Device-to-Device assisted user clustering for Multiple Access in MIMO WLAN

Zhao Hongyi[1], Wu Weimin, Lu li and Liu Yingzhuang
[1]School of Electronic Information and Communications, Huazhong University of Science and Technology
Wuhan, Hubei, 430074 China.
[E-mail: zhaohongyi@hust.edu.cn, wuwm@hust.edu.cn, li_lu@hust.edu.cn, liuyz@hust.edu.cn]

Received March 3, 2016; revised April 15, 2016; revised May 3, 2016; accepted May 20, 2016; published July 31, 2016

Abstract

WLAN is the best choice in the place where complex network is hard to set up. Intelligent terminals are more and more assembled in some areas now. However, according to IEEE 802.11n/802.11ac, the access-point (AP) can only serve one user at a single frequency channel. The spectrum efficiency urgently needs to be improved. In theory, AP with multi-antenna can serve multiple users if these users do not interfere with each other. In this paper, we propose a user clustering scheme that could achieve multi-user selection through the mutual cooperation among users. We focus on two points, one is to achieve multi-user communication with multiple antennas technique at a single frequency channel, and the other one is to use a way of distributed users' collaboration to determine the multi-user selection for user clustering. Firstly, we use the CSMA/CA protocol to select the first user, and then we set this user as a source node using users' cooperation to search other proper users. With the help of the users' broadcast cooperation, we can search and select other appropriate user (while the number of access users is limited by the number of antennas in AP) to access AP with the first user simultaneously. In the network node searching, we propose a maximum degree energy routing searching algorithm, which uses the shortest time and traverses as many users as possible. We carried out the necessary analysis and simulation to prove the feasibility of the scheme. We hope this work may provide a new idea for the solution of the multiple access problem.

Keywords: MIMO WLAN, Multiple Access, Network Search, Device-to-Device (D2D)

http://dx.doi.org/10.3837/tiis.2016.07.006 **ISSN : 1976-7277**

1 Introduction

Multiple access in wireless networks has always been a research focus. Conventional multiple access methods include Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), and Code-Division Multiple Access (CDMA) [1-3]. Recently, Multiple-Input-Multiple-Output (MIMO) Wireless Local Area Network (WLAN) is proposed as a novel wireless network to enable space division multiple access (SDMA) and have received much attention from both academic and industrial communities. Hereby leveraging the spatial diversity from digital beamforming, a MIMO WLAN Access Point (AP) is able to simultaneously serve multiple devices. Therefore, the MIMO WLAN is promising to reduce the collisions by orders of magnitude, especially in densely populated areas.

However, the core protocol of WLAN as known as Carrier Sense Multiple Access/ Avoid Collision (CSMA/AC) is not compatible with the digital beamforming of the current MIMO technologies. Specifically, the cellular MIMO systems require that devices transmit particular signals called pilots to base-stations before the transmissions at each time epoch. These pilots are used to estimate the corresponding channel state information (CSI) matrixes whose inverse are the time-space precoding matrixes for digital beamforming. Obviously, adding uplink pilots to CSMA/AC violates the design principle of such a listen-and-talk paradigm since the collections of the individual pilots must be synchronized and centralized. Thus, designing a novel CSMA-compatible multiple access strategy has recently become one of the most urgent issue in wireless communications.

Clustering user devices to estimate downlink CSI matrixes is one of the most promising way to enable SDMA in MIMO WLAN systems. In this scheme, a MIMO WLAN AP periodically attaches downlink pilots to synchronization broadcasting frames. Then, each device can estimate CSI individually according to the downlink pilots. To this end, the devices can be grouped into small clusters to execute space-time precoding to reduce collisions in MIMO WLAN. Note that uplink CSI matrixes can be obtained from the downlink CSI matrixes by leveraging the channel reciprocity.

A preamble technique is used in present OFDM-based WLAN systems to accomplish synchronization and channel estimation. The authors in [4] study the conditions under which superimposed pilots can be successfully used for jointly estimating the channel and detecting data. An efficient compensation scheme for the 802.11x is proposed in [5]. Neale and Mohsen analyzes the performance of the TCP/IP protocol according to the different scheduling strategies of free time slot allocation in Combined Free Demand Assignment Multiple Access [6]. These research suffer from the centralized control paradigms and may not be pragmatic in densely populated areas.

Users' antenna is randomly distributed. The irregular antenna array outperforms the regular antenna array in the achievable rate of massive MIMO communication systems when the number of antennas is larger than or equal to a given threshold [8]. In [9], authors propose a hierarchical cloud computing architecture to enhance performance based on D2D communication. In this paper, we propose a distributed user clustering based on Device-to-Device communication (D2D). D2D technology allows User Equipment (UE) that are in the proximity of each other to exchange information over a direct link, and can be operated as an underlay to cellular networks by reusing scarce spectrum resources [10-11]. D2D brings numerous benefits including the proximity gain, the reuse gain and the single-hop (multi-hop) gain [12]. In the proposed user clustering method, we convert the user clustering problem into network searching problem. Specifically, we first use CSMA/AC to select a user as a source node. With the help of the users' broadcast cooperation, we can search and select other user to construct an appropriate CSI matrix [13-16]. In order to efficiently search collaborating users, we propose the maximum degree energy routing searching algorithm, trying to use the shortest time and as many traversal users as possible.

Our contributions are as follows:

- We proposed a CSMA-compatible and distributed method using users' collaboration for user clustering to achieve time-space precoding in MIMO WLAN systems.
- We proposed a maximum degree energy routing searching algorithm, which is suitable for WLAN system, trying to use the shortest time and traversal as many users as possible.
- We give the specific operation protocol and frame format. Our analysis and simulations illustrate that the proposed protocol enjoys significant performance gain in densely populated areas.

2 System model

For a simple wireless LAN an access point has 2 antennas, and there are M users randomly distributed in a limited area. Each user has a single antenna. Since the access point has 2 antennas we have this channel model [17]:

$$\boldsymbol{Y} = \boldsymbol{HX} + \boldsymbol{w}, \tag{1}$$

where $\boldsymbol{X}$ stands for data from users, $\boldsymbol{Y}$ denotes the data that AP received, $\boldsymbol{H}$ denote the channel matrix, $\boldsymbol{w}$ denotes noise.

Suppose we have N_{acs} users access at the same time:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & \cdots & h_{1N_{acs}} \\ h_{21} & h_{22} & \cdots & h_{2N_{acs}} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \cdots \\ x_{N_{acs}} \end{pmatrix} + \begin{pmatrix} w_1 \\ w_2 \end{pmatrix}, \tag{2}$$

where y_i stands for the data received at the i-th antenna, x_i denotes the sending data of i-th user, h_{ij} denotes the channel coefficient of j-th user to the i-th antenna of AP.

