Self organised cellular networks as the future of wireless communication

Osianoh Glenn Aliu, Muhammad Ali Imran, Barry Evans
Centre for Communications Systems Research, Guildford, University of Surrey
Guildford, United Kingdom
e-mails: {o.aliu, m.imran, b.evans}@surrey.ac.uk

***Abstract*— An introduction into self organizing cellular networks is presented. This topic has generated a lot of research interest over the past few years as operators have identified it as a necessary feature in future wireless communication systems. We review projects which have studied self organization and with knowledge of system model design in computing, we suggest design rules in developing robust and efficient self organizing algorithms. We finally demonstrate a channel assignment example based on the concept of *sectorial neighbours* where the system autonomously changes its allocation scheme based on external factors in the environment (e.g. geographical location, interfering sectors and demand for resources). Further research directions are also highlighted.**

Keywords- self organising networks; neighbours; dynamic spectrum management; channel allocation.

I. INTRODUCTION

Future cellular wireless networks will need to be more efficient and very dynamic as compared with current system design which uses long term statistics to select system configuration parameters irrespective of varying user distribution, geographical location and type of wireless devices.

A myriad of techniques have been developed in the literature to ensure interference is minimised and the limited frequency spectrum is utilized as efficiently as possible and with fairness. The inquisitive mind would be prompted to inquire: Could any single scheme be sufficient or would the application of multiple schemes introduce too high a level of complexity in future communication networks? Could future networks become intelligent and organise their operations autonomously? How do we design systems that could carry out network functions without being directly programmed for such functions?

The clear need to develop intelligent wireless communication networks has been identified and a much work has been done in the area of cognitive radio [1]. However, Cognitive networks is the next step which will incorporate high level intelligence and self organization. In some systems such as the human brain, millions of complex information units will constantly be processed and still give efficient non-interfering outputs. One unique feature of the human brain is also its ability to learn and improve performance with experience. Perfect modeling of the human brain is however a non trivial task and is still an ongoing study in field of Artificial Intelligence (AI). Building systems or machines to function optimally requires careful study of how the brain works. The brain is known to use pattern recognition as a key feature for its classification and decision process. When machines are faced with unique inputs different from the regular pattern already programmed, they could become unreliable.

Nature has provided us with so many examples of how simple individual units can work as a group to form a robust efficient network. The interesting observation is that each entity is aware of its neighbours and they function to achieve the same global objective. For a simple system; it is assumed a Base station (BS) is located in the centre of each cell with no relays. Future cellular wireless networks would consist of many enodeB's, home enodeB's, and relay stations. There is a need to maintain organisation in the functioning of all these devices to ensure the network operates efficiently and with reduced interference among the nodes. The demand for more intelligent architectures in wireless communication systems is increasing as the size of the networks grow larger and new standards have envisaged that future generation cellular systems would have to self organise their nodes with some element of cooperation.[2]

The obvious question is how do nodes recognise the presence of other nodes? How do existing nodes adapt their operating parameters due to insertion of a new node or sudden malfunction of any node in the cluster? Can the system adapt its parameters based on varying user distributions? Due to the large number of nodes and complexity of the network we set out to develop and analyse systems that would update their own operating parameters autonomously and in real time. Self organisation of wireless networks can be classified under two main categories: self configuration and self optimisation. Authors have identified various *use cases* with classifications based on numerous applications [7] but it is simpler in developing an integrated algorithm to acknowledge that all parameter settings would be grouped as configurations while further adjustment of these parameters for an efficient network would be grouped as optimisation.

In this paper we present our ideas on self organizing networks and we go further to present a guide in developing algorithms that would exhibit features of a self organised system in cellular networks. A simple example of channel allocation will be demonstrated introducing the concept of neighbouring sectors as against neighbouring cells in future cell organizing systems.

Self organizing systems will be a necessary feature in future generation of broadband wireless services with particular interest for LTE and LTE-A systems. The first release of the 3GPP LTE release 9 [2] and IEEE806.16m standards [3] have the scope for the deployment of Self Organised Networks (SON). While much interest focuses on machine learning, it must be emphasized that the aim of this paper is to present our ideas in designing a self organised system The rest of this paper is organised as follows; Section II gives an overview of existing work that have focused on automated and self organized systems. Section III discusses self organised networks, giving a clear description of SON, unique features and applications of such systems. Section IV presents our approach to developing self organised algorithms for wireless cellular networks highlighting research interests and future work to be done in developing a system level simulator.

