RECONFIGURABILITY FACILITATING COMPOSITE RADIO

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ABSTRACT

The key objective of End-to-End Reconfigurability (E²R) is to devise, develop and trial architectural design of reconfigurable devices and supporting system functions to offer an expanded set of operational choices to the different actors of the value chain in the context of heterogeneous mobile radio systems.

1. INTRODUCTION

This paper presents E²R research, the initial system concepts and simulation approach to tackle the problems and opportunities reconfigurability faces and the advantages they offer in composite radio environments. The concept of composite radio (CR) assumes that different radio networks, e.g. GSM (Global System for Mobile communications) [i], GPRS (Generalized Packet Radio Service) [ii], UMTS (Universal Mobile Telecommunications System) [iii], BRANs (Broadband Radio Access Networks) or WLANs (Wireless Local Area Networks) [iv,v,vi] and DVB (Digital Video Broadcasting) [vii] can be co-operating systems within a heterogeneous, wireless-access infrastructure. Users will be directed to use the most appropriate Radio Access Technologies (RATs), and this allocation may be different depending on service area regions and time zones, based on profile requirements and network performance criteria, etc. The deployment of CR systems relies on the concept of reconfigurability. Reconfigurability provides essential technological solutions that enable terminals and network elements to dynamically (transparently and securely) select, and adapt to, the set of RATs, which are most appropriate for the conditions encountered in specific areas and times of the day. Thus, the development of mechanisms for dynamic planning and management of heterogeneous, coupled and multi-standard radio access networks is necessary.

Dynamic network planning and flexible network management (DNPM) will be the facilitator for CR. The E2R DNPM concept follows two main phases; these are a planning phase and a management phase. In the planning phase, feasibility of setting the radio interfaces is being evaluated, the locations of the candidate element sites are specified and the Radio Access Technologies (RATs) that participate in the wireless access infrastructure are selected. The management phase implements the new resource allocation, i.e. it configures the resources to be utilized among the RATs and implements traffic splitting mechanisms. In addition, Joint Radio Resource Management (JRRM) can further extend the DNMP concept by utilizing the previously selected frequency allocation, splitting the traffic accordingly and, if needed, (re)selecting the proper RAT and even some Radio Bearer attributes but at a much smaller time scale than the usually managed by DNMP. In fact developing signaling procedures between JRRM and DNMP entities is part of the management of heterogeneous networks.

For this purpose, this paper is structured as follows: section 2 describes the general concepts of Composite Radio, while section 3 focuses in DNPM mechanisms in composite reconfigurable networks. In addition, section 4 deals with spectrum management methods and JRRM techniques. Finally, in section 5 the respective system constraints come into view and section 6 presents the conclusions of this working approach.

2. SCOPE OF COMPOSITE RADIO

The future of telecommunications has been envisaged as an evolution and convergence of mobile communication systems and IP technologies, to offer a multitude of services over a variety of access technologies. To fulfill and implement this vision, it is mandatory to embrace the requirements with respect to the support of heterogeneity in wireless radio technologies accesses, services, mobility, devices etc.. It is equally important to promote and further highlight the requisite research in the field of networking technology, by providing a guiding framework for research.

The fundamental technical principles are based on the idea of cooperation between networks that belong to any wireless access infrastructure. The concept has been developed in order to maximize the efficiency of the offered services, by exploiting the advantages of networks of different nature and at the same time, minimizing their faults [viii,ix]. As aforementioned, the basic idea is the coexistence of different Radio Access Technologies (RATs) that form part of a heterogeneous infrastructure. The innovation of this approach, compared to the traditional telecommunication networks, is the active cooperation among such RATs which comes into effect, as they do not compete with each other anymore, but try to exploit the alternative solutions offered through coexistence aiming at an overall optimization of the spectrum efficiency. The above issues are depicted on Figure 1.

A network provider (NP) participating in such an infrastructure should have licenses to operate in more than one RATs this means that they can count on alternative solutions, in case they are not able to achieve the desired capacity in one of their systems. At the same time, an NP can cooperate with other NPs, in case they cannot offer the required QoS levels in an economically acceptable manner.

