DSASim: A simulation framework for dynamic spectrum allocation

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Abstract— **The current methodology for distributing the frequency spectrum among users is in need of revamping. This is necessary in order to increase the number of users able to access the communication channels; to better manage usage in metropolitan areas, where the usage of wireless communication is still rapidly increasing; and to ensure adequate frequency allocation for users during peak usage times. Several methods and paradigms have been suggested as replacements for the current scheme of distributing spectrum among users. This paper proposes a simulation framework to simulate a broker-based system to implement a dynamic spectrum allocation environment. The broker operates based upon pre-defined spatial and temporal requirements in a manner where operational parameters are set up or collected dynamically. The broker system responds to the radio devices, allocating the suitable amount of frequency spectrum required for a particular application. The results of the simulations show a promising and efficient utilization of frequency spectrum resources.**

I. Introduction

With the explosion in general usage of wireless communication and the limited nature of the frequency spectrum capable of transmitting these communication signals, spectrum is becoming one of our most valuable resources. Technology and markets are evolving to incorporate many more different devices and applications that make use of this medium. The availability of spectrum for the increased demand is becoming a major problem. One the other hand, studies [1] in this area show that most of the allocated spectrum is vastly underutilized. This has been caused by various reasons: i) the spectrum was allocated for old technologies that require wide guard bands and ii) the emerging technologies allowed user to move from legacy systems leaving the previously allocated frequency bands underutilized. A good example of these reasons is the analog UHF TV band, which is being replaced by digital signals, even while many receive their signals via cable or satellite. Another reason is that some services such as public safety are usually allocated for peak demand usage.

The frequency spectrum is a limited resource and the current methodology for frequency allocation is a fixed spectrum allocation (FSA). This is done through several agencies around the world. The FCC regulates the US market along with the NTIA which regulates spectrum assigned to US Federal agencies. Europe on the other hand, has its own regulatory body. In the US, licenses for frequency bands are sold at auctions. This portion of the spectrum is then available for the exclusive use by the purchasing agent and cannot be utilized by other interests. However, there are many disadvantages associated with this approach. For instance, varying concentrations of usage of wireless services lead to local underutilization in one area and congestion in another for the same spectrum range. Those who purchase frequency ranges base their need on the peak-hour usage to ensure adequate space for the clients. The reasons discussed and many others leave the spectrum inefficiently allocated.

Recently, researchers and manufacturers have taken advantage of unlicensed frequency bands, as proven by the explosion in 802.11 based wireless networking, Bluetooth devices, cordless telephones, and so on. The availability of these bands have sparked unprecedented innovation and wireless access for the consumer.

Developing a different and more effectual allocation model is inevitable. Various models have been proposed, such as XG [2], DRiVE [3], DIMSUMNet [4], and DSAP [5]. It is apparent from these approaches that the spectrum can be most efficiently utilized through a dynamic allocation of bandwidth on as-needed basis. This determination can be realized by a multi-agent system in which brokers can allocate the available resources among the clients requesting usage in a given area at a certain time. A detailed survey of this area can be found in [6], [7].

Our simulation framework, based on the architecture of DIMSUMNet, consists of a spectrum broker and several radio access networks (RANs). DSASim develops the broker system to manage and allocate frequency spectrum resources and its dynamically changing parameters increase the efficiency of the spectrum allocation as a whole. These parameters are mainly temporal and spatial. In this manner, the broker can make sure the free spectrum is distributed in such a way that as many requestors as possible are satisfied based upon historical data, rolling in one week intervals. The system components include database, GUI, and simulator.

The core of the DSASim is the algorithm which makes the decision of how to allocate the spectrum more efficiently between the contending RANs. This decision needs to take into consideration the dynamically changing parameters such as the time of the day, the demand of each RAN, the available spectrum, the geographical position of the RAN, and so on.

The rest of the paper is organized as follows. We surveyed the literature work in Section II. Section III introduces our proposed DSASim simulation framework. Simulation results based on the generated data are presented in Section IV. We discuss future directions and conclude in Section V.

