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Multicast Device-to-Device Communication underlaying WPCNs

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Abstract - *In this paper, we maximize the sum throughput via joint time scheduling and power control of device-to-multi-device (D2MD) wireless communications. We investigate the resource allocation problem for D2D communications underlaying wireless powered communication networks (WPCNs), where multiple D2D pairs harvest energy from a power station equipped with multiple antennas and then transmit information signals simultaneously over the same spectrum resource. The use of multicast communications opens the possibility of reusing the spectrum resources also inside the groups. The optimization problem is formulated as a mixed integer nonlinear joint optimization for the power control and allocation of resource blocks (RBs) to each group. The aim is to maximize the sum throughput of D2Dmulticast groups through resource allocation and power control scheme, which considers the quality-of-service (QoS) requirements of both cellular user equipment and D2D groups. Simulation results demonstrate that the proposed scheme works well in different scenarios.*

Key Words: **Device-to-Device (D2D) Multicast, Resource Allocation, Cellular network, sum throughput maximization, power consumption retransmission.**

1. INTRODUCTION

Simultaneous wireless information and power transfer (SWIPT) refers to using the same emitted electromagnetic (EM) wave field to transport both energy that is harvested at the receiver, and information that is decoded by the receiver. The dual use of radio frequency signals, wireless energy transfer (WET) has attracted much attention for improving the system energy efficiency [1][2].

In this context, simultaneous wireless information and power transfer (SWIPT) and wireless powered communication networks (WPCNs) have been extensively studied in the literature. Moreover, since electromagnetic waves decay quickly over distance, energy beamforming is generally designed to achieve efficient WET. In WPCNs, a power station (PS) transfers wireless energy to some low-power users with a single antenna due to the hardware constraint [3]. Afterwards, the users transmit information signals with the harvested energy. For the multiple users scenario, the signals are transmitted typically based on time division multiple access (TDMA) as in [5]. However, the spectrum efficiency can be greatly improved with appropriate interference management methods by allowing multiple users to transmit signals simultaneously.

The demand for multimedia data is increasing rapidly now-a-days, which has led to the insufficiency of available spectrum resource [4]. The continuously increasing demand for wireless access especially data services for geographically proximate user has brought great challenges to current mobile communication infrastructure. Under this circumstance, the direct connectivity between mobile devices, namely, Device-to-Device (D2D) communication emerges as a key component for the fifth generation (5G) wireless communication system [5]. D2D communication is a kind of close range data transmission over a direct link which coexists with cellular networks. It increases the total throughput of a cell with limited interference impacts on the primary cellular network. Furthermore, the D2D communication has potential at saving the power and reducing delay. Assume modern smart phones and tablet PC have sufficient storage capacity and capable battery, they can transmit multimedia data to the users nearby in D2D multicast communication.

A further improvement of D2D is to allow individual devices to form clusters where one device can broadcast information to multiple receivers. Multicasting through D2D (MD2D) [8] communication is appealing when the same data is requested by multiple devices in restricted geographical areas. By leveraging the multicast nature of wireless communications, MD2D technology delivers the shared content to multiple users simultaneously. In particular, as the traffic of local content sharing grows rapidly, MD2D scenarios are reasonably possible. However, the MD2D implementation leads to a more challenging and complex control problem in real-world cellular network operations.

In D2D communication, user equipment (UE) [6] in the proximity region transmits data signals to each other over a direct link instead of through the base station (BS), which improves spectral utilization and saves power consumption. As one of the main features, D2D multicast transmission provides an effective solution to mitigate the burden of BS and improves transmission efficiency, which is important for scenarios such as content sharing, device discovery, and public safety. D2D multicast communication underlaying cellular.

