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Multi-Layer Traffic Steering: RRC Idle Absolute Priorities & Potential Enhancements

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***Abstract*— This paper investigates the potentials of traffic steering in the Radio Resource Control (RRC) Idle state by evaluating the Absolute Priorities (AP) framework in a multi-layer Long Term Evolution (LTE) macrocell scenario. Frequency priorities are broadcast on the system information and RRC Idle users can be steered towards higher priority carriers whenever coverage allows it. However, such an approach may overload the prioritized layers. For that purpose, an enhanced scheme is proposed, where priorities are adjusted on a user basis and are provided to the terminal via the connection release signaling. The priority adjustment is based on both the Composite Available Capacity (CAC) and the radio conditions of the candidate layers. Compared to broadcast AP, the proposed scheme achieves better load balancing performance and improves network capacity, given that the User Equipment (UE) inactivity periods are not significantly long. Finally, better alignment between the RRC Connected and Idle mobility procedures is observed, guarantying significant decrease of handovers/reselections and potential battery life savings by minimizing the Inter-Frequency (IF) measurement rate in the RRC Idle.**

Keywords-LTE, Load Balancing; Mobility; Absolute Priorities; Self Organizing Networks (SON); Radio Resource Control (RRC)

I. INTRODUCTION

According to traffic predictions [1], mobile broadband is growing exponentially and communication service providers should upgrade their deployments accordingly, in order to meet the future capacity requirements. Network evolution dictates for the migration towards multi-layer deployments consisting of multiple overlaid networks with different characteristics in terms of carrier frequencies (*pathloss properties*), Radio Access Technology (RAT), cell sizes, etc. However, this diverse communication environment introduces additional Operation Administration and Maintenance (OAM) complexity, requiring self-optimizing traffic management techniques for efficiently exploiting the vast pool of network resources. In principle, the autonomous traffic management is only one of several automation deployment elements that the 3rd Generation Partnership Project (3GPP) has defined within the Self-Optimizing Organizing Networks (SON) framework [2] (*i.e. mobility optimization, interference management, energy saving, etc*).

Traffic steering (TS) is defined as the ability to control and direct traffic to the best suitable cell/layer [3]. Specific criteria such as cell load, UE speed, power consumption, UE capabilities and backhaul capacity could be utilized for adaptive TS decisions depending on the operator's policy. Additionally, a further classification can be done based on the UE RRC state. Both RRC Connected and Idle TS mechanisms are strongly coupled with the respective mobility procedures, whereas decisions at the state switching are performed via redirection information that instructs the UE to connect or camp on a specific carrier (*Table I*).

Prior state-of-the-art focuses on utilizing TS primarily for load balancing purposes. In [4-5], RRC Connected schemes are applied for biasing handover events in favor of under-utilized cells whereas a theoretical approach on TS exploiting the connection setup phase is adopted in [6]. Compared to RRC Idle, the aforementioned techniques react faster to load fluctuations and resolve potential overload conditions. However, without a proper idle mode policy, the cost in signaling overhead might be large. Examples of RRC Idle studies can be found in [7-8]. Nevertheless, those former studies only analyze the impact of Idle Mode mobility management on the UE power consumption.

In this paper, we focus on the 3GPP-defined Absolute Priorities (AP) framework [9] and evaluate its performance as a load balancing mechanism via the RRC Idle state. The study is performed on a co-sited LTE macrocell scenario consisting of 3 carrier frequencies at 800 MHz, 1800 MHz and 2600 MHz respectively. According to AP, frequency priorities are broadcast on the system information and UEs reselect to the higher priorities layers whenever coverage allows it. The broadcast scheme (*common frequency priorities for all UEs*) is compared against a developed SON-based algorithm that dynamically adjusts the priorities on a UE resolution during the connection release procedure.

The paper is organized as follows. Section II outlines the basic TS schemes depending on the RRC state. In section III,

Table I. TRAFFIC STEERING SCHEMES

RRC State	Method
Connected	via forced handovers and/ or dynamic mobility parameters tuning (range extension)
Idle	via basic cell biasing and priority thresholds
Idle-to-Connected Transition	via redirection to the proper layer during the connection setup phase
Connected-to-Idle Transition	via redirection to the proper layer during the connection release phase

the AP framework is described along with the UE-dedicated priority adjustment proposal. Simulation assumptions are presented in Section IV, followed by the numerical results in Section V. Finally, Section VI concludes the paper.

