An Interference Management Strategy for Dynamic TDD in Ultra-dense Networks

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Abstract. Ultra-dense networks (UDNs) are considered to meet demands for fast increasing throughput requirements per unit area in hotspots. Along with the dynamic variation of the throughput for the uplink/downlink (UL/DL), flexible resource allocation schemes become very important in UDNs based on time division duplex (TDD) for densely deployed access points (APs) and user equipments (UEs). In this paper, we propose a strategy to resolve the interference problem brought by dynamic TDD in UDNs. Firstly, we design a clustering method based on the Chameleon algorithm to reduce the inter-cluster interference. With the clustering results, the throughput requirements of each cluster become similar. Then we adopt a dynamic UL/DL resource allocation (DRA) for small cells in each cluster, with fewer adopted frame structures reaching more users' throughput requirements adequately. At last, in each cluster, we adopt multi-cell beamforming (MBF) in small cells with the same frame structure to further mitigate inter-cell interference (ICI). Simulation results show that our proposed strategy could achieve satisfactory performance in UL/DL throughput.

Keywords: UDNs · TDD · Clustering · ICI · MBF

1 Introduction

Cisco Visual Networking Index (VNI) in 2017 forecasts that by 2021, the global mobile data traffic will reach up to 49 EBs/month and the average mobile transmission rate will exceed 20 Mbps [1]. Ultra-dense networks (UDNs) could improve the throughput per unit area by densely deploying low-power and small-coverage access points (APs) in hotspots. The density of APs λ_a and the density of user equipments (UEs) λ_u are in the same order of magnitude [2]. It is considered as an inspiring research field in the fifth generation (5G) mobile communication system [3].

Many new network applications have high demands for uplink (UL) traffic, which achieve or even exceed demands for downlink (DL) traffic. And in hotspots,

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throughput requirements for UL/DL of UEs per unit area have a significant dynamic variation due to the densification of UEs [4]. The cases drive UDNs design to consider dynamic time division duplex (TDD) schemes as one of the feasible solutions. Dynamic TDD schemes, in which DL and UL subframes can be dynamically allocated to APs due to real-time UL/DL throughput requirements of small cells, were proposed to allow APs to effectively adapt the quick variation of UL/DL throughput requirements. Still, the scenario considering both UDNs and TDD schemes causes severe inter-cell interference (ICI) [5], which contains ordinary inter-cell interference (OICI) and cross-subframe inter-cell interference (CICI). The CICI is caused by adjacent cells in different transmission directions.

Various technologies were proposed to mitigate ICI in TDD networks. [6] offers a dynamic resource allocation scheme which reduces interference with lower complexity for dynamic TDD-based heterogeneous cloud radio access networks. [7] proposes a distributed user-centric clustering algorithm which focuses on DL interference. But these technologies may not work well in TDD-based UDNs because algorithms of them do not need to process high density and dynamic data reflecting information about APs like that in UDNs. And they often only focus on the interference in DL, because the interference in UL caused by low-power UEs without a high density is often ignored in considered scenarios. However, the interference in UL is also severe in UDNs because of the shorter distance between UEs.

The authors in [8] prove a beneficial performance of the traffic adaptation to the service time and energy efficiency in UDNs with dynamic TDD schemes. But an effective dynamic UL/DL resource allocation (DRA) and an interference management (IM) method of the TDD scheme require a dynamic inter-cell coordination, which could be hard to implement in high-density, high-dynamism and low-cost UDNs. That impels TDD-based UDNs to perform a flexible and real-time IM strategy whose algorithm can process large data dynamically. Considering the above problems, we propose an IM strategy jointly using the Chameleon clustering (CC) algorithm, a DRA and the multi-cell beamforming (MBF) in dynamic TDD-based UDNs.

In this paper, we consider that adopting TDD schemes in UDNs could bring high throughputs per unit area and high UL/DL resource utilization efficiency in time domain by utilizing appropriate technologies. We use the CC algorithm considering dynamic locations of small cells and dynamic throughput requirements of UEs as two significant parameters. Besides, the CC algorithm can process large and dynamic data to adapt to high-density and complex UDNs. The clustering result reduces inter-cluster ICI and makes the throughput requirement of each cluster similar. And the similar throughput requirement ensures fewer UL/DL frame structures can meet more users' throughput requirements in each cluster. Then we jointly adopt the DRA in time domain and the MBF in spatial domain in each cluster to mitigate intra-cluster interference and ensure users could get on-demand throughputs of UL/DL.

