

Carrier aggregation techniques among Licensed and unlicensed Spectrum in Wireless Heterogeneous Networks: A survey

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Abstract- The exploitation of wireless networks and progressions in smart mobile devices claim high need for multimedia streaming over wireless network. The quick increasing demand for multimedia content is the present challenges for all parties in multimedia streaming scheme, specifically, content providers, wireless network service providers, and smart device makers. Mobile network service providers and Content providers are both striving to progress their streaming services by utilizing progressive technologies. Energy efficiency is one amongst the most renowned field on which numerous research circle and organizations over the globe are increasingly working. This work spotlights on diverse technologies for pruning energy utilization in Heterogeneous networks (HetNets). These inclinations drove researchers to examine an extensive spectrum of solutions, at diverse layers of the protocol stack that exploit obtainable interfaces in certain devices by aggregating the LTE carriers by using carrier aggregation (CA) scheme. This state of the art provides an indication and scrutinizes the progression of carrier aggregation solutions over time. The investigation commences by relating the carrier aggregation crisis and handover techniques. Afterwards, discussion on the evolution trends in the literature and discusses some open challenges requiring further research. The survey ends up with a brief presentation of related work in tangential research areas. It may be measured by streaming bitrate, video quality metrics like Peak to Signal Noise Ratio, and other user satisfaction factors.

Keywords - Heterogeneous wireless networks, Carrier aggregation, Wireless networks, Energy efficiency.

I. INTRODUCTION

Heterogeneous networks are seen as a promising way to meet the increasing demand for mobile broadband traffic in cellular networks. The new Pico nodes complement the macro nodes to provide higher capacity in areas with higher user density. They are assumed to use the same frequency and the same radio access technology (RAT) as the macro nodes.

Depending on the demand, a large number of pico nodes might be needed per macro cell to achieve a sufficient capacity increase during busy hours. With the rise in the number of deployed radio access nodes, the energy consumption is expected to be larger in a heterogeneous network compared to current networks with only macro nodes [1]. This work investigates techniques that enable to reduce the energy consumption in a HetNets, while maintaining the same user performance. Also analyses of how a heterogeneous network featuring energy efficiency (EE) schemes [2] can have lower energy consumption than the reference macro network under certain conditions has been examined.

Mobile Network Operators (MNOs) try to find methods to solve scarcity of resource problem and integrating LTE/Wi-Fi could be one of the solutions. The idea is that when there does not exist a single radio access technology (RAT) that offers sufficient bandwidth to meet an applications requirement (e.g. Users at the

cell edge), two or more RATs are merged so that the application is able to experience a scaled-up capacity. In fact, it is expected to be

a key ingredient of the next-generation 5G wireless to efficiently use heterogeneous wireless networks in an integrated manner. Two candidate RATs to aggregate are LTE and Wi-Fi, due to their popularity in the state-of-the-art mobile devices, which are also the focus of this paper.

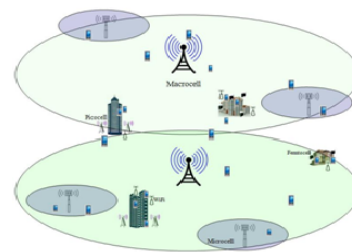


Fig 1: LTE advanced Heterogeneous Networks

An LTE-Advanced device can aggregate up to five component carriers (CCs), each of up to 20 MHz. With the largest configuration; this implies a total bandwidth of 100MHz. To support backward compatibility with LTE user equipment (UE), each of the CCs shall be configured as a typical LTE carrier. Therefore, any of the CCs used for CA should also be accessible to LTE UEs. However, mechanisms, such as access barring[8], already exist to prevent LTE UEs from camping on specific CCs. This way, operators have the flexibility of adjusting the characteristics of the CCs to support a mixture of LTE and LTE-Advanced services.

A lot of research efforts on opportunistically using LTE networks with unlicensed spectrum are in progress to offload the traffic from LTE networks to the Wi-Fi group. Generally the delay-tolerant applications have been made in the name of Wi-Fi offloading. Other notable examples to aggregate LTE and Wi-Fi, rather than opportunistically using one of them, include MPTCP (Multi Path TCP) [3] at the transport layer. In CA one CC perform as the Primary Cell (PCell) and others performing as Secondary Cells (SCells). The SCell is a Time Division Duplexed (TDD) carrier which is accomplished to transfer the data in both Uplink (UL) and Downlink (DL) directions.

