Uplink Coordinated Multi-Point for LTE-A in the Form of Macro-Scopic Combining

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***Abstract* — For the future LTE-Advanced network, one of the requirements in the uplink (UL) direction is to enhance the cell-edge user performances. Coordinated multi-point reception in the UL is one of the techniques being investigated to further improve the performance of LTE networks. With the help of the information coordination through the links between the sites and advanced receivers the UL performance can be improved. The simulation results show that, with the ideal interference cancellation, inter-Site maximum ratio combining, and optimized closed-loop and open-loop fractional power control, there are about 27% gains for the 5% outage user throughput and 12% gains for the average user throughput. As shown in this paper, these gains from UL macro-scopic multi-cell combining between sites are achieved for optimized power control, ideal interference cancellation receivers, and X2 with no delay and high bandwidth.**

I. Introduction

The 3[rd]. generation partnership project (3GPP) has just finalized the first release work on Long Term Evolution (LTE), which is referred to as Release-8. In order to exceed the performance requirements for IMT-Advanced defined by ITU-R, the work on further evolution of LTE is started, which is called LTE-Advanced (LTE-A) [1][2]. The requirements on LTE-A are described in [3]. Currently LTE-A is in the study item phase, where some of the potential key technologies are being studied to fulfil the target, such as carrier aggregation (CA) to support up to 100 MHz bandwidth, advanced multi-input multi-output (MIMO) antenna system with 8x8 transmission in the downlink (DL) and 4x4 in the uplink (UL), coordinated multi-point (CoMP), advanced repeaters/relaying nodes (RN) and autonomous component carrier selection (ACCS) for low power eNodeB (eNB) deployment [4].

CoMP is one of the potential candidate technologies to combat the inter-cell interference and boost the system performance dramatically, especially the cell-edge user performance. The basic idea behind CoMP is to co-operate multiple network nodes with distributed and/or centralized structures. CoMP involves the techniques such as joint transmission/reception, coordinated scheduling and/or beamforming. In the DL CoMP, specifications are required for both eNB and user equipment (UE), while less specification effort is foreseen to have support for UL CoMP [1][2].

In the open literature, the CoMP systems are explained in detail in [5]. In [6], the coordinated multi-point transmission from several MIMO eNBs is studied in the DL for the users located at the cooperation areas. In [7] and [8], coordinated inter-cell scheduling and power allocation is also designed for the DL transmissions. In [9], UL macro diversity is studied with different cooperation range for two cooperation modes and the corresponding requirements on backhaul capacity are also discussed.

In this paper, we concentrate on the system level performance of UL CoMP in the simplest form of macro diversity reception in the LTE-A networks. We demonstrate that special optimization of power control and use of advanced receivers is more or less needed to have significant gains of UL macro-scopic combining in LTE. In Section II, the related UL LTE network concept is introduced. In Section III, the assumptions of UL CoMP macro diversity reception and ideal interference cancellation are presented. In Section IV, system level simulation assumptions are presented followed by the simulation result analysis in Section V. Finally, the conclusions are made in Section VI.

II. UL LTE Network Overview

In 3GPP LTE, single carrier frequency division multiple access (SC-FDMA) is adopted as the UL multiple access scheme. Hybrid automatic repeat request (HARQ), link adaptation (LA) and dynamic packet scheduling (PS) are the entities in the medium access control (MAC) layer [10]. HARQ ensures the fast Layer 1 retransmission. Either chase combining or incremental redundancy can be applied. LA includes adaptive modulation and coding (AMC), outer loop link adaptation (OLLA) [11] and power control (PC). The fractional power control (FPC) has been agreed in the LTE [12], where it consists of open-loop fractional power control (OLPC) and close-loop fractional power control (CLPC). The dynamic PS, it aims at efficiently utilizing the spectrum resources. Its allocation algorithm can be divided into time domain PS (TDPS) and frequency domain PS (FDPS), where the TDPS indicates a phase of user selection and the FDPS indicates a phase of physical resource block (PRB) allocation, where the PRB is defined as the minimum frequency and time domain scheduling granularity consists of 12 consecutive OFDM sub-carriers and 14 OFDM symbols [13].