Obviously, when $N_{acs} \leq 2$ the equation (2) is solvable. Theoretically, the access points have the ability to accommodate 2 users simultaneously. However, how to select these two users is a user clustering problem. We need select some users among lots of users, that is, C_M^2 possibilities. It is a combinatorial optimization problem. These two users need to meet some conditions. First of all, they have communication need right now. Secondly, because the information is uplink transmission to the access point, naturally, we hope their channel conditions are relatively good, their transmission power is relatively high, their channel matrix is preferred to be orthogonal, so they will not cause form strong interference to each other. And then, we hope that the strategy is to balance the fairness of all users, to make every user have equal access opportunity. To solve this problem, we can pick up one user first, and then base on these conditions and surrounding of the first user to select the second user.

To select the first user, we can exploit the existing CSMA/CA protocol. Each user performs the energy detection for the channel. In CSMA/CA protocol, when users need to access, if no signals are detected for a specific channel, users will first send a communication request signal RTS to the AP, and apply to access the channel. This is the first time for a user to broadcast. In order to ensure that the information is able to reach the AP, the user will utilize the maximum power to do the transmission. If AP receives RTS frame correctly, it returns CTS frame. So the user who send RTS frame correctly is selected. The way CSMA/CA select users is with stronger randomness but we hope we can be more objective by considering fairness to users.

In order to consider the fairness of the random access of WLAN, we introduce the fairness parameters here.

The common fairness parameters are calculated in this way [16]:

$$\text{FI}=\frac{\text{Throughout}_{\max}}{\text{Throughout}_{\min}} \tag{3}$$

$$\text{IFI}=\frac{\text{Throughout}_{\max}\text{-Throughout}_{\min}}{\text{Throughout}_{\text{total}}} \tag{4}$$

For this scheme, we propose the normalized fairness parameters F_Rank:

$$\text{F\_Rank}=\frac{\text{Throughout}_{\max}\text{-Throughout}_{\text{i}}}{\text{Throughout}_{\max}} \tag{5}$$

where $\text{Throughout}_{\text{i}}$ denotes the last calculated throughput rate in a unit time, i stands for the i-th user. The $\text{Throughout}_{\max}$ denotes the highest throughput rate in its records or the highest throughput that can be achieved in theory. The F_Rank denotes the fairness parameter of one user. It's value is in (0,1), the closer this user is to 1, the greater priority should be afforded to him. In order to be compatible with 802.11 protocols, CSMA/CA protocol is used to select the first user.

Our objective is $\max\{C_1+C_2\}, \Phi=\{\text{STA}_{acs1},\text{STA}_{acs2}\}$, $C_1=C_{\text{STA}_{acs1}}$, $C_2=C_{\text{STA}_{acs2}}$ the constraint is $s.t\begin{cases}\zeta^{\text{FI}}>\zeta^{\text{FI}}_{sys\_avg}\\ N_{acs}\le 2\end{cases}$, C_1 is selected randomly. Then we focus on C_2, $C_2=B\log(1+\dfrac{S_2}{I_{1,2}+w_2})$. $I_{1,2}=P_1\times\dfrac{<\boldsymbol{H}_1,\boldsymbol{H}_2>}{|\boldsymbol{H}_1||\boldsymbol{H}_2|}$, P_1 is the transmit power of the first user. So we develop a strategy to make $I_{1,2}$ as small as possible.

The access point can add a public pilot to the CTS frame, to support the STA to calculate their channel information. The frame structure is as follows:

Table 1. The CTS frame structure

Control frame CTS	Public Pilot
CTS content	public pilot inf.

Users who do not have an access right to AP, after receiving the CTS frame of the AP broadcast, calculate their own channel matrixes, and then keep silent.

The user who receives the CTS confirmation, knowing itself to be the first user of the selected user, first calculates its channel information. Then it needs to select the second appropriate user to access together through in a distributed way.

As for the selection of the subsequent users, we propose to solve the problem by collaboration between users and so the AP does not need to participate.

In the process of selecting the first user, AP has become a good assistant. Since the feedback of the CTS frame, each user could work out his channel matrix. But so far, each user's channel information exists in the user's own place, AP is not aware of this information, and users do not know each other’s channel information either.

In this distributed manner, the first selected user knows and confirms the second user who could communicate at the same time. We make collaboration between users like D2D, or more generalized collaboration between users, D2MD (Device to Multi-Device), by way of users broadcast information under certain conditions.

We define the first user as the source node D_s. The second user is defined as the target node D_t. So we change the problem into a node search process, where each user becomes aware of his channel information through the source node to find the target node.

We define a value function for determining the target node:

$$V_k = m \times \mathrm{F\_Rank} + n \times \mathrm{PI}_k + l \times \frac{< H_s, H_k >}{|H_s||H_k|} \tag{6}$$

where $\mathrm{F\_Rank}$ is the normalized fairness parameter for the k-th user. And m is the weight value of fair parameter. PI_k is transmit power parameter of the k-th user. And n is the weight value of this parameter. H_k is channel matrix of the k-th user. H_s is the channel matrix of the source node. $\frac{< H_s, H_k >}{|H_s||H_k|}$ represent the correlation characteristic between the k-the node and the source node. l is the weight value of it.

It should be emphasized that although the value function is consist of three factors, the value function is not required to be added directly. We make the high L bits of the bits sequence mapped to $\frac{< H_s, H_k >}{|H_s||H_k|}$. We make the less high N bits of the bits sequence mapped to PI_k. And we make the next M bits of the bits sequence mapped to $\mathrm{F\_Rank}$. In order to avoid the repetition of the value further, we can add X bits at the end as the random number. **Fig. 1** shows the data format.

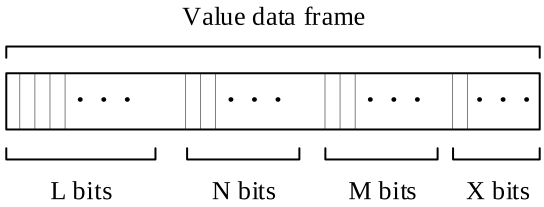

Fig. 1. the Value data frame format

The next step is to show how to find the target node.

2.1 D2D assisted user clustering for multiple access without the consideration of power control

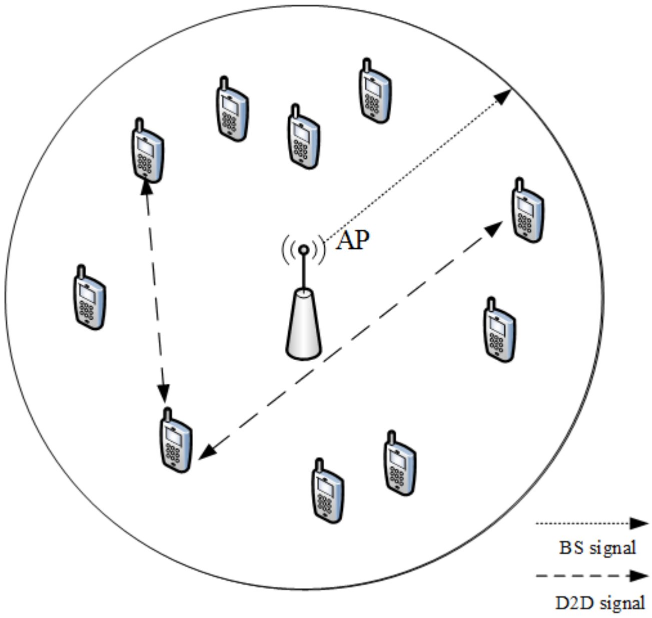

Fig. 2. Illustration of user cooperation without considering power control

As shown in **Fig. 2**, if we do not consider that the user transmission power is limited, we can assume that each user can broadcast information and be heard by all other users. At this point, the distance between any nodes and the source node can be regarded as one unit hop, and then the node searching process can be analyzed as follows:

Step 1: Source node broadcasts the search frame to all other users. We can define the format of the search frame as follows:

Table 2. The Search frame (without considering power control)

Channel matrix of the source node	The current target node value
H	Value

Step 2: Users who receive radio frame immediately calculate their value according to the function (5).

