Hybrid Full and Half Duplex Networking

Jinyi Huang⋆, Kaiqiang Qi⋆, Zhikun Xu† and Chenyang Yang⋆
⋆ Beihang University, Beijing, China † Research Institute of China Mobile Communications Corporation, Beijing, China
Email: jinyihuang@buaa.edu.cn, kaiqiangqi@buaa.edu.cn, xuzhikun@chinamobile.com, cyyang@buaa.edu.cn

***Abstract*—Full-duplex (FD) technique is expected to double the spectral efficiency. Yet the performance gain of the FD network over half-duplex network is limited by severe inter-cell interference and depends on the uplink and downlink traffic load. In this paper, we propose to employ hybrid full and half duplex (HFHD) network to mitigate the strong interference and adapt to the traffic variation. We first introduce the notion of FD reuse factor, borrowing the idea of frequency reuse factor from traditional cellular networks to alleviate inter-cell interference. Then, we provide a joint uplink and downlink power control policy to balance the uplink and downlink throughput by further controlling the interference among base stations. Considering the time-varying and location-dependent traffic load in practical networks, we present a dynamic round-robin strategy to allocate FD subframes efficiently to further improve throughput. Simulation results show that the HFHD network can provide remarkable gain in the overall uplink and downlink throughput over the half duplex network, and can improve the fairness among uplink and downlink transmission with respect to the FD network.**

***Index Terms*—Full-duplex, half-duplex, interference, frequency reuse, cellular networks**

I. INTRODUCTION

Full-duplex (FD) technique can theoretically double the spectral efficiency with respect to half-duplex (HD) technique, which is a promising candidate to boost the throughput for the fifth generation (5G) cellular networks [1–3].

Self-interference has long been an obstacle of applying FD technique, hence significant research efforts have been made to reduce it [4–6]. However, when FD base stations (BSs) are deployed in multi-cell cellular networks, inter-cell interference (ICI) and the interference among BSs with high transmit powers, severely degrades the uplink (UL) throughput [7], even after the self-interference can be completely eliminated. The strong inter-BS interference also causes the unfairness among the users requesting the UL and downlink (DL) transmission.

To deal with the ICI in FD cellular networks, where all BSs operate in FD mode simultaneously over the same frequency band, several approaches have been proposed. In [8], interference cancellation was proposed to remove ICI in a heterogeneous FD network. In [9], a fractional frequency reuse scheme was presented to avoid the ICI. In [10], transmit powers at the femto-BSs and their users were coordinately controlled. Based on the observation that the interference in FD networks is similar to that occurs in dynamic time division duplex (TDD) networks, several simpler solutions were proposed in [11]. In [12], a clustering algorithm was proposed to alleviate the interference among the BSs in dynamic TDD network, where the cells in each cluster operate in the same TDD mode to avoid the ICI, and those in different clusters can operate in different TDD modes. In [13], an UL power control mechanism was investigated for dynamic TDD, where different power control parameters were set based on the estimated interference level. In [14], the impact of increasing UL transmit power and decreasing DL transmit power on mitigating ICI was evaluated.

On the other hand, high spectral efficiency does not necessarily lead to high throughput. In real-world networks, the traffic load is time-varying and location-dependent, and UL traffic load is not the same as (usually lower than) the DL traffic load. Actually, if UL and DL traffic loads are unequal, the bi-directional transmission capability of each BS will not double the overall UL and DL throughput, even if all the interference in the network can be thoroughly removed.

In this paper, we propose a hybrid full and half duplex (HFHD) network, where only a fractional BSs operate in FD mode at the same time, to mitigate the strong interference in multi-cell FD cellular networks and adapt to temporal and spatial traffic variation. To illustrate the performance of the HFHD network, we provide simple and viable resource management scheme to enhance the throughput in both UL and DL under dynamic traffic load.

