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A Real-time Platform for End-to-Edge QoS Evaluation in Heterogeneous Networks

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Abstract: This paper describes a platform developed in the framework of the European AROMA project that allows emulating in real-time a complex heterogeneous wireless access network. The objective of the AROMA project is to devise and assess a set of specific resource management strategies and algorithms for both the access and core network parts of an all-IP heterogeneous wireless access network that guarantee the end-to-edge quality of service. The complexity of the interaction between Beyond 3G systems and user applications, while dealing with the quality of service concept, motivates the development of this kind of emulation platforms, where algorithms and applications can be tested in realistic conditions that could not be achieved by means of off-line simulations. The project developed the techniques necessary to support the Always Best Connected concept, which are relevant for system performance planning, especially for operators. The benefits of the project have been proven by means of the economic studies and results may lead to a decrease in CAPEX and OPEX.

Keywords: All-IP; beyond 3G; common radio resource management; DiffServ/MPLS; end-to-edge quality of service; heterogeneous wireless access network; real-time emulation; testbed.

1. Introduction

The Quality of Service (QoS) concept has become an essential key in innovative and future mobile communications systems. On the other hand, these systems, referred to as Beyond 3G (B3G), should integrate different wireless access technologies into heterogeneous infrastructures where the Internet Protocol (IP) technology is becoming the cornerstone around which such networks are converging. These types of communication systems are facing the challenge of providing continuous and ubiquitous connectivity through different technologies while preserving the negotiated QoS level for the end-user during the entire session. In this scenario, one of the main challenges that heterogeneous wireless systems must overcome is the ability to guarantee the seamless interoperability and efficient management of the different Radio Access Networks (RANs) in order to provide the user with a suitable and consistent QoS level. To this end, efficient Radio Resource Management and Common Radio Resource Management (RRM/CRRM) strategies need to be developed. Moreover, the Core Network (CN) features need also to be taken into account and efficient QoS policies to coordinate the RAN and CN parts must be defined to provide the required end-to-edge (e2e) QoS level.

The complexity of the interaction between B3G systems and user applications, while dealing with the QoS concept, generates an important research topic within this area. In this context, the development of emulation platforms, where strategies and applications can be tested in realistic conditions that could not be achieved by means of off-line simulations, appears as an interesting element for improving the design and validation process [1].

In this context, the aim of this paper is to present a sophisticated real-time platform that has been developed in the framework of the AROMA project [2]. The objective of the AROMA project is to devise and assess a set of specific resource management strategies and algorithms for both the RAN and CN parts that guarantee the e2e QoS in the context of an all-IP heterogeneous wireless access network. The main objective of the AROMA testbed is to provide a framework where the benefits of the developed RRM/CRRM algorithms and the proposed QoS management techniques can be demonstrated.

The rest of this paper is organized as follows. First, section 2 captures the objectives to be achieved with that platform. Section 3 presents the methodology and architecture of the AROMA testbed. To illustrate the applicability of the developed tool, some results are provided in section 4. Finally, section 5 summarizes and concludes the paper.

2. Objectives

AROMA addresses the e2e QoS provision in Mobile networks in an integral way. In particular, AROMA focuses in both a heterogeneous access network and an IP based CN. AROMA contributes to the development of an efficient wireless access assuming IP based services. The results coming from the AROMA project will provide a manufacturer-independent analysis of the e2e QoS strategies, which allows the mobile operators to evaluate and compare solutions coming from the market with an available reference of the system performance.

To carry out these objectives the project evolves around three main technical activities:

1. Algorithmic development and simulation by means of advanced simulations tools.
2. Economic evaluation on the impacts of the novel solutions considered by the project.
3. Demonstration of the technology by means of implementing a real-time testbed for proof of concepts.

As it has been said, one of the key objectives of the presented testbed is to enable testing the e2e QoS performance and to evaluate, in real-time, the effects that the implemented e2e QoS management algorithms have over the user's perception when using different QoS classes. In this sense, suitable applications aligned with the state of the art have been chosen in the testbed for evaluation of objective user's QoS perception.