Both the LA and the dynamic channel aware PS entities rely on the Channel state information (CSI) to perform the AMC and FDPS, where the CSI is measured in the serving

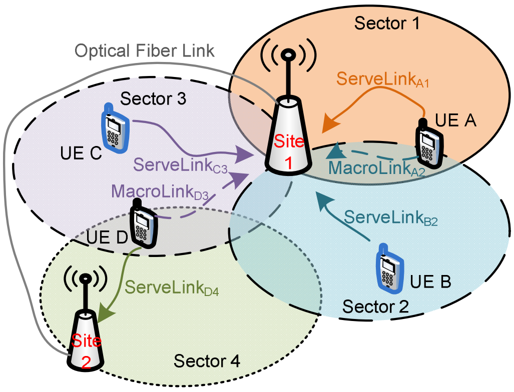

Fig. 1. Intra-Site vs. Inter-Site Network Layout

eNB from the sounding reference signal (SRS) transmitted by the UE [13].

The flat LTE network architecture is composed of eNBs with connections to access gateway via the S1 interface, and eNB to eNB communication via the X2 interface, where the X2 interface facilitates both seamless hard handover and multi-eNB coordination [10].

III. UL CoMP Macro Diversity Reception

In this study, a CoMP structure is assumed where the serving cell independently performs the radio resource management (RRM), i.e. dynamic PS, for the UEs served and it can request coordination from the neighbouring cells for a specific UE through the X2 interface. An ideal X2 interface is assumed in order to find the upper bound for the performance of UL CoMP, where the link connections, e.g. optical fibre, between the sites have unlimited bandwidth and no delay is considered, as shown in Fig. 1.

Practically, full coordination over the whole network is not feasible because of the limited signalling feedback and delay time. So limiting the collaborations to a small and reasonable number of cells is required [14]. In this paper, the coordination of up to three neighbouring cells is studied.

The collaboration of cells can be implemented as either Intra-Site or Inter-Site. If the serving and coordination cells are limited to have the same site cooperation, then it is called Intra-Site coordination. As shown in Fig.1, for UE A, the serve link 'A1', where the signal received in the serve cell, and the macro link 'A2', where the signal received in the coordination cell, are jointly received in the same Site 1. In this case no X2 is needed for coordination. Otherwise if it is allowed to make the cross site cooperation through the X2 interface, then it is called Inter-Site coordination, i.e. the serve link 'D4' and macro link 'D3' of UE D can be jointly received in different Site 1 and 2 as shown in Fig. 1. In this paper, both cases are studied and Intra-Site coordination is mainly used as a reference to the Inter-Site coordination.

The UL CoMP reception implies the joint receiving of UE transmitted signal at multiple geographically separated eNB antennas. Signal combining from different sites (eNBs) is here-after called UL CoMP macro diversity reception. The selection and triggering of the macro diversity reception is assumed to be UE-assisted and network-decided, where the UE measure the reference signal received power (RSRP) measurements received from the neighbouring cells and report the averaged measurements back to the network [15]. Based on the measurements, the network will make the decision on whether the eNBs should make the macro diversity reception or not according to the below criteria:

$$RSRP_{ServeLink} - RSRP_{OtherLinks} \leq X\ (dB) \quad (1)$$

where $RSRP_{ServeLink}$ is the RSRP measurement from the serving cell, $RSRP_{OtherLinks}$ is the RSRP measurement from the other cells except serving cell and X is called triggering threshold or combining window size (CWS).

A. Macro Diversity Combining:

Either the maximum ratio combing (MRC) or the selection combining (SC) is used to combine the signals received from both the serve link and selected macro links. The MRC and SC are modelled according to:

$$SINR_{MRC} = SINR_{ServeLink} + \sum_{n=0}^{N} SINR_{MacroLink\_n} \quad (2)$$

$$SINR_{SC} = \max(SINR_{ServeLink}, SINR_{MacroLink\_0}, \ldots, SINR_{MacroLink\_N}) \quad (3)$$

where SINR is the signal to interference plus noise ratio and N is the number of macro diversity links for a given UE.

