A SURVEY ON DYNAMIC SPECTRUM ALLOCATION PROTOCOLS

Narcis ILISEI
PhD Student at "Gheorghe Asachi" Technical University of Iasi
inarcis@etc.tuiasi.ro

Abstract. *The current telecommunications systems face an increasing pressure on a limited natural resource – the electromagnetic spectrum. However, the spectrum usage is not evenly distributed: there are significant bands with little or no activity. Due to advances in the development of software radios, now the wireless devices have the capability to dynamically allocate and switch to unused or under used spectrum bands. The current work is an analysis of several dynamic spectrum allocation protocols .*
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Introduction

Current spectrum allocation rules set by regulatory bodies have lead to an artificial spectrum scarcity, even though large swaths of spectrum remain underutilized. The electromagnetic spectrum is reusable in time and in space, but the today's allocation is statically defined. Static allocation consequently implies not exploiting the time and space re-usability of the spectrum. That is, at different moments in time, chunks of spectrum otherwise allocated may be not used, in a specified geographical area. As an example, in Fig. 1 is depicted a typical spectrum usage in a metropolitan area.

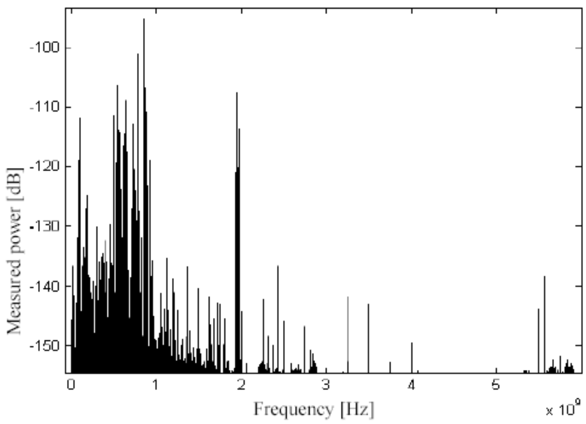

Figure 1. Spectrum utilization measurement between 0-6 GHz, in a typical metropolitan.

The term *cognitive radio* has been coined by J. Mitola [8] and refers to a device's ability to sense surrounding environment conditions and adapt its behaviour accordingly. This process is often referred to as cognitive cycle: (sense - characterize - learn - adapt). Devices equipped with cognitive radio can change very fast their operating frequency, can change the employed modulation and they have spectrum monitoring capabilities.

The current work addresses the *coordination protocols* of such intelligent radio devices in their attempt to find and exploit underused parts of the electromagnetic spectrum. Specifically, the currently proposed dynamic spectrum allocation protocols are reviewed and analysed.

What is a Dynamic Spectrum Allocation Protocol

One of the key problems in a radio communication system is the frequency where it operates. This frequency is often confined to some restricted bands where the individual stations may transmit and receive. In order to avoid or reduce interferences, many systems have provisions for dynamic channel allocations to individual stations. The stations would then change the operating frequency to the newly prescribed band.

The Dynamic Spectrum Allocation is a generalization of the dynamic frequency channel allocation encountered in many communication systems.

The main actors are: the *spectrum controller*, the owner of a wider area of a 'spectrum pool' [5], and the *spectrum consumer*, a device or a group of devices that need a certain frequency band in order to communicate.

The Dynamic Spectrum Allocation Protocol (DSAP) is the control protocol used for the dynamic spectrum allocation process between the spectrum controller and the spectrum consumers.

The functions of the spectrum controller

Detection of spectrum usage information

The identifying of spectrum bands not used at a given moment in time in a given geographical area is a problem in itself. One assumes here that some devices, at least, have this capability.

The spectrum usage information is assembled from several sources:
• static information from regulatory bodies
• a set of rules that specify what frequency bands can/cannot be used for the location (e.g. some air traffic control frequencies might be kept 'untouched')
• dynamic information coming from detector stations 'in field'

The dynamic spectrum planning

The channel allocation in a given frequency band has been addressed very often in the context of optimizing the performance of cellular mobile stations. The existence of various algorithms that can resolve this problem constitutes another assumption for the current work. (e.g. in [6])

Despite the existence of detection and planning capabilities, the very cognitive nature of the new devices implies a high degree of freedom and unpredictability in how they find a new, free frequency. Left uncoordinated, each device or group of devices would make their own frequency planning which it is reasonable to result in a less effective frequency allocation when compared to a cooperative approach.

DSA approaches

In order to implement the functions above, some way of communication among the devices is necessary. In the literature and practice so far one can identify several approaches.

No explicit spectrum allocation protocol

This is the case for communication systems that are reliable enough to resist to interference from other systems by means of some implicit channel hopping capability. An example would be Wireless LAN IEEE 802.11 standards and Bluetooth devices. The performance degrades because of frequency bands collision, but the devices can coexist.

Collaborative approach. No centralized planning

In this case all involved devices broadcast their spectrum usage information. This helps other parties that otherwise would potentially collide, to chose free frequency bands [2]. A spectrum server could broadcast periodically this information in a specific geographical area.

CSCC [2] features a Medium Access Control (MAC) protocol that transports information like: radio type, channel used, priority, price tag. The important point in this protocol is that each device decides alone what channel to use. There is no attempt to assign a governing role to some participant.

The advantages of this approach are:
• the simplicity. With an incremental improvement added to an already collision resistant protocol one achieves significantly better results.
• there is no need of feedback among participants for spectrum allocation.