II. TRAFIC STEERING & RRC MODE ALIGNMENT

Fig. 1 depicts the interaction between the UE RRC states and the potential schemes in terms of steering a user towards a cell. The curved arrows (*initiating from/ ending at the same state*) represent the handovers and reselections that a terminal performs while being active or idle respectively.

TS in RRC Idle is rather challenging as the network has less accurate information about the UE location, compared to RRC Connected. In principle, cells are grouped in Tracking Areas (TA) and idle users autonomously reselect to nearby eNodeBs (eNB) according to the provided information that is available on the broadcast channel (*priorities, thresholds, minimum acceptable signal power/ quality, etc* [9]). Hence, reselections between cells that belong to the same TA are transparent to the network. Despite the aforementioned network knowledge limitation, optimized RRC Idle management can provide significant gains in terms of control signaling minimization by eliminating idle-to-connected ping pong events. An idle-to-connected ping-pong is declared whenever a user that switches to connected, is immediately handed over to a different cell either due to radio conditions or load balancing purposes [3].

RRC Idle policies can be supplemented with redirections at the connection establishment. In such a manner, TS decisions can be further enhanced by exploiting the load information at the UE state switching. Nevertheless, additional latency in the connection setup time is introduced, as the user has to re-initiate the connection establishment procedure at the redirected carrier. In principle, RRC Connected TS policies are the most effective load balancing mechanisms, since the network is fully aware of the most important TS-related key performance indicators such as cell load, user throughput, channel conditions, etc. Thus, the eNB can react faster to the load fluctuations and perform either the necessary load-based handovers or adjust mobility parameters in favor of less utilized neighboring cell.

In order to improve the autonomous UE cell reselection in the RRC Idle state, and minimize the signaling overhead introduced by both redirection and handover events, network knowledge during the connection release phase could be utilized, as the *RRC CONNECTION RELEASE* message can provide explicit RRC Idle mobility management parameters on a UE basis [10]. Furthermore, redirection information can also be included, requesting the terminal to reselect to a different cell for load balancing purposes.

III. ABSOLUTE PRIORITIES & POTENTIAL ENHANCEMENTS

A. Absolute Priorities Framework

AP is a priority-based scheme for Inter-Frequency (IF)/ RAT Idle mode TS and mobility management. For the cell reselection criteria, those are defined as follows:

- ***Criterion 1***: A UE reselects to a higher priority cell N if:

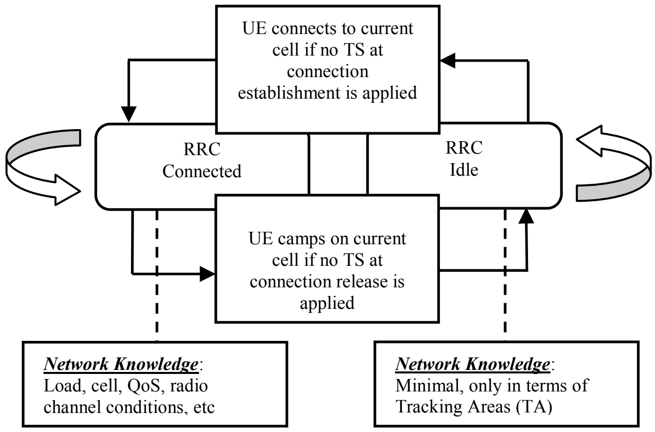

Figure 1: Interworking between RRC states and TS policies

$$TargetMeas_N > ThreshX_{high} \tag{1}$$

- ***Criterion 2***: A UE reselects to a lower priority cell N if:

$$\begin{array}{c} TargetMeas_N > ThreshX_{low} \\ \& \\ ServingMeas < ThreshServing_{Low} \end{array} \tag{2}$$

where *ServingMeas and* $TargetMeas_N$ correspond to the signal power/quality measurements of the currently camping cell and the IF target cell *N* respectively. Whenever (1) is satisfied for more than one cell that belong to frequencies with different priorities, the UE reselects to the layer with the highest priority. Absolute thresholds ($ThreshX_{high}$, $ThreshX_{low}$, $ThreshServing_{Low}$) and frequency priorities can be provided to the UE by either the system information (broadcast) or via the RRC CONNECTION RELEASE message. Note that for the current study, measurements are performed in terms of Reference Signal Received Power (RSRP).