II. Related Work

There is a growing interest in the literature towards developing self organised networks. Different ideas and frameworks have been presented with algorithms still being developed. A major vision was presented by Spilling et al [4] where the need for wireless communication networks to become intelligent and sensitive to changes in their environment was emphasized. Among the various technologies discussed, the main focus was on capacity gains by techniques such as load balancing using relay stations. Cognitive radios would obviously play a vital role in sensing the environment and their ability to learn from events in their environment. This vision for Cognitive radios as introduced in [1], has since been carefully analysed, pointing to useful research directions. These have certainly shown the trend for future wireless communication systems and the role of cognitive and machine learning in modelling a self organised cellular network.

The past few years have seen research projects dedicated to investigating, analysing and the possible deployment of self organisation. The interest in self organised cellular networks and its vast applications have been identified in recent research works. Identifying the heterogenous prospects and increased complexity of future radio access technologies, the European Celtic Gandalf project [5] has studied the broad perspective of SON. They evaluated the effect of automation in network management and joint radio resource management in WLAN/UMTS networks with automated fault troubleshooting and diagnosis. The European "end-to-end efficiency" project [6] focused on integrating current and future heterogenous wireless systems into cognitive systems for self-management, self-optimisation, self-repair etc (described as self-X systems by the authors). An ongoing project is the SOCRATES project [7] which has identified various use cases and their inter-relations. System models and proposed algorithms are still being studied. However their expected results are targeted at developing methods and algorithms for self-optimisation, self configuration and self healing of future radio access networks.

The projects mentioned above, as well as other relevant publications in SON, are useful and related to the India UK Advanced Technology Centre (IU-ATC) project. Theme 9 of this research initiative focuses on self organised cellular multihop networks. We concentrate here by specifically focusing on major use cases of future self organised networks. We will analyse and develop algorithms for dynamic spectrum management showing how inter-cell interference will be minimised. The performance limits and system performance of our system will also be investigated.

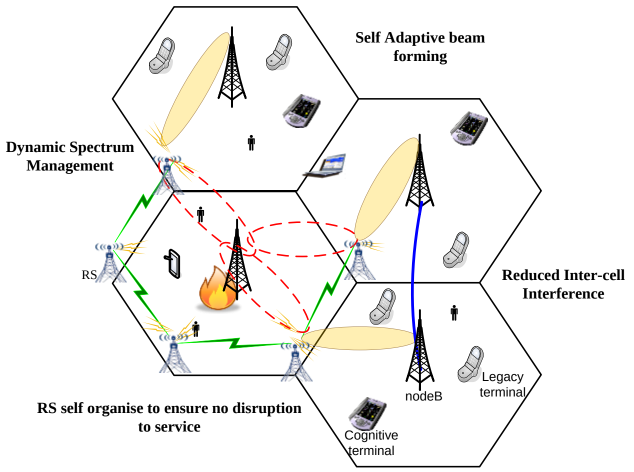

Fig. 1. Disaster management

III. Self Organising Networks

The interest in self organised cellular networks and its numerous applications have been highlighted in a some EU projects [5], [6], [7]. These applications are interrelated and used in developing algorithms for an efficient dynamic spectrum management which also minimizes the intercell interference. In general, algorithms in SON should not be treated in isolation. However it is challenging to develop a single efficient algorithm that would address all applications. A modular approach is adopted address the major applications that would inevitably affect other applications of a cellular system. For example, solving the load balancing problem can easily be extended to power allocation and radio resource management.

Self organised spectrum management is a major application that can be implemented by first developing adaptive algorithms to optimise system parameters as changes in input are detected or as system configuration parameters reach a defined threshold. The algorithm then proceeds to the interesting stage of learning where the system would dynamically set thresholds and adapt one or more system parameters to maintain a defined global objective.

Some interesting applications, where research efforts in this field will be channeled in the coming years, are to develop standards that include auto-positioning and auto-configuration of enodeB's, relay stations and home enodeB's. This can be demonstrated using software to simulate the behaviour of other nodes when a new node is inserted and then recommend the best position for the placement of new nodes.

