Progression In The Concepts Of Cognitive Sense Wireless Networks – An Analysis Report

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Abstract – This paper illustrates the conception of networks, their primary goals (from day one to the present), the changes it had to endure to get to its present form and the developments which are in progress and in store for further standardization. The analysis gives more importance to the specifics of the Cognitive Radio Networks, which makes use of the dynamic spectrum access procedures, framed for better utilization of our available spectrum resources. The main conceptual difficulties and current research trends are also discussed in terms of real time implementation.

Keywords – wireless networks, cognitive radio, spectrum management, spectrum access, dynamic decision, game theory, wireless security, internet of things

I. INTRODUCTION

Fixed spectrum analysis and allocation of usage bands went together in governing the usage methods of the available spectrum ranges for so long that it was thought to be the pinnacle of wired and wireless networking concepts. However, with the advent of more effective network equipment manufacturing procedures and the increase of potential users for them, it was later understood that the pinnacle was not at its highest point with the fixed policies. Newer strategies and better variations in the spectrum assignments were needed in order to compensate for the usage losses. With this in mind, researchers were able to bring about many new changes and one such successful paradigm is the Dynamic Spectrum Access (DSA) conditions for spectrum allocations. Sporadic and drone-like utilization of spectrum decreases the efficiency and performance of the network, even to as high a percentage as 85%.

Dynamic Spectrum Access prohibits situations like the ones shown in Figure 1 and Figure 2, by opportunistic methods. [1] [2] The field of wireless communication and networks have gained so much importance that almost all existing technologies are extensively used in all possible scenarios to find the best technology suited for providing cognitive capabilities in the latest 4G, 5G and LTE based systems. Researchers are further comparing different mathematical and analytical models to bring out the best decision and detection model for Cognitive Radios over the past decade. To carry out all these factors in real time, data concerned with the current spectrum usage and their license information needs to be thoroughly analysed and modified for present scenarios and conditions. Most channels, being fading channels, need special decision models and data logging in order to estimate the channel effectiveness under overlay methods (Primary user or Secondary user access to spectrum) and underlay conditions (Primary and Secondary users together with special considerations).

This needs a collection of prerequisite information on when the spectrum is free, what type of priority is needed for each part of the base network, the type of users present and methods of managing the network effectively. This paper shows the past and present functionalities perfected for the effective network architecture, by providing adequate details on spectrum mobility, sensing and management for sharing mechanisms. An overview of the DSA and CRNs,
along with an investigative report on the influence of all such functionalities is also being presented here. As a final touch, the design possibilities are also discussed with suggestions to improve the present status of CRNs [2].

**II. EVOLUTION OF WIRELESS NETWORKS TO ITS PRESENT FORM**

Though the present generation of networks craves the usage of wireless networks for simplicity and easier implementation, they are to be used in careful ways so as to avoid wastage and loss of resources when there are already so little to spare. The users who first made use of wireless networks were uncomfortable with the amount of spectrum utilized for even one single transaction of information to be successful. This lead to doubts whether all could get resources from the communication spectrum in the days to come. After all, 10 kHz to 30GHz cannot be sufficient for all kinds of communication techniques which are currently in use and for those which are being brought into the market every other day.

**Figure 2 – Spectrum under-utilization**

Thus, people turned their attention to the “use and reuse” concept for their wireless networking resources. The first step towards this concept is the advent of Frequency reuse principle, which made the sharing of spectrum frequencies possible between geographically separate plains. It helped users to share spectrum resources between predefined distances and still be efficient in providing the required QoS for the users’ requirements.

But this still was not enough for feeding the enormous appetite of the wireless users and better solutions were required from service providers. Methods like dynamic frequency allocations, sharing of frequencies and dynamic licensing of spectrum resources and so on are popularly being implemented these days. In the midst of such innovative designs and theoretical endeavors, the most commonly studied concept is that of the Cognitive Radio Networking and Technology, which is the heart of this research study paper.

**III. COGNITIVE RADIO TECHNOLOGY**

Dynamic accessing of spectrum is being heavily studied for the past three years and many articles, research findings and theoretical ideas are being deployed for the scientific community’s usage. One of the methods used for fine-tuning the working of the DSA (Dynamic Spectrum Access) is the Cognitive Radio Networks. [3]
The power to provide the capability to opportunistically, share the licensed wireless channel with others is the key to the working concept of DSA. Effective spectrum management techniques are needed if high bandwidth is to be provided for the mobile users’ around the required regions, who are all under different versions of wireless (heterogeneous) architectures.