II. Related Work

A. Dynamic spectrum allocation approaches

There are several approaches for spectrum allocation dynamically in programmable wireless networks. The XG [2] program is intended to enable interference free communication for everyone. The DRiVE [3] program on the other hand, aims to develop methods for dynamic frequency allocation and for co-existence of different radio technologies such as GSM, GPRS, UMTS, DAB, DVB-T. The goal is to integrate allocation of these different radio technologies into one frequency band to increase the total spectrum efficiency and availability. Spectrum can be then allocated via usage patterns. In other words, GSM services would receive more spectrum during the work day while some of that spectrum would be dynamically allocated to DVB-T services during high demand evening hours.

Several approaches discussed coordination of communication in specific bands. Raychaudhuri [8] presents the "common spectrum coordination channel (CSCC)", a spectrum etiquette protocol for coordination of radio coordination devices in unlicensed frequency bands. Each node in the network broadcasts onto the CSCC its particular abilities (e.g. available frequencies, powers, modulation schemes), and then as a group the nodes allocate spectrum equally. Because this data is made up of small bursts and nodes only utilize the CSCC when requesting spectrum, the channel can be narrow and use low bandwidth. The protocol was studied for specific bands (2.4 GHz and 5 GHz). Based on the 802.11b physical layer and the periodic broadcast protocol at the MAC layer, Raychaudhuri shows that the 2.4 GHz ISM band, contending 802.11 and Bluetooth devices can achieve improved throughput and delay for both devices.

A different approach was proposed by Brik's DSAP [5] in which a mechanism is introduced to deal with densely populated localized areas. DSAP can be implemented at the endpoint of an infrastructure-based network, i.e. if the DSAP server is connected to an Internet gateway. DSAP however does not alleviate the problem of allocating frequencies across the entire radio spectrum or over wide geographic areas. It is most effective in very small geographical areas because of its ability to manage spectrum allocation in limited spatial and temporal scales.

DIMSUMNet [4] is yet another approach based on spectrum brokerage and it is considered a dynamic alternative to the fixed spectrum allocation regulated by FCC. Its main functionality is to manage spectrum based on regional setup and lease portions of it to domains or users.

B. Optimization algorithms

Leaves [9] discusses several basic schemes for the dynamic allocation of spectrum. The first scheme, *contiguous DSA*, can be seen as an evolution between fixed and dynamic assignment. Contiguous assignment still uses contiguous blocks of spectrum allocated to different RANs, and these are separated by a suitable guard band, much like fixed assignment. This scheme has been investigated [10] in DRiVE [3].

Another approach is the *fragmented DSA* in which spectrum segments are treated as a single pool and each RAN is arbitrarily assigned a piece anywhere in this pool. This algorithm is not dependent on adjacent fragments and is more complicated than the contiguous approach. Finally, in the *fully dynamic DSA* approach each RAN can be allocated any part of the spectrum dynamically.

III. DSASim: DSA simulation framework

A. Architecture

DSASim simulates an infrastructure based dynamic spectrum allocation (DSA) system where each radio access network (RAN) communicates with the broker to request and receive spectrum allocations. These allocations grant the right to emit a prescribed amount of power in a certain frequency band throughout a geographic region.

Implicit in this design is the requirement of the mobile nodes (MN) to have a spectrum token in order to transmit. This token is issued by the RAN Controller (RANC) according to the spectrum allocation granted by the broker. The token expires along with the allocation expiration.

Upon bootstrapping, a RANC requests its desired amount of spectrum from the governing broker. The broker in turn grants spectrum to the RAN according to the algorithm described below. This communication path may be via landline or via a CSCC. The RANC decides how to utilize this spectrum (e.g. signaling channel, channel bandwidth, etc.) and creates tokens which encapsulate the core information that MNs will need to communicate with the base station. The RANC then issues these tokens to each of its MNs via a CSCC. The MNs then configure themselves according to the terms of the token and communicate as needed. Some modifications to this process are needed in ad hoc situations. Namely, a RANC must be elected by the RAN itself. The contents and format of the token change accordingly.