2 System Model

We consider a typical TDD-based UDN consisting of N densely and randomly deployed single-antenna APs, M densely and randomly distributed single-antenna UEs and one central controller. The density of APs and UEs is respectively λ_a and λ_u. Also, we assume the central controller knows the perfect channel state information (CSI) and one UE accesses only one AP in each small cell, so there are corresponding M small cells to be clustered. The network deployment is shown in Fig. 1, where B_0 and B_1 are orthogonal, and the icon U (UL) or D (DL) expresses a real-time transmission mode of small cells. Figure 1 shows that by using the proposed strategy, the ICI remains between small cells with the same bandwidth B_1 in adjacent clusters.

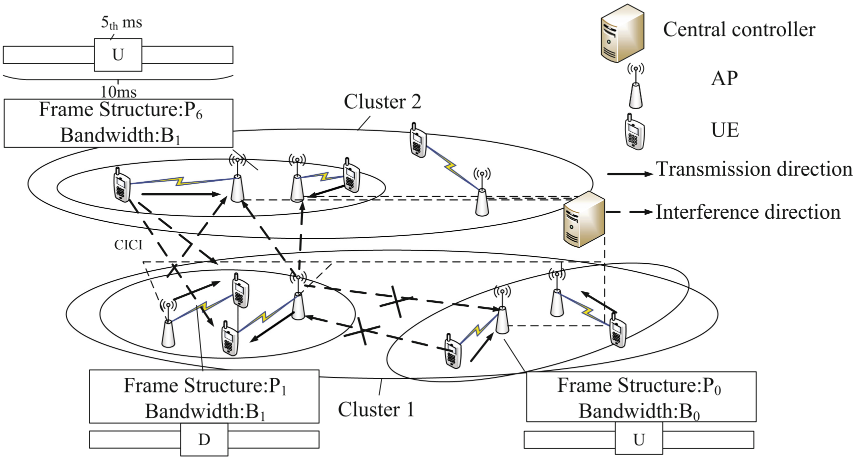
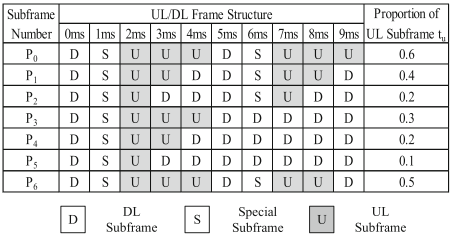


Fig. 1. A typical TDD-based UDN deployment



Subframe Number	UL/DL Frame Structure										Proportion of UL Subframe t_u
	0ms	1ms	2ms	3ms	4ms	5ms	6ms	7ms	8ms	9ms	
P_0	D	S	U	U	U	D	S	U	U	U	0.6
P_1	D	S	U	U	D	D	S	U	U	D	0.4
P_2	D	S	U	D	D	D	S	U	D	D	0.2
P_3	D	S	U	U	U	D	D	D	D	D	0.3
P_4	D	S	U	U	D	D	D	D	D	D	0.2
P_5	D	S	U	D	D	D	D	D	D	D	0.1
P_6	D	S	U	U	U	D	S	U	U	D	0.5

D DL Subframe S Special Subframe U UL Subframe

Fig. 2. Dynamic TDD frame structures of TD-LTE

We adopt the frame structures defined in TD-LTE, which is shown in Fig. 2. Based on the proposed clustering algorithm, M small cells will be divided into

K clusters, denoted by $\mathbb{CL} = \{CL_1, CL_2, \ldots, CL_K\}$. For CL_k, the sum of the throughput requirements is denoted by TR_k, where $k = \{1, \ldots, K\}$. And the throughput requirement of each cluster is similar after the proposed clustering algorithm. If TR_k is too large without being controlled, it will be difficult to effectively satisfy users' requirements with the finite number of UL/DL frame structures. In the CL_k, by comparing throughput requirements of the given small cells in the same cluster with one threshold value β, the central controller will reconfigure frame structures for each AP into the matched configuration to constitute the secondary cluster. Each secondary cluster uses one matched configuration. At the same time, in each cluster, the system spectrum will be divided into different secondary clusters to eliminate the ICI in the same cluster. After that, the central controller will transmit the precoding matrix to APs for using the MBF to eliminate the ICI further.

