Transmission Scheme for D2D Multicast Communication in LTE-Advanced Networks

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***Abstract*—We consider D2D multicast communication which reuses cellular uplink frequency resources in LTE-Advanced networks. In this case, the cellular uplink signal will interfere to the D2D link communication. The data transmission rate of D2D multicast communication is determined by the user having the worst signal-to-interference plus noise (SINR) condition. Conventional schemes assume that the D2D transmitter employs SC-FDMA transmission scheme because it is already used for cellular uplink transmission in LTE-Advanced system. However, if SC-FDMA is employed in D2D transmitter, it is very difficult to reduce the interference from the cellular user in D2D receiver and D2D multicast transmission is allowed only when the interference from the cellular user is very small in all users within the D2D multicast group. In this paper, we propose to employ MC-CDMA transmission scheme in D2D multicast transmitter. The interference signal from the cellular user can be eliminated by applying the interference cancellation schemes in the D2D multicast receivers and D2D communication becomes possible even in the high interference cases. Through simulation, we show that the proposed scheme has better SINR performance than the conventional scheme.**

***Index Terms*—Device-to-device communications (D2D), multicasting, LTE-Advanced, SC-FDMA, MC-CDMA.**

I. INTRODUCTION

Recently, there has been an explosive increase of the number of mobile devices such as smart phones, tablet computers, smart watches, PDA, etc. Many communication experts have predicted that the number of mobile devices will exceed the world population in the next few years. In the past, mobile phone was mainly used for voice service and the traffic for that service was not very high. However, these days the smart phones are mainly used for the data transmission and reception, and the data traffic for that service has been increasing explosively. Since a frequency spectrum is limited, it becomes difficult to satisfy the data traffic requirements by using the conventional transmission schemes [1], [2].

In order to overcome the shortage problem of frequency spectrum, many researchers have paid their attention to reusing the frequency spectrum. Device-to-device (D2D) direct communication is one of the frequency reuse technologies. In D2D direct communication, the nearby mobile devices transfer data each other without going through evolved Node B (eNB) usually by reusing the cellular frequency resources that are already used by cellular users. D2D communication has many advantages such as eNB offloading effect, transmission power reduction of mobile devices, reduced communication delay, increased spectral efficiency, etc [2].

D2D link could reuse cellular uplink resources and/or downlink resources. However, it is well known that cellular uplink resources are more proper to be reused in D2D communication. If cellular downlink resources are reused in D2D communication, the decoding performance of the cellular users will be decreased and it is not acceptable.

Third Generation Partnership Project (3GPP) has identified device-to-device (D2D) communication as one of the key technologies that could be used to improve the spectral efficiency, energy efficiency, and to save the transmission power of user equipment. 3GPP has been working for the standardization of D2D communications named as Proximity-based services (ProSe) [3]-[5].

D2D communication can be categorized as unicast transmission, multicast transmission, and broadcast transmission. In unicast transmission, one transmitter sends its data to one desired receiver and in multicast transmission one transmitter sends the same data to multiple receivers. The main target use cases of the D2D multicast transmission could be the multimedia streaming, advertisement, device discovery, and public safety. The key advantage of using the D2D multicast communication is the saving of resources in comparison with the D2D unicast communication [6]-[10].

In D2D multicast scenario, all users within a multicast group receive the same data. Therefore, the data transmission rate in D2D multicast group should be equal for all users in the group [11]-[15]. In general, the data transmission rate is chosen by considering the link condition between the transmitter and the receiver. The link condition of each user within the multicast group is different and the optimal data transmission rate could be different to each user. However, since the transmission rate within the group should be equal, it will be determined by the user with the worst channel condition [10], [16]. In the extreme case, if a channel condition of one user within the multicast group is severely worse, D2D communication cannot be allowed.

In conventional D2D schemes [11]-[15], D2D transmitter employs SC-FDMA transmission scheme by reusing the cellular uplink frequency resource. Therefore, there is

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interference from the cellular uplink signal in the received signal of the D2D receiver. Since both cellular user and D2D transmitter employ SC-FDMA, it is very difficult to eliminate the interference in the D2D receiver. In the conventional schemes, D2D transmission is allowed only when the interference from the cellular user is very small in all users within the multicast group. On the contrary, D2D transmission is not allowed when the interference is high even in one user.

