Impact of Remote Radio Head on 5G Open-RAN Technology

Sai Jaswanth Seelam, Samya Andra, Prem Chand Jain
Electrical Engg. Dept.,
School of Engineering, Shiv Nadar University,
Greater Noida (UP)
ss197@snu.edu.in, sa891@snu.edu.in, premchand.jain@snu.edu.in

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***Abstract*-5G supports enhanced Mobile broadband (eMBB), massive Machine type communication (mMTC), and ultra-Reliable low latency communication (uRLLC). The 5G technology promises superior network performance but poses a threat to its economic success. The cost of upgrading 5G handsets and 5G infrastructure is quite high. The 4G mobile network used integrated hardware and software Radio access network (RAN) which became a single manufacturer proprietary item. Manufacturers and operators needed to trade off between cost and complexity for 5G RAN. Opening up the RAN brings a new entrants and reduce the total cost of ownership. Open-RAN (ORAN) is an evolved version of traditional RAN where it undergoes multiple stages of disaggregation of its components. The Remote Radio Head (RRH) and Base Band Unit (BBU) was the first level of disintegration. The BBU further disintegrated into Distributed units (DU) and the Centralized Units (CU). The DU and CU further updated into Open-DU and Open-CU connected via the F1-interface and controlled by the RAN Intelligence Controller (RIC). The Remote Radio Head (RRH) is further modified to Open Radio Unit (O-RU). In this paper the basic RRH/O-RU architecture of the Open RAN specified by the ORAN Alliance is implemented and evaluated in the noisy environment, and compared Bit Error Rate (BER) for different fading models added to the environment noise.**

Keywords- 5G, ORAN, RRH, DU, CU, eCPRI

I. INTRODUCTION

Mobile network has connected successfully majority of the global population. The focus of the 5G mobile network is to provide very high speed data of the order of Gigabit per sec. (>10Gbps), connecting massive number of IoT (Internet of Things) devices (1 million per square km), low latency (1ms) for mission critical applications with reliability of 99.9999%, and enhanced battery life of 10 years for IoT devices. The 5G technology is designed to provide huge network capacity, increased availability, and a more consistent user experience to a larger number of users. 5G will push up the mobile industry into a new world with its high speeds, greater reliability, and low latency.

The 5G is going to use FR2 (Frequency Range 2) to improve signal strength, gain, directivity, and BW performance. The 26GHz and above mm wave frequency band will provide large BW, by which one can obtain the data rate of the order of 20Gbps. However, to compensate higher path loss occurred due to mm wave frequency band, multiple beam forming is used, which can be formed with the help of large phased array antenna elements. Due to small wavelength at mm wave frequency band, large number of small size antennas can be fabricated on a small flat panel. Densification of network is possible with small cells that handles fewer devices over a short range (50 to 200m). Instead of using one base station (BS) covering many kms, multiple small cells are constructed to improve the 5G coverage. Considering above factors, there is a significant increase in the cost to upgrade the 5G infrastructure and the handsets.

II. OPEN-RAN

The Radio Access Network (RAN) is the outermost portion of a mobile network, which connects smart mobile phones and IoT (Internet of Things) devices to the core of the mobile network. Today mobile network uses integrated RAN whose hardware and software is proprietary item of a single manufacturer. The traditional RAN design relies on a single vendor's specialized hardware and software to control the RAN. Due to the absence of cross-vendor partnership, proprietary equipment interfaces offer minimal flexibility, higher prices, and lack of alternatives, which restrains innovation. A trade off between the cost and the additional 5G RF components is required by manufacturers and mobile operators. Open-RAN concept is to go beyond the above approach by providing an inter-operable architecture based on vendor-neutral hardware and interfaces that support open, community-driven development standards. It includes the creation of inter-operable wireless cellular networks using open hardware, software, and interfaces. The Open-RAN is the movement in wireless communication to disaggregate hardware and software and to create open interfaces between them [2]. The benefits of the ORAN (Open-RAN) are manifold. An open environment can be created by having more number of vendors to provide the building blocks of ORAN. The adoption of ORAN may result in a transformation on how the operators will operate the networks, and the type of services and delivery they will offer. Operators can offer more features and capabilities by introducing a decentralized, competitive vendor environment with regard to the 5G. The ORAN will give operators the flexibility in different 5G applications. The Smart cities, industrial IoT, and autonomous cars have different network performance, capacity, and latency requirements. Open-RAN is aimed to satisfy above applications at a lower cost. The lower equipment cost with enhanced network performance can be achieved by creating a competition in the market with customer choice [3]. The Open-RAN disaggregated architecture radically alters the RAN vendor environment, and has grabbed the attention of many operators. They