We denote $\mathbf{P_x} = \{p_{t1}, p_{t2}, \ldots, p_{t10}\}$, where x $= \{0, \ldots, 6\}$ to express one of the standard frame structures (SFS) defined in TD-LTE, where $p_t = 0$ (UL subframe) or 1 (DL subframe). When the transmission mode of the transceiver switches from DL to UL, a special subframe is required. For the sake of simplicity, a special subframe is used as a DL subframe in this paper. For example, the SFS of number "0" can be denoted by $\mathbf{P_0} = \{1, 1, 0, 0, 0, 1, 1, 0, 0, 0\}$.

3 DRA and MBF Based on CC Algorithm (DRA-MBFCC)

In TDD-based UDNs, the clustering algorithm should adapt to many new challenges as mentioned above. So the CC algorithm has to process large dynamic data and mitigate the severe ICI caused by the high densification of active APs and UEs. Besides, to reduce intra-cluster ICI and ensure the on-demand throughput requirement of each user, we jointly adopt DRA and MBF. The details are described in the following.

3.1 Chameleon Clustering

The most obvious advantage of the CC algorithm is considering both interconnectivity and closeness between adjacent clusters at the same time [9]. We regard the coordinates of active APs in TDD-based UDNs as coordinates of data set during the clustering process. Firstly, we need several sub-clusters as a data set of the clustering algorithm, and each sub-cluster should contain at least two small cells. We get required sub-clusters by using the k-nearest algorithm by setting a proper k in this paper, which is related to the number of small cells. Then we merge sub-clusters by the Chameleon algorithm. The interconnectivity called relative interconnection (RI) is associated with the geographical position of the given small cells (denoted as the coordinates of active APs). The closeness called relative closeness (RC) is subjected to both geographical position and throughput requirements of clusters. The two values, RI and RC co-determine if adjacent sub-clusters can be merged. $RI(sCL_p, sCL_q)$ is calculated to measure the ICI between adjacent sub-clusters, sCL_p and sCL_q, which is expressed as:

$$RI(sCL_p, sCL_q) = \frac{2|EW(sCL_p, sCL_q)|}{|EW(sCL_p)| + |EW(sCL_q)|} \tag{1}$$

where $|EW(sCL_p)|$ indicates the sum of edge weights between APs in the sub-cluster sCL_p. It is the same for $|EW(sCL_q)|$. $|EW(sCL_p, sCL_q)|$ is the weight of edges that connect APs between sCL_p and sCL_q. The weighted value is the reciprocal of the corresponding edge length, and the above defined parameters can be calculated as: $|EW(sCL_p)| = \sum_i \frac{1}{l_p^i}$ and $|EW(sCL_p, sCL_q)| = \sum_i \frac{1}{l_{p,q}^i}$, where l_p^i, $l_{p,q}^i$ is respectively the length of the corresponding weighted edge, and i is the index of corresponding small cells.

In each cluster, adopting more frame structures means more CICI exists, which is hard to mitigate. On the other hand, with the constraint of the throughput requirement of each cluster, fewer frame structures can efficiently satisfy the throughput requirement of each UE as required, so it is necessary to restrict the sum of the throughput requirement of each cluster. $RC(sCL_p, sCL_q)$ is calculated to measure the closeness between adjacent sub-clusters sCL_p, sCL_q, and the threshold γ restricts the sum of the throughput requirements in each cluster. $RC(sCL_p, sCL_q)$ is calculated as:

$$\begin{cases} 0, & TR_{p,q} > \gamma \\ \dfrac{(|n_p| + |n_q|)|\overline{EW}(sCL_p, sCL_q)|}{|n_q||\overline{EW}(sCL_p)| + |n_p||\overline{EW}(sCL_q)|}, & TR_{p,q} \leq \gamma \end{cases} \tag{2}$$