By using the broadcast method, priority assignment is done on a per-frequency basis and users are steered to higher priority layers whenever sufficient coverage is available. An example case is shown in Fig. 2, where the high frequency layer (*orange*) is assigned higher priority than the lower frequency one (*purple*). Basically, the $ThreshXServing_{Low}$ threshold determines the coverage of the orange layer and therefore AP can guarantee that cell center users will camp on the high frequency layer regardless of the different pathloss properties of the two layers. However, since the network is not fully aware of the UE distributions in the RRC Idle mode, it is

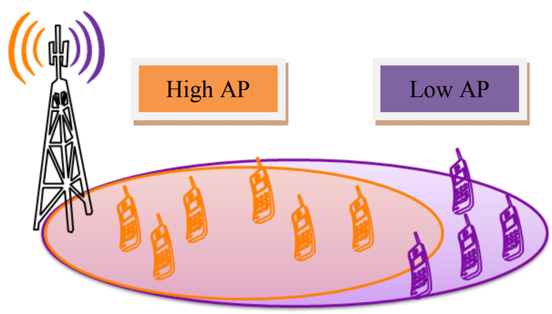

Figure 3: Example of multi-layer deployment

possible that a large amount of users is camping on the orange layer. Consequently, all these users will be served by the same carrier when they switch to Connected mode, a fact that may result in overload. RRC Connected TS or TS at the connection setup could resolve the inefficient resources utilization; however at the cost of excessive control plane signaling, as AP constantly pushes users to the high priority layer.

Finally, UE power consumption considerations must be also be taken into account. Generally, idle UEs go into a wake-up state at every Discontinuous Reception (DRX) cycle in order to listen to the paging channel and measure nearby cells. Intra-frequency measurements are triggered whenever the serving signal power falls below the $S_{IntraFreqSearch}$ threshold:

$$ServingMeas < S_{IntraFreqSearch} \quad (3)$$

whereas the IF measurement rate depends on the frequency priorities. More specifically, the $ThreshServing_{Low}$ and $S_{PrioritySearch}$ thresholds control the IF UE measurements, for lower and higher priorities respectively. Typically, the $S_{PrioritySearch}$ is higher than the $ThreshServing_{Low}$ in order to steer terminals to the high-prioritized frequencies. However, this can be extremely inefficient from a UE battery life point of view in areas where high priority carriers are not available (e.g. cell edge regions).

B. SON-based Dedicated Priorities at the Connection Release

The aforementioned drawbacks of broadcast AP can be resolved if priorities are assigned on a UE resolution. In such a manner, users at different locations can have different priorities per frequency. Since the RRC CONNECTION RELEASE message includes the option of updating the frequency priorities, expanding the framework on a dedicated UE resolution is possible.

The proposed scheme dynamically adjusts the priorities of the candidate frequencies based on both their load and coverage conditions. For the load estimation, the concept of Composite Available Capacity (CAC) [11] is utilized, declaring the amount of resources that each cell c_f (index f *denotes the frequency*) is willing to offer for load balancing. A detailed description of the priority adjustment scheme is presented in Algorithm 1.The additional coverage check in terms of RSRP ensures that unnecessary IF measurements can be avoided in regions where a carrier frequency is not available. The priorities of all available carriers are adjusted in a descending CAC order, assigning the highest one to the layer with the largest CAC value. The required IF measurements for coverage availability might already be present due to the previous measurements that the UE was performing while being in the RRC Connected state. If not, they could be requested explicitly via a measurement trigger before connection release. Finally, the updated frequency priority list $\{p_f\}$ is provided to the UE via the connection release signaling.