To control the unavoidable fluctuations in the spectrum allocations between users, the following characteristics are given to the CR networks;

- Ability to find out free portions of an available spectrum
- Ability to choose the best channel amongst them
- Ability to coordinate the channel access between users
- Ability to vacate the occupied channel when it is needed by the primary user

Thus, these abilities can be coined under the following techniques meant for CR system;

- Spectrum sensing
- Spectrum decision
- Spectrum sharing
- Spectrum mobility

Also the system needs to be implemented in such a way that no major modifications are required to be done from the already existing systems, to avoid increase of expenses.

With these points in mind, this paper is aimed at providing simplified information about the ways of spectrum management and the techniques incorporated in the CR system as mentioned above.

Two main characteristics may be shown with regard to this definition;

- **Cognitive Sense** – Identification of unused and idle spectrum is done with real time information collected in real time from the environment. The best channel spectrum is then selected from them and utilized in such a way that there is no interference to the licensed user in way possible
- **Multi-Configurations** – Reconfigurability of transceiver to use different ways of access methods that are supported through the proper hardware design.

A CR needs to use an optimized transceiver architecture system with two main components – a radio front section and a baseband processing unit. The Front section deals with the amplification, mixing and A/D conversion for the received signal, while the Baseband processing section is necessary for modulation and demodulation of the converted signal. The real time environment changes can be dealt with, by providing a control bus for reconfiguring the components as and when needed by the time-varying conditions.

Another important requirement of a CR technique is the presence of a wideband RF front section which will be useful for sensing simultaneously a wide range of frequencies. Factors that govern the working of the front section would be the RF hardware design, power amplifier, wideband antenna and so on. The system should thus have the ability to detect faint signals as well.

The main factors behind a CR technique may be well explained with the help of its definition;

> “Radio which can change its transceiver parameters with respect to the environment’s interaction and the predefined priorities of the users”

**IV. COGNITIVE RADIO NETWORKS**

A complete description for the CR network architecture is first needed, before entering the facts behind the same. The CR network has two basic modules – a primary (or) licensed network and secondary (or) CR network.

The licensed network is the existing network, which has primary users operating at a certain predefined frequency spectrum. Control for the primary network is given through base stations, which weeds out the presence of unauthorized users in the network.

The secondary or CR network is a network which does not have the required license to operate at a particular spectrum band.
They are allowed opportunistically, to access the network resources through separate single hop CR base stations.[7] Spectrum brokers are spectrum resources distribution agents included in the CR side of the network. Spectrum utilization by the CR networks may be shown to be both in the licensed regions of the primary user spectrum and in the unlicensed regions through wide access band technologies. Such network operations may be divided into two main types like licensed and unlicensed operations.

The licensed operation is done by the primary user network, focusing mainly on the ways to detect primary users. This is to help the system allocate and vacate the resources as and when needed. The unlicensed operations are responsible for providing the same privileges as that of the primary users when they are not in the system, through some spectrum sharing mechanism.

CR users utilize three different types of access methods;

- CR Network access – CR network users are allowed to access the specific CR base station on all spectrum bands
- Adhoc CR access – Communications from one CR user to the other is done through adhoc connection in both the spectrum band types
- Network primary access – Accessing the PR base station by the CR users, by using an adaptive MAC protocol

![Figure 3 – Spectrum management for Cognitive Radio](image)

![Figure 4 – Comparison for Traditional Radio, Software Radio and Cognitive Radio](image)
V. STRUCTURE FOR SPECTRUM MANAGEMENT

Due to the unique nature of the CR based networks, spectrum management conditions are needed to face all the design challenges, such as,

- Avoiding interference – Interference between primary and CR user networks need to be kept zero
- Updated QoS knowledge – The CR networks need to support communication between them for transfer of information regarding the QoS parameters for the heterogeneous and dynamic environment
- Smooth communication – Communication between the CR networks need to be smooth, even during the presence of primary network users

For implementing such challenging grounds in the CR system, a framework for the spectrum management [8] is needed. The management requires four major functions, in general, for all kinds of CR network architectures;