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could pick up effective options rather than a rigid one-size-fits-all approach, by allowing various suppliers to offer Commercial off-the-shelf (COTS) hardware aligned around interoperability and open standards requirements. This will encourage small suppliers to become part of the deployment ecosystem for 5G communication and beyond. According to a research conducted by ABI Research Group -a global tech market advisory firm, the Open RAN market will surpass the traditional RAN market by 2027-28. The total CAPEX spent on Open-RAN radio units (RUs) for public outdoor networks, including both macro and small cells, is expected to reach US$ 40.7 billion by 2026 [4]. Many operators are also involved in the research and implementation of Open-RAN, including Rakuten, DISH Network, Vodafone, Verizon, Deutsche Telekom, Ericsson, Nokia, and Qualcomm, to mention a few. The Open -RAN supply chain is constantly growing, with a huge number of new vendors entering the field.

III. Related Work

Sameer Kumar, et al, in [5] have explored the possible architecture of the ORAN that can satisfy the ever increasing demands of cellular communication. Authors discussed the aspects of functional advancements in RAN over the years in different generations and also pointed out how ORAN is going to be different? Apart from above, authors also discussed the challenges faced by ORAN and how it is important to eliminate them as much as possible? Some of the challenges being difficulty in designing a 5G stand-alone (SA) service oriented architecture to satisfy the quality of service requirements in various scenarios. Another one being that the current network and its future upgrades must be suitable and compatible with current devices. Erik Westerberg in one of the Ericsson technology review article [6] explained how a functional split can make a difference in the 4G/5G RAN deployment. RAN split includes separating the layers of the network to work under separate components like radio unit (RU), distributed unit (DU), and control unit (CU). This split aims at increasing spectral efficiency and optimal resource allocation and usage. The split-RAN architecture mainly focuses on the two user-plane network functions: a packet processing function (PPF) and a baseband processing function (BPF), alongside the antenna-near radio function (ARF), and the control-plane radio control function (RCF). The split architecture, with necessary scaling, can support 5G test cases and traffic in a cost-efficient way. The article emphasizes that the RAN architecture is future-proof and as an evolution of 4G RAN, and the split can be gradually introduced in line with the need of the hour. Salma Matoussi, et al, have proposed agile multi-sited RAN architecture, denoted as AgilRAN [7]. This is one of the advanced solutions to split the network layers into centralized and distributed locations. AgilRAN uses cloud technology to cater to high on-demand RAN deployment and since it utilizes the cloud capabilities, the total cost of deployment is significantly reduced. They proposed a heuristic-based approach called SPLIT HPSO to optimize the allocation of baseband units, taking into account the requirements of the processing network functions and simultaneously the capabilities of the cloud infrastructure. Simulations have shown that SPLIT HPSO performs well while considering the total implementation costs and resolution time. The solution ensures precise linking and allocation of computing resources while achieving low implementation costs. Telefonica white Paper covers the architectural features, design requirements, technological choices, and major chipsets used to construct a comprehensive radio portfolio. It describes most common sites encountered in most 4G/5G deployments, which serve as the foundation for the DU and RU targeted settings. It also covers DU design specifics as well as critical design considerations for distant radio units and active antenna devices. Prakash Sangam wrote about Qualcomm's 5G DX 100 card [8]. It is an inline accelerator that can almost completely offload the latency-sensitive data pipeline, often referred as "HighL1 processing." It is based on the DU platform, which handles latency-sensitive functions such as demodulation and beam forming. The card comes in an industry standard PCle form factor and interface, which means it can be used with any server platform. This is a step forward in implementing ORAN, and further work in this direction will give OEMs and other operators more options in choosing the right server platform for their needs.