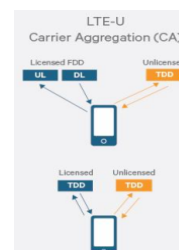


Fig 2: Carrier Aggregation in LTE

In this article, we have presented an overview of the emerging LTE Unlicensed band (LTE-U) technology, which extends LTE over the unlicensed spectrum band to fulfill the ever increasing mobile traffic demands. The regulations, principles, and typical deployment scenarios for LTE-U have first been elaborated, followed by the potential LTE-U benefits. Furthermore, three challenging issues have been identified in bringing LTE-U to reality, and related research directions have been discussed together with some existing works. Finally, simulation results have been presented to demonstrate that LTE-U can achieve higher throughput for small cell users.

The rest of this work is organized as: Section II explains the sharing of licensed spectrum and unlicensed spectrum in HetNets, Section III deals with the design principles, Section IV shows the general research topics, Section V demonstrates the design challenges, Section VI depicts energy efficiency in HetNets followed by handover process, Section VII explains carrier aggregation as a promising solution for next generation of mobile communication, Finally performance metrics, conclusion and future scopes are discussed in section IX and X respectively.

II. LICENSED VS UNLICENSED SPECTRUM

The growing number of users who are usually in 5 GHz for both Wi-Fi and LTE networks [12] in different situations is a strong indication that the unlicensed spectrum for LTE systems may be an important alternative for this growing transmission rate demand. Due to the availability to work on unlicensed mode, the band between 5150 and 5925 MHz is potentially interesting for LTE's operation on secondary mode. However, the total operation in this band is only allowed to networks that implement a series of mechanisms capable of keeping interoperability among every system. To contact LTE in both licensed and unlicensed band a technique of Listen Before Talk (LBT) is required.

The unlicensed spectrum has enabled many low-cost wireless services from monitor's to walkie-talkies and Wi-Fi. The 2.4 GHz band is currently the most utilized by different wireless users such as cordless phones, Zig Bee, Bluetooth, and WiFi enabled devices. It provides broadband wireless access in local and personal areas. Compared to the 2.4 GHz band, the 5 GHz band is less congested and mainly used by Wi-Fi (11a) devices. In addition, it has a shorter communication range due to higher path loss but has wider available bandwidth. The unlicensed 60 GHz band [31] has more abundant bandwidth than the 28 GHz band, making it feasible for bandwidth multimedia services.

However, attenuation at 60GHz imposes great challenges in the design of physical layer specifications and air interfaces. In general, wider spectrum, clear channel conditions, and easier execution, LTE-U at present spotlights on 5 GHz bands to offer broadband multimedia services. Figure 2 illustrates the unlicensed spectrum layout in numerous diverse main regions at 5 GHz.

III. DESIGN PRINCIPLES

Even though to access LTE over unlicensed spectrum can be cost efficient, certain primary standards and regulations are forced to assure harmonious coexistence among LTE-U and added incumbent schemes. The synchronized items include the transmission power, spectrum aggregation, channel access methods, and so on.

a. Transmission Power

The primary issue in of unlicensed spectrum utilization is the guidelines of transmission power. Certain regulation controls the

interference amongst unlicensed users. Utmost transmission power, such as 5.47–5.725 GHz and 5.25–5.35 GHz spectrum has authorize transmit power control (TPC) methods [13]. TPC decreases the power of a radio transmitter to the least in order to circumvent interference to users and/or broaden battery life to uphold the link transmission.

b. Dynamic Frequency Selection

An interference avoidance mechanism named dynamic frequency selection (DFS) is adopted in 5.25–5.35 GHz and 5.47–5.725 GHz spectrum. Under DFS, LTE-U devices [14] periodically detect the radar signals and switch the operating channel to one that is not interfering with the radar systems upon detection.

c. Licensed Assisted Access

Transmission on unlicensed spectrum is unstable and hard to provision guaranteed QoS [15]-[16]. To guarantee QoS and to improve the user need, the unlicensed LTE-U always comes with the usage of certified spectrum. With the use of CA, carriers in diverse frequency bands can be combined into wider bandwidth to provide greater data rates.