- Sensing – Determining unused / idle frequency portions for the sake of a CR user, through monitoring and detecting of spectrum holes
- Decision – Allocation of channel to CR users through the implementation of predefined policies
- Sharing – Spectrum sharing between CR users without collision between them
- Mobility – Ability to continue the CR user's work in another vacant spectrum region, when the current spectrum region is needed by the licensed user

In cognitive radio system, unlicensed secondary users can use the resources which are licensed for primary users. When primary users want to use their licensed resources, secondary users has to vacant these resources. Hence secondary users have to constantly sense the channel for detecting the presence of primary user. It is very challenging to sense the activity of spatially distributed primary users in wireless channel. Spatially distributed nodes can improve the channel sensing reliability by sharing the information and reduce the probability of false alarming. [6]

Similar to the importance of the architecture management issues, there are many sub-functions meant for spectrum management, under each function;

A. Sensing

One of the most important functions needed for a CR network environment is the presence of a sensing algorithm, which is designed solely for informing the CR about the changes taking place in the entire system.

With sensing capabilities, the system will be able to adapt itself and detect spectrum holes effectively, thereby eliminating primary network interference.

The sensing techniques that are used here will be of three categories; [4]

a. Detection of primary user transmission

CR user observations are responsible for the detection of transmission and such detections are done by,

- Matched filter based detection – By incorporating the primary user characteristics into the matched filter, it will serve as a detector for the primary user signals
- Detection of energy – In the event of insufficient information from the primary user about its signal characteristics, it is best to use detection methods based on the presence of energy patterns. But the method is prone to false alarms and uncertainty of correct results
- Detection of inherent features – Periodic flow of signals is detected and analysed first; a special correlation spectral function is used for the same. The method is robust and certain of better results, but poses to be a very complex method to implement.

Some of the major problems involved here are,

- Lack of interactions between PR and CR users
- Interferences (external, internal and environmental)
- Line of sight and shadowing problems

Hence, it is best to go in for the method of cooperative detection in such cases, to get a more accurate detection of primary user transmission. It is both advantageous and inefficient at the same time – it is best suited due to its robust
nature, its ability to avoid shadowing and multipath fading, while it is not capable of reducing the network overhead for such a heavy traffic. [5]

b. Detection of primary user reception

Even if the cooperative detection pattern is useful in reducing interference, the most common method for detecting spectrum holes is to detect the users in the primary network within the range of a CR user, by using the leakage power of the receiver system. However, it is only possible in TV receivers due to the fact that weak local oscillator leak is not enough for other forms of receiver detection.

c. Management of Interference temperature

Control measures for interference in the transmitter side can be governed with the help of analyzing the power radiated and the position of transmitters. But since, interference happens at the receivers, a separate model called interference temperature is considered and the same is used to bring down the interference by the setting a limit for it.

Now the CR users are allowed to use the band until the Interference temperature does not reach beyond the specified limit.

However, fixing a plausible limit for the interference temperature is not easy.

Challenges involved in sensing;
1. Measurement of Interference temperature – cannot be fixed easily
2. Sensing for networks with multiple users – difficult to implement
3. Sensing through spectrum efficiency – decreases efficiency as CR users need to stop sensing to allow sensing

B. Decision

To equip a CR network to decide the best channel for the user, the system needs to be incorporated with the ability to consider QoS requirements based decision making. This is termed as spectrum decision. This term, however, has little importance in research papers, due to the fact that most people consider some rule for minimal allocation strategies without putting efforts into this part. Difficulty in decision making arises due to the presence of multiple CR users in the system, interference from other users, faulty access and sensing methods used and finally due to the complex format needed to implement such a procedure.

It is essential to know more about the characteristics of the channel, procedures for decision making and challenges involved in decision making.

a. CR networks’ channel characteristics

All spectrum holes present in the system should be considered for providing a time-varying environment along with parameters related to the spectrum. Such parameters are as follows;

- Interference – Useful for estimating the capacity of the channel and for deriving the power of a CR user
- Path loss – Depends on the frequency involved and the distance. Path loss increases with increase in the frequency of operation, which in turn decreases the range of transmission.
- Errors in the wireless links – Changes with each modulation technique used and with interference levels too
- Delay via link layer – When the system uses different types of link layer protocols, delays are incurred. So identification of spectrum bands for combining the parameter characterizations together.

b. Procedures for decision making

Decision making involves reconfiguring of the mode of transmission and the bandwidth needed for such a transmission. There is no guarantee for a spectrum band to be available for a CR user during the entire period of time, as primary user has more priority in the system. In this context, the CR users will not be able to use a particular channel indefinitely and as this is true for all CR network cases, decision making needs to be dynamic, as well as continuous in nature.

