw_n)(rb_n) \log_2(1 + \gamma_{dn}) \quad (3)$$

Where, γ_{dn} is the SINR of nth user, which can be approximated to average SINR denoted as γ_d. rb_n denotes number of resource blocks of band width bw_n allocated.

III. Resource Block Allocation to Overlay Mode

The inband operation of D2D connections are given dedicated resources when there exists high call traffic density. The problem thus arises for the assignment of optimum number of RB to overlay mode such that the resources are well managed and our aim for better spectrum utility is fulfilled. In order to avoid the spectrum wastage, based on historical data in the cells, the future requests can be predicted and resources can be assigned dynamically. Based on the historical data collected over regular intervals of time for considerable spatial separation, the areas with dense call traffic can be predicted.

A. Problem Description

The problem addressed in this section focuses on maximizing the number of resource blocks for overlay operation in a cell over an interval of time. Historical data is employed such that it captures the spatio-temporal correlations in the traffic data within a cell. Thus, based on this data, the joint probability mass function (PMF) is estimated. Considering a single cell scenario, a cell coverage area can be divided into three sectors. With such a three sector cell model, we get the values of probabilities p_1, p_2 and p_3, which correspond to the call traffic density in that particular sector and are sorted in increasing order. Here, the RB allocation depends on the number of D2D requests. In order to maximize the RB allocation, more RB must be assigned to the area with higher probability. We formulate the problem to maximize average number of RB assigned for overlay mode dynamically based on traffic.

Maximize:

$$\begin{aligned} Z &= E[RB_X] \\ &= X^T \widetilde{C} X \end{aligned} \quad (4)$$

Subject to:

$$\sum_{i=1}^{K} n_i = M \quad (5)$$

$$\sum_{d} x_d \; \epsilon \; \{0, 1\} \quad (6)$$

$$\sum_{d'} x_{dd'} \; \epsilon \{0, 1\} \; , d = 1, 2, ..., K \quad (7)$$

The objective function thus formulated is to maximize the expectation and equation (4) is solved using quadratic programming. The value of resources assigned to overlay mode are essentially integers. Thus, integer programming aids in finding an optimal solution. The constraint in (5) limit the number of assigned resource blocks to D2D users to M, the total available RB for overlay mode. The value of M depends on total call traffic in the cell. Based on the value of M, the overlay resources are assigned to D2D users. The constraint (6) is used so that each D2D user gets at most one resource block for operation. The constraint (7) is used so that at least one RB is shared among the D2D users. The constraints (6) and (7) play a vital role in overlay assignment after collection of the call traffic data as each resource can be reused by many D2D users.

B. Proposed Mechanism

The radio resources can be managed well when allocated optimum resources for overlay operation. The problem formulated in equation (4) is solved using quadratic programming. An additional constraint is imposed such that each variable, n_i gets at least one resource block corresponding to the probability p_i ($\forall p_i \neq 0$). Such a non-linear programming (NLP) problem can be solved using either deterministic (exact) algorithms or a heuristic algorithm. In this work, we use a deterministic algorithm to solve the problem called the interior-point method [16], [17]. The objective function along with the constrains is simulated and is presented in the results section. By using this mechanism for RB assignment for overlay mode, we find the optimum value of the objective function for the call traffic density variations over time.

IV. Resource Management in Overlay Mode

After the optimum assignment of resource blocks to overlay mode, the next problem to be addressed is to optimally share the resources among the D2D pairs for overlay operation fulfilling the SINR requirements.

A. Problem Description

The objective function in the overlay mode with mmWave propagation is to maximize the data rate of a D2D user. The necessary solution for the resource management problem is to share RBs with more number of admitted devices per unit area while the SINR is maintained above the threshold level.

$$Max \sum_{d=1}^{M} R = Max \sum_{n=1}^{B} (bw_n)(rb_n)\log_2(1+\gamma_d) \tag{8}$$

Subject to:

$$P_d H_{dd} \geq \gamma_d^{th} \sum_{d'=1} [x_{dd'} P_{d'} H_{dd'}] + N_n \ , d = 1,2,...,K \tag{9}$$

$$P_d \leq P_{dmax} \ , d = 1,2,...,K \tag{10}$$

$$P_d \leq P_{Bmax} \ , d = 1,2,...,K \tag{11}$$

$$\sum_{d'} x_{dd'} \geq 1 \ , d = 1,2,...,K \tag{12}$$

Where, $\widetilde{C}$ is the PMF matrix generated based on the probabilities p_1, p_2 and p_3 corresponding to the call traffic data. X is a three element matrix corresponding to the optimum RB assignment, RB_X, based on the $\widetilde{C}$. The constraints in (9) provide the target SINR requirement for D2D users. Constraints in (10) limits the maximum power transmitted by D2D transmitter less than the maximum allowed transmit power. Constraint (11) ensures that D2D power is maintained below the maximum base station transmission power, P_{Bmax} as D2D should communicate to devices in proximity and the BS signal should reach the cellular user equipment at a distance. The constraint (12) ensures that each D2D user shares at least one RB with other D2D user in overlay mode. The above formulated problem falls in the class of mixed non-linear programming. Such a problem is hard to solve within the scheduling time to be realistic. Hence, we propose a heuristic algorithm for resource block selection which allocates the overlay resources.

