A Novel Resource Sharing Mechanism for Device-to-Device Communications Underlaying LTE-A Uplink Cellular Networks

Devarani Devi Ningombam[1], Suk-seung Hwang[2], and Seokjoo Shin[1]
[1]Department of Computer Engineering,
[2]Department of Electronics Engineering,
Chosun University
309 Pilmun-daero, Dong-gu, Gwangju 501-759, Republic of Korea
devaraninin@gmail.com, hwangss@chosun.ac.kr, sjshin@chosun.ac.kr (Corresponding author)

***Abstract*— Underlaying Device-to-device (D2D) communication is intimated as an encouraging technology for the next generation cellular network, where nearby devices can directly communicate to one another abstaining the evolved nodeB (eNB). In this paper, we propose a resource sharing mechanism which employs for multiple D2D communications by sharing a single cellular link simultaneously. In order to minimize the interference caused by multiple D2D pairs while sharing single cellular link at a time, we propose a meta-heuristic algorithm based on the comprehensive interference minimization with reference to an uplink cellular network. The simulation results demonstrate that the proposed algorithm attains efficient performance compared with basic schemes.

Keywords— device-to-device communication; resource-sharing; transmit power; meta-heuristic algorithm.

I. INTRODUCTION

The increasing demand for higher data rates for various mobile applications has triggered research interests on Device-to-device (D2D) communication. This ever-growing demand requires a novel mechanism for improving the system spectrum efficiency to accommodate the capacity of cellular networks. Recently, D2D communication underlaying cellular network has been proposed as one of the key techniques, where devices in close proximity can communicate directly without traversing data traffic to the evolved nodeB (eNB). This technique can enhance the spectrum efficiency, reduce network load, and increase the cellular coverage. Due to these advantages, D2D communications have been widely popular for the next generation cellular network. However, D2D communication engenders significant interference to the conventional cellular network. Therefore, reliable resource allocation for D2D communication while reusing the cellular link is necessary.

So far, many researchers have been done on interference limited schemes as presented in [1]-[4]. In these proposed schemes, only one D2D pair can able to reuse a cellular link which limits the capacity of the network. In order to improve the capacity of the network, [5] proposes a relaying based D2D communication. Resource partition method also known as fractional frequency reuse (FFR) method to improve the capacity of the system is presented in [6]. The fundamental idea of this scheme is to partition the overall bandwidth into different sections so that the devices do not interfere with each other. [7] proposes an underlay D2D communications using FFR based orthogonal frequency division multiple access (OFDMA) cellular networks. In the paper, authors analyzed the performance of devices far away from the eNB. An optimize resource sharing technique of an uplink D2D communications for multiple cells was developed in [8]. In the paper, to further increase the capacity of the system and spectrum efficiency, we propose a resource sharing technique with a meta-heuristic algorithm, where multiple D2D pairs can reuse single cellular link simultaneously. We first calculate the outage probability of the D2D pairs as well as cellular users in terms of their signal-to-interference-plus-noise ratio (SINR). Secondly, select cellular users which can reduce the total outage probability of the D2D pairs. Finally, we applied meta-heuristic algorithm to select the best D2D pairs for sharing cellular link at a time. Simulation results show that the proposed scheme outperforms the basic schemes as proposed in the literature.

Furthermore, the contributions in this paper are summarized as follows:

I. Different from the existing works in this paper, we analyze the cellular resource sharing by considering a partitioned hexagonal shaped cellular cell and defined the SINR and power bound, which gives a novel outage probability analysis.
II. According to different outage probability range, the cellular users are selected which can minimize overall D2D pairs outage probability.
III. In addition, we applied meta-heuristic algorithm to search the best D2D pairs, which can improve the system capacity and spectrum efficiency.

The remainder of this paper is organized as follows. Section II presents the system model. In Section III, problem formulation is presented. Section IV provides meta-heuristic algorithm. Section V presents throughput optimization. Simulation results and analysis are presented in Section VI. Finally, Section VII concludes the paper.