Noncontiguous spectrum bands are used for the transmission in CR networks simultaneously. Thus, this method can help form signals with high throughput and which is not deterred by primary users and interferences. So when one of the bands is undergoing handoff, the rest of system remains in the same condition.

c. Challenges involved in decision making

As in the cases of sensing, there are a few common challenges in the process of decision making;
• Model for decisions – Since SNR based spectral estimation is not enough, different QoS requirements pose a difficulty for the framing of a compatible model of decision making procedures.

• Reconfigurable cooperation – Reconfiguration, being an integral part of the system of decision making, helps in changing parameters as and when needed. So reconfiguration is to be combined with the cooperation among users is difficult.

• Heterogeneous spectrum decision making – Making a CR network to accommodate both the licensed and unlicensed bands alike is not easily done

C. Sharing

Sharing of wireless channels in CR networks needs the cooperation of transmission attempts among the users, which shows the importance of MAC protocol in sharing. Some of the most high spoken for challenges in the sharing procedures are coexistence of users, range of spectrum available and the actual user priorities involved.

The four main aspects of the sharing procedures in CR networks may be explained as;

1. Sharing procedure architectures
2. Spectrum allocation ways
3. Techniques for spectrum access
4. Intra/Inter networking
   a. Sharing procedure architectures
      The main architecture models in sharing will be either decentralized or centralized; centralized sharing mechanism will be controlled only with the help of one control entity while the decentralized mechanisms will have many node based local or global policies rather than a single version of standards.
   b. Spectrum allocation ways
      Two ways of allocating shared spectrum will be cooperative type and non-cooperative type;
      Cooperative sharing of spectrum will make sure that the interference from each node is considered, in order to form a cluster based network model for balanced sharing.
      Distributed or non-cooperative sharing methods are selfish solutions for the CR network systems, as they do not communicate between one another. Performance is degraded due to non-cooperative approaches while cooperative techniques prove to be effective.
   c. Techniques for spectrum access
      Other forms of sharing techniques include overlay and underlay spectrum sharing mechanisms; overlay method deals with the sharing of spectrum with CR users only in absence of primary users in the spectrum, while in underlay mechanisms the CR users are allowed to use the spectrum even during the presence of primary users, with the spread spectrum techniques. Such techniques will make sure that the presence of CR users will be regarded as noise by the primary users.
   d. Intra / Inter networking
      • Intranetworking mode of sharing – Focuses on the sharing and allocation of spectrum between primary and CR users alike. The CR users are permitted to try accessing the channel, even in the presence of primary user, without causing interference.
      • Internetworking mode of sharing – Overlapping system locations enabled via multiple CR systems, governed by policies.
   e. Challenges involved in sharing
      Some of the common spectrum sharing challenges involved in the tuning of a CR network may be given as follows;
      • Channel based common control – A CCC or a common channel control is needed in sharing of spectrum but it is not possible to use a fixed CCC in real time systems, for single or clustered systems
      • Range of the actual dynamic radio – As the radio operators and their frequencies are not dependent, the consequent changes in the frequency of operation is possible, which cannot be addressed always
      • Basic unit of spectrum - Without considering the spectrum as single unit, the sharing is not possible in real time and this consideration is not easily included in our algorithms.
• Information on the location of the CR user – An assumption that the CR users know the location of primary users and vice versa cannot always be proved right when it comes to real time systems

D. Mobility

Managing the CR network users’ change of operating bands, when the primary user requires that band, is an ultimate requirement of the concepts of Cognitive Radio networks. It does not mean that once a CR user locates a perfect band in the operating spectrum, it can be used by the same user indefinitely or even till the end of the transmission.

The primary user will sometimes immediately require the use of a particular spectrum band which was allocated by the decision algorithm to the CR user. This update of priority should make sure that the CR frequency is released and handed over, back to the licensed owner.