We take TDD system as an example. We first build up the network topology by dividing the network into multiple basic units, and introduce a notion of FD reuse factor. Within each basic unit, the FD subframes are inserted into UL or DL frames according to the UL and DL traffic load, and only one of the cells in a basic unit operates in FD mode. Then, different network topologies can be obtained by allocating HD and FD subframes. To further alleviate ICI in HFHD network, we provide a simple joint UL and DL power control strategy. In practical networks, the traffic load is highly dynamic both in time and in location, hence a fixed FD subframe allocation to each cell can not meet the demand of users. To address this issue, we present a dynamic round-robin FD subframe allocation strategy to use FD resource efficiently. Finally, we use simulations to evaluate the performance gain provided by the HFHD network.

II. HYBRID FULL AND HALF DUPLEX NETWORK

To illustrate the basic idea of how a HFHD network operates, we consider a TDD cellular network with hexagonal cells,

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each with three sectors. In TDD systems, every UL frame and DL frame consist of multiple subframes. Suppose that every sector can switch between FD and HD modes in one or several subframes, and self-interference can be thoroughly eliminated.

To reduce the interference among UL and DL transmission, we borrow the idea of *frequency reuse* from traditional cellular networks. Specifically, we introduce *FD resource reuse* in a HFHD network, where only the sectors possibly generating low interference are allowed to operate in FD mode simultaneously. We use *FD reuse factor* to describe the density of sectors that operate in the FD mode during a subframe. The whole network is divided into multiple basic units, each consisting of N adjacent sectors. If there are M_0 sectors of a basic unit operating in the FD mode in a subframe, the FD reuse factor is $\frac{N}{M_0}$. A large reuse factor indicates a sparsely operated FD sectors. Fig. 1 shows the topology of the HFHD networks respectively with reuse factor three and seven.

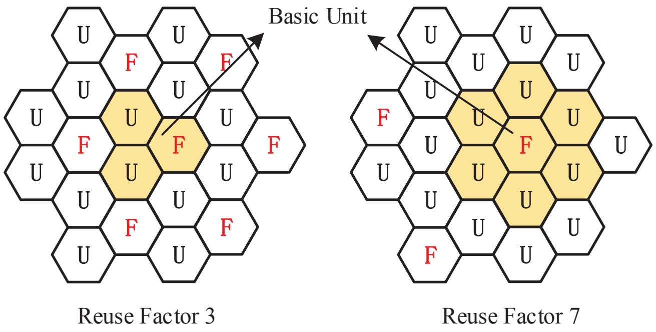

Fig. 1. Topology of the HFHD network

Different from the frequency reuse factor in traditional cellular networks, which is fixed, the FD reuse factor can be dynamically changed to match the traffic load in an area, considering the time variation of the UL and DL traffic in practice. In this way, the FD resource can be fully used, and the energy consumption at the BSs can be reduced as a byproduct, since a BS operating in FD mode consumes more circuit power [7]. This can be implemented by adjusting the number of FD subframes inserted into UL or DL frame.

The FD subframes can be flexibly inserted into either UL or DL frame, depending on the traffic load. Without loss of generality, in this paper we only address the more relevant scenario where the DL traffic load is high, hence the FD subframes are inserted into the UL frame. The design issues for the other scenario where the FD subframes are inserted into DL frame are similar. Fig. 2 shows one example of the UL frame structure for a cell with three sectors in the HFHD network, where "F" indicates a FD subframe and "U" indicates a subframe for UL transmission.

Sector1	**F**	**F**	**F**	**U**	**U**	**U**	**U**	**U**	**U**	**U**
Sector2	**U**	**U**	**U**	**F**	**F**	**F**	**U**	**U**	**U**	**U**
Sector3	**U**	**U**	**U**	**U**	**U**	**U**	**F**	**F**	**F**	**U**

Fig. 2. Structure of an UL frame in the HFHD network

Though the interference in a HFHD network is weakened compared with a FD network where every BS operates in FD mode, the interference among UL and DL transmission is not removed and hence still needs to be controlled. In addition, a new issue of FD subframe allocation arises, which needs to be addressed to achieve good performance in practical networks.

