Dynamic TDD Interference Mitigation by Using Soft Reconfiguration

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***Abstract*—Since uplink (UL) and downlink (DL) traffic loads are time-variant in femtocells, it is essential to adapt dynamic-TDD (D-TDD) to effectively adjust the UL and DL transmission resources. However, due to the cross-link interference of D-TDD, the benefits of dynamically adjusting the UL and DL resources are diminished. The currently used interference mitigation scheme, the clustering scheme, achieves interference mitigation but reduces the ability of DL and UL resource adaptation. In this research, we propose "Soft Reconfiguration" to reduce interference while allowing femtocells to dynamically adjust their UL and DL resources. In Soft Reconfiguration, the femtocells which highly interfere with each other will be categorized in the same interference group, but unlike the clustering scheme, the femtocells in the same group are allowed to choose different subframe configurations. In the simulation, we compared Soft Reconfiguration with two schemes, D-TDD without interference mitigation and the clustering scheme. The results show that the soft reconfiguration scheme outperforms the other two schemes in better throughput and effective resource utilization.**
Keywords- Dynamic TDD, Femtocell, Interference mitigation

I. INTRODUCTION

Due to the drastic variations of uplink (UL) and downlink (DL) traffic loads in femtocells, the typical method for pre-configuring UL/DL resources needs further adjustments. A novel method, dynamic TDD (D-TDD), has been gaining increasing popularity in that it provides the capability of dynamically adjusting UL and DL resources. However, dynamic TDD base stations suffer from interference between two different direction base stations, known as cross-link interference.

D-TDD is also supported in 3GPP standard [1]. Recent meetings of 3GPP discussed the measurement and feedback mechanisms of UL/DL Channel State Information (CSI). Several interference mitigation methods have been proposed in support of D-TDD. Among these methods, clustering is the most popular. In the clustering scheme, the femtocells which severely interfere with each other are grouped into a cluster. Each cluster then chooses the same ratio of UL/DL resources. Such a scheme is able to effectively mitigate the interference, but reduces the flexibility of UL and DL resource adaptation. D-TDD without interference mitigation provides suitable configuration for cells with high interference, while D-TDD with clustering provides interference avoidance by using a common configuration to protect uplink direction while losing the flexibility of UL and DL resource adaptation. It is therefore necessary to design a new scheme which mitigates the interference problem and also has the flexibility to adapt to different UL and DL traffic loads.

The main contribution of this paper is in proposing a scheme, named "Soft Reconfiguration". It is a cooperative system designed to solve the interference and to consider suitable configurations for each cell. There are three parts in Soft Reconfiguration. In the first part, the user equipments (UEs) will be grouped as in the clustering and obtain a reconfiguration group tag, which will be used in the reconfiguration. In the second part, if some base stations experience high interference, a high interference alert is raised and the group will be reconfigured based on the reconfiguration group tag and the concession map (which will be defined later), which helps mitigate the interference. In the third part, each base station in the algorithm will revert back to D-TDD without interference mitigation when the high interference alert is lifted. In addition, we also observe the problems in D-TDD without interference mitigation and the clustering scheme respectively. They both take care of only one side of DL or UL traffic when the loading of traffic is unbalanced. By using Soft Reconfiguration, this problem is greatly mitigated.

II. RELATED WORKS

The earliest D-TDD based system research paper appeared in 2000 [2]. It applies D-TDD on the TDD based macrocell. Recently, D-TDD was also discussed in 3GPP as a study item and there is a technical report of D-TDD, TR36.828 [1]. There are also some works analyzing the performance of D-TDD in LTE networks [3] [4] and other cellular system [5]. In these works, the issue of cross-link interference in D-TDD systems is also discussed. This cross-link interference problem in TD-LTE systems is studied in the work of Shen *et. al.* [6]. The interference mitigation schemes, clustering and downlink power control, are also mentioned in this work.

Further details of the clustering scheme are described in the work of Zhu and Lei [7]. In a clustering scheme, femtocells that severely interfere with each other are grouped in the same cluster. The femtocells in the same cluster will choose the same configuration, and thus the interference is mitigated. However, it also reduces the flexibility of DL/UL configuration adjustment on each femtocell.