II. System Model

As shown in Fig. 1(a), we considered a hexagonal shaped cell structure in which the whole cell area is divided into two non-overlapping regions. The region near to eNB is named as inner cell region and region far away from the eNB is named as edge cell region. Furthermore, both the regions are partitioned into three equivalent sections by using three 120° directional antennas. The bandwidth partition model is shown in Fig. 1(b).

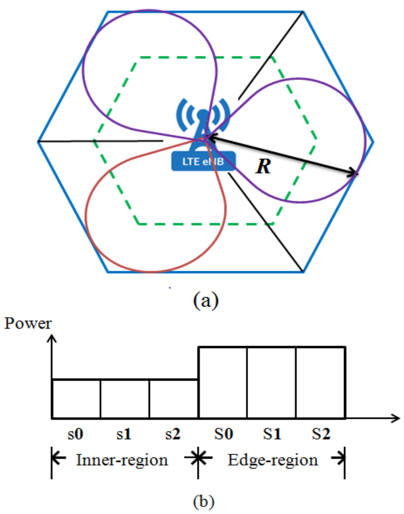

Fig. 1. System model: (a) hexagonal shape cell, (b) bandwidth partition.

According to the bandwidth partition method, we have $S_T = s + S$, where $s = s_0 + s_1 + s_2$ and $S = S_0 + S_1 + S_2$, s is allocated for users located in inner cell region and S is allocated for users located in edge cell region.

The resource sharing mode and interference scenario introduced by the D2D communication while sharing an uplink cellular link is depicted in Fig. 2(a) and Fig. 2(b), respectively. As shown in Fig. 2(a), the spectrum resource is sharing between a cellular user and a D2D pair in an orthogonal manner, which can promote the system overall throughput and spectrum efficiency. It is assumed that the eNB is located at the center of the hexagonal cell, and both cellular users and D2D pairs are uniformly distributed in the cell. For an uplink cellular network, there are two main interferences generated due to D2D communication, namely interference from the cellular user to the D2D receiver, and interference from the D2D transmitter to the eNB. These inevitable interferences directly influence the system performance.

In this paper, we considered that in a cell there are n cellular users, where $n = 1,2,..N$ and m pairs of D2D users, where $m = 1,2,..M$. In our proposed scheme, we assumed that the number of D2D pairs which can reuse the cellular links is more than cellular users, i.e. $M > N$. Consequently, cellular users and D2D pairs fall into four aggregations, namely N_{in}, N_{edge}, M_{in} and M_{edge}, respectively. N_{in}, M_{in} refer to the users located in inner cell region and N_{edge}, M_{edge} are the users located in edge cell region.

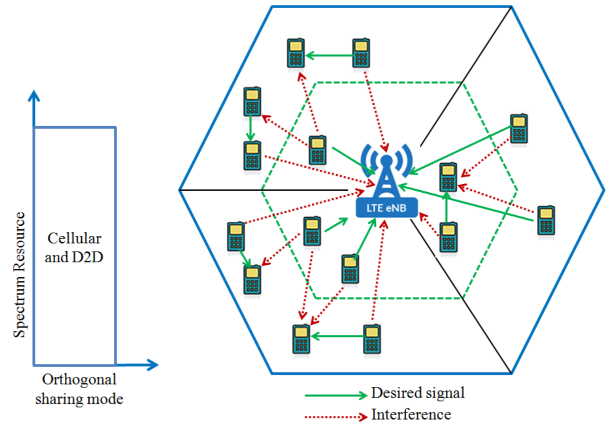

Fig. 2. (a) Uplink resource sharing mode: (b) Interference scenario for D2D communication in an uplink cellular network.

TABLE 1: VARIABLES USED FOR ANALYSIS.