A. BS-BS Interference

In the HFHD network, the signal received at a BS from the user in UL transmission (e.g., the BS in the 2nd cell in Fig. 3) suffers from not only the interference caused by the users in UL transmission in other cells (i.e., I^{UB}), but also the interference caused by other BSs in DL transmission (i.e., I^{BB}), analogous to a FD network [7]. Similarly, the signal received at a user from the BS in DL transmission (e.g., the user with DL in the 3rd cell in Fig. 3) suffers from not only the interference caused by other BSs in DL transmission (i.e., I^{BU}), but also the interference generated by the users in UL transmission in other cells (i.e., I^{UU}).

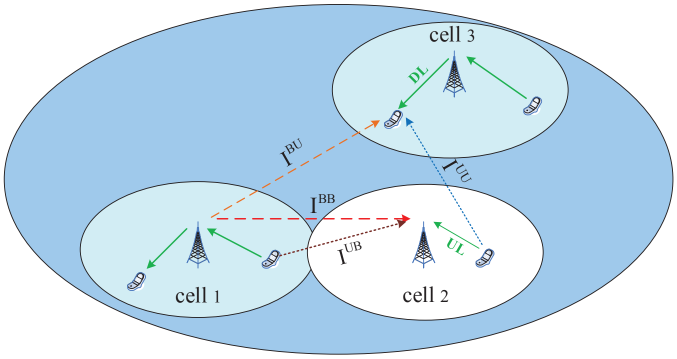

Fig. 3. Interference in the HFHD network

Due to the low transmit power of the user and large attenuation between the user and adjacent BSs, the impact of I^{UB} on the UL transmission performance is negligible, which is true for the small cells where the number of active users in each cell is small. By contrast, the transmit power of a BS is relatively high and the attenuation between the BSs is usually small due to the most possibly existed line of sight path, hence the *BS-BS interference*, I^{BB}, should be mitigated in order to reduce its negative impact on the UL transmission.

B. Traffic Load Variation

In real-world systems, the UL and DL traffic loads are inhomogeneous among sectors and may vary over time. This suggests that inserting fixed number of FD subframes in each UL frame can not adapt to the traffic fluctuation. To fully use the FD resource, we need to determine the number and positions of FD subframes in the UL frame for each sector according to the traffic variation, for a given FD reuse factor. To simplify the implementation, we can assign the FD subframes of the UL frame periodically.

III. RESOURCE MANAGEMENT OF HFHD NETWORK

In this section, we provide simple and viable resource management mechanism to mitigate the BS-BS interference and adapt to the traffic load variation.

A. Joint UL and DL Power Control

While there are other possible approaches such as interference avoidance or cancellation to alleviate the BS-BS interference, we employ power control in this paper, considering that the interference is not strong in the HFHD network.

Denote the set of all sectors in the HFHD network, the sets of the sectors operating in FD mode and in HD mode in the uplink as $\mathcal{S}$, $\mathcal{F}$ and $\mathcal{U}$, respectively, where $\mathcal{S} = \mathcal{F} \cup \mathcal{U}$. To avoid multi-user interference, time or frequency division multiple access can be applied, say orthogonal frequency division multiple access (OFDMA) for downlink and single carrier frequency division multiple access (SC-FDMA) for uplink as in the LTE systems, where each user employs one or several physical resource blocks (RBs) for transmission.[1]