In particular we stress studies addressed to:

- Evaluate how different network procedures impact over the user perceived QoS of real multimedia applications, like Net-Meeting® and QuickTime® [3].
- Evaluate RRM/CRRM functions, such as admission control or RAT selection algorithms, in a realistic scenario.
- Evaluate subsystems and protocols that rely on real implementations.
- Analyze how the dynamic Label Switched Path (LSP) management through the CN impacts on the e2e performance.
- Test mechanisms such as IP fast handover with mobility support [4].
- Evaluate e2e QoS signalling procedures and policies developed within the testbed and how they impact on the user's QoS preservation.
- Test the performance of innovative RAT such as HSPA under realistic conditions and traffic patterns [5].

3. Methodology and Architecture

The AROMA testbed allows real-time emulation of an all-IP heterogeneous wireless access network that includes the UMTS Terrestrial Radio Access Network (UTRAN), GSM/EDGE Radio Access Network (GERAN), and Wireless Local Area Network

(WLAN) as well as the corresponding common CN based on DiffServ technology [6] and Multi-Protocol Label Switching (MPLS) [7]. The evaluation platform emulates, in real-time, the conditions that the behaviour of the all-IP heterogeneous network, including the effect of other users, produces on the User Under Test (UUT) when using real multimedia applications such as videoconference, streaming services, or web browsing.

In Figure 1 all the entities and connections of the AROMA testbed are depicted. Solid connections correspond to user data interfaces, whereas dashed and dash-dotted connections correspond to control plane interfaces. The UUT has at his disposal one stand-alone PC to run the application, and one additional stand-alone PC is used to run the main functionalities associated to the User Equipment (UE). To test symmetric services as video-conference and to serve multimedia applications as web-browsing, streaming or mail, a correspondent node is used (called Application's Server) in another stand-alone PC.

The three mentioned RANs emulate the radio protocols using five PCs. The CN has been built using seven Linux PCs acting as routers. A Traffic Switch (TS) is mainly used to establish different interconnection configurations between RANs and the Ingress Routers (IRs) in the CN. For the emulated users passing through the testbed there is a PC called Traffic Generator (TG) that is in charge of generating real IP traffic coordinated with the traffic emulated in the radio part to load CN. Finally, a graphical management and configuration tool called Advanced Graphical Management Tool (AGMT) controls the execution flow among other functionalities. For more technical aspects of the testbed the reader is referred to [8].

3.1 RAN Emulators

The software modules in charge of emulating the RANs in the testbed have been designed to cope with the following goals and requirements:

- Support for live users as well as fully emulated users, up to several thousands depending on scenario and traffic configuration. Traffic of all of the users is processed by RAN emulators. Therefore, the UUT behaves as any other user in the system.
- Emulation of the transmission chain between the User Equipment (UE) and the Radio Network Controller (RNC). Different functions performed at each level of the protocol stack have been faithfully modelled in accordance to the corresponding specifications.
- Execution of RRM functions (admission control, congestion control, radio resource allocation, handover management, outer and inner loop power control and transmission parameters management) as well as support for CRRM capabilities.
- Support for different communication scenarios, according to the requirements and visions of the four mobile operators that participate in the AROMA project.

A comprehensive description of the implementation details can be found in [5]. The main novelties introduced in the RAN emulators in the context of the AROMA project consist of the inclusion of an IP-RAN emulation model, and the implementation of recent technological solutions such as High Speed Downlink/Uplink Packet Access (HSDPA/HSUPA).

3.2 Core Network

The CN is not emulated; it is composed by real PCs acting as routers: three of them serve as edge routers (2 Ingress Routers – IR, and 1 Egress Router – ER) while the other four behave as Core Router (CR). Those routers work using the communication stack of the Linux operating system enhanced with MPLS support.