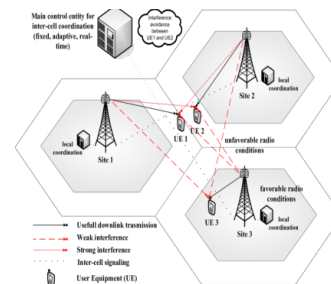


Fig 4: Dynamic Frequency Selection for transmission

IV. RESEARCH ISSUES

a. Co-Channel Coexistence with Wi-Fi Systems

The unlicensed bandwidth is comparatively abundant, still no clean channel is sensed, and therefore LTE-U and Wi-Fi have to distribute the similar channel. This may happen due to an ultra-dense small cell deployment, bandwidth range regulations for one operator, or limitations of BS CA capabilities. Since LTE has shown dominant system performance over Wi-Fi in the co-channel scenario [17], some restrictions need to be imposed on LTE resource allocation in order to protect the Wi-Fi performance.

b. Dynamic Channel Selection

As the unlicensed spectrum is bandwidth-rich, the large number of available unlicensed channels offers high probability for an LTE-U small cell to find an unused channel with very low-level interference as shown in figure 4. By enabling small cells to choose the cleanest channel based on the LTE and Wi-Fi measurements, the interference can be avoided not only among small cells but also between the LTE and Wi-Fi devices. LBT requires the LTE-U device to periodically stop the channel occupancy and detect the activities of other channel occupant on scale of milliseconds.

In addition to the time sharing strategies, LTE transmit power manages to assist LTE/Wi-Fi coexistence inside the uplink. The uplink power control [18] is based on the UE path loss, which does not take the Wi-Fi into attention. Cell edge UEs may have a high

transmits power, thus affecting the Wi-Fi transmissions in the vicinity. An improved uplink power control method has to be proposed to involve the LTE interference [19] measurements in power control decisions.

V. DESIGN CHALLENGES

An efficient Wireless Heterogeneous Networks requires support from other fields such as signal processing (especially digital signal processing), embedded systems and so on. This is because MM handling demands much more than what traditional systems usually do, thus a more powerful system has to be built.

a. Bandwidth

In wireless networks, bandwidth is not simply limited, although unstable. MM streaming wants extremely high bandwidth to deal with the enormous amount of information varying from scalar to multimedia. High bandwidth with low power spectral density can be offered by Ultra Wide Band (UWB) technology in recent times.

b. Energy Consumption

For HWNs, energy is a vital resource, which is even of a much more paramount importance for Heterogeneous networks if a given standard of QoS [19]-[20] is to be ensured. In this network, very huge computations are carried out; a lot of data processing and transmission of huge data are inevitable. All these operations require energy/power. Unfortunately, one of the most energy consuming operations is radio transmission, which right now is the most common means of transmission in most sensors.

c. End-To-End Throughput

This is responsible for the links in a Heterogeneous Networks from source to sink [20] regardless of the route used. Currently, there is no protocol specifically designed to serve paramount importance if good performance and QoS is to be achieved.

d. Delay

Carrier aggregation results approximate the end-to end delay to be utilized in loss recognition and/or scheduling. For instance, many solutions, especially transport layer protocols, estimate the round trip time (RTT) as the average time difference between sending a packet and receiving its acknowledgement and use it to calculate the retransmission timeout (RTO).

On the other hand, to take the delay into account while distributing traffic across interfaces, argue that it is sufficient to calculate the differences in latency between the interfaces, not the actual latency of each interface. The sender transmits numerous packets at the similar time on diverse interfaces and computes the difference among receiving their ACKs. To enhance the precision of computation, they force the receiver to transmit all the ACKs [21] by means of a single path.

VI. Energy Efficiency in HetNets

From the green communications point of view, offloading traffic from macro BSs to small cell BSs should improve the (bits-per-joule) energy efficiency of BSs while serving users. Nevertheless, performance over traffic allocation/offloading among diverse kinds of BSs to achieve a definite level of energy efficiency is barely examined in the literatures. Traffic flow characteristics in a HetNets are considerably exaggerated by the cell (user) association approaches. If there exists an energy efficient cell association means to make all the traffic flow into

BSs with high energy efficiency [4], saving huge amount of energy can be certainly anticipated.