Suppose that the numbers of transmit and receive antennas for each user and each BS are one.[2] Then, the received signal at the BS from a user in the UL of the ith sector can be expressed as

$$\begin{aligned} y_i^{UL} = & \sqrt{P_i^{UL}} h_{ii}^{UB} x_i^{UL} + \sum_{k\in\mathcal{S},k\neq i} \sqrt{P_k^{UL}} h_{ki}^{UB} x_k^{UL} + \\ & \sum_{j\in\mathcal{F},j\neq i} \sqrt{P^{DL}} h_{ji}^{BB} x_j^{DL} + n_{UL}, \end{aligned} \tag{1}$$

where P_i^{UL} is the uplink transmit power of a user in the ith sector, P^{DL} is the downlink transmit power of a BS in the adjacent sector of the ith sector that operates in the FD mode, h_{ki}^{UB} is the channel gain from the user in the kth sector to the ith BS, h_{ji}^{BB} is the channel gain from the jth BS to the ith BS, x_k^{UL} is the transmit signal of the user in the kth sector, x_j^{DL} is the transmit signal of the jth BS during the DL transmission, and here $\mathbb{E}\left\{\left|x_k^{UL}\right|^2\right\} = \mathbb{E}\left\{\left|x_j^{DL}\right|^2\right\} = 1$, and n_{UL} is the additive Gaussian white noise subject to $\mathcal{CN}\left(0, \sigma_{UL}^2\right)$.

Then, the data rate of the user in UL transmission in the ith sector can be obtained as

$$R_i^{UL} = W^{UL} \log_2 \left(1 + \underbrace{\frac{P_i^{UL} \left|h_{ii}^{UB}\right|^2}{I_i^{UB} + I_i^{BB} + \sigma_{UL}^2}}_{\gamma^{UL}} \right), \tag{2}$$

where W^{UL} is the UL bandwidth, $I_i^{UB} = \sum_{k\in\mathcal{S},k\neq i} P_k^{UL} \left|h_{ki}^{UB}\right|^2$ is the interference to the ith BS generated by the users in UL transmission in other sectors, $I_i^{BB} = \sum_{j\in\mathcal{F},j\neq i} P^{DL} \left|h_{ji}^{BB}\right|^2$ is the interference to the ith BS generated by other BSs in DL transmission. γ^{UL} is the UL received signal to interference plus noise ratio (SINR).

For the DL, the signal received at the user in the jth sector can be expressed as

$$\begin{aligned} y_j^{DL} = & \sqrt{P^{DL}} h_{jj}^{BU} x_j^{DL} + \sum_{i\in\mathcal{S}} \sqrt{P_i^{UL}} h_{ij}^{UU} x_i^{UL} \\ & \sum_{k\in\mathcal{F},k\neq j} \sqrt{P^{DL}} h_{kj}^{BU} x_k^{DL} + n_{DL}, \end{aligned} \tag{3}$$

where h_{kj}^{BU} is the channel gain from the kth BS to the user in the jth sector, h_{ij}^{UU} is the channel gain between the user in the ith sector and the user in the jth sector, and n_{DL} is additive Gaussian white noise subject to $\mathcal{CN}\left(0, \sigma_{DL}^2\right)$.

Then, the data rate for the user in DL transmission in the jth sector can be obtained as

$$R_j^{DL} = W^{DL} \log_2 \left(1 + \frac{P^{DL} \left|h_{jj}^{BU}\right|^2}{I_j^{UU} + I_j^{BU} + \sigma_{DL}^2} \right), \tag{4}$$

where W^{DL} is the DL bandwidth, $I_j^{UU} = \sum_{i\in\mathcal{S}} P_i^{UL} \left|h_{ij}^{UU}\right|^2$ is the interference generated from the users during UL transmission in other sectors to the user in the jth sector, $I_j^{BU} = \sum_{k\in\mathcal{F},k\neq j} P^{DL} \left|h_{kj}^{BU}\right|^2$ is the interference from other BSs during DL transmission to the user in the jth sector.

It is shown from (2) that the UL data rate R_i^{UL} monotonically increases with P_i^{UL}, but monotonically decreases with P^{DL}. Therefore, both reducing the transmit power of the BS and increasing the transmit power of the user can improve the UL transmission performance. It can also be observed from (4) that the DL data rate R_j^{DL} monotonically increases with P^{DL} but decreases with P_i^{UL}. This means that reducing the transmit power of the BS or increasing the transmit power of the user will degrade the DL transmission performance. It suggests that joint UL and DL power control is able to achieve a tradeoff between UL and DL performance.