Variable	Definition
γ_n	Received cellular SINR
γ_m	Received D2D pair SINR
P_n	Transmit power of cellular user
P_m	Transmit power of D2D pair
$l_{n,B}$	The distance between cellular user and eNB
$l_{m,B}$	The distance between D2D pair and eNB
$H_{n,B}$	Channel coefficient between cellular user and eNB
$H_{m,B}$	Channel coefficient between D2D pair and eNB
I_m	Interference from the D2D pair
I_n	Interference from the cellular user
I^{nb}	Interference from the neighboring cells
P_N	Noise power
α	Path loss coefficient
β	Power control factor, [0,1]
γ_{Th}	Threshold SINR
τ	Outage probability
τ_{req}	Predefined outage probability
T_n	Throughput for the cellular user
T_m	Throughput for D2D Pair

III. Problem Formulation

After introducing D2D communication in the traditional cellular network, overall system performance is increased and reduces traffic load on the network. However, setting up for a reliable D2D communication requires proper utilization of the D2D communication in the system by guaranteeing minimum Signal-to-Interference-Plus-Noise Ration (SINR). Considering interference scenario introduced in Section II, we can express the SINR of both users as follow.

A. Inner cell region

The SINR of the cellular user and the D2D pair in the inner cell region is expressed as

$$\gamma_n^{in} = \frac{P_n^{in}\ l_{n,B}^{\alpha(\beta-1)}|H_{n,B}|^2}{I_m + I_n^{nb} + P_N} \geq \gamma_n^{min}, \forall n \epsilon N_{in}, m \epsilon M_{edge} \quad (1)$$

$$\gamma_m^{in} = \frac{P_m^{in}\ l_{m,B}^{\alpha(\beta-1)}|H_{m,B}|^2}{I_n + I_m^{nb} + P_N} \geq \gamma_m^{min}, \forall m \epsilon M_{in}, n \epsilon N_{edge} \quad (2)$$

where

$$I_m = \sum_{m=1}^{7} P_m^{edge} l_{m,B}^{\alpha(\beta-1)}|H_{m,B}|^2 \quad (3)$$

$$I_n^{nb} = \sum_{n=1}^{7} P_n^{in} l_{n,B}^{\alpha(\beta-1)}|H_{n,B}|^2 \quad (4)$$

$$I_n = \sum_{n=1}^{7} P_n^{edge} l_{n,B}^{\alpha(\beta-1)}|H_{n,B}|^2 \quad (5)$$

$$I_m^{nb} = \sum_{m=1}^{7} P_m^{in} l_{m,B}^{\alpha(\beta-1)}|H_{m,B}|^2 \quad (6)$$

where γ_n^{min} and γ_m^{min} represent the minimum SINR requirements of a cellular user and D2D pair in the inner cell region, respectively. From the expressions (1)-(6), the outage probability is defined as,

$$\tau_n^{in} = 1 - \frac{1}{1 + \frac{(I_m + I_n^{nb})\gamma_t}{P_n^{in}\ l_{n,B}^{\alpha(\beta-1)}}} exp(-\frac{\gamma_t P_N}{P_n^{in}\ l_{n,B}^{\alpha(\beta-1)}}) \leq \tau_{req} \quad (7)$$

$$\tau_m^{in} = 1 - \frac{1}{1 + \frac{(I_n + I_m^{nb})\gamma_t}{P_m^{in}\ l_{m,B}^{\alpha(\beta-1)}}} exp(-\frac{\gamma_t P_N}{P_m^{in}\ l_{m,B}^{\alpha(\beta-1)}}) \leq \tau_{req} \quad (8)$$

B. Edge cell region

The SINR of cellular user and D2D pair in edge cell region is expressed as

$$\gamma_n^{edge} = \frac{P_n^{edge}\ l_{n,B}^{\alpha(\beta-1)}|H_{n,B}|^2}{I_m + I_n^{nb} + P_N} \geq \gamma_n^{min}, \forall n \epsilon N_{edge}, m \epsilon M_{in} \quad (9)$$

$$\gamma_m^{edge} = \frac{P_m^{edge}\ l_{m,B}^{\alpha(\beta-1)}|H_{m,B}|^2}{I_n + I_m^{nb} + P_N} \geq \gamma_m^{min}, \forall m \epsilon M_{edge}, n \epsilon N_{in} \quad (10)$$