In other works, Ji *et. al.* [8] discuss the interference between the macrocell and D-TDD femtocells, and apply inter-cell interference coordination on the D-TDD system. This method is different from ours since it focuses on mitigating the

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Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number										Number of UL subframe	Number of DL subframe
		0	1	2	3	4	5	6	7	8	9		
0	5 ms	D	S	U	U	U	D	S	U	U	U	6	2
1	5 ms	D	S	U	U	D	D	S	U	U	D	4	4
2	5 ms	D	S	U	D	D	D	S	U	D	D	2	6
3	10 ms	D	S	U	U	U	D	D	D	D	D	3	6
4	10 ms	D	S	U	U	D	D	D	D	D	D	2	7
5	10 ms	D	S	U	D	D	D	D	D	D	D	1	8
6	5 ms	D	S	U	U	U	D	S	U	U	D	5	3

Fig. 1: Analysis of Configuration

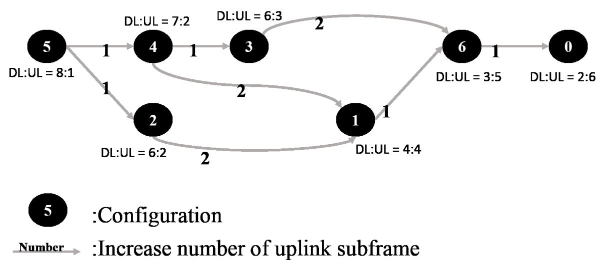


Fig. 2: Concession Map for 3GPP

interference between the macrocell and the D-TDD femtocells. Ding *et. al.* [9] have studied the performance of D-TDD with cell clustering, power control and an interference cancellation scheme. There has also been some research of using beamforming or smart antenna as interference mitigation scheme in the D-TDD system [10]. In our work, we propose an enhanced scheme which is different from cell clustering and improves the system performance.

III. D-TDD System description & Interference problem

We consider a femtocell networks having several femtocells distributed in a macrocell service area. We assume the frequency band used by the macrocell and femtocells are different to avoid the interference from the macrocell to the femtocells.

To allow femtocells using different ratios of UL/DL resources, D-TDD supports different UL/DL configurations. In 3GPP, seven different UL/DL configurations are supported [11]. As shown in Fig. 1, downlink subframes are denoted as "D", uplink subframes are denoted as "U", and the subframes for some signals are represented by an "S". Each configuration has a different number of UL/DL transmission resources and is suitable for a different traffic load. For example, configuration 0 has two DL subframes and six UL subframes. Configuration 0 is suitable for a traffic load which has more UL traffic. Configuration 5 has eight DL subframes and one UL subframe. It is suitable for a traffic load which has more DL traffic. In D-TDD femtocell networks, femtocells select the configuration according to their own UL/DL traffic ratio, and thus get the maximal utilization in a frame period.

The traffic load ratios on the current configurations are different, and these configurations can be sorted by the ratio from high to low. According to the sorted configurations, we can know the transition of configurations on a femtocell when the traffic load ratio of DL traffic over UL traffic is from high to low. We therefore can build a transition map according to the current configurations. The map is shown in Fig. 2. From left to right we start with the configuration which has the maximum number of DL subframes to the configuration which has the minimum number of UL subframes. The increased number of uplink subframes is on the transition path. Therefore, the transition of configurations of a femtocell will follow this map. This map can also be used to reduce the interference from the target femtocell to other femtocells. The transmission power of a femtocell is larger than the power of a UE. Therefore, when the configuration transits to the right configuration, it reduces the interference. After the transition of the configuration, the target femtocell does not achieve the maximal utilization in a frame period. However, it reduces the interference. Since it reduces the utilization of the femtocell, we called this map "Concession Map". Concession Map will be used in our interference mitigation scheme which is described in section IV.

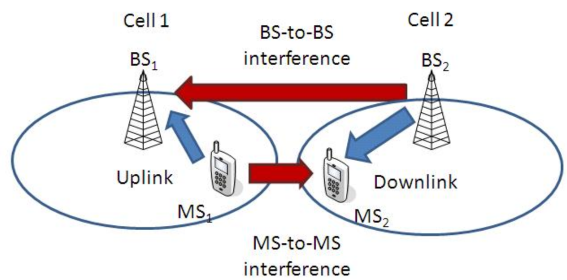


Fig. 3: Cross link interference in Dynamic TDD

A. Interference problem in D-TDD femtocell networks

There is a serious interference issue in D-TDD femtocell networks. This is due to the different configurations of neighboring femtocells since femtocells choose the configuration according to the different traffic ratio. This causes a new type of interference, cross-link interference, between femtocells with different configurations, which is shown in Fig. 3. Compared with typical interference on UL shown in Fig. 4, when two neighboring femtocells have different transmission directions in a subframe, the transmission signal of the DL femtocells cause severe interference on the UL femtocells as shown in Fig. 5. This happens because the power of the signal from the femtocell is higher than the signal power of signal from the user equipment (UE). Therefore, it is necessary to consider the interference between femtocells when choosing the configuration of each femtocell.