IV. Methodology

The two most prominent organizations working on open RAN standards are the Telecom. Infra Project (TIP) and the O-RAN Alliance. The O-RAN Alliance, an Open-RAN Group formed in February 2018 with the goal of promoting open and intelligent RAN, is at the forefront of the Open RAN movement. For Open-RAN interfaces and components, the O-RAN Alliance provides a well-documented architecture.

A. *Open RAN Architecture*

With advancements in 5G, the RAN is splitted in to RRH (Remote Radio Head) and BBU Base Band Unit). The RRH placed near the antenna on top of the tower. The RRH RF digital signal is connected to the BBU via fiber cables which resulted in much lesser path losses compared to RF coaxial cables in mm wave frequency band. The signals between BBU and RRH are sent using a proprietary Common public radio interface (CPRI). The RRH is proprietary hardware, and the BBU is composed of proprietary hardware and software with vendor specific applications. In a Centralized radio access network (C-RAN) BBUs are further centralized at a location of core network, called BBU Hotel. It is a single location which houses BBU with many distributed RRH. The BBU can be many kms away from RRH. This architecture had several other advantages that include reducing infrastructure costs, reducing space requirements, and RRH heating issues. Two of the leading technologies in this area are the virtual RAN (vRAN) and the Open-RAN (ORAN). The vRAN uses commercially off the shelf (COTS) hardware, which means the servers and other physical hardware can be purchased from any vendor. Taking this a step ahead, ORAN aims to implement using general purpose processors and COTS hardware using proprietary CPRI interface. The RRH in ORAN is updated to Open Radio unit (O-RU). Furthermore, BBU in ORAN is disaggregated into Open Distributed unit (O-DU) and Open Centralized units (O-

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CU) connected through a F1 interface as shown in Fig.1. The O-DU and O-CU are further connected to a RAN intelligence controller (RIC) equipped with artificial intelligence (AI)/ML (Machine Learning) for intelligence and automation. Both non-real time and near-real-time RICs are logical functions, which governs and optimizes ORAN components. A non-real time RIC employs AI and ML processes as well as model training, to learn how to better regulate and optimize RAN components and resources. The near-real-time RIC with granular data gathering is connected to the O-CU and O-DU through E2 interface. This will enhance interoperability and increase scope for innovation. Successful implementation of the ORAN will mean that various cellular operators will have a chance to deploy a fully automated network that can take its own decision in cases of unplanned network issues without any manual assistance.

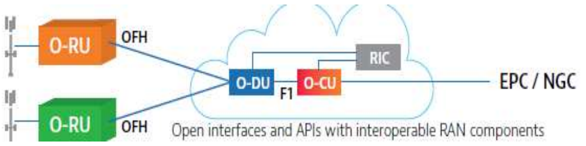

Fig. 1: Architecture of O-RAN [9]

The Radio resource control (RRC), Service data adaptation protocol (SDAP), and Packet data convergence protocol (PDCP) are handled by O-RAN Centralized Unit (CU) as shown in Fig. 2. The O-CU control plane (CP) hosts the Radio Resource Control and control plane component of the PDCP, whereas the O-CU user plane (UP) hosts the service data adaptation protocol and user plane portion of the PDCP. The distributed unit (DU) handles, the medium access control (MAC) protocol, the radio link control (RLC) protocol, and the high physical interface protocol to connect with the low physical layer in RU. The digital Front-end (DFE) and analog RF is part of RU (Radio Unit). The enhanced CPRI (eCPRI) interface also known as Front-haul (FH) sends the processed radio frequencies in the digital format to the RU. The RU interprets radio frequencies received from high physical layer of DU. The Open-RAN plays from COTS-based servers for DU and CU applications to RU procured from any vendor [11].