Load balancing is another interesting application as it helps to maintain a high QoS irrespective of user distribution. This proposes fairness and by using techniques such as adaptive beam forming, signaling and traffic load sharing among neighbouring cells to ensure no cell is overloaded while resources in neighbouring nodes are under utilised over a given period.

An emergent behaviour is the auto detection and compensation in event of a natural disaster. Future networks would be able to trigger timely compensating actions to neighbouring cells which would reduce network downtime in the affected region and ensure seamless network service. The system is designed in such a way as to ensure communication of users within a given region but when other close by users are experiencing a poor QoS the network could for example change its modulation scheme to ensure more users from the affected node are compensated. The key feature of a self organised system is its ability to learn. Learning from previous action-event pairs or learning unique hidden patterns from the inputs. To model an intelligent system that is able to learn we adopt practical algorithms and ideas from neural networks.

Various contributions have suggested different designs for complete self organized wireless networks but as at the time of this publication we are not aware of any generally accepted algorithms. As a guide we present key features that must be considered in developing such algorithms and in categorizing systems as self-organising in wireless cellular systems

- Design a network that would improve overtime, by building a simple model gradually introducing and incorporating other functionalities. To achieve complete self organisation a transition from systems with minimal human intervention and finally zero human intervention should be designed. Intelligence comes from learning, and learning does not happen in one instance. One caveat is that the designer should still have a clear vision of the overall goal to be achieved at the outset.
- SON should be able to adapt and serve efficiently for scenarios that were not envisaged at the design stages. New structures and functions that were not directly programmed at the design stages should emerge. In other words, the system should be able to learn without supervision.
- Individual network elements must be aware of the arrival, departure, active or idle modes and configuration changes of their neighbours. They should also learn means of communicating major system configuration changes only to direct neighbours without causing huge signaling overheads on the network.
- System performance should be monitored over a long time scale via feedback mechanism, where system measurements are generated from the network and during idle mode, the system is able to characterise its performance and prompt optimum configuration changes.
- Self organisation might not be the best solution in all scenarios. To prevent underutilization of the system, simulations should always be compared with conventional approaches to determine the gains and added functionalities (if any) that would be introduced.

Learning algorithms can also be applied to develop robust systems whose performance improves with time. Artificial neural network tools have found applications in various disciplines as they efficiently model systems used in control, optimisation and prediction [9]. For a detailed tutorial on neural networks, the reader can refer to [9], [10] and [11]. Expected results would reveal the prospects of novel applications in wireless cellular networks and gains in demonstrating reduced inter-cell interference and improved system capacity.

Self organized system models consist of simple independent components but with localized behaviours. These local interactions lead to complex highly organized behavior of the entire system. To define a region of locality or specify a neighbourhood where local interactions exist, we present in the next section a system model of a sectorised cellular system.

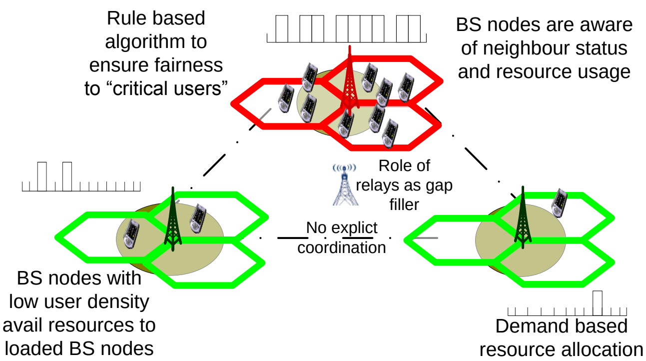

Fig. 2. System Model

IV. SYSTEM MODEL

A Matlab based system simulator to demonstrate a self organized cellular network is being developed and some preliminary results presented in the next section.

Our vision is to design systems where network configuration parameters are changing to meet with varying conditions in the environment. We thus seek to design an intelligent network that would autonomously organize its configuration settings, monitor its performance and optimize its settings to further improve performance as input features change. This requires system elements to be aware of neighbours, the need for the network to be able to learn and for it to be designed in such a way that it could monitor its performance and give feedback to the system.

A two layer system will be designed to accomplish this task. The first layer consists of an adaptive cellular network whose configuration parameters (e.g. antenna downtilt, power control, active and idle nodeB set, modulation & coding scheme) would be optimised as changes in the network prompts it.