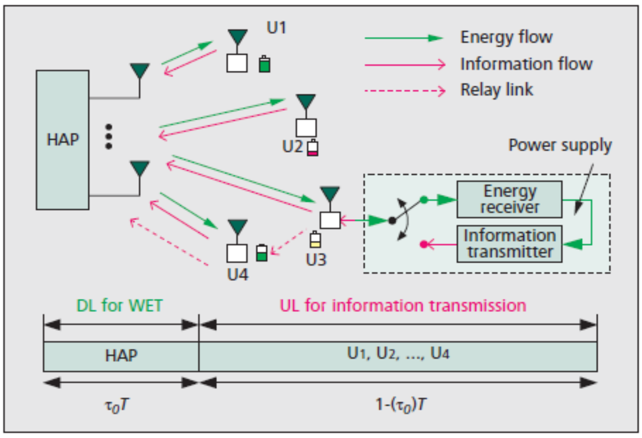

Fig 1.A network model of wireless powered communication

networks refers to the transmission scenario that a transmitter, namely, cluster head(CH), sends the same packet to a group of destination UE items over the D2D links which reuse the resource of cellular links. By exploiting the inherent broadcast nature of wireless channels, [9] D2D multicast transmission disseminates the same content simultaneously to multiple recipients. Compared with traditional point-to-point unicast D2D communication, multicast D2D transmission reduces overhead and improves resource efficiency. However, multicast D2D transmission underlaying cellular network also has its own challenges.

The first challenge faces with D2D multicast transmission are how to energy-efficiently form a specific multicast group and how to select an appropriate CH for each multicast group. Due to the increasing power consumption of information and communication technology (ICT) industry, the progress in battery technology of user terminals is rather slow. Given the limited battery capacity of mobile devices, energy-efficient solutions are imperative to be integrated into the D2D [9] communications. On the other hand, recent studies show that the social behaviors of human beings who carry the handheld communication devices can be leveraged to improve the performance of D2D communications. Consequently, it is worth discussing whether the knowledge of social characteristics can benefit the quality of service (QoS) of D2D multicast communication.

In a multicast group, the situation is especially undesirable when most of the UE items are in good channel condition and capable of high data transmission, while only a small fraction of the UE items are suffering from deep fading. Thus, how to allocate resource within a multicast group so as to guarantee reliable QoS requirement of different UE is very essential. Besides, when D2D communication reuses the spectrum resource of the regular cellular users, effective interference management strategy is indispensable so as to deal with complex resource reuse interference. Hence, how to energy-efficiently allocate spectrum resource and power for D2D multicast groups is also a big challenge.

2. SYSTEM MODEL

This work focuses on the reliable multicast of common data from BS in a cell of cellular network to *N* user devices which are close to one another, forming a D2D-MC [8], as shown in Fig. 2.

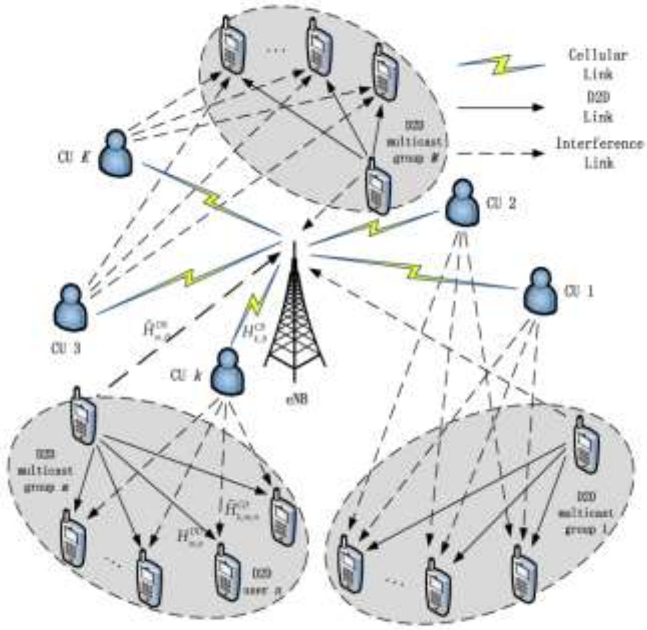

Fig 2. System model of MD2D Communication

In underlay D2D communication, cellular and D2D communications share the same radio resources.