The SINR value in the serve link and macro links is calculated using Equation (4):

$$SINR = \sum_{Ant=1}^{J} \frac{\sum_{\Pr b=1}^{M} S_{J,M}}{\sum_{\Pr b=1}^{M} \left(\sum_{Interf=1}^{I} I_{J,M,I}^{InterCell} + n \right)} \quad (4)$$

where S is the signal strength per PRB per antenna, $I^{InterCell}$ is the interference strength per PRB per antenna while assume intra-cell interference is ideally zero, J is the number of reception (Rx) antennas per cell, M is the number of assigned transmission PRBs to a certain UE, I is the number of inter-cell interferences and n is the noise spectral density,.

Since the UL CoMP is the main interests in this study, Inter-Site coordination MRC is the main focus, where the Intra-Site coordination MRC and Inter-Site coordination SC are used as reference.

The UL macro diversity reception is also applied to the CSI measurements. By applying the CSI macro diversity, more precise channel knowledge can be acquired and better performances of the LA and PS can be achieved [11].

B. Ideal Interference Cancellation

Normally the macro diversity UE experienced interference in the macro link is much higher than the serve link, where the main interference comes from the UE served in the coordination cell. The performance of macro diversity scheme is limited by the SINR imbalance between the serve and the macro links. If the advanced receiver is deployed in the eNBs, e.g. successive interference cancellation (SIC), receiver, in the coordination cell the correctly received serving signal can then be deducted from the total interference in the macro link of the macro diversity UE, as shown in Equation (5). So the $SINR_{MacroLink}$ can be enhanced and the total combining gain can be further improved. In this study, an ideal interference cancellation (IC) scheme is assumed, where the $S_{MacroLink}$ can always be successfully cancelled out and the upper bound by using the IC can be studied.

$$SINR_{MacroLink} = \sum_{Ant=1}^{J} \frac{\sum_{Prb=1}^{M} S_{J,M}}{\sum_{Prb=1}^{M} \left(\sum_{Interf=1}^{I} I_{J,M,I}^{InterCell} - S_{J,M}^{MacroLink} + n \right)} \qquad \mathbf{(5)}$$

where $S^{MacroLink}$ is the signal of UE served by the coordination cell. For further references, a more detail system level modelling approach for serial interference cancellation receivers can be found in [19] as discussed in 3GPP.

C. Macro Diversity Power Control:

For the UE transmission power P_{Tx}, all UEs are initialized with OLPC at the start. As shown in Section V.B, if the UE is identified as macro diversity UE, the CLPC with absolute control command [12] can be applied to the macro diversity UE on the top of the OLPC to further improve the overall performances.

IV. SYSTEM-LEVEL SIMULATOR

Following the guidelines in [18], the performance of the UL CoMP macro diversity is evaluated by using a semi-static system-level simulator. The system bandwidth is fixed to 10 MHz. UEs are created in the system with balance load in each cell and full (infinite) buffer model is assumed. The network layout is a regular grid comprising 57 cells and wrap-around technique is also applied. The link-to-system level mapping is based on the actual value interface (AVI) method. For each UE, the distance dependent PL and SF are kept constant, where the FF is updated every TTI based on the ITU Typical Urban (TU) power delay profile assuming a UE speed of 3 kmph. The SF is fully correlated between the Intra-site cells and 0.5 correlations between the Inter-Site cells. The Round-Robin (RR) TDPS and proportional fair (PF) FDPS with fixed transmission bandwidth (FTB) for each UE are assumed. The CSI based fast LA together with ACK/NACK based OLLA is applied and the synchronous adaptive HARQ with chase combining is also used. [11]

TABLE I
MAIN SIMULATION PARAMETERS

Parameter	**Assumptions**
Simulation Time	5 runs, 10 s/run, 2 s/run (Warm Up)
Layout	19 sites, 3 cells/sites
Deployment Scenario	Macro 1, ISD = 500 m
UEs per cell	30 UEs/cell
Freq. Reuse Factor	1
Carrier Frequency	2 GHz
UE Ant. & BS Ant.	1 Tx Ant./UE & 2 Rx Ant./cell
Number of PRBs	48 PRBs for data, 2 PRBs for control
FTB	6 PRBs/UE
Thermal Noise per PRB	-116 dBm
BS/UE Height	32 m/1.5 m
BS Antenna Pattern	Horizontal Beamwidth 70° Vertical Beamwidth 10°
BS Antenna Gain	14 dBi
UE Tx_{max}	250 mW [~24 dbm]
Path Loss	128+37.6*log10(distance in km)
Penetration Loss	20 dB
BLER Target	30%
OLPC α & P0 value	α=0.6 & P0=-58dBm, α=1.0 & P0=-106dBm
CSI Resolution	2 PRBs
CSI Error	Mean = 0, and Std. = 1 dB
CoMP Cells	3 cells (1 serve cell + 2 coordination cells)
Combining Win. Size	3 dB