A simple UL power control method is provided in the LTE standard to compensate the path loss [15]. The transmit power of the user in the ith sector is controlled by

$$P_i^{UL} = M P_0 d_i^{c\alpha}, \quad P_i^{UL} \leq P_{max}^{UL}, \tag{5}$$

where M is the number of RBs allocated to a user in a subframe, d_i is the distance between the user and the BS in the ith sector, $c \in [0, 1]$ is a path loss compensation coefficient, α is the path loss factor, P_{max}^{UL} is the maximum transmit power of each user, P_0 is the UL target receive power, which can indirectly reflect the average interference level or noise level. This method can not control the interference effectively in the HFHD network.

Because I_i^{BB} depends on the transmit power of the BS and $I_i^{BB} \gg I_i^{UB}$, it can approximately reflect the interference level of the whole network. Since the locations and hence the propagation environment of the BSs are fixed or at least change very slowly, it is not hard to obtain the channel gain between two BSs, h_{ji}^{BB}. With the estimated BS-BS channel, the BS-BS interference power can be estimated as

$$\hat{I}_i^{BB} = \sum_{j\in\mathcal{F},j\neq i} P^{DL} \left|\hat{h}_{ji}^{BB}\right|^2. \tag{6}$$

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[1] In the LTE standard, a RB occupies one time slot in time domain and 12 subcarriers in frequency domain.

[2] The principle of joint UL and DL power control is also applicable to multi-antenna systems.

We can introduce this estimated interference level to the UL power control and express the UL transmit power as a function of the transmit power of the BS. Then, we can reduce the interference of the whole network by decreasing the transmit power of the BS. Alternatively, we can improve the UL transmission performance by increasing the transmit power of the user.

In fact, we can formulate an optimization problem to trade off the UL and DL transmission performance, say by maximizing the DL sum rate (i.e., throughput) under the constraint of satisfying a target UL data rate for each user. Nonetheless, the solution is very complicated. Since the major scope of this paper is to propose HFHD networking, the joint optimization for UL and DL power control will not be addressed, which is left as an interesting topic for future work.

To illustrate the performance of the proposed HFHD network, in what follows we provide a simple yet practical method to control the UL and DL powers.

Given the UL target receive SINR, γ_0^{UL}, which can reflect the UL target data rate of each user, the corresponding target transmit power is $\gamma_0^{UL}\left(\hat{I}_i^{BB} + I_i^{UB} + \sigma_{UL}^2\right)$. Moreover, considering that $\hat{I}_i^{BB} \gg \sigma_{UL}^2$ and I_i^{UB} is negligible, the transmit power of the user for the uplink transmission in the ith sector can be obtained as

$$\begin{aligned} P_i^{UL} &= M\gamma_0^{UL}\left(\hat{I}_i^{BB} + I_i^{UB} + \sigma_{UL}^2\right) d_i^{c\alpha} \\ &\approx M\gamma_0^{UL}\hat{I}_i^{BB} d_i^{n\alpha}, \qquad P_i^{UL} \le P_{max}^{UL}. \end{aligned} \tag{7}$$

Substituting (6) into (7), we have

$$P_i^{UL} \approx P^{DL} M\gamma_0^{UL} \sum_{j\in\mathcal{F}, j\neq i} \left|\hat{h}_{ji}^{BB}\right|^2 d_i^{c\alpha}, \quad P_i^{UL} \le P_{max}^{UL}. \tag{8}$$

It is obvious that P_i^{UL} is a monotonically increasing function of P^{DL}. After obtaining the distance between the user and the BS in the ith sector, we can conduct the joint UL and DL power control with (8), noting that the BS-BS channel gain can be pre-estimated due to the fixed BS location.