Much as in DCHP, sometime before the allocation lease expires, the RANC negotiates a new lease with the broker. As a result, it issues new tokens to its MNs. In a situation where a MN is out of coverage when its token expires, it scans one or more CSCCs to find its RANC in order to download its token. The details of this process are left to the RAN designer; however, it is understood that this system requires a certain number of CSCCs in order to function properly.

B. Our approach

After careful evaluation of the options, we have chosen to base our algorithm on the contiguous DSA approach. It is the most suitable solution for our simulation framework. In

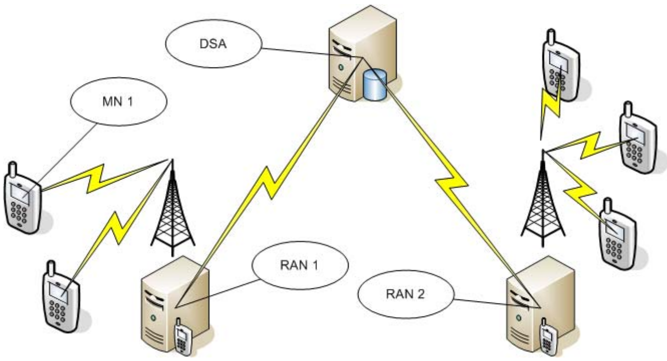

Fig. 1. System Architecture

this approach, the borders between the adjacent blocks are not fixed as shown in Figure 2; therefore, a RAN can "steal" channels from its adjacent neighboring block as long as they are not currently in use. In other words, this model allows dynamic spectrum partitioning at the expense of the adjacent block, which is allocated to another RAN. The aim of the brokers engine is to determine and coordinate the shifting of the boundaries between different blocks.

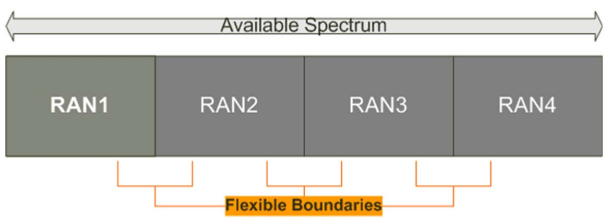

Fig. 2. Contiguous DSA scheme

Load history of each RAN, meaning the statistical average of the past spectrum usage, plays a great role in the contiguous DSA approach. More specifically, we only take into consideration the previous week's spectrum usage on the same day and time that the current demand is made. As a result, the static allocation takes place for the first week since we have no history. We use two configuration tables from the database module. This generates artificial real-life conditions that will help bootstrap the algorithm. The first table divides each given week into days and time slots for each day. We categorize the days and hours of each week according to their spectrum demand in real-life. The second table is used to generate a random number for the spectrum usage of each RAN. This random number however is limited and is chosen from a range of two fields, namely, the minimum possible spectrum usage and a respective maximum as well as the RAN ID in the first field. These min and max borders are not chosen arbitrarily. They are carefully set in the configuration table according to the time slot of each day. Hence, we have 33 min-max pairs resulting in 33 time slots for each week. For example, for night time during a week day, the min-max range will be smaller that at noon on a regular working day. This contributes to the illustration of real-life conditions.