Clustering scheme categorizes the femtocells which highly interfere with each other into clusters. This scheme forces the femtocells in the same cluster to choose the same configuration, thus solving the interference problem. However, this causes femtocells with different traffic ratios to choose the same configuration, thus reducing the traffic adaptation flexibility on these femtocells.

The difference between our proposed scheme and the previous work is that the proposed scheme remains the flex-

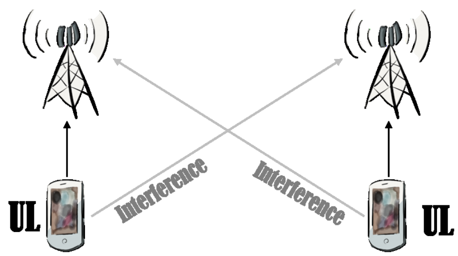


Fig. 4: Uplink to Uplink interference

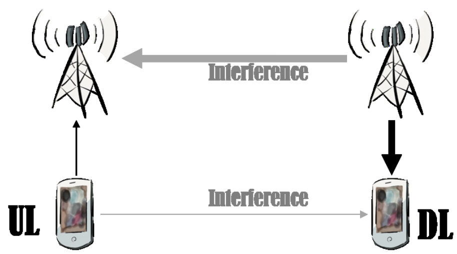


Fig. 5: Downlink to Uplink interference

ibility of traffic adaptation on femtocells while mitigating the interference. In our paper, we propose a method called Soft Reconfiguration to choose the proper configurations for femtocells. Soft Reconfiguration allows the femtocells in a group to choose different configurations which are closer to their traffic load. The details of Soft Reconfiguration are described in the next section.

IV. Soft Reconfiguration

In this paper, we propose the Soft Reconfiguration scheme, which chooses the configuration for a femtocell according to both the traffic ratio and interference on other femtocells. Unlike the clustering scheme, Soft Reconfiguration also allows the femtocells in the same group to choose different configurations which are more suitable for their traffic ratio, thus increasing the flexibility of the traffic adaptation.

In Soft Reconfiguration, we first form interference groups. Since the femtocells which interfere with each other are needed to make the decision of configuration coherently, we group these femtocells together. Then we assign different tags to the femtocells in the same group in order to make them choose configuration separately. These femtocells in the same group can choose different configurations. After the interference groups with group tags, we take the Concession process to reconfigure the femtocells in these groups. In the reconfiguration on each femtocell, the transition between the configurations is according to the Concession map. It allows the femtocells to adjust its interference to others by step. After the Concession process, new configurations are obtained which reduce the interference in the network.

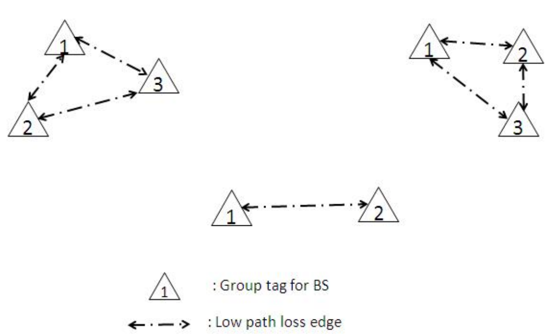


Fig. 6: Illustration of Interference Group with Group Tag

A. Interference Group & Group Tag

In our proposed scheme, the target femtocell will choose the configuration related to the femtocells which cause the interference on the target femtocell. Therefore, we group together the BSs which severely interfere with each other, just like in the clustering scheme, in order to make these femtocells choose their configurations accordingly. Also, in the proposed scheme, the femtocells in a group are allowed to choose different configurations, so the configurations of these femtocells can be related to their traffic ratio. Therefore, we make these femtocells change their configurations by turns instead of changing configurations together. In implementation, we give different group tags to these femtocells, to make them choose their configurations by turns.

To forming the interference group, we calculate the pathloss of the link between each two BSs and if the pathloss is smaller than a certain threshold, we link them together. After the calculation of all BSs, the femtocells which are linked together are grouped in the same interference group.