Most prior works on cell association and traffic offloading focused on the study of the energy-free interactions between cell association, coverage and throughput. A biased received power association, studied the average throughput of a downlink channel [5] in a HetNet, but no energy efficiency analysis is involved in this work. Although the optimal BS intensity problem for achieving high throughput and energy efficiency is studied, the impact on the energy efficiency due to cell association is not addressed at all.

The energy-saving approach for a cellular network by considering dynamic BS operation and cell association together was studied, for example; however, these works only considered the traditional one-tier macro BS model so that its proposed scheme cannot be applied in a multi-tier HetNet [6]. The joint resource allocation, cell activation and traffic offloading problems that originate dynamic traffic variations in a HetNet were investigated and they are approached from the perspective of energy-efficient resource allocation, not from the perspective of making users associate a BS having high energy efficiency.

As a result, in general their proposed schemes on cell association and traffic offloading cannot ensure to achieve high link and/or network energy efficiency. A crucial concept that user association schemes should consider the energy cost in the backhaul communications [7]-[8] in order to attain a certain level of energy efficiency, it still does not consider the link energy efficiency of BSs in its proposed context-aware user association scheme.

A radio access node, i.e. a base station, is composed of different components: power amplifier (PA), radio frequency (RF) transceiver, the base band (BB) unit and finally the power supply (DC) and cooling (CO). Basically in current base stations, all components contribute to the overall power consumption of the node even during the idle time when there is no data nor signaling transmission to perform, as shown in Fig. 1.

The two energy efficiency features considered here are based on the deactivation of certain base station components during the idle time of a BS [9]. Thus, lower power consumption in idle mode can be achieved. This puts however new requirements on the hardware of a BS that may not be met by current BSs but could be taken into account when designing future base stations.

Macro and pico nodes [10] have different roles in the network and therefore shall meet different requirements concerning their availability. Consequently different kinds of sleep mode can be applied to them. Macro nodes provide the basic coverage meaning they must be always reachable by potential users. For that purpose, even if there is no active user in a macro cell and no data transmission is scheduled, the macro node still needs to broadcast regularly cell-specific signaling information and monitor the uplink [11] to identify if a user wants to establish a connection. A sleep mode based on the complete shutdown of a macro base station is thus hardly conceivable. Even if several RATs are implemented at a macro node, the radio components related to at least one RAT should remain active so as to supply mobile communication coverage. Pico nodes are redundant nodes deployed to help the macro node handle high traffic demand at certain points in time. A larger variety of sleep mode mechanisms are hence applicable to pico nodes.

VII. CARRIER AGGREGATION

The maximum capabilities of LTE-Advanced are known as Carrier Aggregation, which enables mobile network operators to merge a sum of LTE providers. This lets to amplify the user data

rates and complete network capability and to make use of fragmented spectrum allocations.

Generally, Carrier Aggregation is functional to either TDD or FDD LTE variants and used to merge carriers during contiguous or in non-contiguous or even with same frequency band. The aim of Carrier Aggregation is to combine up to five distinct LTE carriers, up to 20MHz each. For instance, the prevailing 3GPP standards guide the aggregation of two providers and subset of full LTE variety operating frequencies. However, these early implementations have momentous advantages. Certain Telecom recognized Carrier Aggregation to combine 10MHz carriers in its 800MHz and 1.8GHz bands to achieve peak downlink user data rates of 150Mbps.

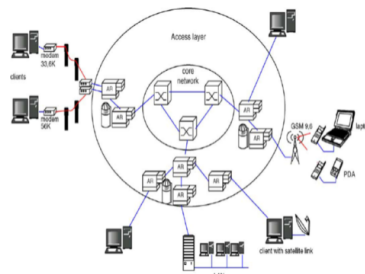


Fig 5: Data Aggregation in Heterogeneous Networks

Carrier Aggregation has offered higher benefits and look forward as an important research work for 3GPP, and network operators. In future, a number of important developments in LTE includes: Increasing the component carriers amount and total bandwidth support in both downlink and uplink. This supports a higher amount of frequency bands and amalgamation of frequency bands. By means of Carrier Aggregation among the cells, to improve small cells and Heterogeneous Networks (HetNets) by enabling flexible aggregation of TDD and FDD LTE carriers. In addition, it supports LTE Carrier Aggregation among licensed and unlicensed spectrum.