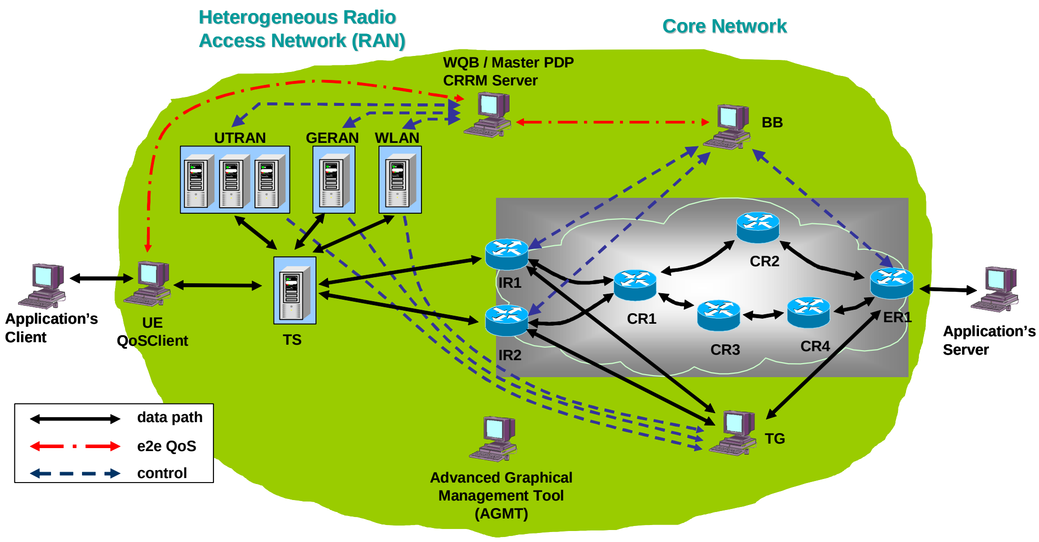


Figure 1. Entities and connections of the AROMA testbed.

The CN routers are managed by a Bandwidth Broker (BB) entity, which interworks closely with the MPLS. The BB is the main architecture element of the control plane of the DiffServ model proposed by IETF for supporting e2e QoS in IP-based networks. In the testbed BB plays an important role creating on demand LSPs to accommodate the traffic being requested by the user. An additional objective of a BB is to perform admission control, used to evaluate whether requested resources are available in the CN, if the routers in the traffic path have enough resources available to support the new traffic.

For more details about the implementation details of the AROMA testbed's CN the reader is referred to [8].

3.3 QoS Framework

The QoS management is provided by the WQB (Wireless QoS Broker) entity in the radio part and by BB (Bandwidth Broker) in the CN. Additionally, other entities such as the QoS Client (i.e., the QoS negotiation application of the UUT) and the CRRM (in charge of managing the radio resources and running the radio admission and congestion control algorithms) are also involved in the e2e QoS negotiation.

The e2e QoS support is enabled by making interaction between these entities. WQB leads the QoS negotiation. It receives a QoS request from the QoS Client, and it consults CRRM and BB about their QoS capabilities for the acceptance of a new session. Then WQB takes final decisions on session establishment (or modification) based on the information provided by the CRRM and BB. The information that CRRM provides during the e2e QoS negotiation is a result of Admission Control and RAT Selection algorithms, whereas the BB decision is based on its proper Connection Admission Control (CAC) algorithms. Thus, it may be concluded that the WQB includes the functionalities of a Master Policy Decision Point (MPDP) in e2e negotiation.

4. Results

4.1 Case Study I

The objective of this section is to show how the testbed may be used to compare the behaviour (in terms of QoS perception) of two streaming applications when the bandwidth of the channel is limited as it is common in wireless networks. Concretely, Darwin Streaming Server is run in the Server machine and it contains a video sequence of approximately 120 seconds coded with a H.264 128kbps variable bitrate video codec (in the following Video Under Test – VUT). Two streaming clients have been used in the demonstrations, Apple QuickTime 7.0 (QT) and open-source VideoLan Client (VLC). For this demonstration, the UUT is static and located near a WLAN base station. Then the CRRM policies are configured to serve the UUT through WLAN when a streaming session is requested. Values for the requested guaranteed bandwidths in different trials are 64kbps, 128kbps, 192kbps and 256kbps. Figure 2 shows the UUT's transmitted bits through WLAN for both Downlink (DL) and Uplink (UL) with increasing guaranteed bandwidths. Figure 2(a) and (b) depict QT whereas Figure 2(c) and (d) show VLC behaviour. Figure 2(c) and (d) show the radio buffer occupancy.