The second layer consists of an intelligent network with the ability to learn. Just like the human brain, this layer is able to learn from pervious events and has a knowledge base to determine the necessary configuration changes to be made. Designing this layer involves the use of algorithms that have directly or indirectly been implemented in Artificial Intelligence. This layer would monitor the system performance and autonomously detect the cells whose resources are not being optimally utilized and trigger to the lower layer the necessary configuration settings that would be made. This task can be complex; as changing one parameter might affect other responses of the system. Efficient feature extraction algorithms to transform the high dimensional data from the cellular system to a lower dimension before analysis and optimization will also be demonstrated in future work

A neighbouring scheme is introduced which is motivated by the fact that self organized systems are composed of individual local entities. Individual local groups with their individual constraints but would still coordinate to obtain a global organized behavior. In a cellular system, system performance of a given cell has direct effect on the adjacent cells due to inter cell interference. Consider Fig 3, we model the system as a three sectored cellular system using the clover leaf pattern. Our simulation results consider a 3 sector cellular system where intersecting sectors from adjacent cells are regarded as *neighbours*. Sectors belonging to the same base station are not regarded as neighbours. This model conforms to the idea that despite a hexagonal representation for a cellular system, users in a given cell are usually associated to adjacent sectors in neighbouring cells due to shadowing, antenna pattern and fading.

The following notations give more insight into the system model.

Let $\mathcal{K}$ denote the total number of users in the system and

$\mathcal{K}_S$ describes the set of users in sector s

$\mathcal{K}_S \subseteq \mathcal{K}$ since $\cup_S \mathcal{K}_S = \mathcal{K}$.

Neighbour Matrix:

$\mathbf{N} = [n_{i,j} \mid n_{i,j} \in \{0,1\}]_{S\times S}$, a S by S square symmetric binary matrix, depicting the interfering neighbours among S sectors.

$$n_{i,j} = \begin{cases} 1, \text{sector } i \text{ and } j \text{ interfere with each other and } i \neq j \\ 0, \text{ sector } i \text{ and } j \text{ can use the same set of channels} \end{cases}$$

Thus the neighbour of any sector i in a cell is any sector j such that $n_{i,j} = 1$. We assume for the results in this paper that sectors of each cell have a non-uniform distribution of neighbours depending on their location either at the centre or at the edge of coverage area. In implementing the algorithm, the number of interfering neighbours Ω_S is a set of neighbour ing sectors in sector s

$$\Omega_S = \{ j \mid n_{s,j} = 1\} \qquad (1)$$

Channel usage: For each set of sectors, in order to ensure an orthogonal scheme, once a channel has been used by any of its neighbours, the channel is removed from the available set of channels until the last channel is utilized and then the entire set of channels is made available once again.

Let $\mathbf{U} = [u_{s,m} \mid u_{s,m} \in \{0,1\}]_{S\times M}$, a S by M binary matrix for the channel availability in each sector:

$$u_{s,m} = \begin{cases} 1, \text{channel } m \text{ is available for sector } s \\ 0, \text{ channel } m \text{ is being used by a neighbour} \end{cases}$$

$\forall\ M$ channels available to each set of neighbours.

Given a cellular system of 7 base stations with 3 hexagonal sectors each, we demonstrate a resource allocation scheme where changes in the system would cause the neighbouring cells to update their allocation scheme in their sectors based on these events. A simple scenario is user localized in a remote industrial estate with neighbouring residential areas. During office hours on working days, there might be a high concentration of users in a given sector while neighbouring intersecting sectors have lower demand on its resources. We assume a given geographical area located at the edge of town where there is a non-uniform number of neighbours. Modeling an interference matrix which determines which neighbours would form a set to coordinate their resources in a common pool and minimizing interference among themselves. This symmetric matrix is represented in Fig 4

For example in Fig 4, the interfering neighbours are denoted with black boxes. We observe sector 20 for example has sectors 3, 16 and 18 only as neighbours which is also seen in Fig 3.