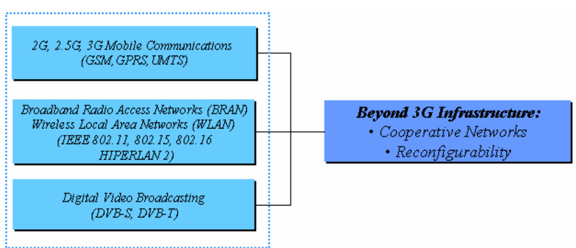

Figure 1: The CR concept

These solutions are facilitated through a new management functionality attached to each RAT. However, the RATs' platforms can cooperate and, in doing so, putting into effect the operation of the management system, without revealing each NP's confidential data. This management system is responsible for directing users to the most appropriate RAT, for encountering specific conditions at different space regions and time zones, based on users' requirements and some efficiency criteria [x, xi]. Such conditions are usually related to a hot spot somewhere in the service area, or the introduction of a new class of users, or even some network maintenance reasons. All the above may require some re-distribution of users to RATs. The infrastructure to facilitate cooperation among networks will be based on IPv4 (Internet Protocol Version 4), however, the future use of IPv6 is also considered. This has the aim to reduce the number of network technologies used and thus to lessen the system complexity.

The CR concept is facilitated by Reconfigurability. Reconfigurability is an evolution of Software Defined Radio (SDR) and offers to terminals and network elements the essential mechanisms to:

(i) Dynamically, transparently and securely select the most appropriate RAT from the set of available RATs, in order to cope with the aforementioned situations.
(ii) Optimally setting the level of interworking between the selected RATs.
(iii) Configure the resources used within each RAT dynamically by properly setting the implementation parameters, in order to achieve the maximum efficiency of the resources deployed. Even allowing simultaneous access to them.
(iv) Reconfiguring jointly mobile terminals. Network takes measure to maximize the spectrum efficiency based on the terminal profile in terms of the capability constraint, the user profile and the service profile.

In general, through reconfigurability, we can envision network segments that change RAT, in a self-organized manner, in order to better handle the offered demand. In this context, reconfigurability also supports the dynamic allocation of resources (especially spectrum) to RATs [xii]. Consequently, many new requirements are posed with respect to the efficient management of the whole reconfiguration process. Efficient planning and management solution mechanisms must be designed and carefully deployed, in order to facilitate the operation of a new generation of communication networks, called composite reconfigurable networks. These are described in the following section.

3. MECHANISMS FOR DNPM IN CR ENVIRONMENTS

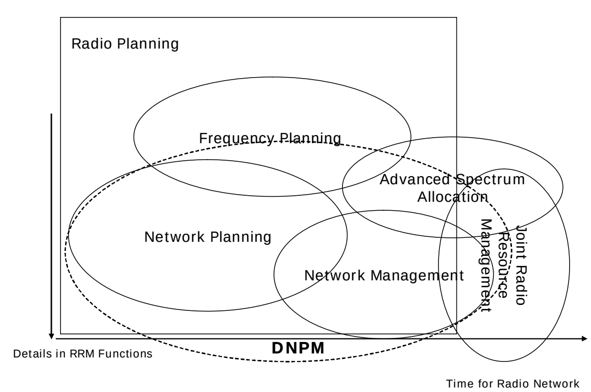

Figure 2: Relationships between DNPM and related techniques

DNPM falls into the category to enhance the spectrum efficiency for a reconfigurable system. In the composite radio environment, DNPM is among other methods for this purpose, such as advanced frequency management (ASM), joint radio resource management (JRRM). As an overview on the related technologies, the position of DNPM is depicted in Figure 2. In the planning phase of DNPM, deployment of the radio network is outlined, and the coupling levels based on reconfigurable network elements as Base Station (BS), Access points (AP) and Radio Network Controller (RNC), etc., the location of them, the initial spectrum usage of them, the implementation parameters such as the power value, antenna tiling angle, antenna pattern etc., are planned.

Facilitated by ASM, JRRM and some mechanisms and procedures that take place during the management phase, the network deployment will be positively affected by the capacity gain resulting from these technologies. At the management phase, research work aims to deliver principles of network reconfiguration and to show the goodness of reconfigurable network with enhanced capacity. In this phase, mechanisms like autonomous selecting/sharing/accessing spectrum, adjusting radio parameters, adjusting apparatuses parameters are taken place. In order to support those algorithms, signaling taken place in future radio network will taken place for those so called “self-tuning” RAN’s. Both the planning and management problems can be solved through the appropriate optimization algorithms such as greedy, simulated annealing, taboo search, genetic algorithms and meta heuristic algorithms.