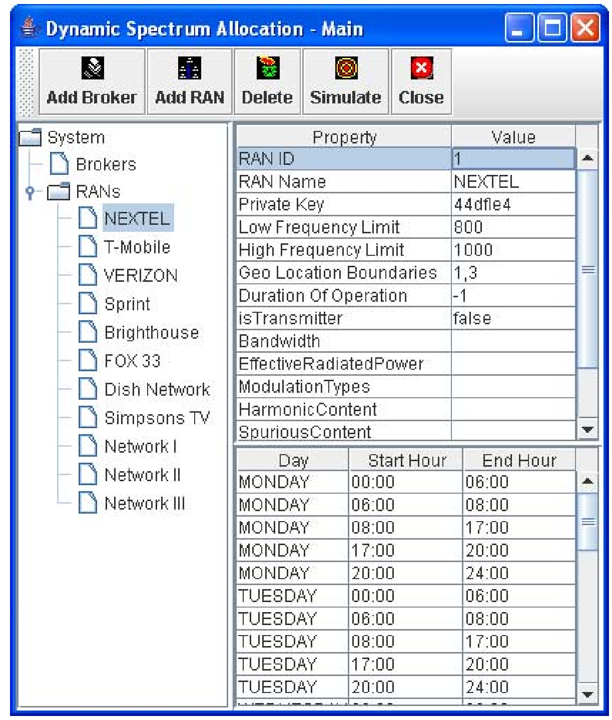

Fig. 3. A screen shot of the main application

For the first week of operation, the RANs are assigned equal spectrum portions, their random usage is generated and recorded as history for the specific time slots of the week. This history is then used for the next week at the same time in order to appropriately allocate the additional channels needed. More specifically, every week each RAN is allocated 20% more than its previous week's utilization. This reduces the amount of unused spectrum and encourage the RANs to avoid over-allocation of channels. The same process is repeated every week.

C. System components

The system is implemented on a Java platform with MySQL database engine and it includes the following three modules:

- **Database.** The database consists of data and configuration tables. Data tables hold the data objects such as the brokers and the RANs. Configuration tables on the other hand, handle the configuration data used for the simulation engine to function.
- **Graphical User Interface.** The interface is designed mainly to manage the data objects, control the simulation, and export the results. Data objects are manipulated through a simple Create-Update-Select-Delete options and a GUI for the user to manipulate the data. Figure 3 shows a screen shot from the main application interface.
- **Simulator.** This module uses the data saved in the database to simulate an environment and outputs numerical results such that they can be analyzed. Our algorithm is simulated by reading the objects and the