Consider a WPCN [7] with a PS equipped with *K* antennas and *N* low-power MD2D pairs denoted by *N= {1, 2, ..., n, ...,N}*. The MD2D pair carries a single antenna due to the size and cost constraints, such as the sensor node . With no embedded energy supply, each MD2D-Tx first harvests energy from wireless signal transmitted by the PS(i.e., WET phase). Then, they utilize the harvested energy to transmit information signals to their intended receivers in the wireless information transmission (WIT) phase. According to the harvest-then-transmit protocol, in each block denoted by *T*, the first $\tau 0T$ amount of time, $0 \le \tau 0 \le 1$, is assigned to harvest energy for all D2D pairs, while the followed $\tau 1T$ amount of time in the same block is assigned to transmit information signals. We consider a normalized unit block time T = 1 in the sequel without loss of generality. Then, there is $\tau 0 + \tau 1 \le 1$. All the users considered in this paper operate on a single spectrum band.

In the WET phase, the $K \times 1$ transmitted signal [8] is given by $\sqrt{p_{PS}}\mathbf{w}$, where p_{PS} is the transmit power of the PS, and the beamformer $\mathbf{B}$ is designed to improve the energy transfer efficiency and subject to $\mathbf{B} = 1$. Let $\mathbf{h}_n$ represent the M dimensional energy transfer channel vector between the PS and n-th MD2D-Tx. The energy harvested from the noise can be ignored since the noise power is usually much smaller than that of the PS. Therefore, the energy harvested at the n-th D2D-Tx is given by

$$E_n = \eta \tau_0 p_{PS} |\boldsymbol{h}_n^H \mathbf{w}|^2 \qquad (1)$$

Denote $\mathbf{g}_{\mathbf{n,n}}$ as the channel power gain from the n-th MD2D-Tx to its receiver. The channel power gain of the interference link from the n-th MD2D-Tx to the k-th MD2D receiver (D2D-Rx) is denoted by $\mathbf{g\tilde{}}_{\mathbf{n,k}}$. Since all MD2D-Txs transmit information signals simultaneously over the same spectrum resource, the signal to interference plus noise ratio at the n-th D2D-Rx is as follows:

$$\gamma_n = \frac{p_n\, g_{n,n}}{\sum_{m \neq n}^{N} p_m g\tilde{}_{m,n} + \sigma^2} \qquad (2)$$

Where p_n is the transmit power of n-th D2D-Tx and σ^2 is the noise power. The achievable throughput at the n-th receiver in bits/second/Hz is thus given by

$$r_n = \tau_1 log_2(1 + \gamma_n)\,. \qquad (3)$$

Due to this, a MD2D pair closer to the PS can harvest more energy in short time and vice versa, which potentially results in various energy constraints for different MD2D pairs. The aim is to maximize the sum throughput of all MD2D pairs via time scheduling and power control, while satisfying the energy causality constraints. Thus, the optimization problem can be formulated as the following:

$$P1: \max_{\tau_0, \tau_1, \{p_n\}} \tau_1 \sum_{n=1}^{N} \log_2(1 + \gamma_n)$$

$$C1: \ \tau_1(p_n + p_c) \leq \eta \tau_0 p_{ps} |h_n^H w|^2, \forall n,$$

- $C2$: $\tau_0 + \tau_1 \leq 1$,
- $C3$: $0 \leq \tau_0, \tau_1 \leq 1$,
- $C4$: $p_n \geq 0, \forall n$, (4)

Where $\boldsymbol{p_c}$ represents the non-ideal circuit power consumption (e.g., AC/DC converter, analog amplifier, and processor). $C1$ guarantees that the consuming energy by any D2D-Tx cannot exceed its harvested energy. $C2$, $C3$ and $C4$ are the time and power control constraints. Hence, the optimization is possible by implementing the Throughput maximization algorithm. The optimal solution to the problem (4) is achieved if and only if all the time is used, i.e., $\tau_0 + \tau_1 = 1$.