B. Proposed Heuristic Algorithm

During the uplink phase, the heuristic algorithm shown in Algorithm 1, provides resource sharing while maximizing the achievable rate. The main goal is to find the optimal usage of resources by controlling the transmit power with distance while accounting for interference mitigation. Consider the set N such that $\{N\} = \{M - L\}$. The set N consists of the RB which are not allocated to any D2D user in overlay and can be directly allocated to D2D pair as D2D communication provides high gain and low attenuation advantages when the interference is avoided. In this case, $x_{dd'} \rightarrow 1$. In this case, SINR decomposes to SNR. We define a set P be the list of D2D connection requests to be fulfilled and the optimal set of RBs for assignment is $U = u_1, u_2, ..., u_B$. We assume that $U_i \neq 0 \ , i = 1,2,..,B$ which implies that optimal set of resources are available for allocation. Here, the complexity decreases as only the interference because of D2D transmission needs to be calculated.

Algorithm 1 Resource Management Algorithm in Overlay

$x \leftarrow 1$
while $P \neq \phi$ and $x \leq M$ **do**
  if $N \neq \phi$ **then**
    Select a RB, n, $n \epsilon N$
    Solve (8) to (12)
    Assign n to D2D request
  else
    Solve (8) to (12) for selected RB, $m \epsilon M$
    if $\gamma_d \geq \gamma_d^{th}$ **then**
      Assign m to D2D request
    end if
  end if
  $x \leftarrow x + 1$
  Update: Update the list P and interference of RBs based on allocation.
end while
for $x == M$ **do**
  Ignore Overlay mode D2D connectivity and assign resources as per direct cellular user or as a D2D underlay user.
end

Two cases can be inferred from Algorithm 1 which are described as follows:

Case 1: A resource block can be assigned from the set N which contains unassigned overlay resources which can be assigned to the D2D requests without SINR calculation. This reduces computation complexity and helps in quick resource allocation. Since, all the D2D requests are handled by the base station, this kind of allocation felicitates to admit more D2D connections by fulfilling the D2D requests.

Case 2: A resource block can be assigned from the set of overlay resources which are already assigned to a D2D user. Here, the SINR for D2D connection must be calculated. However, unlike the case of underlay mode, in overlay mode

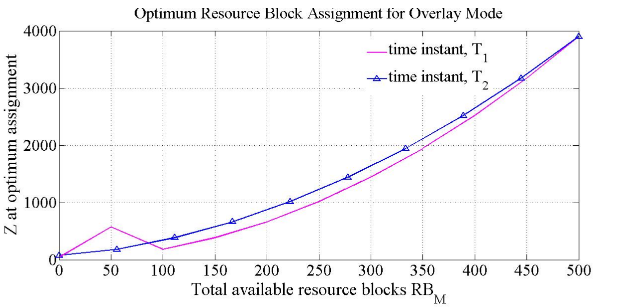

Fig. 2: Value of Z when optimum number of RB are assigned at different instants of time.

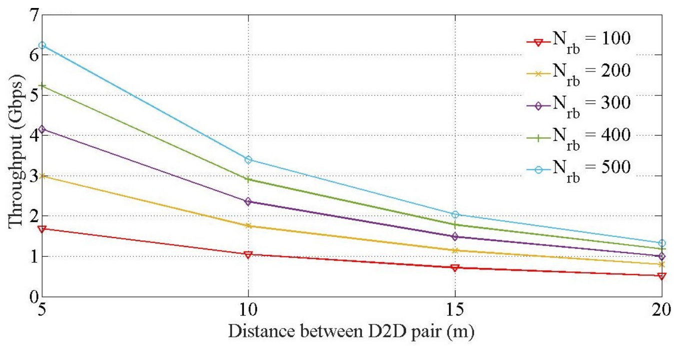

Fig. 3: System Throughput for varying distance between D2D pair and with fixed N_{rb}

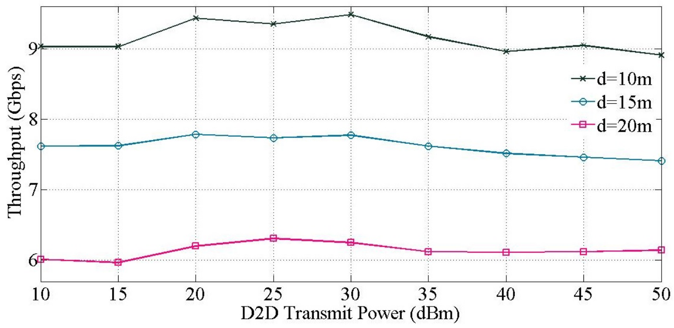

Fig. 4: System Throughput for varying transmit power and with fixed distance between D2D pair.

the cellular user interference is absent. This reduces the computation complexity in resource allocation.