In this paper, we propose to employ MC-CDMA transmission scheme in D2D transmitter. By using the MC-CDMA transmission scheme, it is possible to reduce the interference from the cellular user by applying the interference cancellation schemes. Hence, in the proposed scheme, D2D transmission can be allowed even in the high interference cases.

The rest of the paper is organized as follows. In Section II, the conventional scheme is described. In Section III, a proposed scheme is presented. Simulation results are given in Section IV. Finally, the paper is concluded in Section V.

II. CONVENTIONAL TRANSMISSION SCHEME

Fig. 1 shows the D2D multicast communication scenario in LTE-Advanced networks. We assume that the D2D link reuses the cellular uplink resource. In the figure, eNB means evolved node base station (eNB) and DUE 1, …, DUE 4 represent D2D users and CUE 5 means the cellular user. The DUE 1 is the transmitter in the D2D link and DUE 2, …, DUE 4 are the receivers. The solid lines mean the desired signals and the dotted lines mean the interference signals. For simplicity, we assume that there are three D2D receivers, but it can be extended to any number of D2D receivers.

We assume that each user is equipped with single transmit antenna and single receive antenna. The received signal vector $\mathbf{y}_k(i)$ of length $M \times 1$ at DUE k, $k = 2,3,4$, can be written as

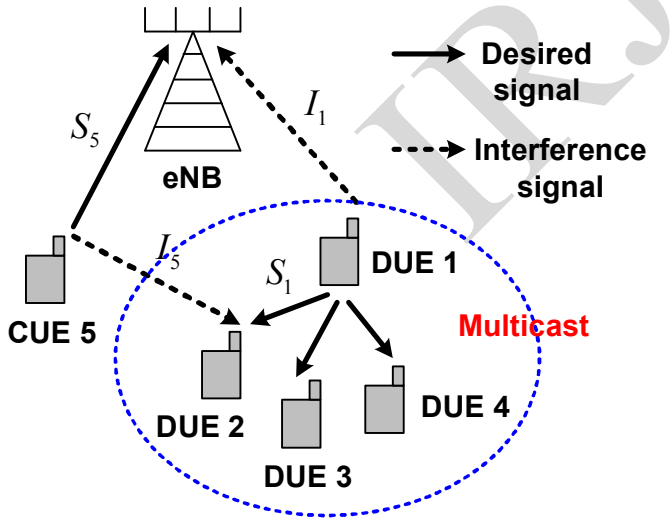


Fig. 1. D2D multicast communication scenario.

$$\mathbf{y}_k(i) = \sqrt{P_{1,k}}\mathbf{H}_{1,k}\mathbf{D}\mathbf{x}_1(i) + \sqrt{P_{5,k}}\mathbf{H}_{5,k}\mathbf{D}\mathbf{x}_5(i) + \mathbf{z}_k(i), \quad (1)$$

where the first term on the right of the equation is the desired signal from the D2D transmitter DUE 1 and the second term is the interference signal caused by the cellular user CUE 5. The vectors $\mathbf{x}_1(i)$ and $\mathbf{x}_5(i)$ of length $M \times 1$ are the transmission data of the DUE 1 and CUE 5, respectively. The parameters $P_{1,k}$ and $P_{5,k}$ mean the received signal power of the DUE 1 and CUE 5 at the DUE k, respectively. The matrix $\mathbf{H}_{1,k}$ is the frequency domain channel from the DUE 1 to DUE k and $\mathbf{H}_{5,k}$ is the frequency domain channel from the CUE 5 to DUE k. The matrix $\mathbf{H}_{1,k}$ and $\mathbf{H}_{5,k}$ are given by