Among disadvantages we can enumerate:

•the decision of what channel to use next is left up to the device. A certain level of trust is assumed. Devices with different decision strategies or implementing different versions of the protocol may cause confusion in the system.
• the system is applicable only to new, intelligent devices that implement the protocol. There is no compatibility concern about legacy primary users that might be using a less reliable physical layer protocol.
• there is no authentication and no encryption involved. Without authentication there is no trusted base for spectrum mini auctions.

A spectrum controller device coordinates the frequency allocations

This approach involves a governing entity that actively assigns frequency bands to devices upon request. The controller shares a common protocol with the involved radios, dynamically leases channels and gets confirmation from the other party [4],[1]. The slower changing information can be available on the Internet, in specialized servers (e.g. 'spectrum.net' [2]). This solution may have several flavours, two of them being presented below.

The controller is part of a network involving other controllers and eventually a central database server. The policies are decided in a centralized manner. The approach in [1] is suitable for extending the current cellular networks, or inside large organizations, but not applicable for small, ad-hoc networks.

The controller implements spectrum monitoring function. It is itself aware of the surrounding spectrum usage, but not necessarily part of large governing infrastructure. It coordinates itself with immediate wireless neighbours and possibly with a server hosting a spectrum usage database.

In any case, a well defined protocol, both at physical level and at MAC level is needed for this bidirectional communication between individual devices and the spectrum controller. The work presented in [4] goes well in this direction. The Dynamic Spectrum Allocation Protocol (DSAP) features:
• dynamic channel leasing for a period of time – resembles much the Dynamic Host Configuration Protocol (DHCP), a protocol for assigning dynamic IP addresses to devices on a network.
• active network performance monitoring and active reconfiguration of the allocated channels

The main advantages:
• the client devices are not required to have any planning and detection capabilities on their own. They just have to ask and trust the DSAP server.
• the server adjusts dynamically the channel configuration for best performance. Again, simplicity for the clients.

The disadvantages:
• the DSAP server is required to understand the physical layer protocol of the clients, in order to decide anything about the network performance. That makes the DSAP server harder to scale up to many client devices using different protocols.
• there is no provision for client detecting the incumbent primary user.
• the DSAP protocol does not provide secure authentication and encryption

Conclusion and future work

The currently proposed DSA protocols are part of the MAC layer, and as such, specialized for a certain communication system.

We see the need for a separation between the DSA and the associated protocol and the specifics of the employed modulation. A new protocol should also have minimum provisions for the authentication of the traffic participants and for the allocation secrecy.

The new protocol will be supported by a dynamic spectrum controller (DSC), the machine that implements the DSAP and manages the spectrum in a specific geographic area. The DSAP tries to accommodate the main advantages of the other proposals and some

additional features that could make it of practical use in the current environment.
The DSA architecture, while infrastructure based, reminds more of peer to peer computer networks than the traditional centralized approach. That is, the individual controllers tend to connect to a higher level planning entity, but this is not required. The DSCs could be deployed only in areas where the spectrum is crowded and and the flexibility really needed.

A simplified version is shown in the Figure 2. The DS controller (DSC) is the machine that covers the last mile of dynamic frequency allocation. It talks to the clients asking for a frequency band where they are allowed to communicate. The actual policy maker is the machine that controls the main DSA database. The connection between DSC and DSA is assumed to be fast, possible over Internet. The DSCs have to coordinate the local frequency allocations.

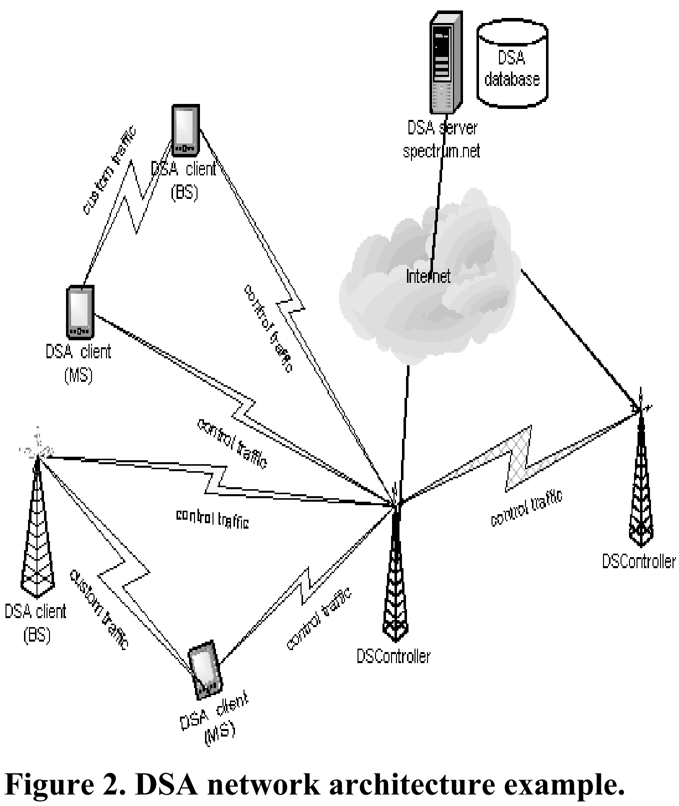

Figure 2. DSA network architecture example. Two different networks are controlled by one DSC.

Future work aims at defining and implementing the new DSAP protocol embodying the advantages of several presented protocols and new requirements on security and portability.

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