B. *FD Subframe Allocation*

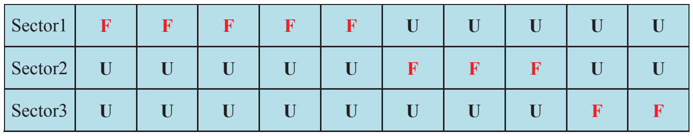
Since the network is divided into basic units according to the FD reuse factor as shown in Fig. 1, we only need to allocate the FD subframes for each basic unit according to the traffic load distribution. In the following, we introduce a round-robin method to allocate the FD subframes in a basic unit.

If the traffic load in a basic unit is uniformly distributed, we can employ a uniform round-robin strategy, where the same number of FD subframes is allocated to each sector in each UL frame, as illustrated in Fig. 2. If the traffic load in a basic unit is not uniformly distributed in different sectors at different time, which is often the case in practice, uniform round-robin strategy is inefficient to exploit the FD resource and yields low DL throughput gain over a HD network. To address this issue, we present a dynamic round-robin FD subframe allocation strategy that can adapt to the traffic variation.

We first need to determine the round-robin cycle. Since the traffic load is time-varying, the duration of a round-robin cycle can be adjusted according to the variation rate of traffic load, say one hour. Specifically, the BS measures the DL traffic load of each sector in the past half an hour and uses it as the prediction of the DL traffic load in the next half an hour, and calculates the ratios of DL traffic load in a sector to the DL traffic load in other sectors in the basic unit.

Then, we assign the number of FD subframes for each sector in the basic unit within a round-robin cycle. The ratio of the number of FD subframes in an UL frame for each sector to the number of FD subframes for another sector is set equal to the ratio of DL traffic load that has been calculated above. The sector with more traffic load is assigned with more subframes to serve the users better and improve the DL throughput.

Finally, we need to arrange the positions of FD subframes in the UL frame for each sector. The FD subframes of each sector can be arranged continuously to avoid switching between FD and HD too frequently. Fig. 4 shows an example of the strategy, where the reuse factor is three, and the ratio of traffic load of sector 1 to sector 2 is 5/3 and the ratio of traffic load of sector 1 to sector 3 is 5/2. There are ten subframes in an UL frame. Only one of the three sectors can operate in FD mode in a subframe with the reuse factor three. The total number of FD subframes in an UL frame is ten. According to the strategy, the first five FD subframes are assigned to sector 1. The next three FD subframes are assigned to sector 2 and the last two FD subframes are assigned to sector 3.



Sector1	F	F	F	F	F	U	U	U	U	U
Sector2	U	U	U	U	U	F	F	F	U	U
Sector3	U	U	U	U	U	U	U	U	F	F

Fig. 4. An example of allocated FD subframes

After a round-robin cycle, the FD subframes are allocated to each sector again according to the measured traffic load. In this way, the FD resource can be used more effectively compared with the uniform round-robin strategy, because the BS can serve DL users in longer time to improve DL throughput when the DL traffic load is high.

IV. SIMULATION RESULTS

In this section, we evaluate the performance of the proposed HFHD network via simulations.

Consider a cellular network that consists of 19 hexagonal pico cells, each consisting of three sectors. The FD reuse factor is three. Ten users are randomly distributed in each sector, and hence there are 30 users in a basic unit all together. The bandwidth is equally allocated to the users in each sector, and the transmit power at the BS is equally allocated to the users in each cell during DL transmission. We only insert FD subframes into the UL frame, and consider full buffer traffic model. Table 1 provides a list of parameters used in the simulation [16]. This simulation setup is used in the sequel unless otherwise specified.