QT tries to retrieve the movie from the server in the client side as soon as possible making use of all available bandwidth. Therefore, a flat and non-bursty behaviour is shown in the DL transmitted bits when the bandwidth is less than or equal to the VUT source rate, and when the bandwidth available is above the VUT bitrate, then QT downloads the video until a buffer in the client side is full. From that moment, video packets are transmitted burstily as long as the buffer is being empty. On the other hand, VLC streaming client retrieves packets from the server as long as they are needed depending on the source video encoding and, if the video rate is below the guaranteed bandwidth the packets are transmitted without problems. Otherwise the packet is stored in the radio buffer and a 'flat' behaviour is shown. This will cause delays in the transmitted packets and since VLC does not implement any buffer in the client application, then the perceived QoS is impacted.

Regarding the bits transmission duration, QT shortens total duration of the movie when the guaranteed bitrate is above the source video bitrate thanks to the client. This property makes QT more robust to some disruptions in the radio interface since the lost packets during the disruption might be stored in the buffer some time before the disruption and in consequence, the user does not perceive the packet loss. In all cases (from 64 to 256kbps) the bits transmission lasts the same as the movie duration meaning that until the last second VLC is retrieving packets to show them to the user.

As an illustrative example of the visual QoS experienced by the user, Figure 3 shows a sample frame taken during the tests for different bandwidths and each streaming client. It can be seen that for bandwidths above the streaming video rate the frame is 'clean' as whereas for the rest of the bandwidths that concrete sample frame was blurry, frozen or

