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# Network Time-Synchronization in TDD Based LTE-Advanced Systems

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***Abstract: -***
**In Frequency Division Duplex (FDD) systems or Time Division Duplex (TDD) systems with perfect Uplink (UL) /Downlink (DL) alignment, all UL transmissions receive interference only from other UL links and vice versa. However, take into consideration one of the most important benefits that TDD offers, i.e., dynamic UL/DL switching points, the UL and DL transmission can be mis-aligned. This means UL might be corrupted by DL, and vice versa. The loss of network time-synchronization among different cells makes things even more complicated for TDD systems. Many techniques are developed to achieve network synchronization, e.g., GPS based or IEEE 1588 based techniques. In this paper, the effect that different synchronization and UL/DL switching points introduce to the system performance is studied. The purpose is to find out the benefit that synchronization can offer. Based on the observations, it is suggested to achieve at least *loose network synchronization*.**

*Keywords: - TDD, Time Synchronization, LTE-Advanced, UL/DL Switching.*

## I. INTRODUCTION

To facilitate the two-way communication between enhanced-NodeB (eNB) and users, duplexing of the radio channel is required [1]. This duplexing is normally carried out in frequency or time domain, results in Frequency Division Duplexing (FDD) or Time Division Duplexing (TDD), respectively. FDD-based systems employ paired channels for Uplink (UL) and Downlink (UL) transmission. Due to the symmetry in the two channels, FDD is suitable for voice transmission, where UL and DL traffic is symmetric. However, for Long Term Evolution (LTE)-Advanced system, which is generally recognized as the evolved LTE system, the target is to provide high capacity and multimedia services for improving user experience [2]. For this reason, UL and DL transmission is expected to be asymmetric. TDD has attracted much interest from a research point of view because it allows UL and DL transmission to share the same channel at different time, thereby can be easily adapted according to the asymmetric traffic condition [3, 4].

Although TDD offers the flexibility of adapting to UL and DL traffic load, it has its own disadvantages. One of the most critical one is the requirement of network synchronization among the neighboring cells [5]. If the UL and DL transmissions from different cells are mis-aligned, UL might be corrupted by DL, and vice versa. Many techniques have been developed to improve the UL and DL alignment, by achieving network time synchronization. IEEE 1588 standard defines a protocol for precise clock synchronization in a network [6]. It works based on a master-slave relationship in which each slave synchronizes to its master. This standard has been widely used in both wired networks [7] and wireless networks, e.g., Wireless Local Area Network (WLAN) [8] and Sensor Network [9]. Global Positioning System (GPS) can also be used to provide the common reference clock within a network [10]. Firefly based synchronization algorithms [11] and flow synchronization protocol [12], operate in a distributed manner and can be useful for cases when a master clock is not available. There are also other techniques based on e.g. preamble [13].

In this paper, rather than study the performance for each synchronization technique, we consider three general cases: *Full synchronization*, *loose synchronization* and *un-synchronization*. The meaning of these synchronization types will be introduced in later sections. The effect of different UL and DL traffic load, and hence switching point, is also investigated. The purpose is to estimate the gain obtained by achieving network synchronization, so as to justify the use of these techniques.

The rest of this paper is organized as follows: Section II describes the synchronization types and targeted scenarios; Section III introduces the simulation methodology and assumptions. Section IV shows the simulation results for different synchronization cases and UL/DL loads. Section V concludes and summarizes the paper.

## II. SYNCHRONIZATION TYPES AND TARGETED SCENARIOS

Three cases of network synchronization are considered for this work, including:

*Full synchronization*: all eNBs have the same reference clock. It requires the accuracy of a few hundred microseconds and can be obtained by using IEEE 1588 protocol or GPS.

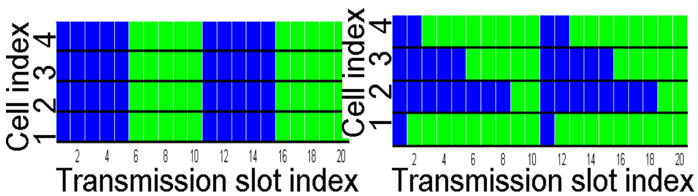
*Loose synchronization*: some residual error in the alignment of the clocks between eNBs is allowed, in the order of a few milliseconds. It can be achieved in a distributed manner by e.g., firefly-based algorithms. For our study, this residual error is introduced in terms of the maximum mismatch in the start time of a frame relative to a common reference clock.