Step 3: Users calculate their delay function according to (6), then execute the delay process, afterwards, send their feedback to D_s . Delay function (6) is defined as a function of negative correlation function with the function of value (5). Therefore the most valuable user will get the shortest time delay to send feedback information. Define the delay function:

$$\mathrm{Delay}(k)=\mathrm{Waiting}_{\max}-\phi\times V_s(k) \tag{7}$$

where $\mathrm{Waiting}_{\max}$ ($\mathrm{W}_{\max}$) is the upper bound of the waiting time for the search process, $V_s(k)$ is the access value of the k-th user, ϕ is value adjustment factor (mostly we set it as 1), $\mathrm{Delay}(k)$ is the delay of time.

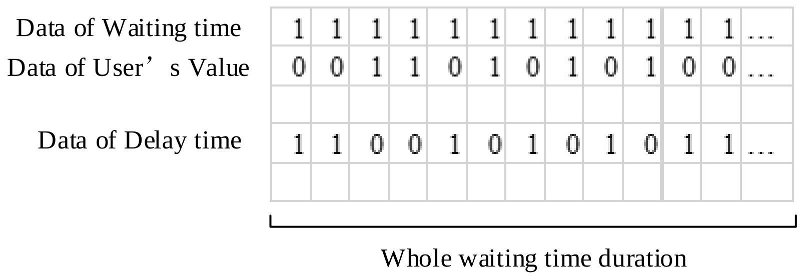

Fig. 3. Subtraction according to the bit sequence

The settings of W_{max} and ϕ can also be regarded as a reasonable setting for the minimum requirements of the second access users. If the value of all users cannot be satisfactory since the waiting time is overflow, the source node will communicate with AP directly.

Step 4: Each user checks its delay data bit sequence. It starts from the highest bit, when it find the first 0, it sends its feedback frame (**Table 3**). User checks the whole delay bit sequence which takes a full waiting time duration. The most valuable user namely D_t, since according to the delay function D_t gets the shortest delay time, so D_t sends feedback information earliest.

Table 3. The feedback frame format (without considering power control)

D2D Response frame	Most Valuable User
D2D_ACK	V

Other users receive feedback information from D_t, they will keep silent. If D_s cannot receive any feedback frame correctly, it will do these steps again.

Step 5: D_s sends a "Ready" message to all the users. And then D_s and D_t start this uplink access communication with AP.

2.2 D2D assisted multiple access with the consideration of power control

In practice, D2D transmission power is unlikely to cover all users in the cell. Generally speaking, D2D communication requires a power control procedure to ensure that there will not be much impact on the original communication system. At this point, the distance between many nodes and the source node is probably not one hop distance. If the source node D_s wants to traverse all of the cell users (D2D users), it needs to relay with other users, through multi hops to complete the traversal.

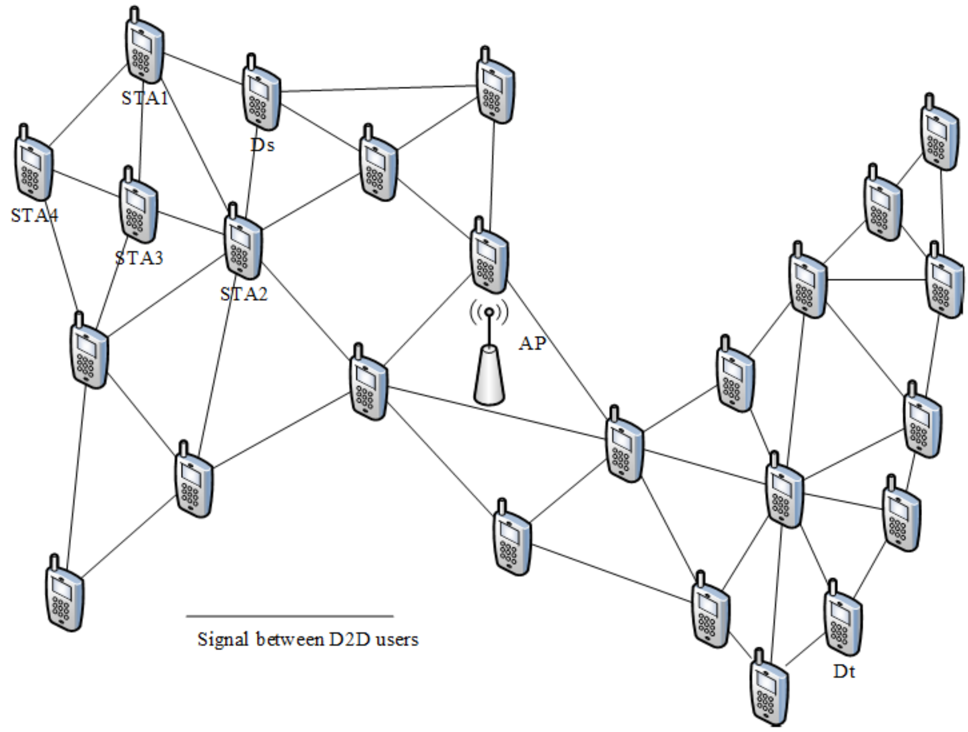

Fig. 4. Distributed search when D2D transmission power is limited.

The phones indicate the mobile terminal user STAs. The STAs are randomly distributed within the cell. A line connecting two STAs means they can have the connection of D2D communication. That is, its D2D signal's transmit power can be covered to the other end of the STA. If there are no connection lines between STAs, it means they cannot directly communicate like a D2D pair.

As shown in **Fig. 4**, the source node D_s is a node that is allowed to access according to CSMA/CA protocol. D_t node in **Fig. 4** is the optimal target node we need to find, that is, the optimal second access user. D_t is the most valuable user according to the value calculation function (6). Although the D_t comes out in the figure, the D_s is not aware of where the D_t is located in the cell when it starts a distributed node search. Through the establishment of such a model, we can clearly transform the problem, that is, starting from the node D_s, how to spend the least time (to experience the least number of edges) to find node D_t.