If we can find a feasible solution to the optimization problem (4) in the remaining time, it demonstrates that the system throughput can also be improved. In other words, the solution is not the optimal solution. The constraint C1 in problem (4) can be transformed as follows:

$$\tau_1(p_n + p_c) - (1 - \tau_1)\eta p_{ps} |h_n^H w|^2 \leq 0 \ \ \forall n \qquad (5)$$

It is non-convex with respect to τ_1 and p_n, which hinders the application of standard convex optimization techniques. It can be observed that the non-convex constraints are transformed into convex functions with a tactful reformulation. Therefore, we try to search an optimal solution to the problem (4) by solving the equivalent problem. Denote $q*$ as the optimal solution of the considered problem (5),which is given by

$$\text{Set } q^* = \sum_{n=1}^{N} R_n(\{p_n\}')/t' \qquad (6)$$

The optimal solution is achieved if and only if

$$\max_{t,\{p_n\}} f(t, q, \{p_n\}) = \sum_{n=1}^{N} R_n(\{p_n\}) - qt. \qquad (7)$$

3. SIMULATION RESULTS

In this section, we perform in-depth simulations to evaluate the performance of the proposed algorithm in a 50 × 50 m area, where multiple D2D pairs are randomly located and the maximum distance between MD2D-Tx and MD2D-Rx is d = 10 m and d = 8 m ,d is the distance between the transmitter and receiver, and α = 3 represents the path-loss exponent. Unless specified otherwise, the bandwidth is 1 MHz and noise power spectral density is −170 dBm/Hz. The transmit power and number of antennas are 5 W and 10 for the PS, respectively. The energy conversion efficiency and circuit power consumption are 0.5 and 0.1 μW. In all simulations, q = 1 is set to start the algorithm and all results are averaged over 100 realizations.

The following are the simulation results of multicast D2D communication,

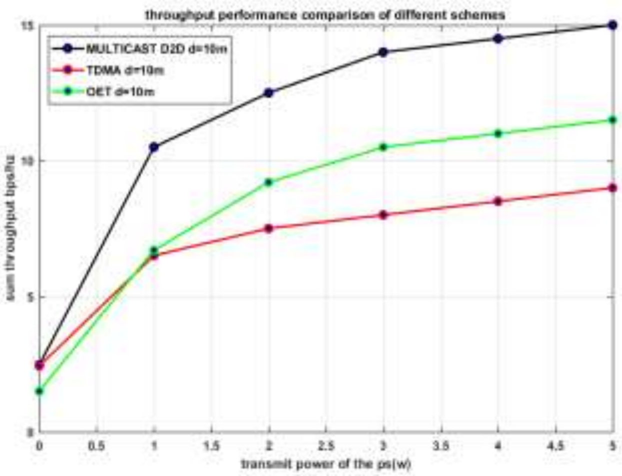

Fig 3. Sum throughput versus transmit power of the ps at d=10m

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Table I-The sum throughput at various schemes (based on distance)

Settings	Sum throughput	
	Distance d=8m	Distance d=10m
TDMA	12.5	9.32
OET	17.2	12.65
MULTICAST D2D	21.5	15.01