The mismatch can vary from 0 (full synchronization) up to one full frame.

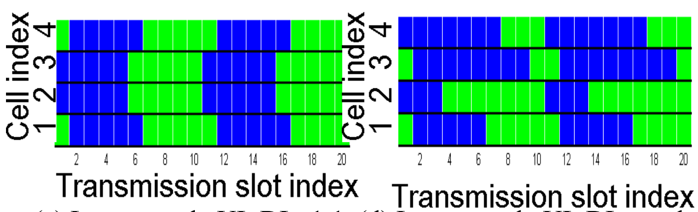
*Un- synchronization*: each eNB has its own clock, independent of other eNBs. Thereby, UL and DL have the highest possibility for mutual interference, as compared to the other two synchronization cases.

We also consider both static TDD (S-TDD) and dynamic TDD (D-TDD) modes. In S-TDD, the same uplink-to-downlink ratio is used in all cells. While in D-TDD, the portions of uplink and downlink transmissions are assigned dynamically in different cells [14].

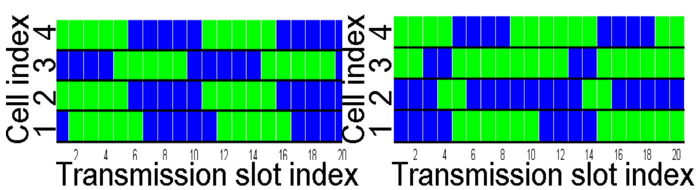
Fig. 1 shows the transmission pattern for different cells under different synchronization and uplink-to-downlink ratio cases. Slots marked in blue are used for DL whereas green is for UL. Fig. 1 (a, c, e) show the cases for different synchronization with S-TDD and uplink-to-downlink ratio of 1:1, while Fig. 1 (b, d, f) show the cases with D-TDD and random uplink-to-downlink ratio.




(a) Full synch, UL:DL=1:1. (b) Full synch, UL:DL=rand.




(c) Loose synch, UL:DL=1:1. (d) Loose synch, UL:DL=rand.




(e) Un-synch, UL:DL=1:1. (f) Un-synch, UL:DL=rand.

Fig. 1. Transmission patterns with different cases of time Synchronization and Uplink-to-Downlink Ratio.

As mentioned initially, the target here is to justify the need for network synchronization techniques, if any. This is of vital importance especially in Local Area (LA) networks where a low-cost solution is preferable. For Wide Area (WA) networks, the additional cost for achieving network synchronization is less critical. For the purpose of this investigation we therefore select some representative LA scenarios, including indoor office scenario and indoor home scenario, as described in [15]. The indoor model is proposed in Information Society Technologies – Wireless World Initiative New Radio (IST-WINNER) project, trying to represent typical office environment.

**Indoor Office Scenario**

In office scenario, the location of eNBs can be pre-planned so that each will cover a certain area. Fig. 2 shows an example of an office scenario with 4 cells. The eNBs are placed at the center point of each cell, with users randomly distributed within the whole office area. In this figure and the later one for home scenario, gray dots are used to represent eNBs; a small block represents one room (surrounded by walls) and several neighboring blocks with the same color form one cell, which is served by the eNB geographically located within it. White part is corridor.

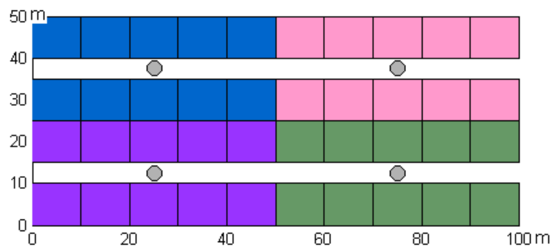



Fig. 2. Indoor Office Scenario with eNBs Located at the Center of Each Cell.

**Indoor home scenario**

The difference between home scenario and office scenario is that, in home scenario, the eNB is placed independently of other eNBs in the area. A user will receive service from its own eNB even if the signal strength from a neighboring eNB is higher. An example of home scenario with 4 cells is shown in Fig. 3.

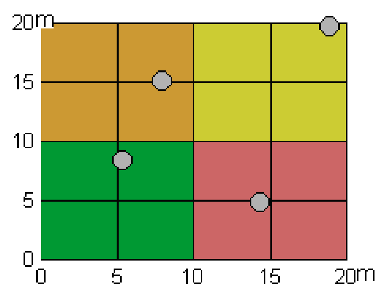



Fig. 3. Indoor Home Scenario, eNBs Located Randomly within Each Cell.