We take the number of neighbors of each node as the degree of the node. For each STA, when it carries on the D2D search, there is no particular direction for its signal. As a result, when any one of the STAs start sending search frame, each with one hop distance of the STA (within range of its transmitted power) can receive the search frame. D_s is the source node, when D_s start sending its search frame, STAs that within one hop distance to D_s can receive a search frame. When they receive the search frame and parse, because there is the possibility of conflict, we cannot let these STAs broadcast the next search frame at the same time. For example, the STA1 and STA2 in **Fig. 3**, if they broadcast at the same time, since the distance between STA3 and STA1 and the distance between STA3 and STA2 are both 1 hop, STA3 will receive two D2D signals at the same time, and there is no channel information and interference elimination strategy will be unable to accurately decode these search frames. This will affect the detection of all the other nodes associated with the STA3 node and the STA3 node. Therefore, to take the breadth of search needs to follow a certain time sequence of cooperation. That will pay a heavy price in terms of time and power, so we propose a maximum energy search strategy.

3 Maximum degree energy search strategy for user clustering

We hope that the coverage of search is large and also that the search time could be as little as possible. So we develop a search strategy called maximum degree energy search strategy for user clustering. Here we define the "degree energy" as a short-term investigation and measurement of average value. Namely every user senses a certain channel activity intensity in a certain period of time. Obviously, this parameter is positively related to the number of active users around itself. The core idea of the max degree energy search strategy is that it is not just a source node as the center and directly to make outward radiation search layers by layers. The direct breadth of search will bring serious interference and power overhead problem. In this way, the search of each search frame broadcast, will choose the max degree energy node as the next hop search frame relay in the range of its coverage, and then continue to expand the search depth and scope. That is to say, the coverage of the max degree energy search path is start from the source node, along the way that the max degree energy nodes path extension. All the STAs within the coverage of D2D power on the path will be searched. In this way, the target node is searched with the least power cost and time cost and the cost of interference management.

Because of the existence of relay nodes, we need to pay attention to two key factors, one is the current optimal target user, and the other is the max degree energy relay node that is the next relay node.

The search frame format of maximum degree energy search strategy is defined as follows:

Table 4. Search for the next relay node，its search frame format

D2D cooperative control frame _ search frame	Degree Energy delay factor	Search depth
D2D_Sch1 (Search for Relay Node)	RT,α	D_{max}

The calculation method of the max degree energy feedback delay is similar to that of the user's value calculation:

$$\text{Delay\_ED}(k)=\text{RT}_{max}-\alpha E_k \tag{8}$$

where RT_{max} is the upper bound of the waiting time for the relay node feedback process, E_k is the degree energy value of the k-th user, α is an adjustment factor, $\text{Delay\_ED}(k)$ is the delay of time.

Table 5. Search frame format of search target user node

D2D cooperative control frame _ search frame	Channel matrix of Source Node	Current optimal target user	Search depth
D2D_Sch2 (Search for Target Node)	H	Value, ID	D_{max}

The search depth factor D_{max} should be set at the beginning and will help us ending the searching process. The ID shows the search depth of the current node, we will use it at the "recall" process. And we define the feedback frame format as follows:

Table 6. Feedback the max degree energy node

D2D cooperative control frame _ response	STA degree energy information
D2D_ACK1	Energy, ID

Table 7. Feedback optimal target user value

D2D cooperative control frame _ response	Current optimal target user
D2D_ACK2	Value, ID

At beginning the max degree energy STA default as the source node, the max degree energy search algorithm implementation steps are as follows:

Step 1: The source node D_s broadcast the relay node search frame (**Table 4**).

Step 2: After users receive the search frame during the RT_{max} time, in accordance with the delay formula (7) and waiting for the delay to send feedback (**Table 6**). And then the source node and the next relay node shall commit to memory the current maximum degree energy node STA.

Step 3: The source node D_s broadcast the target node search frame (**Table 5**).

Step 4: After users receive the search frame during the $Waiting_{max}$ time, in accordance with the delay formula (6) and waiting for the delay to send feedback (**Table 7**). The user who get the highest value of these users, will get the shortest delay to send feedback information. And then the source node and the next relay node shall commit to memory the current target node STA.

Step 5: The source node D_s will decrease the search depth factor and confirm that the current optimal target node information and the next hop relay node information and then broadcast them out.

Step 6: The next relay node replaces the source node in step 1 to step 5 to itself and then continue to repeat step 1 to step 5.

Step 7: When the search depth is reduced to 0, the last relay node will inform the searched optimal target user as it knows its route. We call it the "recall" process. And the source node will also be informed to communicate with AP.

Step 8: The source node D_s and the target D_t start to access AP.

Node search flow diagram as shown below:

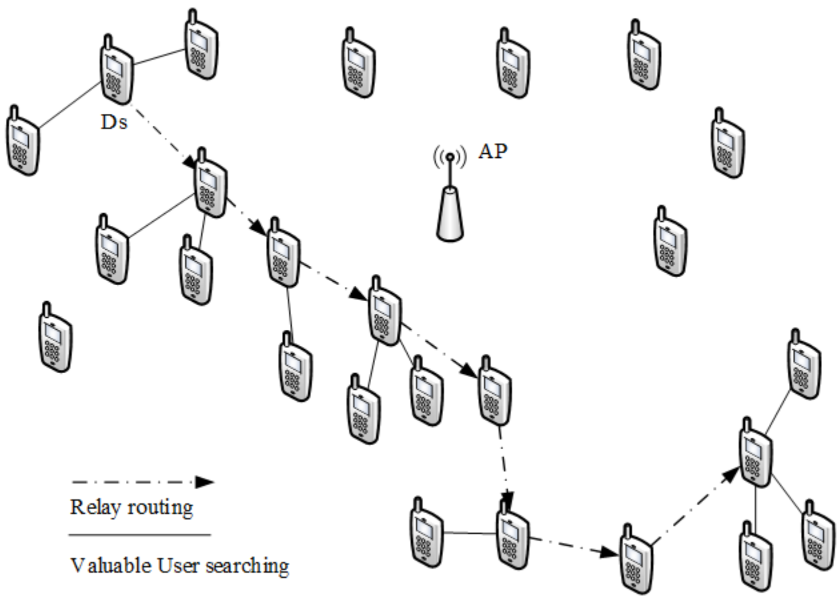

Fig. 5. Node search flow diagram

The **Fig. 6** illustrates the time sequence of max degree energy strategy working process.