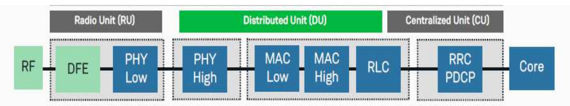

Fig. 2: O-RAN Protocol [11]

B. *Open Radio Unit*

In the ORAN system, the radio unit (RU), distributed unit (DU), and centralized unit (CU) alongwith their hardware and software platforms, are disaggregated. Standardization of interfaces and demonstration interoperability are essential for ORAN networks to succeed. The interface used between the RU and the DU is FH (front haul), whereas between the CU and the DU is MH (Mid haul), and between DU and 5G core network is BH (Back haul). Different latency with different distances can be tolerated in above different interfaces because of the various control loops within the system. The front-haul is the most important interface. A point-to-point connection between DU and RU can withstand latency of 160us with distance of 30kms. The Radio Unit (RU) transforms radio signals sent to and from the antenna into digital format to transmit to the DU over the front-haul (eCPRI Interface). The Radio front-end (RF FE) consists of phased arrays of antenna elements, band pass filters, power amplifiers (PA), low noise amplifiers (LNA), digital to analog converters (DAC), and Analog to digital converters (ADC) as shown in Fig. 3. Digital front end (DFE) consists of digital up converter (DUC), digital down converter (DDC), digital per-distortion (DPD), and crest factor reduction (CFR). For synchronization, GPS/PTP (Precision time protocol IEEE 1588) modules are utilized. The PTP depends on the time of arrival (ToA) measurement of the IP packets. The O-RU can be synchronized using GPS. The O-RU built- in with GPS receiver, can be synchronized by using GPS clock and time. Multiple RUs can receive the GPS signal from one common GPS active antenna at one site. Front-haul link between the O-RU and the O-DU can be established using fiber cable via Ethernet based eCPRI interface. The FPGAs or ASICs can be used to implement the lower PHY layer processing. It has FFT/IFFT, CP addition and removal, PRACH (Physical Random-Access Channel) filtering, and digital beam forming features (Optional).

In down link after digital modulation, IFFT is used to transform frequency domain data into time domain. A cyclic prefix (CP) is added to the time domain signal to form OFDM symbol. This OFDM symbol is applied to the digital front-end (DFE) for digital up conversion (DUC) and then converted to analog RF signal using digital-to-analog converter (DAC) as shown in Fig.5. The digital FE consists of crest factor reduction (CFR) which reduces peak to average power ratio (PAPR) of the OFDM signal, and digital per-distortion (DPD) linearizes the power amplifier signal as shown in Fig. 3. In up-link, analog RF signal is converted in to digital signal using analog-to-digital converter (ADC) and then digitally down converted (DDC) in DFE. The signal is then transformed to frequency domain using FFT after CP is removed. The signal is then digitally demodulated to get base band data as shown in Fig. 5. The lower PHY consists of physical random-access channel (PRACH) data, which is processed by O-DU after receiving from O-RU via FH interface.

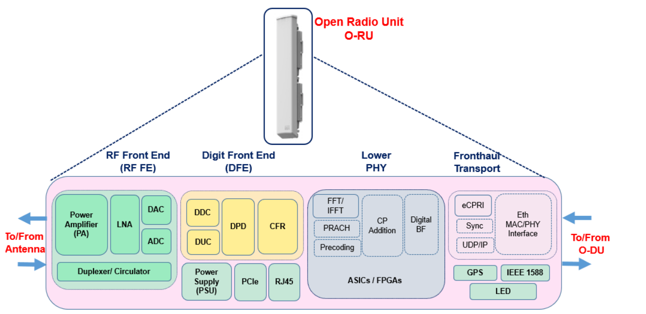

Fig. 3: Architecture of O-RU

5G using FR2 (Frequency Range 2) mm wave frequency band (26GHz and above) provides very small coverage due to short wavelength. Mobile operators need to deploy hundreds of thousands small cells to cover the macro cell

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coverage. However, small cells are more efficient, reliable, and can cover densely populated areas with large capacity. In traditional RAN putting BBUs at every small cell site will be quite expensive while in ORAN a single DU located at CU can provide connection to a large number of RUs in the small cells. The RUs can be installed on existing street furniture like power poles, lamp posts, and pull readily available power from above resources which may cost around a few thousand rupees per pole to the operators. This architecture had several other advantages that include reducing infrastructure costs, reducing space requirements, and RU heating issues. This will reduce drastically the total cost of the ORAN for operators in mm wave frequency band.