## III. SIMULATION METHODOLOGY AND ASSUMPTIONS

In order to investigate the performance, the snap-shot based simulation method is used:

1. Within each snap-shot, the cell layout is generated according to the scenario;

2. Users are generated with uniformly distributed locations inside that particular scenario;
3. The Signal to Interference and Noise Ratio (SINR) is calculated according to the received signal power and interference power level;
4. Throughput is obtained by mapping the calculated SINR according to the ideal link-adaptation based LTE capacity.
5. A few thousands of snap-shots are simulated to get the averaged performance.

In Step 4, the capacity in a Single Input Single Output (SISO) system can be estimated by [16]:

$$S=\begin{cases} 0 & SINR < SINR_{\min} \\ BW_{eff} * \log_2(1+\dfrac{SINR}{SINR_{eff}}) & SINR_{\min} \le SINR \le SINR_{\max} \\ 5.4 & SINR > SINR_{\max} \end{cases} \quad (1)$$

where $S$ is the estimated spectral efficiency in bps/Hz, which is upper limited according to the hard spectral efficiency given by 64QAM with coding rate 4/5; $BW_{eff}$ adjusts for the system bandwidth efficiency of LTE and $SINR_{eff}$ adjusts for the SINR implementation efficiency of LTE. The values for the parameters in Eq. (1) are obtained by extensive link level simulations in macro and micro cell scenarios with 10MHz bandwidth, Turbo coding, 6-tap Typical Urban channel model and LTE frame structure. User velocity is taken as *10*km/h. Table 1 shows the values for a SISO system.

Table 1. Shannon Curve Fit Parameters for LTE Link Level Capacity (SISO) [16].

| | $BW_{eff}$ | $SINR_{eff}$ | $SINR_{\min}$ | $SINR_{\max}$ |
|---|---|---|---|---|
| DL | 0.56 | 2.0 | -10dB | 32dB |
| UL | 0.52 | 2.34 | -10dB | 35dB |

The following metrics are used for the evaluation of the system performance:

1. *Average cell throughput*: This is the cell throughput averaged among all the simulated cells.
2. *Cell edge user throughput*: This is the 5% user outage throughput, obtained as the 5% percentile of the Cumulative Distribution Function (CDF) of user throughput.

To simplify the problem and focus mainly on frequency reuse, we use no power control and simple Round Robin frequency domain scheduling. Also, we do not include the effect of fast fading since the impact is expected to average out over a certain time period.

The assumptions for the simulations in general, including the settings for the link level performance implied by Table 1, is according to the LTE specifications [15,17,18]. Table 2 gives a short summary.

Table 2. Parameters and Assumptions for System Level Evaluation [15,17,18].

| **PARAMETER** | **SETTING/DESCRIPTION** |
|---|---|
| Spectrum allocation | 100 MHz at 3.5GHz |
| Access scheme | DL: OFDMA<br>UL: SC-OFDMA |
| Duplexing scheme | TDD |
| Users per cell | Office: 5 ~ 10 users<br>Home: 2 ~ 4 users |
| **eNB characteristics** | |
| Total transmit power | 24 dBm |
| Antenna system | “Omni-directional”, 3dBi gain |
| Receiver noise figure | 9dB |
| Minimum Coupling Loss | 45dB |
| **User characteristics** | |
| Transmit power | 24dBm |
| Antenna system | “Omni-directional”, 0dBi gain |
| Receiver noise figure | 9dB |
| **Propagation model** | |
| Room size | Office scenario: 10x10m<br>Home scenario: 5x5m |
| Corridor width | 5 m |
| Internal walls | Office scenario: light attenuation, 5dB<br>Home scenario: inside home: light attenuation, 5dB; between homes: medium attenuation, 10dB. |
| Path loss model | Line of Sight (LOS):<br>18.7 $\log_{10}$ (*d[m]*) + 46.8 + 20$\log_{10}$ ($f_c$[GHz]/5.0)<br>None Line of Sight (NLOS):<br>20 log10 (d[m]) + 46.4 + $n_w \cdot L_w$ + 20log10 (f [GHz]/5.0)<br><br>where<br>$d$ = direct-line distance [m],<br>$f$ = carrier frequency [GHz],<br>$n_w$ = number of walls between transmitter and receiver,<br>$L_w$ = wall attenuation [dB] |
| Standard deviation of Shadow fading | LOS:<br>3dB<br>NLOS:<br>Light wall: 6dB<br>Heavy wall: 8dB |