The resource allocation procedure is carried out till all the resource blocks are checked for D2D connectivity. In case, no resource is allocated, the algorithm ignores Overlay mode D2D connectivity and switches to underlay D2D mode or cellular user connectivity. The algorithm is iterated till the set P, which represents the D2D requests becomes null set.

V. Results and Performance Analysis

A. Simulation Settings

A single cell is considered which is divided into three sectors of equal area. As discussed in [1], [3] mmWave outdoor propagation model is considered and the path loss is calculated. Let RB_M be the number of available resources in overlay mode. The simulation parameters are described in Table I. The optimum assignment of RB to overlay mode can be done using the method described in Section III. The system performance is analyzed using Monte Carlo simulations in Matlab.

B. Optimum Allocation of Resources to Overlay Mode

The problem for resource assignment to overlay mode is solved using quadratic programming. Fig.2 shows the optimized value of the objective function Z attained after optimum allocation of available channels to overlay mode when the available channels (depending on call traffic data) is varying. The curve is plotted for two instants of time, T_1 and T_2, when the PMF matrix $\widetilde{C}$ varies with the traffic information. The Fig.2 shows that the value of Z, which is the expectation is an increasing function which shows vividly that more RB are assigned to the area with higher probability. At time instant T_2, the call traffic density is higher compared to the time instant T_1. Hence, the resource blocks assigned to T_1 are less than that assigned to T_2. Also, both the curves converge when RB_M value reaches 500. For the present simulation settings used, the maximum number of resource blocks for overlay D2D mode assignment is 500. Hence, further simulations are carried out with 500 resource blocks as the maximum value to overlay mode. Therefore, this can be said as optimum resource block assignment for overlay mode. The resource blocks in overlay mode reassigned and rescheduled to overcome the spectrum underutilization.

C. System Performance in Overlay Mode

In this subsection, the performance evaluation the proposed algorithm is discussed. The simulation parameters are mentioned in table I. System throughput is largely influenced by transmit power of the devices and distance of separation between the D2D pair. The system throughput is observed for output variation with dynamic assignment of RB to overlay mode in dynamic traffic flows. As discussed earlier, the D2D connectivity is not entertained if devices separation is more than 20 m. In Fig.3, the throughput variation is observed for varying distance, d. The value of d is varied from 5 m to 20 m and the number of resource block available for allocation, N_{rb} are varied from 100 to 500. It can be inferred that the system throughput decreases as the separation distance increases but provides a considerable minimum data rate at 20 m. This validates our assumption that D2D connectivity range is maximum upto 20 m. This is because an increase in the distance d requires more transmit power for communication, in turn decreasing the throughput.

Transmit power plays a key role in interference avoidance. As the distance of separation between devices in a D2D pair increases, the transmit power also increases, which causes interference to other users operating on the same resource block. Fig.4 gives the throughput variation for various transmit powers. From Fig. 4 it can be observed that when the devices are closer to each other in a D2D pair, the throughput achieved is high. The number of resource blocks are maintained constant at 100. The system throughput is achieves maximum for transmission power at around 20 dBm to 30 dBm. Hence, the system performance is efficient within 20 m D2D radius. The results highlight the performance of the system in overlay mode while overcoming the problem of spectrum wastage.

TABLE I: Simulation Parameters

Parameter	Value
Cell radius	200m
Cell layout	Hexagonal with 3 sectors
Bandwidth per RB	200 MHz
Thermal noise density	-174 dBm/Hz
SINR threshold for DU, γ_d^{th}	0 dB
Rician channel K factor	8
Doppler shift	5km/h
Max BS transmit power	20 W
PLOS	65 + $21\log_{10}[d]$ dB
PNLOS	71.1 + $34\log_{10}[d]$ dB

VI. CONCLUSION

In this work, we presented an on-demand switching to overlay mode of D2D inband operation in a dense 5G cellular network. As D2D communication and mmWave are short range communications, we focus on the integration of these to technologies to achieve better performance. Hence, mmWave channel model is considered for D2D communication. The main problem of spectrum wastage in overlay D2D mode is addressed in the paper. In order to improve spectrum utility, some part of the uplink resources are dedicated for overlay operation based on the historical data of the call traffic. We emphasize on achieving better spectral utility by incorporating more number of D2D users sharing the resources. The computation complexity to calculate SINR is fairly decreased as the interference to cellular user does not exist. In order to maintain the channel quality in communication, the distance of separation between D2D users is limited. Hence, two problems are addressed in this paper. The first problem is formulated for resource assignment to overlay mode, which is solved by quadratic programming. The second problem is formulated to maximize the sum-rate, which is solved by the a heuristic algorithm. The proposed heuristic is simulated for performance evaluation. The proposed resource management scheme reduces the complexity while serving large number of D2D users. Since, D2D connections are controlled by the base station, the integration of D2D communication with 5G network will be promising. The selective switching of inband D2D communication to overlay mode will improve the system performance and its adaptive nature to dynamic traffic flow will decrease the spectrum underutilization.

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