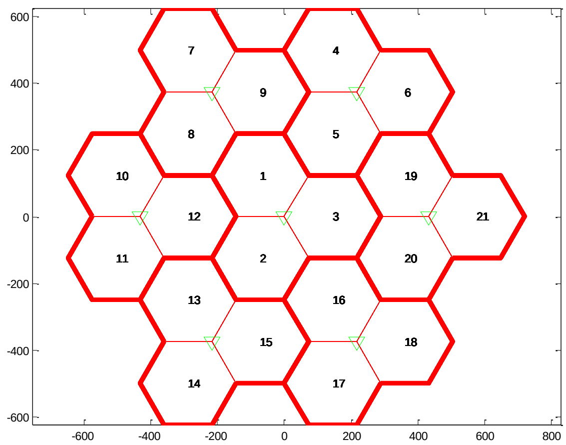

Figure. 3. Sector based model

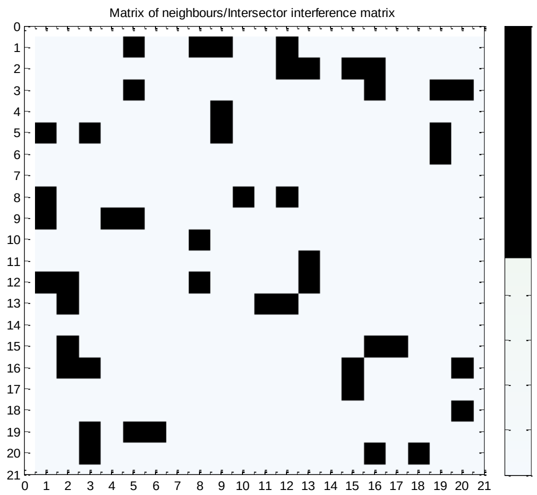

Figure. 4. Neighbour matrix

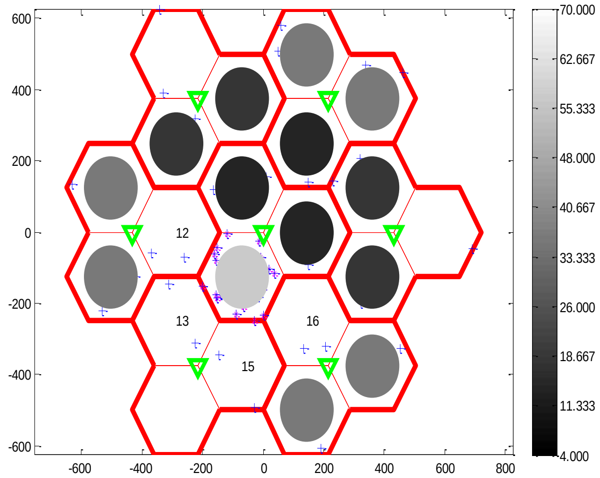

Figure. 5.Layout showing neighbours allocation

Consider a geographical area covered by S sectors belonging to C cells, M channels are available for all sectors in a neighbourhood region to dynamically share. The nodes serving these sectors are able to organize among themselves the maximum amount of channels each node would require. This can be regarded as a “Poverty line” PL. The poverty line would not be a fixed function as described in the literature [12] rather the system would have different poverty lines for each sector. The poverty line would be a function of the user traffic and amount of interference from neighbors. We thus define a load factor LF in a given sector s which depends on the number of users in a given sector relative to the number of users in interfering sectors.

$$LF(s) = \frac{|\mathcal{K}_S|}{|\mathcal{K}_S| + \Sigma_{\Omega_S} |\mathcal{K}_n|} \qquad (2)$$

where $n \subset S$ sectors, N is the number of neighbours of a given sector and $|\mathcal{K}_S|$ is the number of users in sector s and the summation of $|\mathcal{K}_n|$ gives the number of users in neighbouring sectors. The poverty line would simply be a multiple of this factor and the total number of channels available. This is also an orthogonal scheme where the same set of channels cannot be reused by other sectors in the same set except such sectors would not introduce any form of interference.

$$PL(s) = \frac{|\mathcal{K}_S|}{|\mathcal{K}_S| + \Sigma_{\Omega_S} |\mathcal{K}_n|} \times M \qquad (3)$$

M is the number of available channels in that geographical area.

Table I Simulation parameters used

Simulation parameters	
Parameter	***Value***
Number of Clusters	1
Number of cells	7
Number of sectors (sect)	21
Number of Channels (M)	70
Number of User (mUE)	70
Wrap around model	No

We artificially load a sector s and uniformly load other sectors with an even number of users. It is assumed that all users request for a channel and are successfully allocated one. We verify that the algorithm increases the number of resources given just to the loaded sector as against previous schemes [13] where borrowed resources are made available to the entire cell. We validate these results by loading different sectors for different snapshots and we verify that as the increased user concentration changes from one sector to another so also the channel allocation changes ensuring area with more users are given more channels.