where

$$I_m = \sum_{m=1}^{7} P_m^{in} l_{m,B}^{\alpha(\beta-1)}|H_{m,B}|^2 \quad (11)$$

$$I_n^{nb} = \sum_{n=1}^{7} P_n^{edge} l_{n,B}^{\alpha(\beta-1)}|H_{n,B}|^2 \quad (12)$$

$$I_n = \sum_{n=1}^{7} P_n^{in} l_{n,B}^{\alpha(\beta-1)}|H_{n,B}|^2 \quad (13)$$

$$I_m^{nb} = \sum_{m=1}^{7} P_m^{edge} l_{m,B}^{\alpha(\beta-1)}|H_{m,B}|^2 \quad (14)$$

where γ_n^{min} and γ_m^{min} represent the minimum SINR requirements of a cellular user and D2D pair in the edge cell region, respectively. From the expressions (9)-(14), the outage probability is defined as,

$$\tau_n^{edge} = 1 - \frac{1}{1 + \frac{(I_m + I_n^{nb})\gamma_t}{P_n^{edge}\ l_{n,B}^{\alpha(\beta-1)}}} exp(-\frac{\gamma_t P_N}{P_n^{edge}\ l_{n,B}^{\alpha(\beta-1)}}) \leq \tau_{req} \quad (15)$$

$$\tau_m^{edge} = 1 - \frac{1}{1 + \frac{(I_n + I_m^{nb})\gamma_t}{P_m^{edge}\ l_{m,B}^{\alpha(\beta-1)}}} exp(-\frac{\gamma_t P_N}{P_m^{edge}\ l_{m,B}^{\alpha(\beta-1)}}) \leq \tau_{req} \quad (16)$$

IV. META-HEURISTIC ALGORITHM

Optimization issues are mostly related to finding best configuration of a set of variables to achieve good throughput. In this section, we will discuss on how to allocate the cellular resource among D2D pairs by applying the meta-heuristic algorithm, where we can find the best candidates for D2D pairs to reuse single cellular link simultaneously. In order to improve the system total throughput after introducing D2D communication in a traditional cellular network, we consider Tabu search as a promising meta-heuristic algorithm. The outline of the Tabu search framework is depicted as follow.

```
i = 1
Generate the primitive result r
r→r*
while the near optimal solution is not met do
    Re-transition, t for nearby D2D pairs set N(r)
    Defined Tabu set, T(r, i)
    Identify, D2D pairs set, D(r, i)
        (Aspirant users set)
    Decision, best set B(r, i) = N(r)−T(r, i)+D(r, i)
    r := r′
    if, f(r′) < f(r*)then
        r* := r′
endif
    i := i + 1
endwhile
```

Algorithm 1: Tabu search framework summary.

The search of complementary D2D pairs is classified based on the require SINR values. The overview of Tabu search is listed below.

1. Tabu search is used to solve the optimization problems for finite solution set.
2. Tabu search uses pliable memory structures [9] which administered the search information more comprehensive as compared to rigid memory systems.
3. Estimate a Tabu list which deals with the Tabu move or forbidden moves.

The main criteria for selecting Tabu search algorithm is that it may not always generate the optimal result. However, most of the times it can generate near-optimal results for the analysis [10].

V. THROUGHPUT OPTIMIZATION

In the above section, we have discussed how to find the best set of D2D pairs using Tabu search method. In this section, we will formulate the problem of how to maximize the overall throughput while reusing cellular link by the best set of D2D pairs. Combining with the SINR expressions of cellular users and D2D pairs, we can formulate the expression for overall throughput optimization problem as follow.

$$max \sum_{n=1}^{N} \sum_{m=1}^{M} [T_n + T_m] \quad (17)$$

where

$$T_n = log_2(1 + \gamma_n^{in}) + log_2(1 + \gamma_n^{edge}) \quad (18)$$

$$T_m = log_2(1 + \gamma_m^{in}) + log_2(1 + \gamma_m^{edge}) \quad (19)$$

subject to

$$\gamma_N \geq \gamma_N^{min}, \gamma_M \geq \gamma_M^{min}, \beta \in (0,1) \tag{20}$$

$$P_N^{min} \leq P_N \leq P_N^{max}, P_M^{min} \leq P_M \leq P_M^{max} \tag{21}$$

In our proposed resource sharing mechanism, we consider the situation when the power control factor is applied. Particularly, when $\beta = 1$, the proposed scheme have full power control mechanism.