To provide a perfect wider spectrum, channels and easier implementation, the unlicensed frequency band of 3GPP is 5 GHz which is mainly used by IEEE 802.11-based Wireless Local Area Network (WLAN), or Wi-Fi. It should be taken into consideration that the transmission lays only on unlicensed spectrum, which is unstable as the unlicensed nature makes it inflexible to offer guaranteed Quality of Service (QoS). As a result, it is unreasonable to disregard the licensed spectrum usage during LTE extension of spectrum access. To permit users to access both licensed and unlicensed spectrum and to examine the unlicensed band usage under a unified LTE network infrastructure.

The unlicensed spectrum may be utilized by cellular structure in diverse ways, in some systems; the aggregation is based on the 3GPP Release. i.e., the second carrier may be a Time-Division-Duplexed (TDD) carrier or Supplemental DL (SDL) only. In the SDL mode, the unlicensed band is cast off to carry data traffic by staying in the licensed spectrum originally, whereas the UL and control channel remain in the licensed spectrum. In the TDD carrier aggregation mode, the unlicensed band is competent of carrying data traffic in both UL and DL directions whereas the control channel retains in the licensed spectrum. Thus in some systems, the unlicensed spectrum may be employed in standalone configuration, with all carriers operating in the unlicensed spectrum exclusively.

VIII. HANDOVER MECHANISM

a. Handover procedure

The handover procedure in License Assisted Access (LAA) is introduced in the handover preparation phase, UEs send measurement reports to the macrocell periodically, and the candidate small cell list will be generated according to the measurement report by the source small cell. Then, LBT technology is processed to sense the availability of the unlicensed channel. After receiving the unlicensed channel measure request from the source small cell, the candidate small cells will send the unlicensed channel state information to the macro cell. The macro cell will select the target cell with its handover algorithm, and then send the handover request to the target cell. After receiving the handover request, the macro cell prepared the required resource for the admission control and the target small cell send the handover request ACK back [24] to the macro cell. Then, the SN status number will be transferred to target small cell to prevent the data packet being lost during the handover. The synchronization procedure to target small cells is performed. Mobility management entity (MME) is informed that the UE has changed and S-GW switches user plane. At the final step, the source small cell is noticed to release the resource by the macro cell.

b. Mobility Triggered Handover

- The UE measurement report about target cell candidate 1 and target cell candidate 2 is sent to the source serving cell.

- When the UE moves to end position 1, the downlink received signal quality from target cell candidate 1 is significantly better than that from target cell candidate 2. In this case, even though target cell candidate 1 does not have access to the unlicensed bands at that time because of a nearby actively transmitting Wi-Fi AP, the UE will still handover to it as the poor signal quality provided by target cell candidate 2 may very likely lead to transmission failure.

- When the UE moves to end position 2 which is in coverage overlap area of both target cell candidates, the downlink received signal qualities from both cells are good enough. In this case, the UE is handover to target cell candidate 2 due to no surrounding active Wi-Fi AP occupying the unlicensed bands.

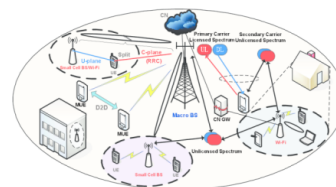


Fig 6: Handover mechanism

c. Availability Triggered Handover

The availability triggered handover scenario is illustrated in fig. 6.

- The UE will try to leave the source cell when the nearby Wi-Fi AP A starts to transmit so that the unlicensed band previously occupied by the source cell becomes unavailable, even that the UE is still in the coverage of the source cell.

- The UE selects target cell candidate 1 because it provides the best signal quality. It's noted that when there are more than one target cell candidates that have sufficient unlicensed spectrum resources available, the one which provides the best signal quality will be selected as the target cell.

d. Vertical Handover (VHO) process

The VHO process is divided into two main phases. Phase 1 is responsible for making the VHO decision and consists of the following steps:

1. Periodically check triggering events which are Signal to Noise Ratio (SNR) and application parameters (CoS, QoS score). SNR is chosen instead of RSS because it reflects the real power of MT signals.
2. The handover is triggered if one of the parameters is below a predefined threshold. Otherwise, the handover will be deferred.
3. MT searches for neighboring networks and chooses two networks that have the top SNR value to be candidate networks.
4. The MT compares the QoS scores of the candidate network. These scores send through an agent advertisement messages.
5. The VHO is executed to target network if the MT can be served with better QoS. Otherwise the VHO is deferred.