where $|\overline{EW}(sCL_p, sCL_q)|$ is the mean of edge weights that connect vertices between sCL_p and sCL_q. It is the same to $|\overline{EW}(sCL_p)|$, $|\overline{EW}(sCL_q)|$. $|n_p|$, $|n_q|$ is respectively the number of small cells in sCL_p, sCL_q. γ is a threshold value set according to both the whole throughput requirement of the network, TR, and the expected number of clusters, K $(\gamma \geq TR/K)$. $TR_{p,q}$ can be calculated as: $TR_{p,q} = TR_p + TR_q$, where TR_p, TR_q is respectively the throughput requirements of sCL_p, sCL_q. Besides, $RIC(sCL_p, sCL_q)$ determines if sub-clusters can be merged, which is calculated as:

$$RIC(sCL_p, sCL_q) = RI(sCL_p, sCL_q) \times RC(sCL_p, sCL_q) \tag{3}$$

If $RIC(sCL_p, sCL_q)$ arrives at a preset threshold δ, the sCL_p and sCL_q can be merged. The pseudo-code of the proposed clustering algorithm is shown in Algorithm 1. The greater the value of $RIC(sCL_p, sCL_q)$ is, the possibility of merging sCL_p and sCL_q is higher, which means that the adjacent sub-clusters could merge when the distance between them becomes far enough. That reduces the inter-cluster ICI. On the other hand, the set of γ makes the sum of the throughput requirement of each merged cluster similar. After the above, the intra-cluster ICI has not been mitigated. Therefore, we should mitigate intra-cluster ICI further in the next steps.

Algorithm 1. CC algorithm

```
Input: update the coordinates of $L$ sub-clusters, $s\mathbb{CL}_l$ consisting of small cells, which are expected to be clustered after the k-nearest algorithm as coordinates of initial data set, and uniformly choose K sub-clusters, $s\mathbb{CL}_m$ from the initial data set, $s\mathbb{CL}_l$.
Initialization:
  a) $\gamma$: the threshold in (2); b) $\delta$: the threshold compared with $RIC$; c) $K$: the number of clusters expected; d) $TR_p$: the throughput requirement of the $p_{th}$ cell; e) $p$=1, variable $q = 1, \cdots, L$.
Output: K expected clusters.
Step1:
while $(s\mathbb{CL}_l\{q\} \neq \emptyset) \bigcap \ (p \leq K)$ do
    if there existing adjacent $s\mathbb{CL}_m\{p\}$, $s\mathbb{CL}_l\{q\}$ for $q = 1, \cdots, L$, and $(TR_p + TR_q) \leq \gamma$ then
        calculate corresponding $RIC(s\mathbb{CL}_m\{p\}, s\mathbb{CL}_l\{q\})$=$\mathbb{C}\{q\}$, put the value $\mathbb{C}\{q\}$ in $\mathbb{C}$, and carry out the step 2
    else
        $p = p + 1$, and carry out the step 1
    end if
    Step2:
    if $\max(\mathbb{C}) = \mathbb{C}\{r\} \geq \delta$ then
        merge $s\mathbb{CL}_m\{p\}$ and $s\mathbb{CL}_l\{q\}$ as a new sub-cluster, $s\mathbb{CL}_m\{p\}$, let $s\mathbb{CL}_l\{r\}$=$\emptyset$, $\mathbb{C}$=$\emptyset$, and carry out the step 1
    else
        $p = p + 1$, and carry out the step 1
    end if
end while
```