VI. Simulation Results and Discussions

In this section, we will provide the simulation results and analysis of the results of our proposed scheme, done using Monte-Carlo simulation. In order to evaluate the performance of the proposed resource sharing scheme, we consider the parameters as given in Table 2 for simulation. A multicell scenario is considered with the radius of 500 m, and the eNB is situated at the center of the hexagonal shape cell. In the simulation observation, we consider resource sharing network scenario without cell sectorization scheme (label as basic scheme), resource sharing technique with cell sectorization scheme but without Tabu search algorithm (label as without Tabu search) and our proposed scheme (label as with Tabu search).

TABLE 2: PARAMETERS USED IN SIMULATION.

Parameters	**Value**
Cell outline	Multicell
Network area	500 × 500 m
eNB transmission power for edge cell region	43-49 dBm
eNB transmission power for inner cell region	40-46 dBm
D2D transmission power	8-15 dBm
Noise Power	174dBm/Hz
D2D pair distance	10-50m
Carrier frequency	2 GHz
Uplink bandwidth	5MHz
Path loss exponent	4
Monte-Carlo simulation runs	10,000

Fig. 3 shows the received SINR distribution of the D2D pairs in the inner cell region. It can be seen from Fig. 2, our proposed resource sharing scheme with Tabu search algorithm achieves better SINR than the basic scheme and resource sharing scheme without Tabu search. Moreover, the proposed scheme can efficiently accommodate the transmit power of the D2D pairs without causing severe interference to the traditional cellular users.

Fig. 4 shows the received SINR distribution of the D2D pairs in edge cell region. From the Fig. 4, we can see that the proposed scheme minimizes the interference while reusing the cellular links by the multiple D2D pairs and also vigorously accommodates the transmit power of D2D pairs. Thus, our proposed scheme outperforms the system without meta-heuristic algorithm as well as basic scheme.

Fig. 5 and Fig. 6 illustrate the SINR distribution of cellular users in the inner cell and edge cell region, respectively.