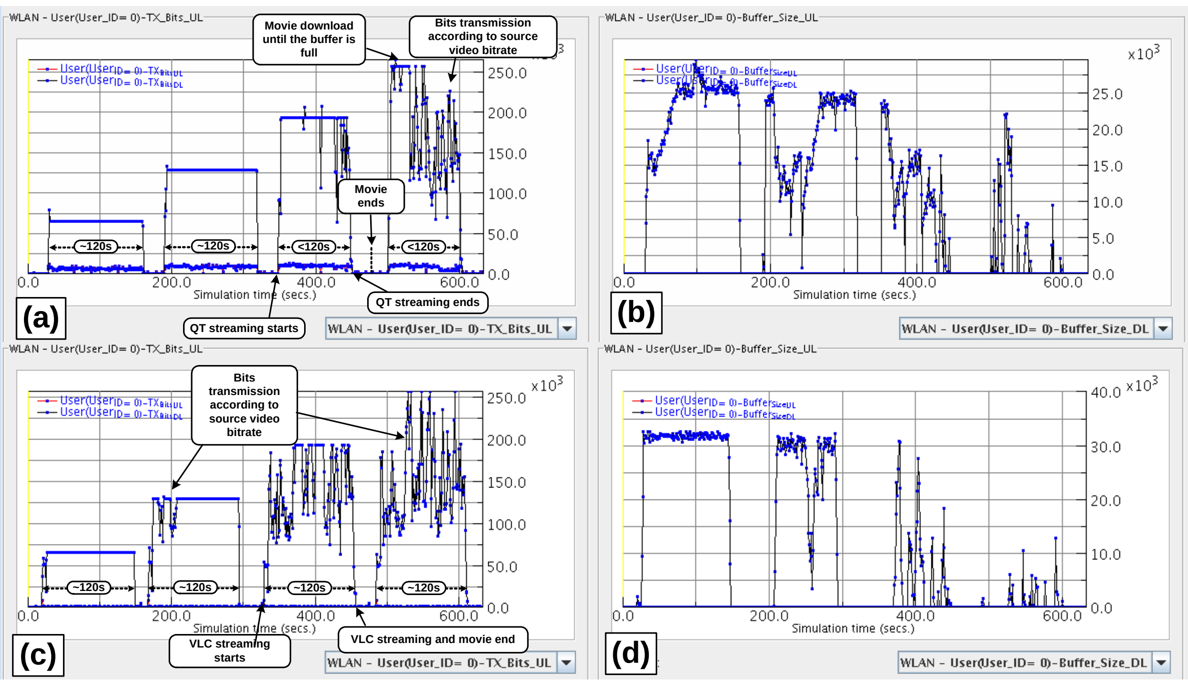


Figure 2 . QT behaviour for different guaranteed bandwidths

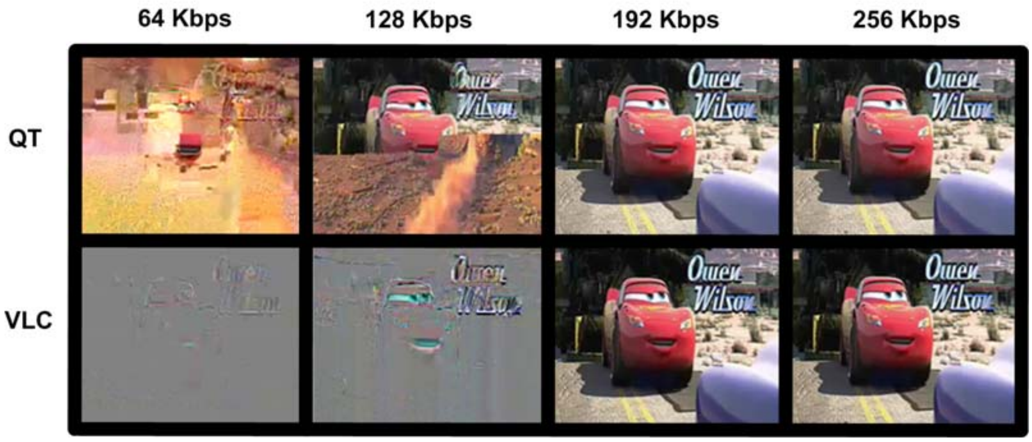


Figure 3 . Illustrative example of the visual effects of bandwidth constrains in the streamed video

merged with previous frames. Table 1 shows the objective Mean Opinion Score (MOS) for VUT streamed with both QT and VLC when different guaranteed bandwidths were requested. The MOS scale is in the range [1-5], where a score of 1 is the worst situation and 5 represent total user satisfaction. The pass threshold is set to 3. Then, as expected, a guaranteed bandwidth of 64kbps was insufficient for streaming the video and the test fails for both QT and VLC. As long as the guaranteed bitrate is increasing, the MOS score is also increasing or maintained in overall. Comparing, QT and VLC, QT obtains greater values since the application buffer allows to show the video to the user cleaner that VLC does. Due to bandwidth constraints, VLC loses some packets and poor videos with frozen images periods are shown to the user.

Table 1 MOS comparison for QT and VLC and different guaranteed bitrates

Guaranteed BitRate	64 kbps	128 kbps	192 kbps	256 kbps
QoS Scale	[1-5]	[1-5]	[1-5]	[1-5]
QT	1,73	4,48	4,60	4,68
VLC	1,58	4,31	4,47	4,46

4.2 Case Study II

The previous case study analysed the performance of two different streaming applications when the system provides e2e QoS guarantees in terms of transmission bit-rate. By contrast, this case study investigates the impact of partly guaranteed QoS on the user's subjective perception. In this case study, the QoS management mechanisms of the CN remain active whereas no QoS guarantees are provided in the RAN. Concretely, all of the users are served through HSPA and all of the connection requests are accepted (no admission control is executed) without QoS guarantees. The system serves users' transmission requests following either a Maximum Carrier-to-Interference ratio (MaxC/I) or Round Robin (RR) scheduling policy. Under this configuration, the UUT requests a streaming service with an average bit-rate of 400 kbps while periodically moving in straight line between two base stations, thus experiencing different channel quality conditions during the session lifetime.

The behaviour of the two considered scheduling algorithms and the visual quality observed by the user are shown in Figure 4. These graphs show the number of HSPA Transmission Time Intervals (TTIs), measured over 10 TTI/20 ms periods, where the UUT requests a transmission (blue line) and the number of times that these requests are accepted/served by the scheduler (green line) or rejected/non served (red line). In the case of the MaxC/I scheduler, the number of transmission requests rejected by the scheduler clearly increases in two instants (from ≈40sec to ≈95sec and from ≈195sec to ≈210sec) that correspond to moments where the UUT experiences unfavourable channel quality conditions. Therefore, the behaviour of MaxC/I is highly dependent on the experienced channel quality. On the other hand, the RR policy exhibits a more homogeneous and channel-independent pattern. In average, around 80% of the UUT's requests are accepted (20% rejected) by RR under both favourable and unfavourable channel quality conditions. To analyse how the behaviour of these two scheduling policies impact on the user's perception, Figure 4 shows some screenshots at different time instants. In the case of the MaxC/I scheduler, the image quality degrades when the scheduler rejects several transmission requests as a result of the reduced channel quality. The degradation accentuates as the number of rejected transmission requests increases. On the other hand, the more homogeneous pattern of the RR policy results in a more constant, although may be lower image quality. To quantitatively determine which policy provides a better image quality to the end-user, Table 2 shows the MOS obtained for two cases. Case I corresponds to a 20sec fragment around time instant 90sec (i.e., when the experienced channel quality is notably deteriorated), while case II corresponds to the entire video sequence. As it can be observed, MaxC/I offers a higher MOS than RR for case II but a lower value for case I, meaning that the MaxC/I scheduling policy is able to provide a better average image quality than RR (measured over the entire video sequence) at the expense of more severe quality degradations during periods of unfavourable propagation conditions.