3.2 DRA-MBF Based on CC in Each Cluster

After the clustering algorithm is finished, intra-cluster ICI should be mitigated further. Firstly, we adopt the dynamic UL/DL frame structure allocation depending on the throughput requirement of UL. Then we adopt dynamic spectrum allocation according to the result of the above to mitigate ICI between small cells with different UL/DL frame structures in adjacent clusters. Finally, we adopt MBF to mitigate ICI further. The details are described as following. As mentioned in Sect. 2, we adopt the SFSs defined in TD-LTE, which are listed in Fig. 2. The proportions of UL subframe in each frame structure are different. We set 5 thresholds to partition them, denoted as $\{\beta_1, \ldots, \beta_5\} = \{0.15, 0.25, 0.35, 0.45, 0.55\}$. These thresholds partition $0-1$ into 6 parts $\{0-0.15, 0.15-0.25, \ldots, 0.45-0.55, 0.55-1\}$, corresponding to frame structures $\{P_5, P_4, P_3, P_1, P_6, P_0\}$. The central controller can obtain the UL/DL throughput requirement of each small cell, TR^U/TR^D. And the ratio of UL throughput requirements can be calculated as $R^u = TR^u/(TR^u + TR^d)$. Small cells will be allocated the corresponding spectrum due to R^u. We choose 6 mentioned frame structures above as candidate frame structures. Small cells which be allocated different frame structures will be uniformly allocated 2 different sizes of the bandwidth in each cluster. Assuming the k_{th} cluster consists n_k small cells, the UL/DL throughput requirement of which is respectively $TR^u_{i,k}/TR^d_{i,k}$ ($i = 1, 2, \dots, n_k$), and the ratio of UL throughput requirements can be calculated as: $R^u_{i,k} = \frac{TR^u_{i,k}}{TR^u_{i,k}+TR^d_{i,k}}$.

Then the central controller collects and sorts $R^u_{i,k}$ in ascending order and respectively calculates the mean of top $n_k/2$ or $(n_k + 1)/2$ and last $n_k/2$ or $(n_k - 1)/2$ values, denoted as $\overline{R^u_{Tk}}$ and $\overline{R^u_{Lk}}$. By comparing $\overline{R^u_{Tk}}$ and $\overline{R^u_{Lk}}$ with $\{\beta_1, \beta_2 \dots, \beta_5\}$, two sets of small cells adopt matching frame structures. The detailed algorithm is listed in Algorithm 2. To mitigate the ICI between small cells with the same frame structure, we adopt space division multiplexing (SDM). The central controller which knows CSI can calculate the matrix of precoding and detection. In this paper, we use zero forcing (ZF) algorithm to get the precoding and detection matrix, which can mitigate the interference among transmitting or receiving antennas in the view of SDM. In [10], the normalised precoding matrix W and detection matrix V based on ZF algorithm are presented to realise SDM, which can be calculated as: $W = \dfrac{H(HH^H)}{\|H(HH^H)^{-1}\|}$ and $V = (HH^H)^{-1}H$, where H is the DL channel matrix.

$$
\begin{aligned}
SINR^D_{i,t_0} = {} & \underbrace{\frac{\|H_{k,k}W_k\|^2 P^a_i}{\|\sum_{l\in\mathbb{CL},l\neq k}\sum_{j\in\mathbb{CL}_k} I_{i,j}J_{i,j}H_{k,l}W_l\|^2 P^a_j + N_0}}_{OICI} \\
& + \underbrace{\frac{\|H_{k,k}W_k\|^2 P^a_i}{\|\sum_{l\in\mathbb{CL},l\neq k}\sum_{j\in\mathbb{CL}_k} I_{i,j}\overline{J_{i,j}}V_k H^2_{k,l}W_l\|^2 P^u_j + N_0}}_{CICI}
\end{aligned} \tag{4}
$$

$$
\begin{aligned}
SINR^U_{i,t_0} = {} & \underbrace{\frac{\|V_k H^H_{k,k}\|^2 P^u_i}{\|\sum_{l\in\mathbb{CL},l\neq k}\sum_{j\in\mathbb{CL}_k} I_{i,j}J_{i,j}V_k H^2_{k,l}W_l\|^2 P^u_j + N_0}}_{OICI} \\
& + \underbrace{\frac{\|V_k H^H_{k,k}\|^2 P^u_i}{\|\sum_{l\in\mathbb{CL},l\neq k}\sum_{j\in\mathbb{CL}_k} I_{i,j}\overline{J_{i,j}}H_{k,l}W_l\|^2 P^a_j + N_0}}_{CICI}
\end{aligned} \tag{5}
$$