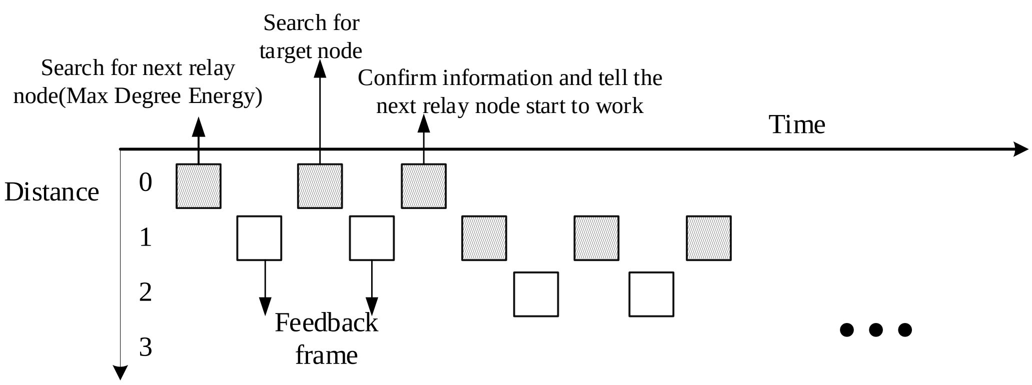

Fig. 6. Time sequence of max degree energy strategy

4 User clustering for AP with multiple antennas

When AP has multiple antennas (more than 2 antennas), our goal will change. In the two antenna case, since the first user is determined, we just need to find the other node (most valuable node). When the number of antennas is N, we shall find another N-1 target nodes via users' collaboration among each other. They can form a set of optimal access user.

We still use CSMA/CA protocol to select a user as the source node user randomly. The core idea is also to search the network nodes through users' cooperation. The source node traverses the user node in accordance with the maximum degree energy algorithm, to find the next hop relay node and to find high value node.

The search process and the feedback process for relay nodes is the same as it happens in the two antennas case. The search frame format is shown in Table 4, the delay function of formula (7).

The search process for the valuable user shall changes a little. The term that is used to record the most valuable node will now to record a set of nodes. The users' channel matrix will be stored in an array in that term.

Table 8. Search frame format of search target nodes (N antennas)

D2D cooperative control frame _ search frame	Channel matrix of Source Node	Current optimal target users	Search depth
D2D_Sch2 (Search for Target Node)	H	Users(H,ID)	D_{max}

In **Table 8**, the item "current optimal target users" is an array, to record the optimal N-1 users currently. The ID shows the current search depth, that tells which relay node find this user node. We will use it at the "recall" process.

It should be emphasized that we will be slightly adjusted the value function and delay function for the valuable node search process. We will improve the orthogonality judgment threshold. If the angle between user's channel matrix and source node's channel matrix is less than α, this user node will keep silent. α is a predetermined value (like 80 degree). In this way, we can eliminate some of the users in the self-check phase. On this account, discrimination increased. Users who have good orthogonality with the source node channel matrix are eligible to send feedback frame. The function that determine the delay time of sending feedback frame is as follows:

$$\text{Delay}(k)=\text{Waiting}_{max}-\phi\times(\text{n}\times\text{PI}_k+\text{m}\times\text{F\_Rank}_k)+\text{X}_{random} \tag{9}$$

where Waiting_{max} (W_{max}) is the upper bound of the wait time, they are bit-sequence that full of one. The power parameter is mapped to high N bits in the bits-sequence, N and n (in equation (9)) are positively related. The fairness parameter is mapped to the less high M bits in the bits-sequence, M and m (in equation (9)) are positively related. There is a sequence of X bits random numbers in the last of the bits-sequence. The delay data is the result of subtraction (9) bit by bit in bits-sequence (this operation shall refer to figure.3).

The operations in valuable users' feedback search frame time cycle will be changed a little. For users who received the search frame, if they satisfy the orthogonality condition they will calculate their delay time according to formula (9). Then, in the feedback frame time duration, they check the delay time bits-sequence, when they discovered the first 0 they do the feedback frame sending operations. If there is conflict, the source node (or relay node) will detect the conflict and cannot decode data correctly and ask for a repeat (telling the collision time, which bits in the bits-sequence). Users receive the instruction and check whether to resend according to the collision time. If so, users choose the second 0 bit time in that delay times bits-sequence to send feedback frame. If the conflict times are more than the time that 0 appears in the delay time bits-sequence. User chooses the last 0 bit time in that delay time bits-sequence to send feedback frame (since there are X bits random number at last).

Feedback frame format is as follows:

Table 9. Feedback frame of target nodes (N antennas)

D2D cooperative control frame _ response	Node inf.
D2D_ACK2	H, ID

The source node (relay node) can know all the users who are orthogonal to the source node channel matrix within their one-hop distances. Comparing with the current optimal users, they compare orthogonality of their channel matrix and current optimal users' channel matrix in order. And then, we update the best orthogonality of N-1 users. If the array is empty, first asking for no further good, giving priority to fill the array.

After the completion of a cycle of search, for the current user optimal users group Users (H, ID) has not been filled, such as the source node, it receives around a user's feedback frame, checks the angle between users' channel matrix, if the angle is less than (can be preset according to the needs, we tentatively 45 degrees) the feedback channel information of shorter time delay of user enters the Users (H, ID), discarding information of another user.

If current optimal user group Users (H, ID) has been filled, analogy for later of relay node, after its search duration, it has the current search of users' channel information, for example one user's channel matrix is h_k, apparently it has a good orthogonality with source node channel matrix (angle in (α, 90)). In the compared with current optimal access user group, set the angle that h_k and each user channel matrix in group is β_k (β_k is an array, which elements consist of all angle value). Take the distance between constant vectors C and β_k (2-norm) as a reference, that is $\Delta_k = \|\beta_k - C\|_2$, each element in C is 90 degrees, C is as long as the length of array β_k. Users with minimum N-1 Δ_k will be populated with an array of Users (H, ID).

When search depth is reduced to one, the last relay node shall implement "recall" operations, to informed by the relay node ID on the path to optimal uplink access communications users in the users group. And two operations on the antenna is also similar.

Finally, N users are selected for uplink access communications.

5 Performance analysis and system simulation

Now, we need to investigate the cost of the time on this algorithm.

For the two antennas, the time required for each relay node to search during its coverage is:

$$t_{D=1} = 5 \times \text{SIFS} + \text{W}_{\max} + \text{RT}_{\max} \tag{10}$$

The final step of the notification operation is required:

$$t_{recall} = (\text{D}_{\max} - 1) \times \text{SIFS} \tag{11}$$

So the total time cost of the search is:

$$
\begin{aligned}
t_{total} &= \mathrm{D}_{\max} \times t_{D=1} + t_{recall} \\
&= \mathrm{D}_{\max} \times (5 \times \mathrm{SIFS} + \mathrm{W}_{\max} + \mathrm{RT}_{\max}) + (\mathrm{D}_{\max} - 1) \times \mathrm{SIFS} \\
&= (6\mathrm{SIFS} + \mathrm{W}_{\max} + \mathrm{RT}_{\max}) \times \mathrm{D}_{\max} - \mathrm{SIFS}
\end{aligned}
\tag{12}
$$

where SIFS represents the time consumed by a frame data transmission. Because the frame data is quite few, so this is a very short period of time. As we can see that complexity of time t_{total} is $O(\mathrm{D}_{\max})$. It is just a linear complexity of the depth of the search range, this is acceptable.