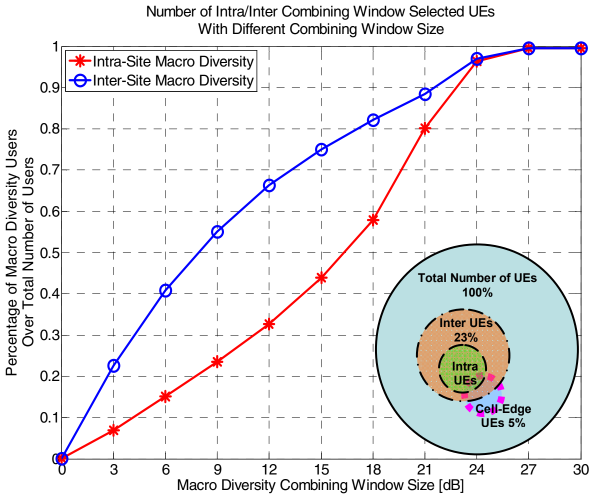

Fig. 2: Number of Intra/Inter UEs vs. CWS

V. SIMULATION RESULTS

In Fig. 2, with different CWS, the percentage of Intra-Site and Inter-Site combining window selected UEs over the total number of UEs are shown. At CWS=3 dB, which is the main interests in this study with limited signal link imbalance between the serve and macro links , there is about 23% of the UEs can be categorized as the Inter-Site macro diversity UEs and about 7% of the UEs can be categorized as the Intra-Site macro diversity UEs. The intra-Site macro diversity UEs is a subset of Inter-Site macro diversity UEs. 5% outage user statistics, in terms of UE experienced average data rate, are also collected for the no macro diversity case, which is also used as the baseline for this study, as described in Fig. 2. The Inter-Site and Intra-Site combing window included about 53% and 12% of the 5% outage users respectively.

A. UL CoMP Macro Diversity with No IC vs. Ideal IC

In Fig. 3, the average SINR of the Inter-Site MRC UEs, without IC and with ideal IC, are shown. As it can be seen, without IC, the SINR differences between the serve and macro link are big. So the total MRC combining gain is marginal. By applying the ideal IC, the SINR in-balanced between the links is reduced about 7 dB. And the final MRC combining gain can increase about two times, which is about 3 dB.

The throughput gain plot of the Intra-Site MRC case, Inter-Site MRC case and Inter-Site SC case compared to the no macro diversity case are shown in Fig. 4. In each case, the average user throughput, 5% outage user throughput, Intra-Site combining window selected user throughput, Inter-Site combining window selected user throughput are presented.

In general, with ideal IC, all three cases have better performances than without IC. For the ideal IC-based Intra-Site MRC case, there are about 57% throughput gains for the Intra-Site combining window selected users. But since there