The above process is one kind of MBF, where the number of transmitting antennas N_t is equal to N_r, assuming that APs not serving UEs is in idle mode. The intra-cluster ICI between the small cells with different frame structures is eliminated because of the allocation of different sizes of the bandwidth. Assuming that the TDD network is strictly synchronous, the OICI refers to AP-to-UE/UE-to-AP interference, and the CICI refers to AP-to-AP/UE-to-UE interference. By adopting MBF, the interference only remains in inter-cluster ICI between small cells with the same frequency spectrum. In the k_{th} cluster CL_k, UL and DL signal-to-interference-plus-noise ratios (SINR) at time t_0 can be calculated as (4), (5) where i, j is the index of AP/UE corresponding to the i_{th}/j_{th} small cell. $\mathbb{CL}$ and $\mathbb{CL}_k$ is respectively the set of all clusters and the k_{th} cluster. $r_{i,j}$ is the distance between AP_i/UE_i and AP_j/UE_j. $I_{i,j}$ is equal to 0 or 1 depending on the frequency spectrum of AP_i/UE_i and AP_j/UE_j at t_0. $J_{i,j}$ is equal to 0 or 1 depending on the subframe types of AP_i/UE_i and AP_j/UE_j at t_0 (0 means they are in the same subframe). $H_{k,k}$, $H_{k,l}$ is respectively DL channel matrix in the k_{th} and k_{th}-to-l_{th} cluster. P_i^a, P_i^u, N_0 is respectively the power of an AP, a UE and the noise per unit.

4 Simulation and Result

In this section, we show the simulation results of the proposed strategy by matlab-based Monte Carlo method. We consider a TDD-based UDN consisting of N APs, M UEs and one central controller in two-dimensional scenes. The detailed values of simulation parameters are listed in Table 1. The distribution of APs follows a Poisson point process and UEs are distributed randomly. The channel fading model is Rayleigh fading. Assuming that the central controller can transmit the precoding and detection matrix to active APs. Besides, we

Algorithm 2. The proposed DRA algorithm

```
Input: $K$ known clusters after CC algorithm, denoted as $\mathbb{CL}$, where there are $n_k$
  small cells in $\mathbb{CL}_k$ respectively, $k = \{1, \cdots, K\}$, and $R_{i,k}^u$
Initialization:
  a) $B_0$: available bandwidth; b) $\mathbb{P} = \{P_5, P_4, P_3, P_1, P_6, P_0\}$: selectable configurations;
  c) $\beta = \{\beta_1, \beta_2, \ldots, \beta_5\}$: thresholds which influence the choices of adopted frame
  structures.
Output: small cells allocated frame structures and expected bandwidth
Step1:
for $k = 1, \cdots, K$ do
    for $i = 1, \cdots, n_k$ do
        Step2: calculate each $R_{i,k}^u$ and sort values in $\mathbb{CL}_k$ in ascending order
        divide $n_k$ small cells in $CL_k$ into 2 sets with the equal cell number according
          to sorting results
        Step3: calculate the mean values $\overline{R_{Tk}^u}$ and $\overline{R_{Lk}^u}$, and adopts matched the frame
          structure according to the comparison result between $\overline{R^u}$ and each threshold
          $\beta$
        Step4: evenly allocate $B_0$ to 2 sets of small cells in $CL_k$ independently
    end for
end for
```

Table 1. Network design parameters

Parameters	Value	Parameters	Value
System bandwidth, B_0	20 MHz	Noise power density	−174 dBm/Hz
AP number, N	150	UE density, λ_u	$200, 400, 600$ UEs/km^2
Cluster number, K	$3, 6, 9$	AP density, λ_a	1000 APs/km^2
UE number, M	$30, 60, 90$	Transmit power of AP	25 dBm
Area	300 m × 500 m	Transmit power of UE	20 dBm

consider x different subcarriers with the bandwidth, B_0/x. In each cluster, x subcarriers will be divided into two equally between two to be allocated in two specific sets of small cells. Each set of small cells refers to the set of small cells allocated the same frame structure.

Figure 3 shows the result of clustering using the proposed clustering algorithm, where 60 small cells are divided into 6 clusters with an area of $300\,\mathrm{m} \times \ 500\,\mathrm{m}$. λ_u and λ_a is respectively 400 active UEs/km^2 and 1000 APs/km^2. The marked points are the central point of each small cell, and different markers, colors respectively mean different clusters and sizes of the bandwidth. As a consequence, the proposed clustering algorithm controls the distances between adjacent clusters and makes the throughput requirement of each cluster similar.