$$\mathbf{H}_{1,k} = diag(H_{1,k,1}, H_{1,k,2}, \cdots, H_{1,k,M}), \quad (2)$$

$$\mathbf{H}_{5,k} = diag(H_{5,k,1}, H_{5,k,2}, \cdots, H_{5,k,M}), \quad (3)$$

where $H_{1,k,m}$ and $H_{5,k,m}$ are the frequency domain channel coefficients of the m-th subcarrier. The matrix $\mathbf{D}$ is the discrete Fourier transform (DFT) matrix and its (m, n) element $[\mathbf{D}]_{m,n}$ is given by $[\mathbf{D}]_{m,n} = e^{-j2\pi(m-1)(n-1)/M}/\sqrt{M}$. The vector $\mathbf{z}_k(i)$ is additive White Gaussian noise (AWGN) with mean 0 and variance σ_z^2 at DUE k.

We define $\mathbf{D}\mathbf{x}_1(i)$ and $\mathbf{D}\mathbf{x}_5(i)$ by $\tilde{\mathbf{x}}_1(i)$ and $\tilde{\mathbf{x}}_5(i)$, respectively. Then, the received signal can be rewritten by

$$\mathbf{y}_k(i) = \sqrt{P_{1,k}}\mathbf{H}_{1,k}\tilde{\mathbf{x}}_1(i) + \sqrt{P_{5,k}}\mathbf{H}_{5,k}\tilde{\mathbf{x}}_5(i) + \mathbf{z}_k(i). \quad (4)$$

Since $\mathbf{H}_{1,k}$ and $\mathbf{H}_{5,k}$ are diagonal matrix, it is very difficult to reduce the interference caused by the cellular user at the D2D receiver. From the equation (4), the signal-to-interference plus noise ratio (SINR) for each D2D receiver k can be calculated. The received SINR of each D2D receiver will be different because the parameters $P_{1,k}$, $P_{5,k}$, $\mathbf{H}_{1,k}$, and $\mathbf{H}_{5,k}$ are different for the different receiver. In the multicast transmission, the D2D transmission rate will be determined by the D2D receiver having the minimum received SINR. In the Section IV, the simulation results for the received SINR of the conventional schemes will be provided.

III. PROPOSED TRANSMISSION SCHEME

In the conventional scheme, SC-FDMA transmission scheme is employed in D2D multicast transmitter of LTE-Advanced networks and D2D multicast transmission is allowed only when the interference caused by the cellular uplink signal is very low in all D2D users within D2D multicast group. In order to overcome this limitation of the conventional scheme, we propose to employ multicarrier code division multiple access (MC-CDMA) scheme in D2D transmitter. In the proposed scheme, eNB assigns Q spreading codes of length M to the D2D transmitter and Q is less than or equal to M. We denote the spreading code vectors by $\mathbf{c}_q$, $q = 1,2,\ldots,Q$. Then, the D2D transmitter spreads data $x_{1,q}(i)$, $q = 1,2,...,Q$ to the M

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subcarriers by applying the vector $\mathbf{c}_q$. By using Q spreading codes, Q data, $x_{1,1}(i)$, $x_{1,2}(i)$, ..., $x_{1,Q}(i)$, are transmitted simultaneously on the M subcarriers. If we want to increase the data transmission rate of the proposed scheme, we could choose large number for Q. However, as Q increases, the SINR performance will be decreased at the D2D receiver. Hence, Q should be chosen by considering both data transmission rate and required SINR at the receiver.

If Q data are transmitted simultaneously by using Q spreading codes, the received signal at D2D receiver, DUE k, $k = 2, 3, 4,$ can be written as

$$\mathbf{y}_k(i) = \sum_{q=1}^{Q} \sqrt{P_{1,k}}\mathbf{H}_{1,k}\mathbf{s}_q x_{1,q}(i) + \sqrt{P_{5,k}}\mathbf{H}_{5,k}\mathbf{D}\mathbf{x}_5(i) + \mathbf{z}_k(i), \quad (5)$$

where the first term on the right of the equation (5) is the desired signal and the second term is the interference caused by the cellular uplink signal.