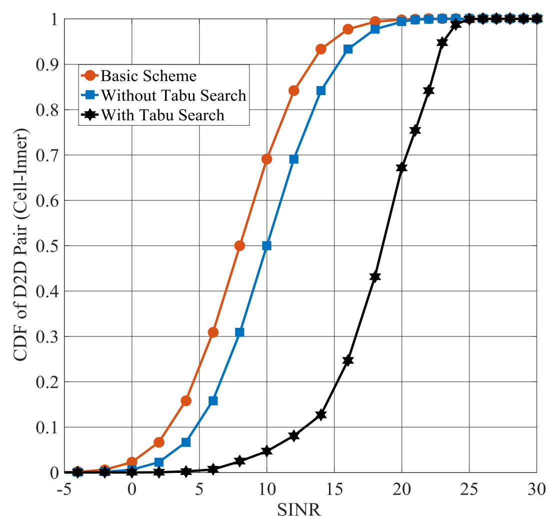

Fig. 3. SINR of D2D pairs in the inner cell region

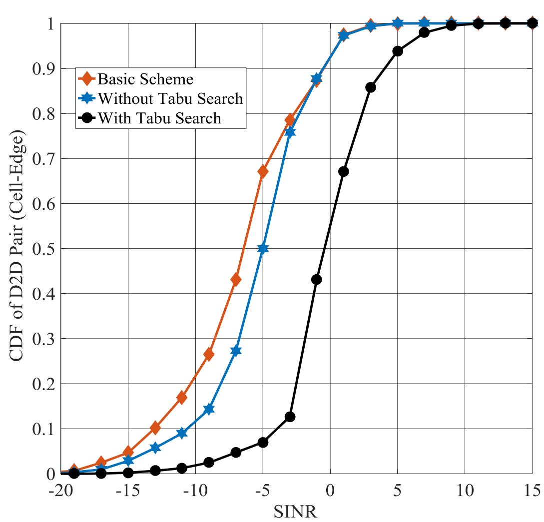

Fig. 4. SINR of D2D pairs in the edge cell region.

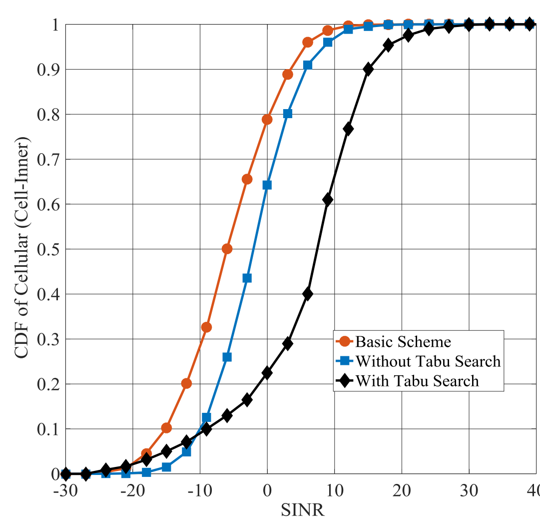

Fig. 5. SINR of cellular users in the inner cell region.

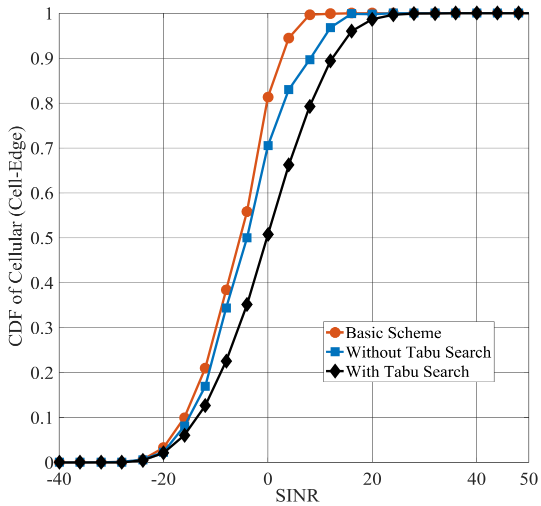

Fig. 6. SINR of cellular users in the edge cell region.

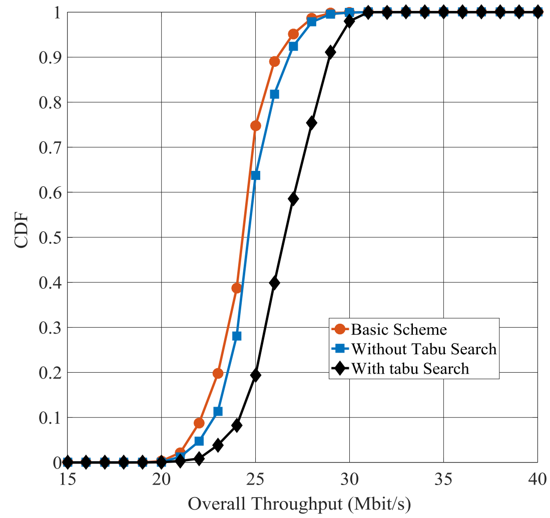

Fig. 7. System overall throughput comparison before Tabu search and after Tabu search.

From Fig. 5, we can see that for cellular users belongs to inner cell region, the SINR distribution for the basic scheme has worse performance and proposed Tabu search scheme is effective. Fig. 6 shows the SINR distribution of the cellular users belongs to the edge cell region. We can see from Fig. 6 that our proposed scheme achieves the best performance among compared schemes.