Algorithm 1 Absolute Priorities Adjustment Scheme

for *f = 1* **to** *number of carrier frequencies* **do**

$\tilde{c_f} = \mathrm{argmax}_{c,j}\{CAC_{c,f}\}$ && $RSRP_{c,f} > ThreshServingLow$

end for

sort $\{\tilde{c_f}\}$ set in descending CAC order and derive the corresponding carrier frequency set {*f*}

adjust priorities $\{p_j\}$ accordingly → assign the highest priority to the first frequency/ element of set {*f*} and continue on a descending priority order

if |{*f*}| < *number of carrier frequencies* **then**

find the unavailable frequencies and move them to the end of the set $\{p_f\}$ by assigning to them the remaining lower priorities based on the relevant CAC information

end if

return $\{p_f\}$

IV. Simulation Assumptions

The evaluation of the proposed scheme is performed on a LTE deployment consisting of three co-sited macrocell layers deployed at 800 MHz, 1800 MHz and 2600MHz, with an inter-site distance (ISD) of 1732m. The bandwidth allocations are 10MHz, 10MHz and 20MHz respectively. Packet arrival is modeled as a Poisson process, and UEs switch to idle whenever downlink transmission buffers are emptied. The size per burst is negative exponentially distributed with a mean value of 400 kbits. For all simulations, both the number of UEs and the mean packet size are kept constant. Hence, the offered load per macro sector area is adjusted by spanning over different packet interarrival times. Terminals are moving in straight line trajectories at 3 km/h.

Since the priority adjustment is done at the connection release, significantly long session interarrival times might degrade the algorithm performance as the decision is based on

Table II. SIMULATION ASSUMPTIONS

Network Layout	Hexagonal grid, 7 cell sites, 3 sectors per site
ISD	1732 m
Pathloss Models	3GPP
Carrier Frequency (Bandwidth)	800 MHz (10MHz) AP = 5 (Low) 1800 MHz (10MHz) AP = 6 (Mid) 2600 MHz (20MHz) AP = 7 (High)
Transmission Power	43 dBm (800 MHz and 1800 MHz) 46 dBm (2600 MHz)
Number of UEs	200 UEs per macro sector area @3km/h
Traffic Model	Finite Buffer (mean burst size = 400kbits)
Offered Traffic	{14, 18, 22, 26} Mbps per macro sector area
ThreshServingLow $\{X_{High}, X_{Low}\}$	-110 dBm {-110dBm, -106dBm}
IF Measurement thresholds	*Connected*: -110 dBm (A2 event [10]) *Idle*: ThreshServingLow = -110 dBm $S_{PrioritySearch}$ = -60 dBm
Intra-Frequency Measeruement Theshold	*Connected*: UEs are always performing Idle: $S_{IntraFreqSearch}$ = -106 dBm
Measurement rate	*Connected*:5 msec every 40 msec *Idle*: 1.28 sec (DRX cycle)
Handover Offset	3 dB / 5 dB (Intra/ Inter-HO) (A3 event [10])
TTT Window	0.4 sec (Intra-HO) / 0.5 sec (Inter-HO)
Trelesection Timer	1.3 sec
L3 Filtering Factor	4

outdated load information. In order to simulate this effect and provide a low algorithm bound, an extreme additional case is considered, where the priority adjustment is done randomly without any load/ coverage knowledge. Note that except for the RRC Idle TS mechanisms, no other TS scheme is applied.

In order to define CAC, traffic is treated in an elastic manner by defining a minimum bit rate requirement *minBR*. If R_u is the achievable instantaneous throughput of user u, and f_u the corresponding resource share, then the actual amount of resources required to meet *minBR* is given as follows:

$$f'_u = \frac{f_u \cdot minBR}{R_u} \quad (4)$$

By assuming that the remaining resources can be utilized for load balancing, the CAC of cell c is modeled according to (5), where $N_{PRB,c}$ is the cell bandwith in Physical Resource Blocks (PRB), and $N_{PRB,min}$ the lowest available bandwidth in the system .

$$CAC_c = \frac{N_{PRB,c}}{N_{PRB,min}} max\left(\rho_{target} - \frac{\sum_{u=1}^{N_u} f'_u}{N_{PRB,c}}, 0\right) \cdot 100\% \quad (5)$$

The bandwith scaling factor emulates the 3GPP-defined Cell Capacity Class Value (CCCV) [11]. *MinBR* is set to 1024 Kbps whereas the target operational load, ρ_{target}, is set to 0.8.

V. RESULTS

The performance of the different schemes is evaluated in terms of the user distribution over the different carriers (*both RRC Idle & Connected, averaged over the whole simulation time*), average user throughput and mobility events rate for different load conditions. Finally, the percentage of DRX cycles performing IF measurements in the RRC Idle state is recorded as well.