We define the spreading code vector set and the transmission data vector of D2D transmitter by

$$\mathbf{S} = [\mathbf{s}_1, \mathbf{s}_2, \ldots, \mathbf{s}_Q], \quad (6)$$

$$\mathbf{d}_1(i) = [x_{1,1}(i), x_{1,2}(i), \ldots, x_{1,Q}(i)]^T, \quad (7)$$

where the size of $\mathbf{S}$ is $M \times Q$.

By using $\mathbf{S}$ and $\mathbf{d}_1(i)$, the equation (5) can be rewritten by

$$\mathbf{y}_k(i) = \sqrt{P_{1,k}}\mathbf{H}_{1,k}\mathbf{S}\mathbf{d}_1(i) + \sqrt{P_{5,k}}\mathbf{H}_{5,k}\mathbf{D}\mathbf{x}_5(i) + \mathbf{z}_k(i). \quad (8)$$

If we compare the equation (1) and (8), we can observe that the length of $\mathbf{x}_1(i)$ is M and the length of $\mathbf{d}_1(i)$ is Q. Also, we choose Q less than or equal to Q. As Q decreases, the received SINR at the D2D receiver will be increased. However, if M is less than Q, the data transmission rate of the proposed scheme will be decreased in comparison with the conventional scheme.

In order to reduce the interference, $\mathbf{H}_{5,k}\mathbf{D}\mathbf{x}_5(i)$, many interference cancellation schemes can be used. In this paper, we used minimum mean square error (MMSE) receiver to eliminate the interference. Then, the received SINR of the proposed scheme can be calculated from the equation (5). In Section IV, the simulation results of the received SINR of the proposed scheme will be given.

IV. SIMULATION RESULTS

We performed computer simulation to compare the performance of the proposed scheme with the conventional scheme for D2D multicast transmission in LTE-Advanced networks. We consider one cellular user, one D2D multicast transmitter, and three D2D multicast receivers. The DFT matrix size M is 12 and the FFT matrix size N is 1024. Since M is 12, the conventional transmission scheme transmits 12 data symbols simultaneously on the 12 subcarriers. On the contrary, the proposed scheme transmits Q data symbols simultaneously on the 12 subcarriers. For the generation of the channel matrix $\mathbf{H}_{1,k}$ and $\mathbf{H}_{5,k}$, complex Gaussian random channel model is used where each element of $\mathbf{H}_{1,k}$ and $\mathbf{H}_{5,k}$ is a random variable with mean 0 and variance 1.

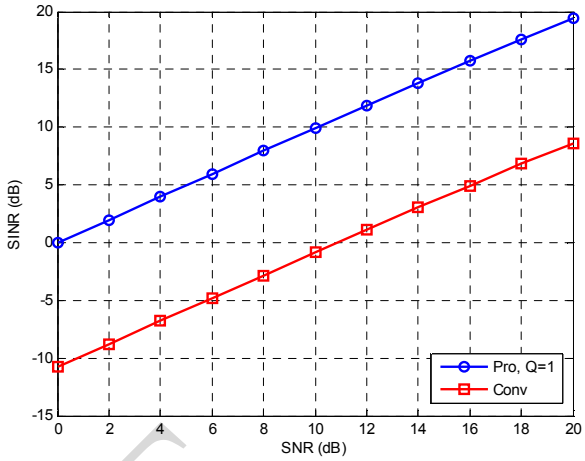


Fig. 2. SINR performance comparison between the conventional scheme and the proposed scheme when Q=1.

Fig. 2 shows the received SINR performance of the proposed scheme and the conventional scheme when Q=1. In the figure, 'Conv' means the conventional scheme and 'Pro' represents the proposed scheme. Since Q=1, the proposed scheme transmits 1 data symbol on the M=12 subcarriers. From the figure, we can observe that the proposed scheme has much better SINR performance than the conventional scheme. This is because the proposed scheme transmits one data symbol on the M=12 subcarriers but, the conventional scheme transmits M=12 data symbols simultaneously on the M=12 subcarriers. Therefore, the data transmission rate of the proposed scheme is much lower than that of the conventional scheme. If the channel condition between the D2D multicast transmitter and D2D multicast receivers is worse, it is reasonable to reduce the data transmission rate as the proposed scheme in order to satisfy the required received SINR value.