After we formed the interference groups in the network, we give the group tags to the femtocells in each group. The group tags are used in the Concession process to make the femtocells in an interference group conduct reconfiguration by turns from the smallest tag to the largest tag. In each group, the femtocells are assigned different group tags. Since the order will not affect the overall reconfiguration effect, the group tags are assigned randomly. For group n, the group tags are from 1 to tag_n, which tag_n equals to the number of femtocells in group n. (In group n, the femtocell with tag k is denoted as $f_{n,k}$.) All the groups are tagged in this manner. An example of interference groups with group tags is shown in Fig. 6.

B. Concession List and Concession Process

Before we perform the Soft Reconfiguratoin, femtocells in the network choose their configurations according to their traffic load. According these configurations, we are able to calculate the interference between the femtocells and find the femtocells which are severely interfered (if a femtocell has an SINR value in a subframe below the threshold, it is a severely interference femtocell). If there is at least one severely interfered femtocell in a group, the group needs to conduct a reconfiguration on its femtocells to reduce the interference. Therefore, we form a list which contains all interference groups which have at least one severely interfered femtocell. We call this list a ”Concession List”.

For the interference groups on the list, we perform a process to help the femtocells in the groups conduct reconfigurations, which we called the ”Concession process”. The reconfigurations adjust the configuration of femtocells according to the concession map. The femtocells with more UL subframes tend to be interfered by other femtocells, and the femtocells with more DL subframes tend to interfere with other femtocells. For the femtocell that interferes with others, the reconfiguration will transit from the current configuration to the right configuration on the map, as shown in Fig. 7, in order to reduce the interference on other femtocells. Conversely, for the femtocell severely interfered by others, the reconfiguration will transit from the current configuration to the left configuration on the map. For each time of reconfiguration, the configuration will only transit once.

The first round of the concession process will start at a randomly chosen concession group from the list. After the reconfigurations of this group are finished, the second round will be started on another randomly chosen concession group on the list. The concession process will continue until all of the concession groups on the list have done the process.

In each concession process round, each femtocell in the interference group will conduct a reconfiguration in turns according to the order of group tags. Assume the SINR of femtocell j in subframe i is $\gamma_{i,j}$. Each round of concession process will end when all subframes of which SINR values are above the threshold, on each femtocell or the timer, t, ends. That is, one round of concession process will end if $\gamma_{i,j} > \gamma_{th}$ for any subframe i and femtocell j of this group, or $t > c$ (the limitation of the timer is c). In one round of a concession process, the reconfiguration is initially conducted on the femtocell with group tag ”1”, and then on the femtocells with following group tags. This is defined as the first period. After that, if there is still a subframe of which the SINR is under the threshold, the reconfiguration will resume for an additional period until there is no subframe of which SINR is under the threshold or unless the timer ends. The pseudo code of the concession process is shown in Algorithm 1. Note that, although, the femtocells in the same group are allowed to choose different configurations, the femtocells can also choose the same configuration if it is the best result after reconfiguration in Concession process.

After performing the concession process on this group, the interference between the femtocells in this group is reduced, and configuration of each femtocell is still related to their original configuration which is chosen based on its own traffic ratio.

C. Signaling cost of Soft Reconfiguration scheme

The signaling cost of Soft Reconfiguration

V. Simulation Result

In this section we evaluate the performance of Soft Reconfiguration with different traffic loadings. D-TDD without interference mitigation and D-TDD with a clustering based scheme are used as the baseline to show the gain. The scenario of the simulation is 19 BSs and 19 UEs in the dual strip building of 6 floors, as shown in Fig. 9. Fig. 10 shows the traffic loading in this simulation. We use different kinds of ratio of UL and DL traffic from high UL traffic and low DL traffic to low UL traffic and high DL traffic.

Algorithm 1 Concession Process

while There is an interference group on the Concession list which has not conducted the Concession process **do**
  Randomly choose an interference group (group n) which has not conducted the Concession process from the Concession list
  while ($\exists\, \gamma_{i,f_{n,k}} < \gamma_{th}$, where subframe $i \in \{1, ..., 9\}$, n belongs to Concession List, $k \in \{1, ..., tag_n\}$ for group n) and $(t < c)$ **do**
    for $k = 1$ to tag_n **do**
      the femtocell $f_{n,k}$ conducts the reconfiguration
    end for
  end while
end while