TABLE I
PARAMETER LIST

Distance between adjacent BSs	80 m
System bandwidth	10 MHz
Carrier frequency	2 GHz
Antenna gain of the user and BS	0, 5 dBi
Noise coefficient at the user and BS	13, 9 dB
Channel model	Out-door pico cell
Transmit power of the user and BS P_{max}^{UL}, P_{max}^{DL}	23, 24 dBm
Number of RBs in an UL subframe M	1
Path loss compensation coefficient c	0.8
Target receive power for the LTE power control P_0	-76 dBm
Target receive SINR for the joint power control γ_0^{UL}	15 dB

A. UL and DL Throughput

Figure 5 shows the throughputs of a basic unit. For the HFHD network, except its UL, DL, and the sum of UL and DL throughputs achieved by the joint UL and DL power control (with legends "HFHD-Joint-UL", "HFHD-Joint-DL" and "HFHD-Joint-UL+DL", respectively), we also show its UL and DL throughputs achieved by the power control in LTE standard (with legends "HFHD-LTE-UL" and "HFHD-LTE-DL"). The UL and DL throughputs are respectively the sum of the 30 users' data rates computed with (2) and (4). In addition, we provide the UL throughput of a basic unit in the HD network as a benchmark (with legend "HD-UL").

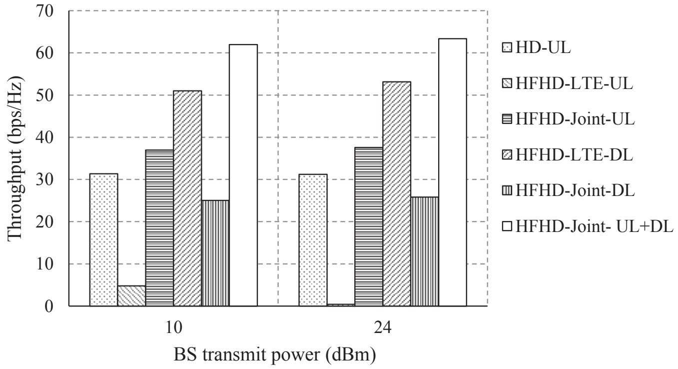


Fig. 5. UL and DL throughputs of a basic unit

The results show that when using the power control in LTE, the DL throughput of the HFHD network increases, but the UL performance degrades severely compared with the UL throughput of the HD network. By contrast, the joint power control improves the UL performance but reduces the DL throughput inevitably, which however attains a tradeoff between UL and DL performance. Furthermore, it also boosts the total throughput of UL and DL in the HFHD network remarkably, which nearly doubles that of the HD network. With the joint power control, the UL and DL throughputs change little when the transmit power of the BS is reduced significantly, say to 10 dBm. This means that the UL and DL throughputs are not sensitive to the transmit power of the BS.

B. Transmit Power of Users

Although the proposed joint UL and DL power control for the HFHD network provides high throughput gain over HD network, it increases the transmit power (and therefore the power consumption) of the users at the same time, which might be a concern due to the limited battery. Taking the HD network (with legend "HD") as a baseline, Fig. 6 gives the cumulative distribution function (CDF) of the transmit power of the users with different transmit powers of the BSs in the HFHD (reuse factor is three, with legend "$n = 3$") and FD (reuse factor is one, with legend "$n = 1$") networks.