4.ADVANCED SPECTRUM MANAGEMENT IN DNPM

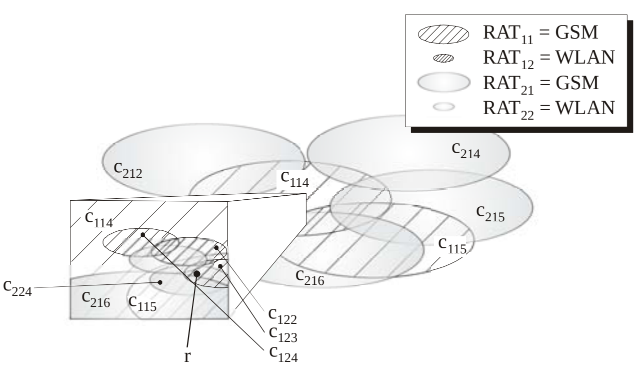

Figure 3: Area covered by GSM and WLAN cells c_{ijk} of Network Providers, NP_1 and NP_2

This concept is based on the assumption that a network provider is able to offer services over several RATs. These RATs are chosen according to special algorithms of the JRRM. As an example WLAN rather than GSM is preferred to transmit bursts of data which in turn is used for voice telephony. Considering a cell structure for all RATs the usage of services depends on time and space. Each NP initially calculates the spectrum used to support QoS by maximum load of all his RATs, e.g., rush hour, soccer games, etc. The spectrum can internally be assigned from one cell to another by Dynamical Channel Allocation (DCA) in a first step in order to get the overload under control. Besides this, in order to increase spectrum efficiency, a rental NP can rent spectrum from another licensee NP, if in one of his cells the maximum capacity is reached. This spectrum pool is limited to a local area in which the spectrum is needed. The cells covering this area can participate in this dynamical allocation mechanism.

To summarize the method (Figure 4) of each NP for any of his cells of different RATs, a NP observes the spectrum usage in his network. The NP assesses whether its current spectrum assignment configuration can handle appropriately the next traffic state. Based on this information he predicts whether parts of his spectrum are unused or his network is overloaded. Given this information, the NP can launch the radio engineering engine to find some alternative options to support the next traffic/spectrum demand state. In the first case he will offer his unused spectrum to other NPs at an auction with respect to a buffer spectrum captured into the alternatives. In the second case he will wait until another NP will proclaim an auction to reach one of its alternative requirements. Since the bandwidth which each operator can offer to other operators is time dependent, the spectrum distribution to the operators is planed dynamically.

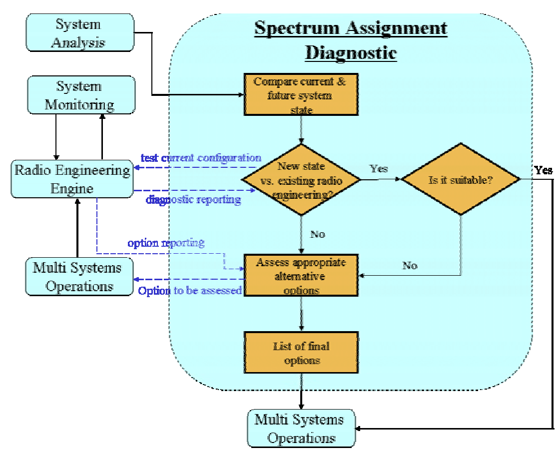

Figure 4: spectrum assignment diagnostic

4.1 Spectrum Pooling

As the mobile terminals become increasingly intelligent implementing cognitive functionality, the spectrum can be allocated dynamically in the sense that the NPs trade with their spectrum [xiii]. In this market there are two different groups: the licensee and the rental NP. The licensee offers parts of his spectrum for a certain time interval. This time interval ends if the licensee reclaims this spectrum for his customers. That is the licensee possesses a higher priority on the spectrum rented than the rental NPs. The spectrum offered can be assigned to the other NPs by a certain selling mechanism. The spectrum will be assigned by auctions, because this kind of market mechanism can instantaneously react on customers demand. An auction leads to an increased effort on the customers side due to the calculation effort of price prediction. But in this case a NP can be both licensee and rental NP depending on his network load at a certain place and at a certain time. The trade takes place locally cell-by-cell. If there is an event in a certain local area and an NP needs additional spectrum from others, the trade will take place only in the cells which are concerned by the event.