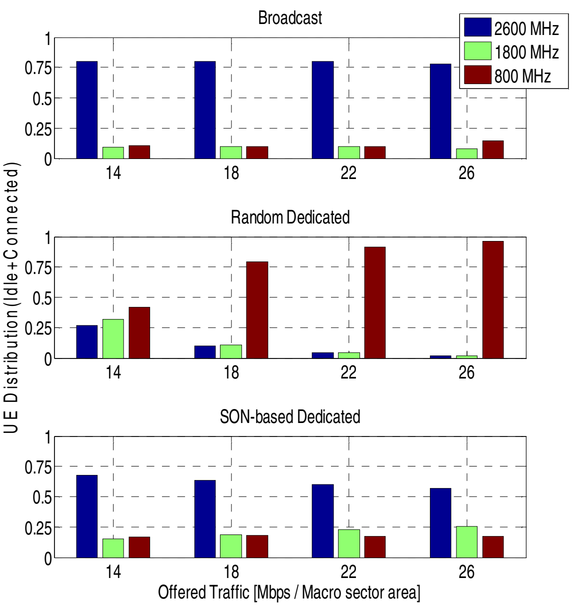

Figure 3: UE Distribution versus Offered Load

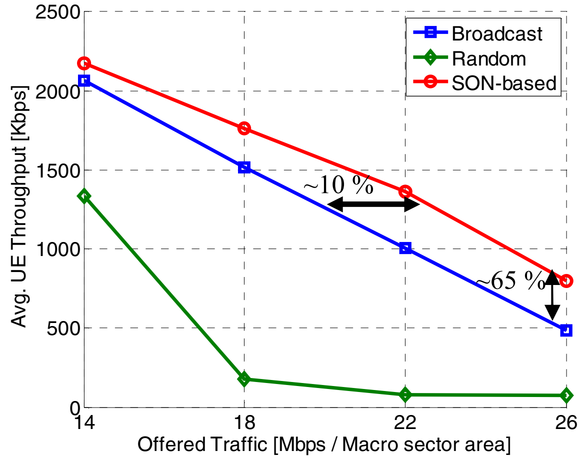

Figure 4: Avg. UE Throughput versus Offered Load

Fig. 3 illustrates the user distribution as a function of load for the different simulated schemes. For the broadcast case, the user distribution is insensitive to load, as it is primarily affected by the absolute RSRP thresholds. Note that the 1800MHz band is left unutilized due to its lower priority compared to the 2600MHz carrier. Therefore, even if (1) is satisfied for both carriers, all cell center UEs reselect to the 2600MHz layer. On the other hand, the random dedicated scheme tends to overload the 800MHz layer as the offered traffic increases. This behavior is explained by the fact that except for cell edge users (*they will reselect to the 800MHz layer regardless of the priority assignment simply due to radio conditions*), cell center users start camping on the 800MHz band due to the random assignment. Hence, session completion times become significantly longer and gradually the RRC Idle state vanishes, *"trapping"* all users in the RRC Connected.

SON-based dedicated priorities offload significantly the 2600MHz carrier primarily towards the 1800MHz one as the offered traffic increases due to the load-aware nature of the priority adjustment algorithm, and cell center are now better distributed between the two higher frequency bands. An important observation is the fact that the user distribution tends to converge to the optimal 0.5/0.25/0.25 ratio since the 2600MHz layer has double bandwidth. However, this is not achieved due to the slower adaptation of the RRC Idle mode to the load fluctuations, as users have to switch to idle in order TS to be applied.