From the point of view of power consumption, for each relay node, they transmitted 3 times data frames at most. For other users that are searched, one times data frames are transmitted at most (when its value is better than the current optimal target node). Therefore, the power cost of the algorithm is also the linear complexity of the search depth.

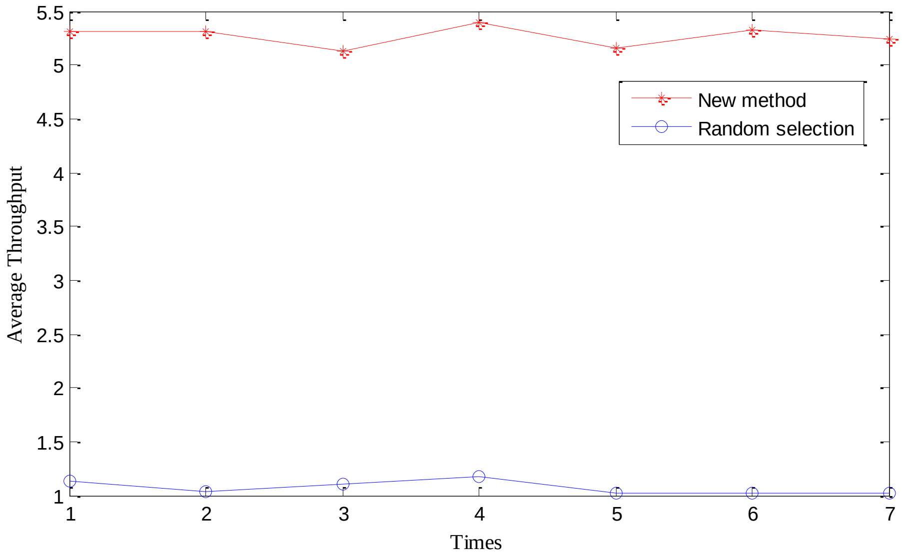

Fig. 7. The comparison of the average throughput

We first compare the max degree energy strategy and strategy of completely random selection, 1000 users are generated in the simulation, and the total uplink transmission is a fixed volume. As shown in **Fig. 7**, we can see that the average throughput of max degree energy strategy shows obvious advantages every time.

And then, we randomly distribute 40 STAs on the 200x200 plane, and we set the maximum distance of D2D cooperative communication range as 40. The transmission power of each STA is randomly selected between 80 and 120.

Time is calculated by the time slot, any one of the data frame will occupy at least a time slot, different STA cannot broadcast frames simultaneously, and there are at least one of the shortest frame interval.

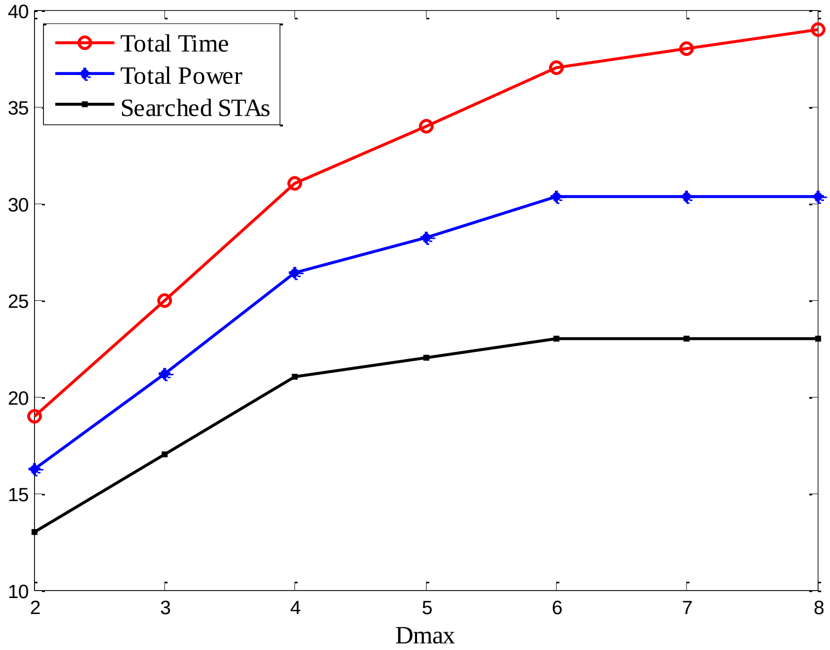

Fig. 8. D2D assisted multiple access in wireless network.

In **Fig. 8**, the figure is the result of the simulation using MATLAB, and the horizontal coordinates of the D_{max} are the pre-set depth of the search. Vertical coordinates for the red line is that we put a W_{max} (or RT_{max} time) as a unit of time, so it denotes the total time cost when search is performed. The implication of the vertical axis for the blue line is that the power of each transmission is regarded as one unit, so it denotes the unit power cost when the search is performed. From this simulation results we can see that with the increase of D2D, the time and power consumption of D_{max} distributed cooperation will keep on increasing, but the growth rate is slower and slower. Thus, it can be concluded that the search depth can make the search more efficient. If the D_{max} needs to be calculated, we recommend

$$D_{max} = \frac{\text{Cell radius}}{\text{D2D Communication radius}} \tag{13}$$

When the search program is started, there are lots of non-searched nodes, as the search program moves on, some STAs have been searched, while the searched STAs will not feedback when it is been asked again. So the cost of time and power will show down as the factor pre-set depth becomes larger. The simulation certifies the derivation before. In terms of time complexity, the extra overhead time and the scale of the explored nodes are linear complexity relations.

Using the max degree energy search approach, although we just take one routing path of relay nodes, but we can get from the simulation that the max degree energy search strategy can traverse more than half of the search node. It can be used to get a larger coverage if the D_{max} can be set appropriate.

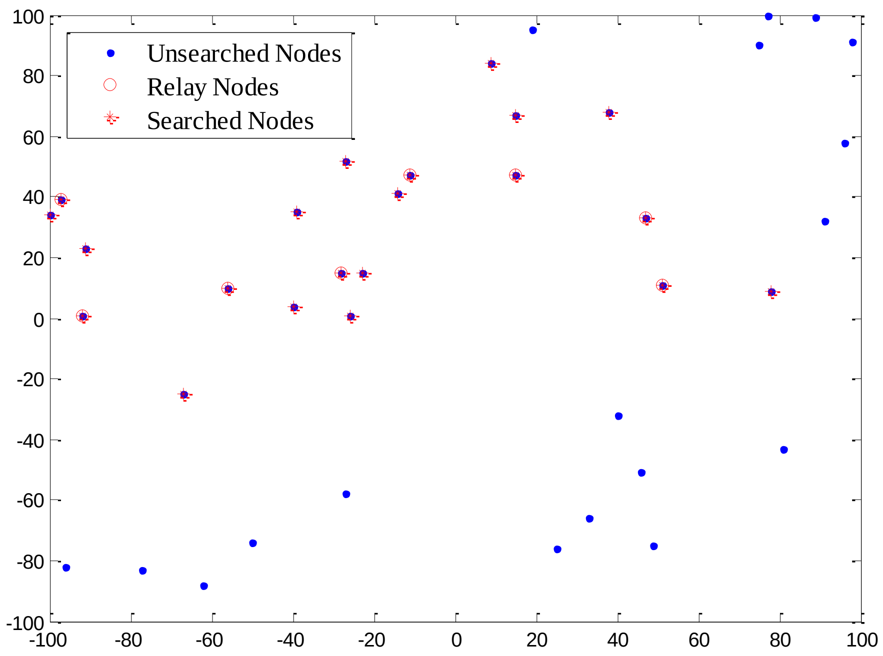

Fig. 9. the searched nodes' distribution by the max degree energy algorithm.