4.2 Spectrum Auctions

If the spectrum can be resold temporarily, a NP who possesses the licenses of certain spectrums needed for running different RATs can temporarily lease his spectrum. This spectrum trading uses spectrum pooling as a new market place. The NPs trade among each other by offering the unused spectrum. The trade takes place depending on time and space, thus this dynamical spectrum allocation only affect parts of network. A NP aims at serving his customers as good as possible by splitting the user's services demanded according to the JRRM mechanism. The NP observes his spectrum usage in any place and aims at predicting the spectrum exploitation in the near future. If the prediction reveals that parts of the spectrum are free, this goods will be offered. The market place encompasses the whole area covered by the cell of his certain RAT. The occurrence of the selling mechanisms is event-driven and not periodically. The goods offered are portions of bandwidth, therefore the selling mechanism is a sealed-bid multi-unit auction [xiv]. Besides the fact that the customers can influence the price instantaneously, the sealed-bid auctions are the fastest kind of auctions with respect to signaling effort.

4.3 Dynamical spectrum pooling

Based on spectrum pooling spectrum auctions as described aforementioned dynamically influences the network structure with respect to spectrum usage. Since the communication systems are able to learn about the environment and get more and more intelligent this approach is a mandatory step to cognitive radio. Assuming there are I NPs (NP_i, i=1,…,I), a NP_i transmits data over his J RATs (RAT_{ij}, j=1,…,J) in order to offer service diversity to customers. Each RAT covers the area by its K cells (c_{ijk}, k=1,…,K). In a cell c_{ijk} the RAT_{ij} can use a maximum bandwidth B_{ijk},max which can vary with DCA and JRRM algorithms. The actual bandwidth $B_{ijk}(t)$ needed at the moment depends on how much services the JRRM algorithms assign this RAT_{ij} in the cell c_{ijk}. In figure 2 a possible cell structure is shown. There are two NPs, NP_1 and NP_2, who possess two different RATs, GSM and WLAN, each. NP_1 can share the services between $_{RAT11}$,GSM, and RAT_{12}, WLAN. For example at place r an event is covered by NP1's GSM cell c_{114} and his WLAN cell c_{123} and also by NP_2's GSM cell c_{216} and its WLAN cell c_{224}.

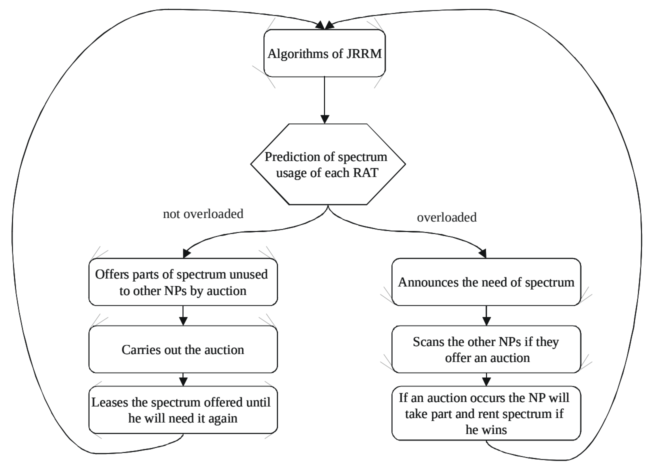

Figure 5: Mechanism of dynamical spectrum pooling in DNMP for cell c_{ijk} of RAT_{ij} of NP_j

If an event like a soccer game occurs at the place r and the network load of some NPs heavily increases, the JRRM of each NP_i has to share the service among their own RAT_{ij} and apply DCA to each individual RAT_{ij}. If all customers' services cannot even be supported, the NP_i will announce that he needs spectrum. In turn if a NP_i possesses unused spectrum, he will proclaim an auction to lease parts of his spectrum. The NP's behavior for each place is illustrated in figure 5. A NP shares the services among its RATs to maximize the QoSs. The algorithm will be executed in the JRRM. Afterwards a prediction about daily events or special events, e.g., a conference, determines how much the network is loaded at place r in the next time Δt.

