Mathematical formulation for Intelligent Resource Allocation in Wireless Communications Systems

We consider a multi-channel cellular system which allows direct communication among users, i.e., D2D communication. In our system model, we assume that the number of channels is K, and for each channel, one cellular user equipment (CUE) transmits data to the BS, i.e., uplink transmission. The number of D2D user equipments (DUEs) is set to N where each DUE consists of one transmitter and one receiver and $\mathbb{I}$ denotes the set of D2D transmitters. Moreover, the channel gain between the i-th transmitter and the j-th receiver for channel k is denoted as $h_{i,j}^k$, where the index 0 is assigned to the CUE and base station (BS).

The transmit power of the DUEs allocated to each channel is denoted as P_i^k where k and i are the index of the channel and the DUE, respectively. Moreover, we assume that the maximum transmit power of DUEs is P_{T} such that $\sum\limits_{k\leq K} P_i^k \leq P_{\mathrm{T}}$ for all i. Furthermore, we assume that the transmit power of CUE is fixed to P_{T}. In addition, we denote W and N_0 as the bandwidth and the noise spectral density, respectively. Accordingly, in our system model, the spectral efficiency (SE) of DUE i, SE_i can be written as

$$\mathrm{SE}_i = \sum_{k\leq K} \log_2\left(1 + \frac{h_{i,i}^k P_i^k}{N_0 W + \sum_{l\in\mathbb{I}\setminus\{i\}} h_{l,i}^k P_l^k + h_{0,i}^k P_{\mathrm{M}}}\right). \tag{1}$$

Moreover, the energy efficiency (EE) of DUE i, EE_i can be written as

$$\frac{\mathrm{SE}_i}{\sum\limits_{k\leq K} P_i^k + P_{\mathrm{C}}}, \tag{2}$$

where P_{C} is the circuit power of the DUE.

In our work, we consider the optimization with three different objectives which are 1) maximize SE, 2) maximize EE, or 3) minimize the total transmit power. Moreover, we take three constraints into account. First, the transmit power allocated to each channel should be non-negative and the sum of the transmit power for a single DUE must not exceed the maximum transmit power, P_{T} (i.e., the transmit power constraint). Second, the amount of interference caused to the cellular transmission must be less than the threshold I_{T} (i.e., the interference constraint). Third, each D2D transmission should satisfy the minimum QoS requirement, i.e., the SE achieved by each DUE must be greater than the threshold, R_{T} (i.e., QoS constraint).

Accordingly, the optimization problem to maximize the SE of DUEs can be formulated as follows:

$$
\begin{aligned}
\underset{P_i^k}{\text{maximize}} \quad & \sum_{i\in\mathbb{I}} \text{SE}_i \\
\text{s.t.} \quad & \sum_{k\leq K} P_i^k \leq P_{\text{T}} && \forall i \in \mathbb{I} \\
& 0 \leq P_i^k && \forall i \in \mathbb{I},\ k \leq K \\
& \textstyle\sum_{l\in\mathbb{I}} h_{l,0}^k P_l^k \leq I_{\text{T}} && \forall k \in \mathbb{K} \\
& \text{SE}_i \geq R_{\text{T}} && \forall i \in \mathbb{I}.
\end{aligned}
\tag{3}
$$

Similarly, the optimization problem to maximize the EE of DUEs can be formulated as follows:

$$
\begin{aligned}
\underset{P_i^k}{\text{maximize}} \quad & \sum_{i\in\mathbb{I}} \text{EE}_i \\
\text{s.t.} \quad & \sum_{k\leq K} P_i^k \leq P_{\text{T}} && \forall i \in \mathbb{I} \\
& 0 \leq P_i^k && \forall i \in \mathbb{I},\ k \leq K \\
& \textstyle\sum_{l\in\mathbb{I}} h_{l,0}^k P_l^k \leq I_{\text{T}} && \forall k \in \mathbb{K} \\
& \text{SE}_i \geq R_{\text{T}} && \forall i \in \mathbb{I}.
\end{aligned}
\tag{4}
$$

Finally, the optimization problem to minimize the total transmit power of DUEs can be formulated as follows:

$$
\begin{aligned}
\underset{P_i^k}{\text{minimize}} \quad & \sum_{i\in\mathbb{I}} \sum_{k\leq K} P_i^k \\
\text{s.t.} \quad & \sum_{k\leq K} P_i^k \leq P_{\text{T}} && \forall i \in \mathbb{I} \\
& 0 \leq P_i^k && \forall i \in \mathbb{I},\ k \leq K \\
& \textstyle\sum_{l\in\mathbb{I}} h_{l,0}^k P_l^k \leq I_{\text{T}} && \forall k \in \mathbb{K} \\
& \text{SE}_i \geq R_{\text{T}} && \forall i \in \mathbb{I}.
\end{aligned}
\tag{5}
$$

The optimization problems formulated in (3) - (5) are nonconvex optimization problem such that it is extremely hard to solve the problem analytically with low computational complexity. Moreover, given that the optimal solutions depend on the channel gain, the optimal transmit power has to be re-derived whenever the channel gain changes. Accordingly, in our work, we have proposed a DNN based resource allocation (RA) to find the optimal transmit power which can solve the aforementioned problems.