V. Results

A. *Implementation of O-RU*

The input data after digital modulation in the frequency domain shown in Fig 4 are translated to the time domain with the help of IFFT in the down-link direction shown in Fig. 5. A cyclic prefix (CP) is added to the time domain signal to form OFDM symbol. This OFDM symbol is applied to the digital front-end (DFE) for digital up conversion (DUC) and then converted to analog RF signal using digital-to-analog converter (DAC).Similarly the analog RF signal in up link is converted in to digital signal using analog-to-digital converter (ADC) and then digitally down converted (DDC) in DFE. The signal is then transformed to frequency domain using FFT after CP is removed. Thereafter the symbols are sent to the digital demodulator to obtain base band data as shown in Fig. 5. The low PHY also includes physical random access channel (PRACH) specific functionalities.

The simulink models of subsystems containing the components for the down-link and up-link operations are shown in Fig. 6 and Fig. 7 respectively. Considerations for system setup have been made at each block of simulation in order to undertake qualitative analysis on the operation of the O-RU unit in ORAN. The lengths of the input data and the cyclic prefix are taken in such a manner that when they are summed together, the result of sum is a multiple of three. The digital to analogue converter (DAC) assumed that the digital signal was a three-bit digital signal converted into an analogue signal value and delivered over the wireless antenna. To minimize the computational complexity that the system may experience throughout the simulation, the digital up-converter elevates the sample rate by a factor of ten. The blocks utilized in up-link operation have been designed with similar principles.

In the noisy environment scenario, attempt was made to include the environmental noise while using various fading models and compared the results. In addition to the default parameters, we observed trends by changing the Rayleigh, Rician, and Nakagami-M fading model parameters. The parameters used for the Nakagami-M fading model were shape (mu) = 1.5 and scale (omega) = 1. For the Rician fading model, the default parameters were used: non centrality (s) = 1 and scale parameter (sigma) = 1. For the Rayleigh fading model, the scale (b) parameter = 0.5 was used. Except for the Nakagami-M fading model, changing the default parameters had little effect. In the case of Nakagami-M modeling, increasing the shape parameter from 1 resulted in better BER improvement. When the same parameter value was reduced to less than one, the BER became worse than the Rayleigh model. The model was tested with Gaussian Random Noise as the system noise at the transmitter end and found a trend of decreasing BER with increasing SNRs (Fig. 8). In addition, above model was tested by adding various fading parameters in the environment noise and observed the trends of BER with different fading models (Fig. 9). The BER rate of AWGN Noise without any fading model was found to be better than that of those with fading models. It has been observed that the Nakagami-M model had the best BER rate, followed by the Rician and Rayleigh models. This is because the Nakagami-M distribution matches some experimental data with greater flexibility and accuracy than the Rayleigh and Rice distributions, and the results are consistent with theory.

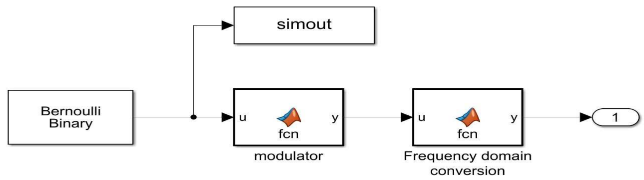


Fig. 4: Simulink model of Basic BBU unit

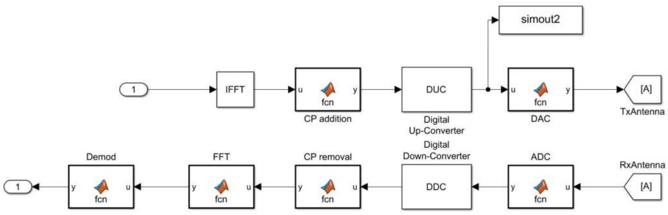
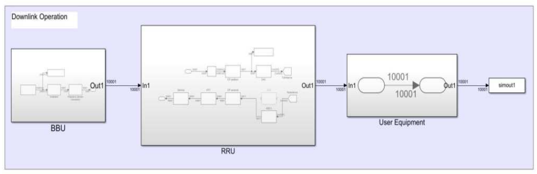
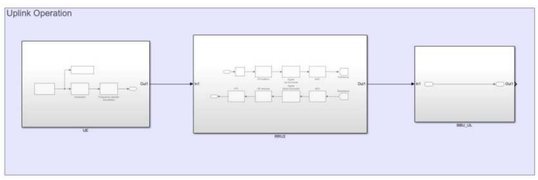