Firstly, if the prediction says there will be unused spectrum of the cell c_{ijk}, the NP will offer this unused spectrum to other NPs by auction in order to use this spectrum in the area of this cell c_{ijk}. The NPs who possess the license and lease the spectrum can finish the rent time if their own customers needs more capacity. On the other hand if he predicted an overloaded network, he is anxious to get additional spectrum. Therefore, he contemporarily announces his spectrum needs and listens if an other NP starts an auction. If he wins additional spectrum, the JRRM module will distribute the service to his RATs in an optimized way.

4.4 Joint Radio Resource Management for Composite Radio

Reconfigurability provides feasibility in using JRRM mechanisms. JRRM is not only a concept by itself, but a framework supported by network configurations in terms of interworking, spectrum assignments and terminal capabilities. By definition, JRRM is a set of network's controlling mechanisms that supports intelligent admission of calls and sessions; distribution of traffic, power and the variances of them, thereby aiming at an optimized usage of radio resource and maximized system capacity. These mechanisms work over multiple RATs with the necessary support of reconfigurable/multimode terminals. JRRM is activated at a time scale measured at most in a few hundred of milliseconds. In turn would interact with DNPM and Spectrum pooling management.

The benefits of applying JRRM mechanisms have not been assessed so far in realistic scenarios. Further, in addition to purely technical QoS aspects, qualitative or business inputs are also necessary to be considered in order to make more suitable RAT or bandwidth selection. In that respect, both extremes of the value chain, i.e. user on one hand and network or service operators on the other hand, could impact the RAT decision somehow by introducing User demand (e.g. retaining the well-known Cobb-Douglass function in economics) and Operator preferences (e.g. based on spectrum available and inter-operator agreements in case not all the RATs are owned by the same operator) could be initially assumed to be decoupled in the short term [xv].

Devising and implementing JRRM algorithms pose a challenging task in terms of vertical handover decision implementation. This decision can not just rely in some electrical measurements, as it happens today in current RAT systems like UMTS. Instead, data exchange between systems offers a great potential for vertical handover or admission control in heterogeneous networks. Information about network state (e.g. load, signal strengths, interference distributions, services profile, etc) should be collected previously by each system to be administrated for locally deployed databases. Signalling for database provisioning and RATs database exchange could also be envisaged to be managed either locally or centrally. Associated signalling and bearers set up delays is a key issue that could prevent the adoption of certain combinations (e.g. loose coupled UMTS and WLAN networks for a real time services). Mobility management techniques different of classical Mobile IP or SIP have already been proposed (e.g. SCTP) for non very tight coupled networks that improve the associated above mentioned delays and open the range of new potential services enabled to be used under the JRRM mechanisms, including multi-homing approaches as described below.

JRRM techniques can also be exploited to perform classical RRM functions as far as JRRM allows for a better organization of the available resources in heterogeneous networks with a broader scope. As a result, a better efficiency would follow. Then, JRRM could not only be responsible of selecting the best RAT at each point of the time and for an active session, but also go beyond that by choosing the more suitable bandwidth or other RAT attributes. More specifically, for example to select the allocated bandwidth on a given UMTS RAB keeping in mind the technical and socio-economical aspects and the current available information of the other RATs like GPRS, WLAN, etc. under consideration.

For multi-mode/multi-band reconfigurable terminals, an extension to conventional IP multi-homing concept is to run simultaneous connections on the radio-frame level, which we call w.r.t. reconfigurable terminals as "Adaptive Radio Multi-Homing" approach. This approach provides multiple radio accesses for multi-mod/multi-band terminals in order to allow terminal maintain simultaneous links with radio networks. It selects the most proper JRRM function based on the identified information from the cooperating subnetworks, terminals, user and services. In order to support the selected JRRM functions, proper traffic classification, calibration, interworking between the service application server and Radio Resource Controller (RRCR) and the configuration of transmission format as well as MAC protocols are managed by ARMH. ARMH enables interworking between subnetworks in the composite radio environment.