Fig. 9 gives us an intuitive impression of a maximum degree energy search strategy. The red node means it is the node that is searched. The blue node means it is the node that is not searched

We also compare our scheme with the CSMA/CA scheme for simulation. The simulation conditions are set as follows. There are 100 users randomly distributed in the area that covered by the WLAN. The access point has 2 antennas. At arbitrary time there are 10 users need to transmit data (CSMA/CA). One data transmission of each user requires 1000 time slots. We assume that D2D communication radius is about 1/10 of the cell radius. Therefore we set the search depth D_{max} to 10. We set W_{max} and RT_{max} to 16 SIFS. Then we have the following results.

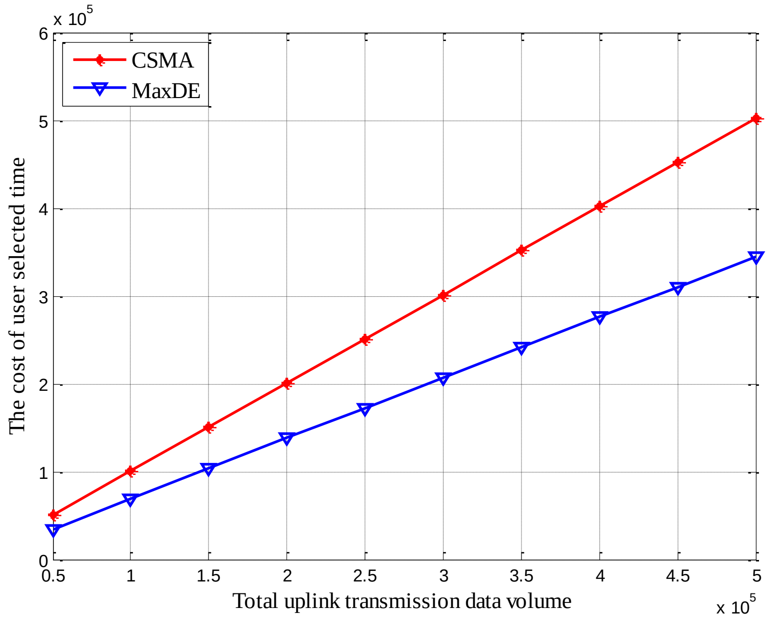

Fig. 10. Compare the proposed scheme with the CSMA/CA scheme

In **Fig. 10** we can see that our algorithm requires less time when the same amount of data transferred. The multi antenna multiplexing can have a significant gain. Predictably, with the increase of the number of antennas and the improvement of the algorithm, the gain will be more obvious.

For the time complexity of the multiple antennas scenarios, if the wait time $\mathrm{W_{max}}$ that the relay nodes search the user node value or other relay nodes($\mathrm{RT_{max}}$) are determined, the total time cost can be expressed as:

$$\begin{aligned} t_{total} &= D_{\max} \times t_{D=1} + t_{recall} \\ &= D_{\max} \times (\mathrm{m} \times \mathrm{SIFS} + \mathrm{W_{max}} + \mathrm{RT_{max}}) + n \times D_{\max} \times \mathrm{SIFS} \\ &= ((\mathrm{n}+\mathrm{m}) \times \mathrm{SIFS} + \mathrm{W_{max}} + \mathrm{RT_{max}}) \times D_{\max} \end{aligned} \qquad (14)$$

Where n is the number of antennas, m is equal to the eligible nodes that during path search traversing, apparently (13) is also linear correlation with search depth. However, n antennas collaboration scenarios in search process there will be more compute operation. But for the computers and intelligent terminal now, it is not difficult, the time consuming is rarely.

We set 1000 users randomly distributed in the area that covered by the WLAN. The access point has 4 antennas. At arbitrary time there are 10 users need to transmit data (CSMA/CA). One data transmission of each user requires 1000 time slots. We assume that D2D communication radius is about 1/10 of the cell radius. Therefore we set the search depth $D_{\max}$ to 10. We set $\mathrm{W_{max}}$ and $\mathrm{RT_{max}}$ to 32 SIFS. Then we have the following results.

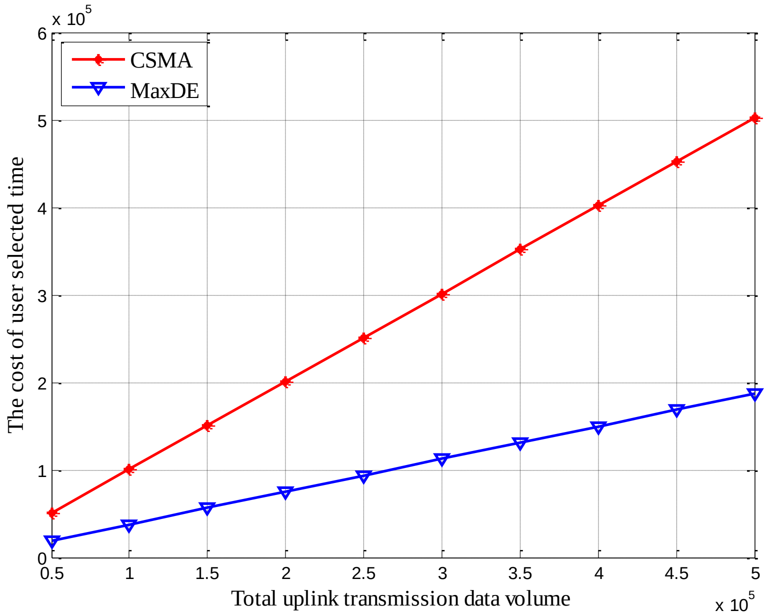

Fig. 11. Compare the proposed scheme with the CSMA/CA scheme (AP with 4 antennas)

Understandably, with the increase of the number of antennas, the total transmission rate will be higher.

6 Conclusion

In this paper, a D2D assisted distributed cooperation multi-user access for MIMO WLAN is proposed. In this method, as we know the symmetry of the channel, after AP broadcasting some specific message, the channel information could be computed by each STA itself. In the traditional strategy compatible with CSMA/CA, a suitable user is selected, and then a user is chosen to select the appropriate access to other users. The problem is transformed into the problem of node searching, and then according to the characteristics of the detection of the channel energy, a search algorithm has been proposed based on the max degree energy search strategy. In the distributed cooperation strategy, the fairness of the user's communication and the factor of the signal to noise ratio are considered, and as a result each user could have more chances to access the AP.