Fig. 3 shows the received SINR performance at one of the D2D multicast receiver when Q=12. In this case, both the proposed scheme and the conventional scheme transmit M=12 data symbols simultaneously on the M=12 subcarriers. Therefore, the data transmission rate of the proposed scheme is the same as that of the conventional scheme. From the figure, we can observe that the received SINR performance of the proposed scheme is perfectly the same as that of the conventional scheme.

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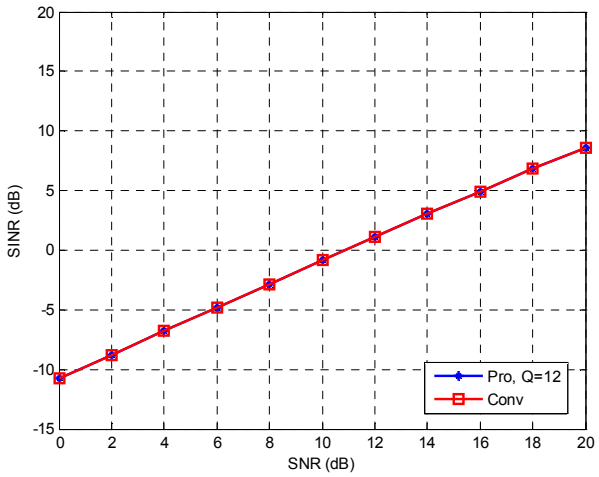


Fig. 3. SINR performance comparison between the conventional scheme and the proposed scheme when Q=12.

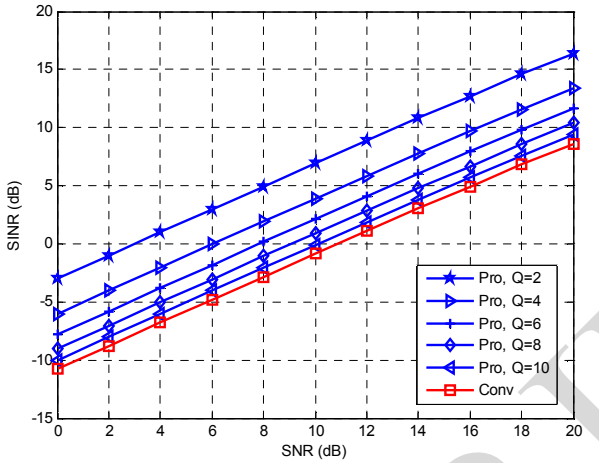


Fig. 4. SINR performance comparison between the conventional scheme and the proposed scheme for different Q.

Fig. 4 shows the received SINR performance of the proposed scheme and the conventional scheme for the different Q where Q=2, 4, 6, 8, and 10. From the figure, we can observe that the proposed scheme has better SINR performance than the conventional scheme and that the SINR performance of the proposed scheme becomes worse as the number of Q increases.

Large number of Q means that the data transmission rate of the proposed scheme is high and small number of Q means that the data transmission rate of the proposed scheme is low. From the results, we can choose appropriate number of Q by considering the required data transmission rate and the required SINR value. If we want to obtain the high received SINR value rather than the high data transmission rate, then we can choose small value for the parameter Q. On the contrary, for the high data transmission rate rather than the high received SINR value, then we can choose high value for the parameter Q.

V. CONCLUSION

In this paper, we considered D2D multicast transmission in LTE-Advanced networks. We assumed that the D2D link reuses the cellular uplink frequency resources. In conventional schemes, SC-FDMA transmission scheme is used in D2D multicast transmitter and D2D communication is allowed only when the interference caused by the cellular user is not high in all D2D receivers within the D2D multicast group. It is because it is very difficult to reduce the interference caused by the cellular user. In this paper, we proposed to employ MC-CDMA transmission scheme in D2D multicast transmitter. In this way, the interference caused by the cellular user can be reduced. Through computer simulation, we showed that the proposed scheme has better performance than the conventional schemes.

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