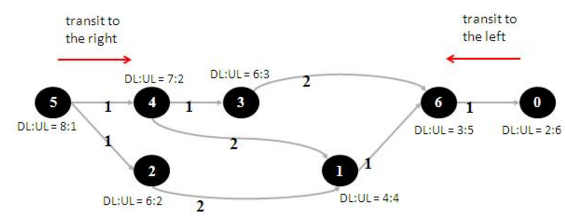


Fig. 7: Conducting reconfiguration by Concession Map

A. Pathloss Model

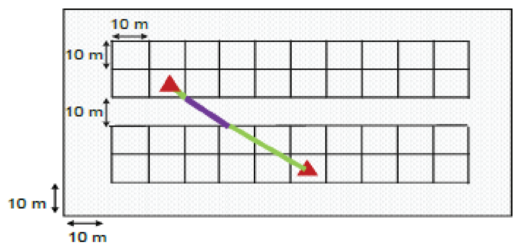
For the pathloss model in dual stripe model, we categorize the pathloss model into three cases. The first case considers that femtocell BSs are inside a different apartment stripe, as shown in Figure 8(a). In this case, the pathloss model is

$$PL(dB) = \max(2.7{+}42.8log10R, 38.46{+}20log10R){+}0.7d_{2D,indoor}$$
$$+18.3n((n+2)/(n+1)-0.46) + q * L_{iw} + L_{ow,1} + L_{ow,2}.$$

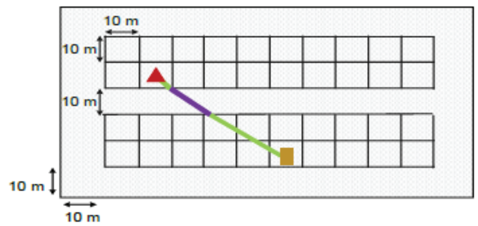
The distance R is composed of a green line and a purple line in Figure 8(a) and the distance $d_{2D,indoor}$ is green line in the same Figure. The notation q is the number of walls separating apartments between femtocell BSs. L_{iw}, $L_{ow,1}$, and $L_{ow,2}$ are the shadowing factors in dual stripe model.

As shown in Figure 8(b), the second case considering the MS is inside a different apartment stripe of femtocell BSs. In this case, the pathloss model is

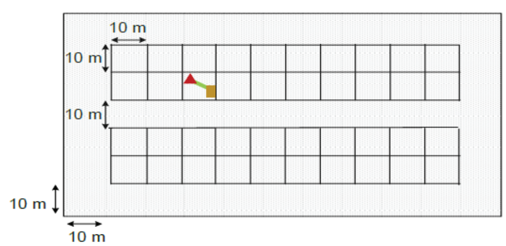
$$PL(dB) = \max(2.7{+}42.8log10R, 38.46{+}20log10R){+}0.7d_{2D,indoor}$$
$$+18.3n((n+2)/(n+1)-0.46) + q * L_{iw} + L_{ow,1} + L_{ow,2}.$$



(a) Pathloss model for HeNBs are inside a different apt stripe



(b) Pathloss model for UE is inside a different apt stripe



(c) Pathloss model for UE is inside the same apt stripe as HeNB

Fig. 8: Pathloss model

The third case considering that the MS is inside the same apartment stripe as femtocell BSs are/do, as shown in Figure 8(c). The pathloss model in this case is

$$PL(dB) = 38.46 + 20log10R + 0.7d_{2D,indoor}$$
$$+18.3n((n+2)/(n+1) - 0.46) + q * L_{iw}.$$

B. Metric: Service Data Ratio

The service data ratio is the served data over the arrival data. If the service data ratio is high, high service quality is provided, increasing the satisfaction of clients and vice versa. This metric can show the level of service satisfaction. If the scheme serves DL data more than UL data, the UL service data ratio will be lower than the DL service ratio. We observe the minimum service data ratio on both the UL and DL. The minimum service ratio shows the service quality in both DL and UL.

C. Simulation:19 BSs and 19 UEs

Fig. 11 shows the minimum service ratio. The X-axis represents ratio of DL traffic loading over UL traffic loading and

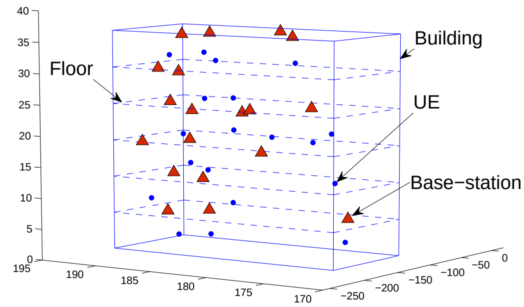


Fig. 9: Illustration of Usual Scale Network Layout

Experiment Set	1	2	3	4	5	6	7	8	9	10	11	12
UL Traffic	2.8	2	1.4	1	1	1	1	1	1	1	1	1
DL Traffic	1	1	1	1	1.3	2.2	2.85	4	6.1	7.6	8.6	11