Fig. 5: Simulink model of Basic RRU unit



BBU RRU UE

Fig. 6: Simulink model of down-link operation



UE RRU BBU

Fig.7: Simulink model of up-link operation

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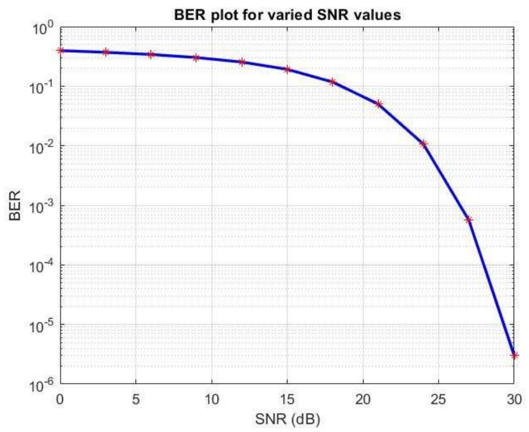

Fig. 8: BER Plot for Gaussian Noise

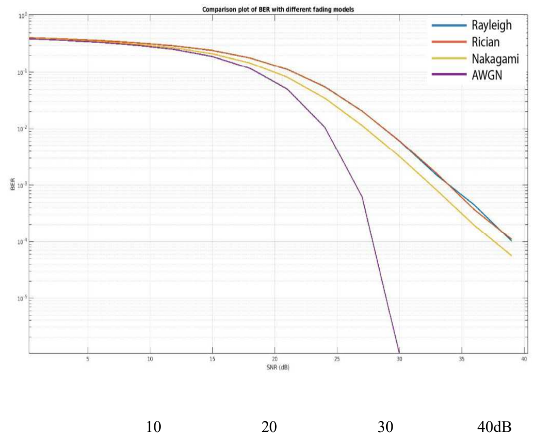

Fig. 9: Comparison Plot of BER for different fading models

VI. Conclusions

Mobile networks are being transformed by Open radio access networks (ORAN). The focus of ORAN is to disaggregates the traditional RAN into radio unit (RU), distributed unit (DU), and centralized unit (CU) components, alongwith their hardware and software. The ORAN promotes new entrants to compete in the market with manufacturers of RAN infrastructure, if they can provide a competitive price advantage.

In this paper Open-RAN Technology was examined and comprehend in depth with a particular emphasis on the 5G ORAN Architecture. The authors modeled and implemented the Remote Radio Head unit of the ORAN using an architecture comparable to the ORAN Alliance's O-RU Category-A. The authors have simulated the architecture in Simulink and got the results for the down-link case of O-RU transmitting a signal from the BBU and receiving it in the UE. MATLAB Simulink was used to model a Remote Radio Head in an open-ended setting with its essential functionalities.

Horizontal openness is what Open RAN is all about, with open interfaces allowing RAN functions to communicate with other functions, from the radio unit (RU) to the BBU (DU-CU), to the controller, to the NMS/orchestrator. With the Open-RAN, a new variety of low-cost radio players might enter in to the market, and mobile operators will have more alternatives for optimization and deployment options for specific performance at a lower cost. Open-RAN means multiple vendors contributing to a single network and thus system integration ownership is more complex. Integration between different network modules from different vendors needs establishment of validation and conformance specifications and procedures. This includes capacity management, latency, and reliability. The operators can source hardware modules from different vendors, and system integrators can integrate the modules and provide a complete built-in solution. Open-RAN will open doors for new implementation of 5G in the enterprise market, which could enable specialized system integrators or even chipsets suppliers to become key-players in the infrastructure supply in the enterprise space. ORAN deployment will find success in small cells using mm Wave frequency band or private networks, rather than large macro cells. Small cell Forum (SCF) created its own ORAN with small cells. It allows any gNB-CU/S-DU to connect to any small cell (S)-RU.

Furthermore, as a scope and extension of this work, one can look at evaluating the channel links of different O-RUs present in the cluster, and finding the co-channel interference and other similar parameters. One can try incorporating Open RAN standards and interfaces to investigate the performance of the network in various use cases, although it requires thorough knowledge and expensive software. The implementation of similar experiments can give significant results and add value to the research in the Open RAN community.

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