## IV. SIMULATION RESULTS

**Performance in office scenario**

Fig. 4 and Fig. 5 show the DL and UL SINR distribution In these two figures, we use ‘full/loose/none’ to represent full-synchronization / loose-synchronization / un-synchronization, and 'UL:DL' to represent uplink-to-downlink-ratio. Generally, it can be seen that time synchronization affects UL more than DL transmission. This is because of the LOS link between the neighboring eNBs. The interference that one eNB receives from its neighboring eNB is likely to be stronger than from the users in neighboring cells, so a large degradation in SINR is observed.

The cell throughput and user outage throughput for different UL:DL switching points and different synchronization cases is summarized in Table 3. The results show a 20 ~ 50% gain in UL cell throughput by achieving time synchronization, as compared to unsynchronized case. In terms of cell edge user throughput, full synchronization gives much better performance than unsynchronized case in both DL and UL. It can also be seen that, loose synchronization offers nearly the same performance as full synchronization.

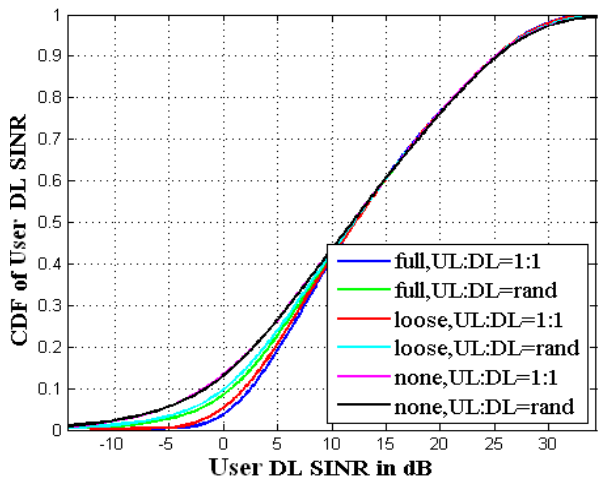



Fig. 4. CDF Distribution of DL User SINR, in Office Scenario and Fixed eNB Location.

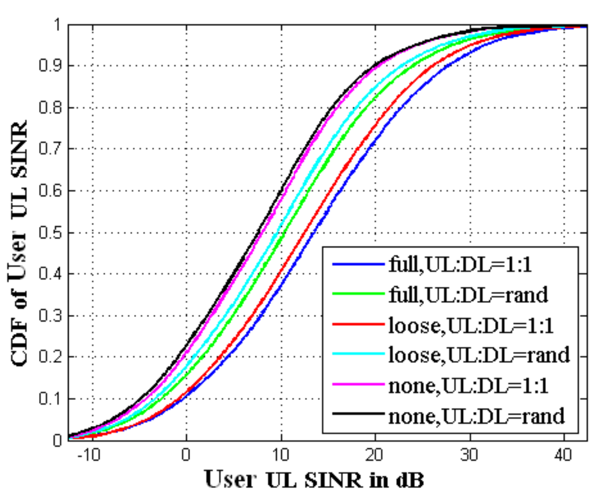



Fig. 5. CDF Distribution of UL User SINR, in Office Scenario and Fixed eNB Location.

**Performance in home scenario**

The performance in home scenario is summarized in Table 4, which differs a lot from the office scenario. Here, different synchronization types offer similar average cell throughput. In terms of outage user throughput, unsynchronized case even outperforms full synchronized case in UL.

Other than the difference in path loss model and the simulated layout, the most important reason for the different behavior is the LOS propagation of the eNB-eNB link in office scenario. In this case, if UL and DL are not perfectly aligned, the eNB to eNB transmission will cause very high UL interference, thereby poor UL performance. In home scenario, such LOS links between the eNBs do not exist. So the channel gain of eNB-eNB links is on average similar to the user-user links. With Round Robin scheduling, users are simultaneously multiplexed in frequency domain. While the total transmit power is the same for the user and eNB, the interference signal coming from users is on average stronger than that from eNBs.

Due to the different signal power level received from users and eNB for UL transmission, an eNB will receive some interference from the other eNBs instead of from users, which leads to a reduction in the total received interference level. For DL transmission, on the contrary, a user will sometimes receive interference from other users but not from eNBs. This will increase the received interference level. As a consequence, the DL throughput will benefit from achieving network synchronization, while UL transmission actually sees a loss in terms of throughput.