Mobility management is the key to the handoff procedures, which we use currently in many situations. Mobility management ensures that the transitions are smooth and quick, without degrading the QoS of the primary user. Since this procedure requires the attention of most layers in the system, it is also in need of using actual real time information related to the duration of handoff procedures. So spectrum mobility and spectrum handoff are still open for research ideas and improved implementation / investigation.

a. Challenges involved in mobility

Two most important problems seen in terms of mobility are,

- Time domain related mobility – Enabling of QoS in time varying channel availability is difficult
- Space domain related mobility – Enabling of QoS when user moves from one place to another is also not easily possible

VI. CURRENT RESEARCH TRENDS IN COGNITIVE RADIO NETWORKS

The notion of providing decision making intelligence to already existing technologies and systems to achieve Cognitive Radio Capabilities has given rise to several prospects of research in this field. Some commonly referred terminologies in this field of research are Emergency system, Cooperative spectrum sharing, non-cooperative spectrum auction, spectrum efficiency and estimation, Dynamic decision models and Spectrum safeguards. Some of the highly noted research interests in this domain (but not limited to) may be discussed as follows;

a. Evaluating Cognitive Radios

Cognitive radios are being deployed and implemented in most parts of scientific community with which many claim to have solved the spectrum access problems. However, the authenticity of such claims and the physical proof of the same needs to be verified as pointed out in [6], [10] and [20].

b. Dynamic Spectrum auction and access

Auctions for spectrum access, under the governing bodies of spectrum utilization in each region of the world, are carried out for both primary access as well as cognitive access. The hierarchical structure of such access are framed during that time and provided to respective takers of the portion of spectrum.
However, the auctioned spectrum needs to be verified from time to time for potential misuse of the policies. Some papers like [11] and [22] gives a detailed account on how auctions for spectrum access are done, how policies for their usages are framed and the steps necessary for controlled strategies to use the shared spectrum effectively. [15] shows the opportunistic behavior and outage statistics of the spectrum usage model with bidirectional relay users control.

c. Emergency Services and Crowd control

[21] shows the collection and manipulation of data concerned with calamity struck regions in order to guide people away from the hazardous location quickly. Random neural networks, Dynamic spectrum utilization and reinforcement learning are used for calculating the best guided routes for different categories of the people with different parametric variations. Similar usage of Cognitive Radio models in the field of Emergency services are researched upon for real time implementation and commercialization of such Cognitive radio modules.

d. Emulation of Cognitive Radios with single / multiple primary and secondary users

Number of primary users in the spectrum corridor plays a major role in determining how well the spectrum can be shared with secondary users and to what extent the secondary users can effectively use the shared spectrum without sacrificing quality of service on both ends of the system. The emulation of Cognitive radio with importance to the number of primary users is shown in [16] and to some extent in [11].

Similarly uncontrolled number of secondary users in the system contributes to induced interference to the primary users and also to self-interference. The statistics in such study reports show that the number of primary users in comparison with the number of secondary users can be a very optimal area of interest for research in this domain.

e. Future Network Throughput enhanced models

In real time Radio scenarios, it is almost impossible to determine the entropy of the system and the prediction of users is therefore uncertain most of the time. [19] shows such environments which exhibit imperfect conditions for user prediction and resource allocation in the system. [31] provide vital results pertaining to the context of imperfect sensing ad the throughput calculations involved in those conditions. The results show the effect of multiple users and Hybrid Automatic repeat requests on the Cognitive Radio model.

[27] states the importance of cloud based data logging and control with improved throughputs for the test conditions involved. It also shows that researchers are combing the concepts of Internet of Things with the Cognitive Radio models to achieve connected emergency services.

f. Security aspects and behavioral pattern logging

Due to the fact that receiver signal is random and fading in nature, the transmission power is fixed high enough at the source which can be utilized by eavesdroppers to determine the data sent or behave like an authorized primary user in the system by studying the signal parameters carefully. Such conditions are discussed in [18] with emphasize on MISO systems.