Figure 4 shows the result that comparing the proportion of achievable UL throughput per UE with the throughput requirement of each UE, where the cluster number $K = 9$, λ_u and λ_a is respectively 400 active UEs/km^2 and 1000 APs/km^2. The horizontal axis expresses the x_{th} user in the considered network. For each UE, the UL-to-DL ratio of achievable throughput (AT) R_{u_d} and required throughput (RT) R'_{u_d} are calculated as: $R_{u\_d} = \dfrac{T_u}{T_d}$ and $R'_{u\_d} = \dfrac{TR_u}{TR_d}$, where T_u/T_d and TR_u/TR_d respectively denote UL/DL achieved throughput and required UL/DL throughput of each UE. By adopting the proposed strategy, achievable UL/DL throughput of each UE will be dynamically adjusted with the variation of the UL/DL throughput requirement. In another word, that also improves resource utilization efficiency by allocating time slot for UL/DL.

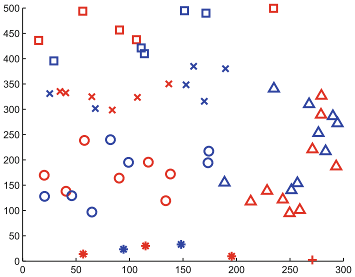


Fig. 3. The result of proposed clustering algorithm

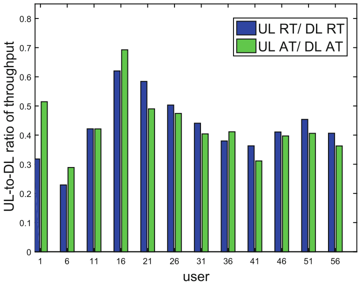


Fig. 4. The performance of the proposed strategy in UL/DL throughput adaptation

Figure 5 shows how the average AT of each UE changes with increasing cluster number and user density by using the proposed strategy. As a result, the throughput of each UE will reduce with the increase of user density, but the cluster number has a little effect. The value of achievable average throughput is calculated as: $T_a = T_u \times t_u + T_d \times (1 - t_u)$, where t_u is the proportion of UL subframes in one frame structure listed in Fig. 2. The result proves the proposed

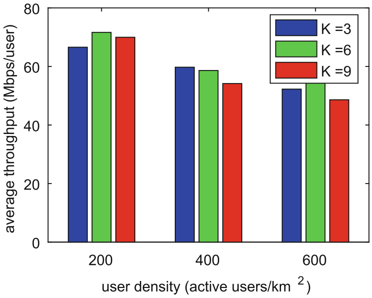


Fig. 5. The result of comparing average throughput of the proposed strategy with different cluster numbers and user densities

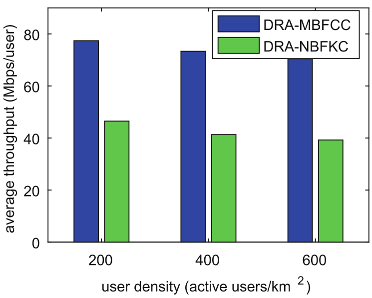


Fig. 6. The result of comparing average throughput of the proposed strategy and DRA-NBFKC

strategy can bring a high throughput gain. In Fig. 6, we compare the average throughput each user gets based on the proposed strategy DRA-MBFCC where $K = 6$ with a conventional interference management strategy: the DRA without MBF using k-means clustering (DRA-NBFKC). The result shows that the former has a $68\% - 72\%$ gain over the latter in the average throughput of each UE because MBF can mitigate ICI further after clustering.

5 Conclusion

In this work, we studied an IM method in based-TDD UDNs by using the proposed DRA-MBFCC algorithm. The proposed clustering algorithm will mitigate inter-cluster interference and make the sum of the required throughput TR of each cluster similar. The dynamic UL/DL frame structure allocation is based on TR of each cluster. If TR is too large, it will be difficult to meet users' requirements with the finite number of UL/DL frame structures. Then we adopt DRA and MBF to meet users' throughput requirements for UL/DL and mitigate ICI between small cells with the same UL/DL frame structure in each cluster. And simulation results prove that the UL/DL resource could be dynamically allocated as required by the proposed algorithm. Furthermore, in each cluster, MBF is adopted between the small cells with the same bandwidth to mitigate intra-cluster ICI between adjacent small cells in the same bandwidth. And simulation results also prove the proposed algorithm can bring a high throughput gain.

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