## CONCLUSIONS AND FUTURE WORK

From the result shown in the previous section, the advantage of and need for time synchronization depends on the deployment scenario. In office scenario, by achieving network time synchronization, the performance can be significantly improved as compared to the unsynchronized case. In home scenario, achieving network synchronization will improve the performance for DL transmission, but at the same time, it will reduce the UL performance.

From throughput point of view, the overall gain of achieving network time synchronization in home scenario is minor. However, in cases when communication among eNBs is needed, achieving network time synchronization enables such kind of eNB to eNB communication, and therefore still beneficial. For the three cases of synchronization, loose synchronization is able to provide similar performance as full synchronization. However, it does not require very strict clock accuracy and is a cheaper solution as compared to full synchronization. Considering the trade-off between complexity and performance, we suggest to achieve loose network time synchronization for TDD-based LTE-Advanced systems.

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Table 3-a. DL Average Cell Throughput in Office Scenario (Mbps).

| UL:DL | 1:2 | 1:1 | 2:1 | rand |
|---|---|---|---|---|
| Full synch. | 131.5 | 93.4 | 56.2 | 96.8 |
| Loose synch. | 129.5 | 92.6 | 55.1 | 94.6 |
| Un-synch. | 125.9 | 89.2 | 53.0 | 93.5 |

Table 3-b. UL Average Cell Throughput in Office Scenario (Mbps).

| UL:DL | 1:2 | 1:1 | 2:1 | rand |
|---|---|---|---|---|
| Full synch. | 53.4 | 88.5 | 124.6 | 66.9 |
| Loose synch. | 45.3 | 82.3 | 117.2 | 62.2 |
| Un-synch. | 27.4 | 56.4 | 93.0 | 53.0 |

Table 3-c. DL Cell Edge User Throughput in Office Scenario (Mbps).

| UL:DL | 1:2 | 1:1 | 2:1 | rand |
|---|---|---|---|---|
| Full synch. | 2.9 | 2.1 | 1.3 | 0.7 |
| Loose synch. | 2.6 | 1.8 | 0.9 | 0.7 |
| Un-synch. | 1.5 | 0.6 | 0.2 | 0.4 |

Table 3-d. UL Cell Edge User Throughput in Office Scenario (Mbps).

| UL:DL | 1:2 | 1:1 | 2:1 | rand |
|---|---|---|---|---|
| Full synch. | 0.4 | 0.7 | 1.0 | 0.4 |
| Loose synch. | 0.4 | 0.7 | 0.9 | 0.3 |
| Un-synch. | 0.1 | 0.4 | 0.7 | 0.2 |

Table 4-a. DL Average Cell Throughput in Home Scenario (Mbps).

| UL:DL | 1:2 | 1:1 | 2:1 | rand |
|---|---|---|---|---|
| Full synch. | 140.4 | 102.7 | 59.9 | 101.9 |
| Loose synch. | 143.7 | 100.0 | 61.0 | 99.6 |
| Un-synch. | 138.3 | 96.0 | 56.6 | 98.0 |

Table 4-b. UL Average Cell Throughput in Home Scenario (Mbps).

| UL:DL | 1:2 | 1:1 | 2:1 | rand |
|---|---|---|---|---|
| Full synch. | 54.1 | 91.8 | 124.3 | 94.0 |
| Loose synch. | 56.6 | 90.9 | 130.2 | 95.4 |
| Un-synch. | 60.2 | 94.2 | 133.2 | 96.5 |

Table 4-c. DL Cell Edge User Throughput in Home Scenario (Mbps).

| UL:DL | 1:2 | 1:1 | 2:1 | rand |
|---|---|---|---|---|
| Full synch. | 4.0 | 2.2 | 1.5 | 1.6 |
| Loose synch. | 3.7 | 2.8 | 1.5 | 1.5 |
| Un-synch. | 4.0 | 2.8 | 1.2 | 1.5 |

Table 4-d. UL Cell Edge User Throughput in Home Scenario (Mbps).

| UL:DL | 1:2 | 1:1 | 2:1 | rand |
|---|---|---|---|---|
| Full synch. | 1.5 | 2.6 | 3.4 | 1.6 |
| Loose synch. | 1.8 | 2.6 | 3.9 | 1.8 |
| Un-synch. | 2.1 | 3.0 | 5.0 | 2.1 |