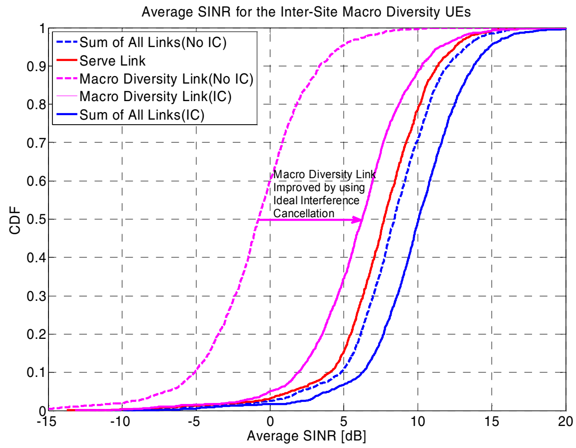

Fig. 3: Average SINR for Inter-Site MRC UEs

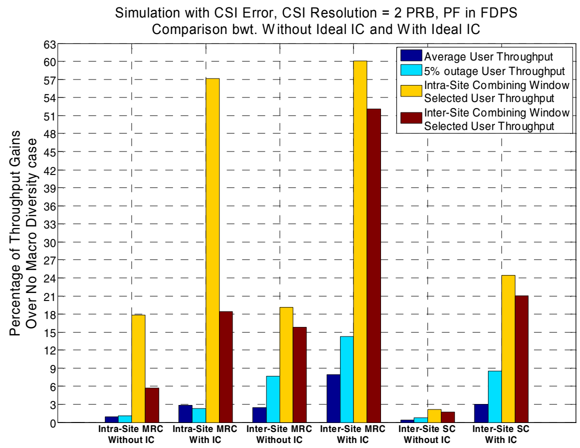

Fig. 4: Bar Plot – No IC vs. IC

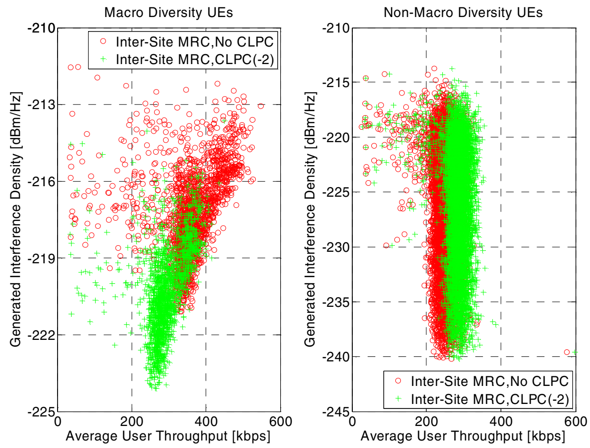

Fig. 5: Generated Interference Density vs. Average User Throughput

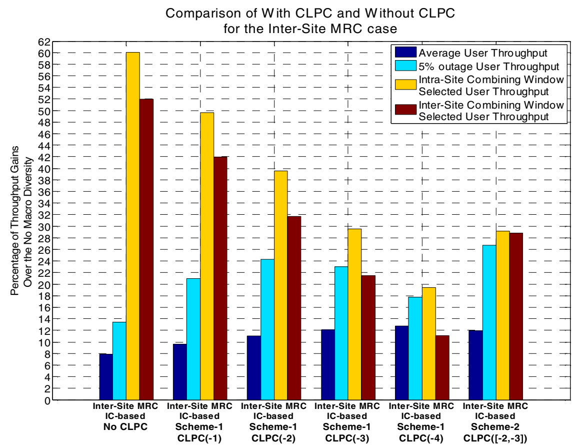

Fig. 6: Bar Plot IC-based Inter-Site MRC with CLPC

are a lot of Inter-Site combining window selected users who are not allowed to make the cross-site combining in the Intra-Site MRC case, the averaged throughput gains for the Inter-Site combining window selected users are reduced to 18%. As shown in Fig. 2, the 5% outage users included by the Intra-Site combining window is small, so the total improvement for the 5% outage users throughput and average user throughput is marginal, which is only about 3% respectively.

For the ideal IC-based Inter-Site MRC case, because of the cross-site combining is applicable through the coordination links between the sites, all four bars have better performances than the ideal IC-based Intra-Site MRC case. There are about 14% gains for the 5% outage user throughput, 8% gains for the average user throughput and 53% throughput gains for the users selected by the Inter-Site combining window.

For the ideal IC-based Inter-Site SC case, the simple balanced link switching between the serving and macro links can only bring about 8% throughput gains for the 5% outage users, 3% average user throughout gains and 21% throughput gains for the Inter-Site combining window selected users.

B. CLPC with the IC-based Inter-Site MRC

As shown in Fig. 4, for the ideal IC-based Inter-Site MRC case, there are huge throughput gains for the macro diversity combining users and those users have also experienced higher SINR. This means that by reducing their Tx power and still maintain the same SINR performance, less interference will be generated to the other non-combining users, which results in a further enhancement of overall network performance. In practice, CLPC command can be applied in LTE to power down the macro diversity combining users. We study two methods for using CLPC for further optimizing the performance for users subject to Inter-Site MRC:

- Scheme-1: The transmission power of all the Inter-Site macro diversity users power down with the same amount, i.e. 1 dB, 2 dB, 3 dB or 4 dB.
- Scheme-2: It is a further optimization of Scheme-1. For the transmission power reduction, the Inter-Site macro diversity users should not all be reduced with the same amount. The users with 2 macro diversity link connections should be reduced by 2 dB, and the users with 3 macro diversity link connections can be further reduced by 3 dB.