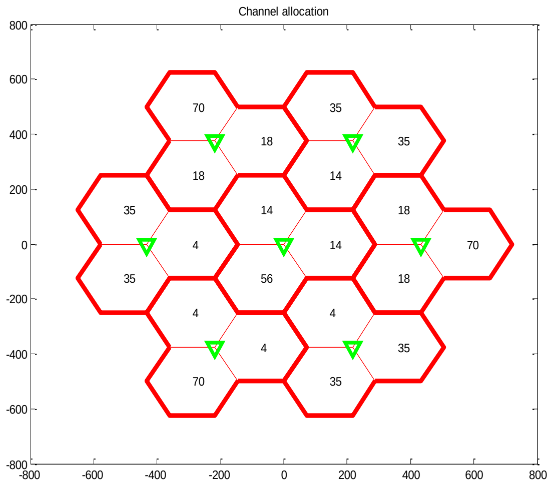

Figure. 6. Channel allocation showing neighbours

VI RESULTS

Table 1 gives a summary of simulation parameters used. The system is shown for a first tier cluster of cells using a cloverleaf design. The results can be extended for larger number of cells which would introduce a greater level of complexity in the definition of sectorial neighbours. However for self organised cellular networks, we are concerned with local behavior or rules. We have artificially loaded sector 2 with users who are being served by the centred base station.

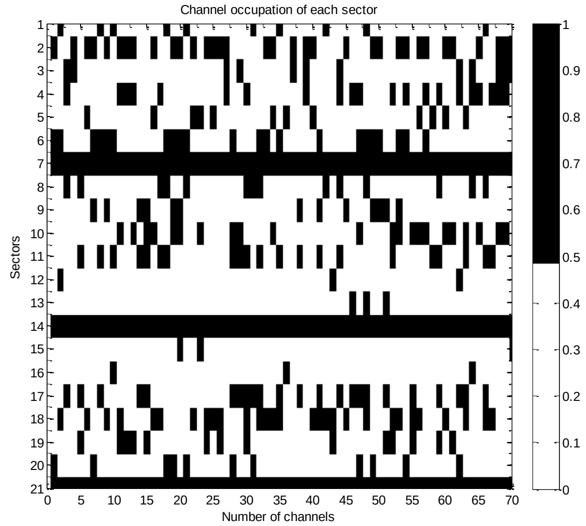

Figure. 7. Channel usage among sectors

The previous result in Fig 5 shows a plot of number of channels allocated to each sector. Sectors 7, 14 and 21 have the maximum number of allocation and are colored white. The neighbours of the loaded sector 2 are 12, 13, 15 and 16. The allocation of theses neighbours can be seen in figure 6.

Fig 6 shows numerically the number of channels allocated to the sector in the system due to the effect of the loaded sector according to equations (2) and (3). It must be pointed out that channels allocated between sector 2 and its neighbours are done with as much orthogonality as possible to avoid interference between neighbours. Each sector was artificially loaded and it is observed that the system organizes itself among its neighbours to adjust the number of channels that would be allocated based on the user density and its number of interfering neighbours. Fig 7 shows the channel usage of the 70 channels by each sector. The rows represent the sectors and the columns, the channels from 1 to 70. Sectors 7, 14 and 21 occupy all channels as they have no neighbours. The adjacent sectors being served by the same base station would introduce no intercell interference and is therefore allowed to utilise maximum number of channels.

VI Conclusion

An overview of the necessary requirements of future wireless cellular system has been described. We have also presented a guide in developing algorithms that would exhibit features of a self organised system in cellular networks. A simple example of channel allocation was demonstrated introducing the concept of neighbouring sectors rather than cells in future self organizing systems and it was observed a dynamic and conflict free allocation would be achieved; minimising the interference among neighbours. Further work will be performed to demonstrate the system convergence time and performance with different cluster sizes. Learning algorithms that improve allocation schemes based on previous allocations would aid an efficient dynamic spectrum allocation and minimise inter-cell interference will also be studied.

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