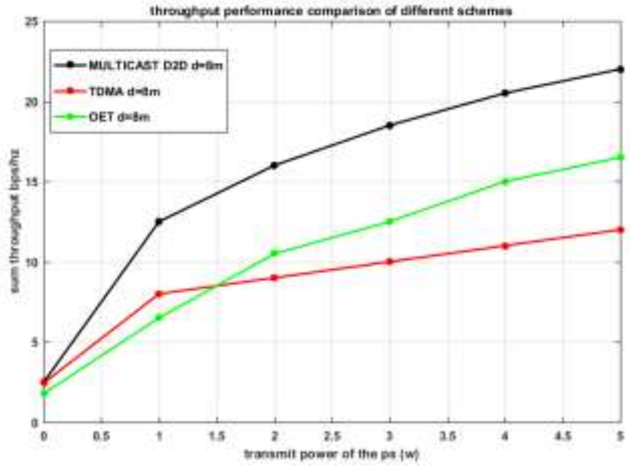

Fig 4. Sum throughput versus transmit power of the ps at d=8m

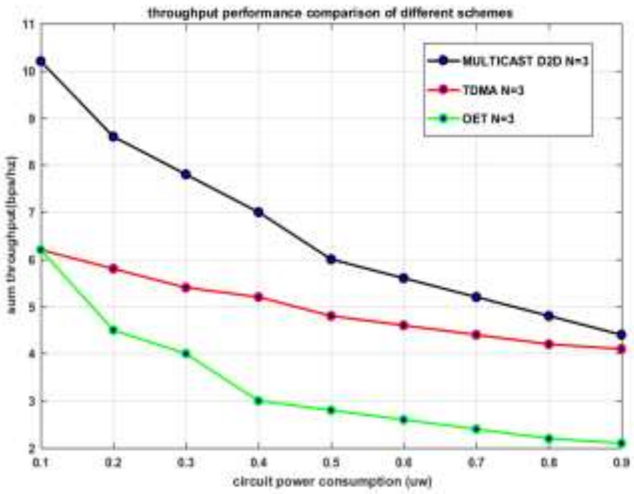

Fig 5. Sum throughput versus circuit power consumption at N=3

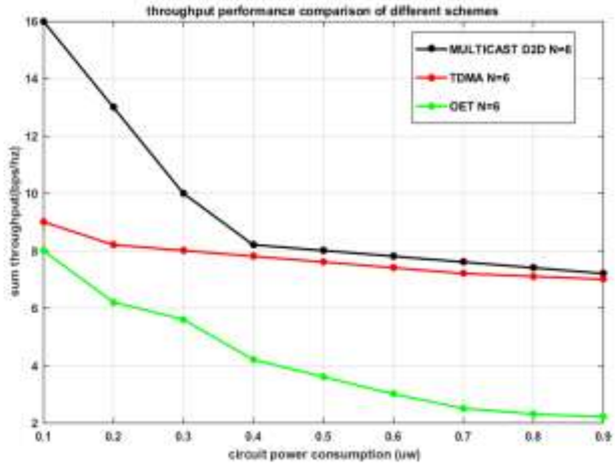

Fig 6. Sum throughput versus circuit power consumption at N=6

Table II-The sum throughput at various schemes (based on number of md2d pairs)

Settings	Sum throughput	
	Number of D2D pairs N=6	Number of D2D pairs N=3
TDMA	9.81	6.12
OET	8.23	6.15
MULTICAST D2D	16.01	10.20

Table III-Overall system sum throughput

Setting	Number of antennas(M)=10	
	MD2D	
No.of MD2D users	Circuit power consumption ($0.1\ \mu w$)	Circuit power consumption ($0.9\ \mu w$)
3	10.15	4.20
6	16.013	7.50

4. CONCLUSIONS

The sum throughput versus the transmit power of the PS is shown in Fig. 3 & 4. For comparison, we also provide an energy transfer scheme without beamforming, namely the omnidirectional energy transfer (OET), and a TDMA-based algorithm where multiple users harvest energy and then transmit information signals based on TDMA. It can be observed that the proposed algorithm outperforms the OET and TDMA-based algorithm in all cases. Furthermore, we can observe that the growth rate gradually becomes slower as the transmit power increases. This is due to the fact that the mutual interference among MD2D pairs dominates the system with sufficiently large transmit power. In addition, the final sum throughput would be better if the maximum distance *D* between D2D-Tx and D2D-Rx is reduced. The reason is that smaller maximum distance results in better channel state.

The sum throughput is plotted against the circuit power consumption p_c is shown in Fig 5 &6. It can be observed that the sum throughput decreases with an increasing circuit power consumption. Meanwhile, the throughput gain between the proposed algorithm and the TDMA-based algorithm is smaller. The reason is that MD2D pairs have little energy for information transmission and some MD2D pairs may even stop working since they have not enough energy.

The impact of number of antennas is further investigated and simulation results are shown in Table I, II & III. The plot confirms the intuition that the sum throughput grows as more antennas are added at the PS since more antennas can make use of the spatial resource to improve diversity gain.

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BIOGRAPHIES

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