The avg. UE throughput versus the offered traffic is shown in Fig. 4. The random scheme shows the worst performance since users are connecting to the 800MHz carrier ignoring the double bandwidth of the 2600MHz band. The better load distribution across the network layers is further proven by the capacity gains that the SON-based scheme provides over the broadcast AP case. In principle, SON-based dedicated priorities improve the network capacity by ~10%, whereas in terms of avg. UE throughput, a ~65% gain is observed for the case of 26 Mbps offered load. It is rather clear that SON-based priorities would minimize the signaling that additional TS mechanisms (i.e. load-based handovers/ redirections) would

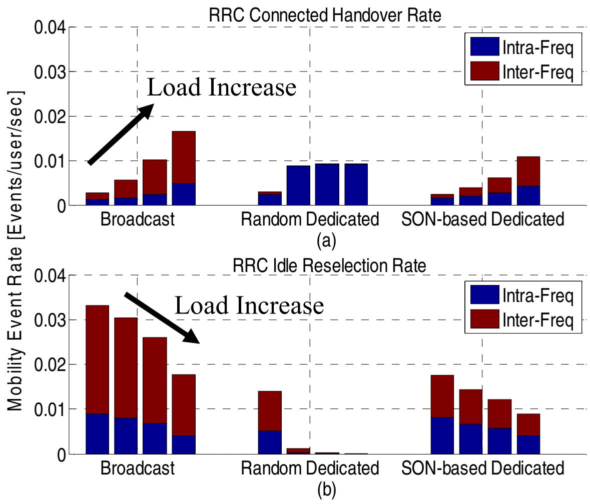

Figure 5: (a) Handover and (b) Reselection Rate versus Offered Load

have generated if they were applied on top of them, as the RRC Idle cell resection procedures have been improved. Consequently, less RRC Idle wrong decision would have had to be corrected at either the connection establishment phase or RRC Connected mode.

The benefits of proper alignment between the RRC Idle and Connected are depicted in Fig. 5, where both handover (Fig. 5a) and reselection rates (Fig. 5b) are presented. Using the SON-based priorities, the signaling overhead generated by the mobility events is decreased significantly due to the fact that idle-to-connected ping-pongs (and vice versa) are minimized. Hence, the observed gains derive from the IF handover/ reselection rate reduction. Note that for the random scheme, IF events are almost eliminated as all users are connected to the 800MHz carrier, thus only intra-frequency ones are performed at the cell borders. Finally, the severe overload that the 800MHz layer experiences at higher offered traffic conditions is further proven by the elimination of reselections, as all users are "*trapped*" in the RRC Connected state.

Finally, the percentage of DRX cycles performing IF measurements in idle mode is illustrated in Fig. 6. The SON-based scheme outperforms the broadcast one, since UEs almost always camp on the higher priority carrier; hence no IF measurements occur and UE battery life savings can be achieved. The noticeably higher IF measurement levels for the broadcast case are primarily caused by cell edge users camping on the 800MHz frequency and perform IF measurements at every DRX cycle. Note that for the random dedicated scheme and offered load conditions above 14 Mbps, the low IF measurement rates are due to the lack of RRC Idle samples.

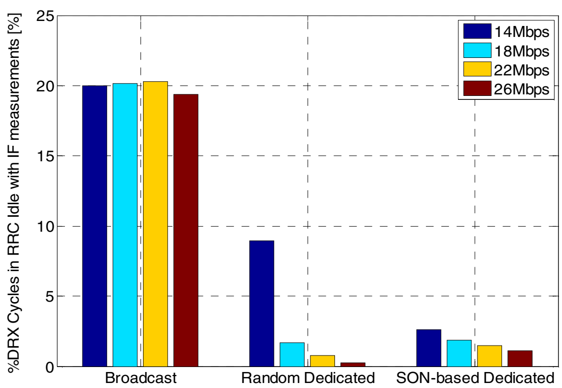

Figure 6: Percentage of DRX cycles performing IF measurements in RRC Idle

VI. CONCLUSIONS

In this paper, a novel SON-based UE-dedicated priority adjustment scheme has been proposed for enhancing the AP framework by utilizing the RRC connection release signaling. Compared to the conventional AP broadcasting, the developed mechanism achieves better load balancing, improving user experience and network capacity. However, long UE inactivity periods can degrade the performance, since the TS decision is taken at the connection release. For that purpose, additional features such as dedicated priority validity-timers and UE behavior prediction based on call history could additionally be applied. Note that under no circumstances, sole idle mode TS could outperform TS at the connection setup or in the RRC Connected due to its slower adaptation to the load variations. However, an optimized idle mode policy can provide better alignment to the TS/ mobility management procedures that take place in the different RRC states, resulting in significant signaling decrease. Future work includes the algorithm evalution in a Heterogeneous Network (HetNet) along with its interaction with additional TS policies at different RRC states.

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