Fig. 7 plots the system overall throughput of different schemes. From the Fig. 7, we can observe that the proposed resource sharing scheme with meta-heuristic algorithm has the outstanding performance compared with the system without meta-heuristic algorithm as well as basic scheme. Moreover, we can notice that proposed scheme effectively control the user transmit power to maintain the target SINR distribution of each user in both cell regions. Therefore, proposed resource sharing scheme outperformed

VII. Conclusion

In this paper, we propose a novel resource sharing mechanism for the D2D communication to improve the system overall throughput by using the most effective meta-heuristic algorithm which is the Tabu search. Combined with spectrum partition scheme, we formulate the throughput optimization problem. Then based on the outage probability of cellular user and D2D pair, we select the best set of D2D pairs by using Tabu search for sharing the same cellular link by the multiple D2D pairs simultaneously. The proposed scheme provides a promising result of the network performance after introducing D2D communication in a traditional cellular network.

Acknowledgment

This research is supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2015R1D1A1A01059962).

References

[1] H. Min, W. Seo, J. Lee, S. Park, and D. Hong, "Reliability improvement using receive mode selection in the device-to-device uplink period underlaying cellular networks," IEEE Trans. on Wirel. Commun., vol. 10, no. 2, pp. 413-418, 2011.

[2] H. Min, W. Seo, J. Lee, S. Park, and D. Hong, "Capacity enhancement using an interference limited area for device-to-device uplink underlaying cellular networks," IEEE Trans. on Wirel. Commun., vol. 10, no. 12, pp. 3995-4000, 2011.

[3] T.-S. Kim, K.-H. Lee, S. Ryu, and C.-H. Cho, "Resource allocation and power control scheme for interference avoidance in an LTE-advanced cellular networks with device-to-device communications,"Int. Journal of Control and Automation, vol. 6, pp. 181-190, 2013.

[4] D.D. Ningombam, and S. Shin, "Radio resource allocation and power control scheme to mitigate interference in device-to-device communications underlaying LTE-A uplink cellular networks," 9th int. conf. on ICT Convergence, pp. 962-964, 2017.

[5] G.P. Zhang, and K. Yang, "Power control for full-duplex relaying-based D2D communication underlaying cellular networks," IEEE Trans. on Veh. Tech., vol. 64, no. 10, pp. 4911-4916, 2015.

[6] D.D. Ningombam, J.-Y. Pyun, S.-S. Hwang, and S. Shin, "Fractional frequency reuse scheme for interference mitigation in device-to-device communication underlying LTE-A networks," 51st Asilomar Conf. on Signals, Systems, and Computers, pp. 1402-1406, 2017.

[7] H. Chae, J. Gu, and B. Choi, "Radio resource allocation scheme for device-to-device communication in cellular networks using fractional frequency reuse," 17th Asia-Pacific Conf. on Commun., pp. 58-62, 2011.

[8] J. Wang, D. Zhu, C. Zhao, J. Li, and M. Lei, "Resource sharing of underlaying device-to-device and uplink cellular communications," IEEE Commun. Letters, vol. 17, no. 6, pp. 1148-1151, 2013.

[9] T. Chun-Wei, C. Hsin-Hung, K.S. Timothy, P. Jeng-Shyang, and J.P.C.R. Joel, "Meta-heuristics for deployment of 5G," IEEE Wirel. Commun., pp. 40-46, 2015.

[10] F. Glover, "Future paths for integer programming and links to artificial intelligence," Comp. Oper. Res. 13, pp. 533-549, 1986.

[11] ITU-R Report M.2135. Guidelines for evaluation of radio interface technologies for IMT-advanced, 2008.

[12] C. H. Yu, K. Doppler, C. B. Ribeiro, and O. Tirkkonen, "Resource sharing optimization for device-to-device communication underlaying cellular networks," IEEE Trans. on Wirel. Communs., vol. 10. no. 8, pp. 2752-2763, 2011.