Fig. 10: Arrival Traffic

also matches to Fig. 10. In Fig. 11, Soft Reconfiguration has a better service quality between different traffic types and also excels when there is high DL traffic loading and low UL traffic loading. The reason for this is that traffic adaptation and clustering schemes prefer to give more resources for DL since DL traffic load is higher than UL traffic load. However, ignoring UL traffic causes a serious problem as the high interference results in a severe data block in the queue. When Soft Reconfiguration is applied, conducting reconfiguration with concession map, the system is forced to increase the UL subframe to support the UL traffic. As a result, the scheme can balance the UL and DL demand.

The resource utilization is shown in Fig. 12 and Fig. 13. The X-axis in the figures is the sets of the experiment which match to Fig. 10. The Y-axis of figures is resource utilization in bits per millisecond. We can observe that there are no obvious differences among the schemes in the left side of both Fig. 12 and Fig. 13. This is because all the schemes prefer to choose the configuration containing more UL subframes, which cause low interference and high service of UL traffic. As for right side of both Fig. 12 and Fig. 13, the chosen configuration is diverse, so that the interference of the UL subframe is serious. As shown on right side of Fig. 12 and Fig. 13, Soft Reconfiguration significantly improves the interference in DL and UL.

VI. Conclusion

We have observed two problems in D-TDD with interference mitigation and clustering based schemes. Firstly, they both make the trade-off between interference and suitable configurations. Therefore, the resource utilization is not fine. The Soft Reconfiguration scheme introduces a mechanism to balance the interference and traffic pattern. Soft Reconfiguration provides a suitable level of resources utilization in both UL and DL. Secondly, both schemes prefer to allocate more

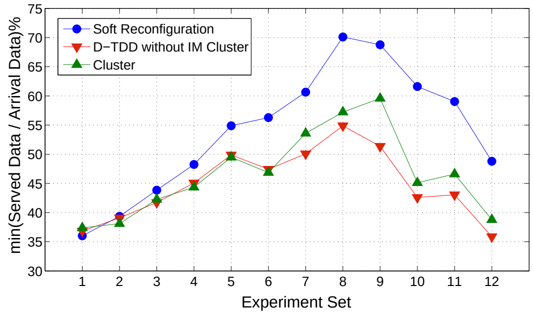


Fig. 11: Minimum Transmission of Data Rate

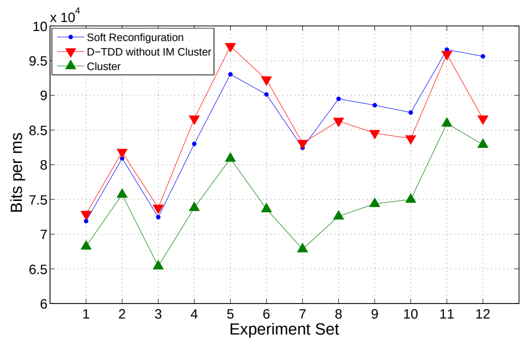


Fig. 12: Throughput Over Using Time Resource in DL

resources for DL traffic in case of high DL traffic and low UL traffic, resulting in severe interference in the UL traffic. Due to the incapability of D-TDD without interference mitigation to control the interference and the inefficiency of the clustering based scheme to protect the UL, the service ratio is unbalanced and thus either DL or UL traffic suffers with a low service quality. In view of this, Soft Reconfiguration introduces two methods to address these issues. One is controlling the interference by using the Concession map, and the other is having the system allocate more resources in support of the uplink traffic. The simulation results show that the performance of Soft Reconfiguration is superior in the service data ratio metric and also provides a more satisfactory service quality in both DL and UL.

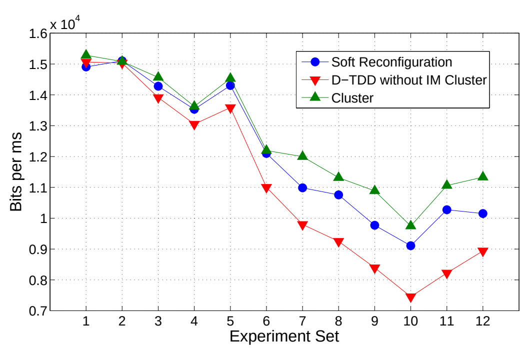


Fig. 13: Throughput Over Using Time Resource UL

VII. Acknowledgement

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