Phase 2 is responsible for executing the VHO to the target network and change point of attachment seamlessly. It performs the handover without the need for any third party agent.

IX. PERFORMANCE METRICS

a. Energy and power consumption

The energy consumption is expressed in units of Joule (J) and the power consumption value is presented in units of milliWatt (mW). Specifically, the average energy consumption is estimated using the energy model. The real-time power consumption is measured using the Monsoon monitor and the receiving traces of different transmission schemes immobile (Wi-Fi+LTE networks).

Analysis of the energy consumption in both networks as in table I. Consider a simplified power model for a radio access node [25] composed of two states: the power consumed during the idle period P_i and the power consumed during the activity time P_A . It is then possible to express and compare in a simple way the power consumption of the reference network E_0 and the one of the heterogeneous network E_1 .

As reference time interval we consider T_0 , the average activity time of a node in the reference network. So the energy consumed during that time interval is $E_0 = P_{A,m} \cdot T_0$.

b. PSNR

PSNR is the standard metric to measure the objective video quality. This parameter is expressed as a function of the MSE between the original and the received video frames. If a video frame either experiences transmission or overdue loss, it is considered to be dropped and may be concealed by copying the payload from the last received frame before it.

c. Delay

The end-to-end and inter-packet delays are measured based on the delay performance of the competing schemes. The ratio of overdue frames is also measured to reveal the playback fluency of the transmission schemes.

d. Throughput

The amount of traffic data successfully reaches the destination within the imposed deadline [26]. The amount of useful data excludes the protocol overhead bits.

e. Deploy ability

Deploying a carrier aggregation system without modification to current infrastructure and devices is one of the most important challenges that prevent most proposed solutions from achieving their ultimate goal [27]. This challenge was not addressed during the past decade until recent work has taken the first steps in doing so. In this segment, to deal with the deploy ability problems that face present solutions and certain solutions have addressed these obstacles. There are four foremost carrier obstructing deploy capabilities at diverse levels: (1) intermediate devices, (2) upgrading clients, (3) upgrading servers, and (4) adjusting applications.

Table I: Observation of Energy Efficiency in Massive system

OBJECTIVE	OBSERVATION
- Enhancing the cellular energy effectiveness by densifying the network topology for superior spatial reuse. Effect on Energy Efficiency (EE) of a massive system with respect to - the number of antennas at the base station (BS) - the number of active user equipment's (UEs) - transmit power and area throughput	- By adding more hardware, power consumption can be considerably decreased, as the dynamic part is decreased, which results in less propagation losses and improved energy efficiency. - Improvement in energy efficiency can be achieved by implementing a network topology. - For maximum energy efficiency as a function of the number of base station antennas, at high SNRs are almost equal. - For all the considered processing schemes, the best energy efficient approach is to increase the radio frequency power.

failure rate compared with conventional handover scheme due to the signal sacrifice when associated to unlicensed bands. In terms

X. CONCLUSION

Carrier aggregation is a promising solution to overcome the spectrum limitation of single wireless networks for providing high-quality mobile video services. As wireless services continue to add utilities such as multimedia and QoS, low-power design remain one of the most important research areas within wireless Communication. Research must focus on diminishing the sum of energy devoted by the wireless terminal. Nonetheless, power conservation within the wireless protocol stack remains an extremely crucial research field for the possibility of wireless services in the future. As well, Handover scheme also has a higher

of availability triggered handover, it's apparently that the availability handover occurrence rate will decline with increasing availability threshold. Moreover, the number of availability handover will have an increment with growing Wi-Fi AP density. The utilization of unlicensed spectrum will have a significantly increase, especially in a dense Wi-Fi system scenario, however, users will Suffer a relatively higher handover failure rate. This work focuses on the broad are of research and suggests some

future improvement in designing the efficient HetNets environment.

For future research, three aspects are of the most interest:

- Analytical modeling and theoretical studies to find an effective interference model for LTE/Wi-Fi coexistence.
- Improve the energy efficiency and perceived quality of adaptive bit rate (ABR) streaming.

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