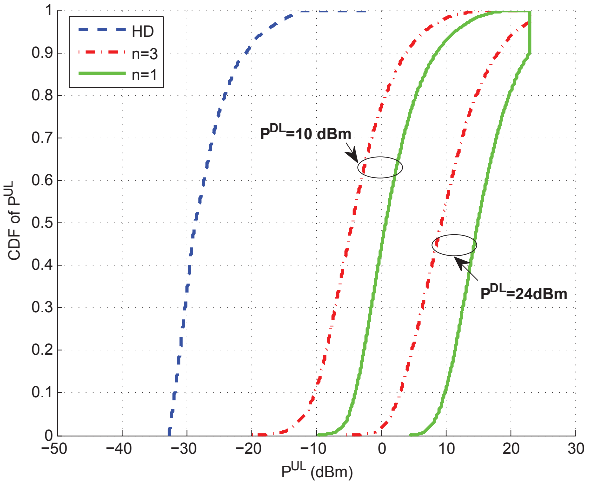


Fig. 6. CDF of the transmit power of the users

The results show that given the BS transmit power, the transmit power of the users in the HFHD network ($n = 3$) is lower than that in the FD network ($n = 1$) but higher than the HD network. In fact, simulation results also show that when the transmit power of the BS is 24 dBm, there are 10% of the users using the maximal transmit power in the FD network. Since these users are usually located at the cell edge, their UL data rates are very low. Reducing the transmit power of the BS can decrease the power consumption of the users. Recall from Fig. 5 that the reduction of the BS transmit power in the HFHD network has little impact on the total UL and DL throughput. Therefore, using the joint power control in the HFHD network can save the power of the users and improve the fairness among UL and DL users compared to the FD network and improve the overall throughput compared to HD network. Besides, simulation results show that the total UL and DL throughput of the HFHD network is almost the same as that of the FD network, when the joint UL and DL power control is applied to both networks (the results are not shown to make the figure clear). Nonetheless, the HFHD network achieves the same total throughput only with 1/3 FD resource of the FD network.

C. DL Throughput with Different Round-Robin Strategies

We evaluate the DL throughput of a basic unit under different traffic pattern, and consider a FD reuse factor of three. Nine DL users are located randomly in the three sectors. The round-robin cycle is set as ten TDD frames. The arrival of the users's request is modeled as Poisson process with average rate $\lambda = 0.5$ requests per second, which means one request per two subframes. Here we assume that each user has the same traffic demand and the total DL traffic load is proportional to the number of DL users. Then, the traffic load in a sector is measured by the number of DL users in the sector.

Figure 7 shows the DL throughput when the users are distributed in different ways. With uniform distribution, there are three users in every sector. With non-uniform distribution, there are six, two and one users in three sectors, respectively. With random distribution, the number of users in each sector is randomly picked from one to nine but the total number of users in three sectors is nine. Simulation results validate the intuition that the dynamic round-robin strategy has throughput gain over the uniform round-robin strategy when the distribution of traffic is not uniform, which is evident.

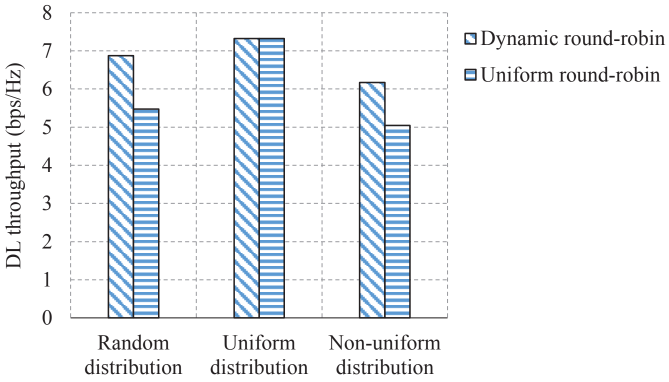


Fig. 7. DL throughput of two FD subframe allocation strategies

V. CONCLUSIONS

In this paper, we proposed a hybrid full and half duplex network to mitigate the strong interference among BSs and adapt to the uplink (UL) and downlink (DL) traffic loads. A notion of full duplex (FD) reuse factor was introduced, where only one sector in each basic unit of the whole network operates in FD mode in one or several subframes. A joint UL and DL power control was provided to further alleviate the interference among UL and DL transmission. A round-robin FD subframe allocation strategy was introduced, aimed at using the FD resource more efficiently to improve the DL throughput for practical scenarios with dynamic traffic load. Simulation results showed that the proposed network can double the overall UL and DL throughput with respect to the half duplex network, and achieve almost the same overall UL and DL throughput as the FD network with much less FD resources. Moreover, it can save the power of users and improve the fairness among UL and DL users with respect to the FD network.

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