Attacks to the resources of the Cognitive radio environment takes place in all lower layer levels of the OSI model and the most common attack region is the physical layer. Spoofing attacks [40], Denial of Services and Data Falsification attacks [42] are some recently studied attack models which are seriously undermining the research in this field. Detailed listings and countermeasures of many such attacks have been discussed and elaborated in [41] and [42].

g. Spectrum access to cloud services and QoS

Cloud based architectures for opportunistic uploads and downloads [33] and Quality of services measurement in relay based machine level communications [34] are some of the latest trends in Cognitive Radio research domains. Many research aspects have been identified in the area of Quality of services enhancement and evaluation for Cognitive radio network. The main idea is to find out the effectiveness of a proposed system in order to make commercialization of the same a lot easier. Also papers like [41] show that the Quality of services is severely affected by user attacks on the system.

h. Power parameter measurements for different CR models and user numbers

Energy analysis, Power controls and thresholds settings for primary and secondary user detection are shown to be alternative options of research in recent years. [17] shows spectral utilization for certain scenarios in real time and calculates estimation of parameters for modeling into a real time installable system. Power usages for specific routing algorithms [26] and transmission strategies for Cognitive wireless sensors [35] are also researched upon by
many. Such results provide useful references to model a good decision model and dependable version of Radio networks, especially for 802.22 Emergency services.

i. Optimal Spectrum Sensing, Mobility and Allocation management

Research in the four major functional domains of Cognitive Radio working model will be another viable option at all times, as newer technologies and systems require different and better tools to operate. The four main functions as discussed in the previous chapter of this survey are Sensing[12][32], Decision[14][36], Sharing/Management[16][37][38] and Mobility. Researchers study the aspects either an individual function or in combination with one or more of the functions together. Also Queuing concepts and mutual cooperation among users with reference the four functions are also being analyzed deeply.

j. Transmission and Reception model for MISO and MIMO Cognitive Radios

Newer concepts like Multiple Input and Single / Multiple Outputs are being analyzed for usage along with Cognitive radio networks as they tend to improve QoS and Transceiver capabilities of a wireless channel. The signal conditioning, multi-copy transmission and SNR adjustments can be done during transmission from source which are discussed and elaborated in [24] and [25]. [36] accounts for the same type of calculations with better considerations in the form of separate sensor nodes and imperfect sensing probabilities.

While transmission parameters play an important role, the parameters concerned with the receiving end have an equally important role towards MISO and MIMO Cognitive Radios. [18], [23] and [29] show us the cooperation of Cognitive systems in terms of MISO, MIMO and Massive MIMO.

k. Interference management algorithms in cooperative models

The detection of spectrum underutilization primarily uses three mechanisms namely, energy detection, cyclostationary methods and matched filtering. Out of these three main methods, energy detection is used commonly for the secondary user access in the absence of primary user in case of Overlay access methods or along with primary users in the case of Underlay access methods. The interference between primary user and secondary user as well as between different secondary users can be a vital key to finding whether the spectrum is in use or not. [15], [30] and [38] show the above points in detail with particular emphasis on primary users’ interferences.

l. Resource utilization statistics for existing commercial Cognitive Radio hardware platforms

The most difficult type of research for CR domain concepts, in general terms, will be to choose commercially available modules and to test the same under various algorithms and design aspects by either fixed parametric calculations or through analytic and experimental scenarios. There are hardware platforms for Cognitive Radio implementations like USRP modules from Ettus research which can be of great use for real time analysis of our algorithmic models.

Companies like Nokia [45], xGTechnologies [44], Alcatel, Ettus Research [49], Wipro [43], Xilinx [48] and many others have been in the field of Cognitive Radio Development for quite some time now and each of their platforms have their own advantages and disadvantages.

Software tools specifically designed for cognitive radios like GNU Radio [46] [47], SDR and libraries written for CR implementations that can be interfaced with existing software platforms are also available in the market.

VII. CONCLUSION

Opportunistically exploiting the spectrum for CR network needs helps achieve total quality of service and to utilize the limited spectrum, while reducing inefficiency in the usage criteria. With the capabilities of a CR network, a system with a complete knowledge of the spectrum is created. In this survey, the main goals of CR networks along with most of the sub category protocols and functions were explained. This survey also deals with the complete set of explanations for all related functions of a CR network such as sensing, decision making, sharing and mobility management. Several factors are playing key roles in the research methodologies of Cognitive radio in real time implementation and some of the common aspects were discussed in brief. Hence, in order to provide an effective communication system with spectrum aware properties, better research results and surveys are needed.

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