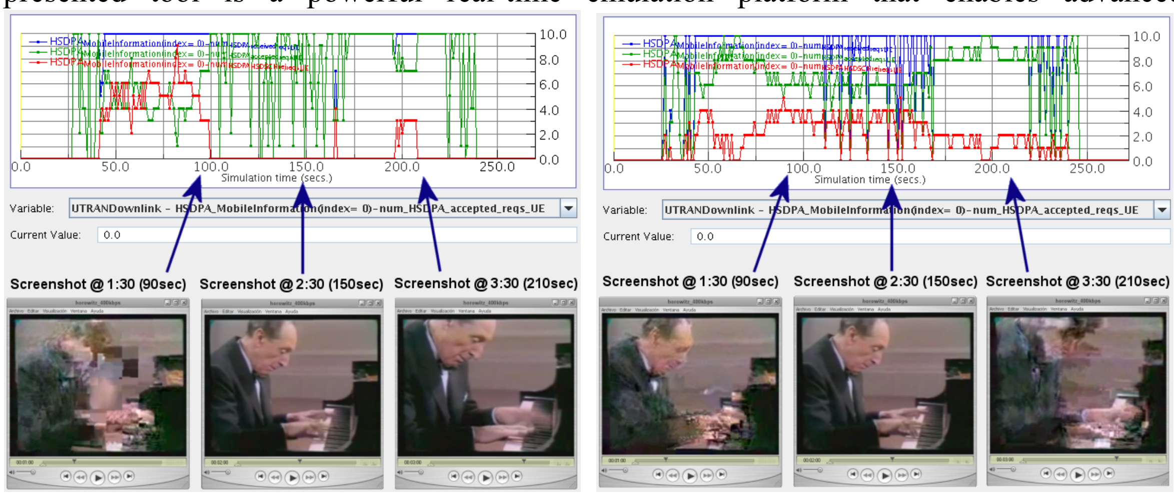
This illustrative example shows how and under which conditions the user perception degrades when no QoS guarantees are provided, and how the AROMA testbed can be employed to evaluate the level of degradation (in a qualitative and quantitative manner) and to identify such conditions in order to optimise the system design, thus effectively providing the end-user with a suitable QoS level.

Table 2 MOS comparison for MaxCI and RR scheduling algorithms

Scheduling Algorithm	MaxC/I	RR
QoS Scale	[1-5]	[1-5]
Case I	1,05	1,88
Case II	4,06	3,54

5. Conclusions

This paper has presented the real-time testbed developed within the framework of the IST AROMA project. The main objective of the AROMA testbed is to provide a framework where the benefits of the solutions developed within the project can be demonstrated. The presented tool is a powerful real-time emulation platform that enables advanced



(a) (b)

Figure 4 . Behaviour of the two considered scheduling algorithms. (a) MaxCI, (b) RR

RRM/CRRM strategies as well as e2e QoS mechanisms to be accurately evaluated in a realistic environment with different real user applications and mobility patterns, which could not be achieved by means of off-line simulations. This platform is used by operators and educational/research institutions to evaluate the e2e QoS experienced by a user in a heterogeneous mobile environment under realistic conditions; to test and validate specific algorithms and mechanisms; and to evaluate real implementations of various subsystems.

The AROMA project developed the techniques necessary to support the Always Best Connected concept. These techniques are relevant for system performance planning, especially for operators. The benefits of the project have been proven by means of the economic studies and results may lead to a decrease in CAPEX and OPEX. It is clearly demonstrated that algorithms and technical solutions envisaged in AROMA project have an economic impact in network optimization.

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