References

[1] R.Liu, "Autocorrelation division multiple access systems (ADMA)," in *Proc. of ICCCAS*, Milpitas, CA, USA, 2009. Article (CrossRef Link)

[2] D.Parthiban, A.J.Philomina, N.R.Raajan, B.Monisha, M.V.Priya and S.Suganya, "Wavelet-based multiple access technique for mobile communications," in *Proc. of PRIME*, Salem, Tamilnadu, Mar. 2012. Article (CrossRef Link)

[3] B.Banitalebi, J.Abouei, "An efficient multiple access interference suppression scheme in asynchronous femtocells," *IET Communications* vol.7, no.14, p.1439-1448, Spet. 2013. Article (CrossRef Link)

[4] T.j.Liang, W.Rave and G.Fettweis, “Iterative joint channel estimation and decoding using superimposed pilots in OFDM-WLAN,” in *Proc. of ICC*, Istanbul, Turkey, June 2006. Article (CrossRef Link)
[5] H.Lin, T.Nakao and K.Yamashita, “Joint Compensation of Frequency-Selective I/Q Imbalance and CFO in OFDM-Based WLAN,” in *Proc. of CCNC*, Las Vegas, NV, USA, Jan. 2008. Article (CrossRef Link)
[6] Neale J, Mohsen, A.-K., “Impact of CF-DAMA on TCP via satellite performance,” in *Proc. of GLOBECOM* , San Antonio, TX, USA, Dec. 2001. Article (CrossRef Link)
[7] M.Jo, A.Almeida, T.F.Maciel et al. “Massive MIMO: Survey and Future Research Topics,” *IET Communications*, Online Publications Version, 2016. Article (CrossRef Link)
[8] X. Ge, R. Zi, H. Wang, J. Zhang, and M. Jo, “Multi-user Massive MIMO Communication Systems Based on Irregular Antenna Arrays,” *IEEE Transactions on Wireless Communications*, Online Publications Version, 2016. Article (CrossRef Link)
[9] M.Jo, T.Maksymyuk, B.Strykhalyuk, “Device-To-Device-Based Heterogeneous Radio Access Network Architecture for Mobile Cloud Computing,” *IEEE Wireless Communications*, vol. 22, no. 3 , pp. 50-58, June 2015. Article (CrossRef Link)
[10] Gao Q, Fei L, Zhang J, Peng XH. “Performance optimisation of a medium access control protocol with multiple contention slots in multiple-input multiple-output ad hoc networks,” *IET Communications*, vol. 4, no. 5 pp. 562-572, Mar. 2010. Article (CrossRef Link)
[11] Doppler K, Rinne M, Wijting C, Ribeiro CB, Hugl K., “Device-to-device communication as an underlay to LTE-Advanced networks,” *IEEE Communications Magazine*, vol. 47, no. 12 pp. 42-49. Nov. 2009. Article (CrossRef Link)
[12] Fodor G, Dahlman E, Mildh G et al. “Design aspects of network assisted device-to-device communications,” *IEEE Communications Magazine*, vol. 50, no. 3 pp. 170-177, Mar. 2012. Article (CrossRef Link)
[13] Yu T, Jun S, Shixiang SH., “Radio resource allocation based on greedy algorithm and successive interference cancellation in Device-to-Device (D2D) communication,” in *Proc. of IET International Conference*, Beijing, China, Apr. 2013. Article (CrossRef Link)
[14] Zheng CH, Cumanan K, Mai X, Zhiguo D., “Robust secrecy rate optimisations for multiuser multiple-input-single-output channel with device-to-device communications,” *IET Communications*, vol. 9, no. 3, pp. 396-403, Feb. 2015. Article (CrossRef Link)
[15] Yang Y, Tao P, Bo P, Wenbo W., “Region Division Based Spectrum Access of D2D Communication under Heterogeneous Networks,” in *Proc. of VTC Spring*, Seoul, South Korea, May 2014. Article (CrossRef Link)
[16] Zhenyu ZH, Mianxiong D, Ota K et al., “Game-theoretic approach to energy-efficient resource allocation in device-to-device underlay communications,” *IET Communications*, vol. 9, no.3 pp. 375-385.2015 Article (CrossRef Link)
[17] David Tse, Pramod Viswanath, “Fundamentals of Wireless Communication,” Cambridge University Press, 2005.
[18] Hongyi Zhao, Yang Cao, Yingzhuang Liu, "Interference Cancellation for Relay-Assisted D2D Communication," *KSII transactions on internet and information system (TIIS)*, vol. 9, issue. 9, pp. 3276-3292, 2015. Article (CrossRef Link)
[19] Schaar M, Sai Shankar, “New fairness paradigms for wireless multimedia communication,” in *Proc. of ICIP*, Genova, Italy , Sept. 2005. Article (CrossRef Link)

Zhao Hongyi is a PhD student in School of Electronics Information and Communications, Huazhong University of Science and Technology, Wuhan, P. R. China. He received the B.S. degree in information and communication engineering at Huazhong University of Science and Technology, Wuhan, P. R. China in 2010. In the following year, he was sent directly to study for the doctorate in information and communication engineering at Huazhong University of Science and Technology. He mainly carries on the research of D2D communication, the distributed cooperation and the capacity of communication system.

Wu Weimin is currently an assistant professor in School of Electronics Information and Communications, Huazhong University of Science and Technology, Wuhan, P. R. China. He received B.S. degree in Xidian University and received his Ph.D degree at Huazhong University of Science and Technology in 2007. His research interests include mobile agent communication protocol and communication system simulation.

LULI received the B.S. degree and master degree in communication engineering from Wuhan University of Technology in 2007, 2010. He is currently working toward the Ph.D. degree with a focus on utilizing convex optimization in multi-cell MIMO networks.

Yingzhuang Liu is a professor of Huazhong University of Sci.&Tech. (HUST). His main research field is broadband wireless communication, including LTE and IMT Advanced system, etc., especially its Radio Resource Management. From 2000 to 2001, hes was a postdoctoral researcher in Paris University XI. From 2003 up to now, he has presided over 10 national key projects, published more than 80 papers and held more than 30 patents in the field of broadband wireless communication. He is now the group leader of broadband wireless research of HUST, which has more than 10 young teachers and more than 20 PhD students. Yingzhuang Liu is a professor of Huazhong University of Sci.&Tech. (HUST). His main research field is broadband wireless communication, including LTE and IMT Advanced system, etc., especially its Radio Resource Management. From 2000 to 2001, he was a postdoctoral researcher in Paris University XI. From 2003 up to now, he has presided over 10 national key projects, published more than 80 papers and held more than 30 patents in the field of broadband wireless communication. He is now the group leader of broadband wireless research of HUST, which has more than 10 young teachers and more than 20 PhD students.