Hence, with these CLPS optimization, we basically reduce the transmit power further of the UEs with inter-site MRC, This is done because those user benefit from the extra combining, and thereby can tolerate to use less power, resulting in less interference.

In Fig. 5, the effects by powering down the macro diversity users are shown. As it can be seen, both the average user throughput and the interference density generated by the macro diversity users are decreased with the reduction of the transmission power. But for the non-macro diversity users, with the same generated interference density, the average user throughput is increased since less of the interference is received from the macro diversity users.

The throughput gain plot with CLPC is shown in Fig. 6 to compare with the previous ideal IC-based Inter-Site MRC case. For Scheme-1, the macro diversity user performances are decreased as expected with compromised transmission power. At the optimal case of powering down 2dB, both the 5% outage user throughput and average user throughput can be further enhanced by 10% and 3% respectively. Further decreasing of the Tx power, i.e. the Tx power down of 4 dB, the average user throughput performance still can be further improved, which means the other non-macro diversity users still can get benefit from the CLPC. But the 5% outage user throughput is penalized by decreasing of the performance for some of the macro diversity users. By applying the Scheme-2, the variety of the Tx power brings both the 5% outage user throughput and average user throughput further improved with marginal gain over the Scheme-1. To compare with the no macro diversity case, there are about 27% and 12% gains for the 5% outage user and average user throughput respectively.

In Fig. 7, the performance of the Inter-Site MRC plus CLPC Scheme-2 case is shown to compare with the other three cases discussed in above. As shown, by simply doing the proposed CLPC scheme without applying the ideal IC, the overall performance of the Inter-Site MRC is quite marginal. To compare with the standing alone Inter-Site MRC case, there is nearly no gain for both the 5% outage user throughput and the average user throughput. This is because that, without ideal IC, the performance enhancement by applying MRC for the macro diversity users is very small. In order to maintain their own performances, they can not reduce more Tx power as it was in the ideal IC based case and therefore the overall performance improvement is quite small.

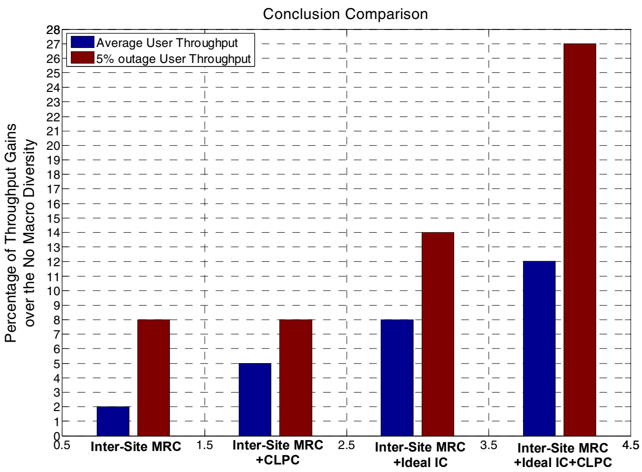

Fig. 7: Concluded Bar Plot

VI. CONCLUSION

In this paper, the UL CoMP macro diversity reception is presented for the LTE-A networks. Three cases, the Intra-Site MRC, Inter-Site MRC and Inter-Site SC, were studied under ideal X2 interface assumptions. Generally, the Inter-Site macro diversity gives better performances than the Intra-Site case and as expected the simple SC gives a small gain to compare with the corresponding MRC case. For the case of without IC, the performance of macro diversity is very marginal. With the help of ideal IC, the SINR in-balance between the serve and macro links is reduced. Further improvement of the overall performances can be achieved by applying the CLPC together with the ideal IC-based macro diversity scheme. Two CLPC schemes are studied, where the Scheme-2 gives better performance than Scheme-1 with 12% of average user throughput gain and 27% of 5% outage gain over the no macro diversity case.

However, the gain of UL CoMP macro-scopic combining comes with high complexity increase and very tight requirements on the X2 interface capacity and delays. Thus, further studies with more realistic assumptions and complexity assessments are need before drawing final conclusions on how attractive uplink multi-cell reception is in practice.

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