The interworking between different subnetworks requires new protocols defined for convergence reasons. It should offer IP packet based convergence sublayers to networks to guarantee QoS. Due to the heterogeneity of coexisting different networks, many different policies are conceivable for JRRM, in particular when considering legacy and new network types. Systems in different generations are equipped with different functionalities, protocols and management requirements. For terminals having simultaneous connections to different RATs is one possible operation mode. In general, loose up to very tight coupling schemes between different types of networks must be considered for such multiple connections. For a possible tight coupling between UMTS subnetwork and a WLAN subnetwork, one must consider the restrictions in each subnetworks, e.g. the transport block size and minimum transmission time interval for each are differently defined according to the specifications. The subnetworks can also be frequency layers.

The JRRM algorithms not only span over RATs, but also over management layers and service types. The estimated traffic types and their volume are useful in dynamic usage of a fixed radio resource for a subnetwork. The load information and traffic information are shared by the cooperating subnetworks. Each subnetwork needs an efficient interworking between traffic volume, measurement (prediction) function, traffic scheduler, load control unit, and admission control function. The traffic estimation module in each system informs the administrative entity Session/Call Admission Control on the predicted traffic and planned traffic information to update the priority information for each connection and the admission decision within the subnetwork. The priority information is an input vector for the scheduling algorithm in a lower layer. The load balancing between software download traffic using broadcast/multicast channels and regular traffic over heterogeneous networks should be performed by a centric intelligent entity.

The system capacity gain obtained from the JRRM is in principle the enlargement of the number of operational servers from the queuing model viewpoint, which therefore results in a higher trunking gain. On the other hand, by alternatively allocating the resource to call units among the interworking radio networks or frequency layers, the load balancing effect among the radio networks and diversity gain are realized. In a typical soft blocking sensitive radio network, such effect is very significant.

Besides the capacity gain from network operation point of view, the advantage of having concurrently parallel streams is manifold: If one bearer service has a high availability in the network (low data rate bearer services result in high coverage, e.g. a 16 kbit/s service is available in 99% of the cases), this link would be used for transferring important information to the terminal. On the other hand, a low data rate service cannot fulfill the requirements for multimedia traffic resulting in high data rate demands. If traffic is intelligently split into rudimentary and optional information streams, a higher QoS for the user is provided. Whenever possible the user combines both streams for yielding a higher QoS and due to the higher availability of a lower data rate service in UMTS a minimal QoS can be fulfilled to the user.

5. SYSTEM CONSTRAINTS

Implementations of those technologies are under constraints which can not be neglected. We need to consider the below listed constrains by mapping them into the cost functions in optimization algorithms, or by designing protocols realized by radio signaling in the network. The primary goal of considering those constraints is to maximize the goodness of the listed methods.

Constraints for DNPM:

- Cost of buying legal sites to place RF sets.
- Cost of deploying base stations. A topic related with co-planning in this issue and the one before is that do we use the old site of second generation base station or create new site of 3rd generation one in order to cater for user traffic?
- Cost of wide Band RF sets in order to enable inter-RAT reconfigurability. Those costs need to be modelled in the DNPM target function before the optimisation mechanisms are executed.
- Maximum allowed delay for network reactions during the management phase

Constraints for Spectrum management [xv]

- Interference temperature for spectrum co-farming
- Realistic terminal duplex distance
- Backward compatibility of RATs
- International level agreed set of standards
- Scanning capability of terminal (how cognitive?)
- Wasted of spectrum used for coordination
- “Spectrum playground” for each RAT

Constraints for JRRM

- Signalling between coupled radio networks
- Terminal capabilities such as multi-mode multi-band or multimode single-band, buffer management and computational power
- Switching methods in terms of packet switching or circuit switching
- Traffic characteristic and degree of user tolerance
- Subnetwork constraints and degree of freedom
- Maximum delay permitted
- Services allowed according the different available RATs.

6. CONCLUDING REMARKS

This paper aimed at presenting the key characteristics of reconfigurability which is envisaged to dominate the telecommunications world in the years to come and giving the necessary research framework in the context of reconfigurable networks. For this purpose, it provided details on the DNPM mechanisms and the related technologies that need to be developed, as well as on the respective system constraints.

In conclusion, given that the positive effects of the introduction of reconfigurability in 4G networks are impressive, special attention must be placed on their commercial success, in order to transform from innovative technological solutions, to useful mechanisms for the users. Such a success must be considered indisputable, only after the necessary Dynamic Network Planning and Management mechanisms have been designed and effectively deployed.

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