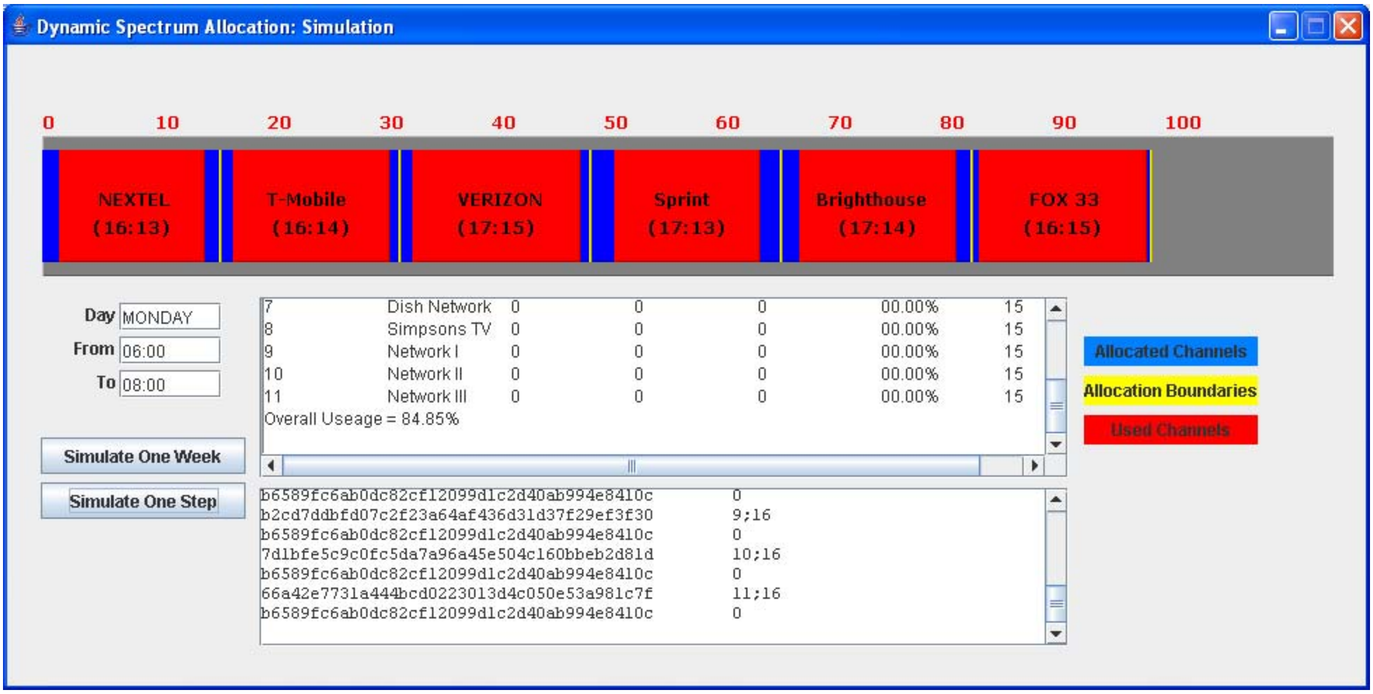

Fig. 4. A screen shot of the simulation framework

configuration tables saved into the database followed by the simulation process. The simulation can be done either per step, where a step is a time range that it is already defined in the simulation steps table, or per week, which simulates a whole pass through all the time ranges in the database table. The data is then saved into text files to be analyzed later. The simulator also utilizes a graphical representation of the available, allocated, and actually used spectrum. Figure 4 shows the graphical representation of the spectrum allocation in our simulation framework.

IV. Simulation Study

A. Environment and metrics

Simulations are conducted in eclipse development platform [11] which is based on Java. We simulated with two different time slots where each simulates different times of the day and different loads for each RAN.

The simulation parameters include the number of RANs with allocated spectrum usage, the percentage of the used vs. allocated channels for all RANS, and the overall channel usage of RANs. These metrics were calculated by varying the number of weeks.

The first experiment (Simulation 1) was carried out in a time slot of the day where RANs are assumed to have normal load. Eleven RANs were used for this simulation. The load of the RANs occupies almost 40% of the initial allocation. However, some RANs were set to have more used channels than others which resembled real-life situation.

The second experiment (Simulation 2) involved more condensed used channels to simulate the peak-time usage hours. Each run was conducted for 10 successive weeks. The collected data was first aggregated and analyzed. The next subsection summarizes our simulation results.

B. Results

The simulation results in figures 5-7 have shown the effectiveness of having a such simulation framework. Figure 5 presents the number of RANs that are successfully allocated spectrum. The other RANs are queued for the next iteration. The figure shows a high response curve for successful allocation in the case of normal load. This gives us an idea of the usefulness of a broker system when a normal load is expected during a time slot. We can also see poor, yet responsive allocation in the case of peak-time usage.

Figure 6 presents the percentage of used channels vs. allocated channels for all RANs. This indicates the ratio of how many channels were in fact in use. If a channel is allocated to a particular RAN, but not used, this affects the outcome of the allocation for that RAN in the next round. It can also be seen a slight improvement of the allocation process in the case of peak-time usage.

The overall channels used by all RANs are shown in Figure 7 for both experiments. The results are much similar to the results in Figure 6 with some improvements in the case of peak-time usage.

V. Conclusions and Future Work

In this paper, we present a simulation framework, DSASim, which simulates an infrastructure based dynamic spectrum allocation (DSA) system where each radio access network (RAN) communicates with the broker to request and receive

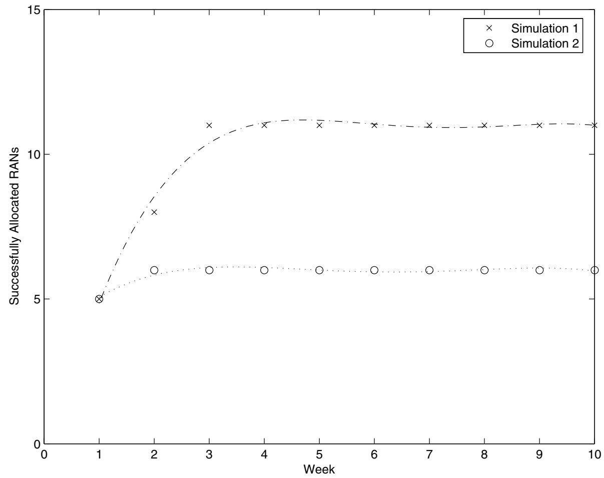

Fig. 5. RANs with allocated spectrum

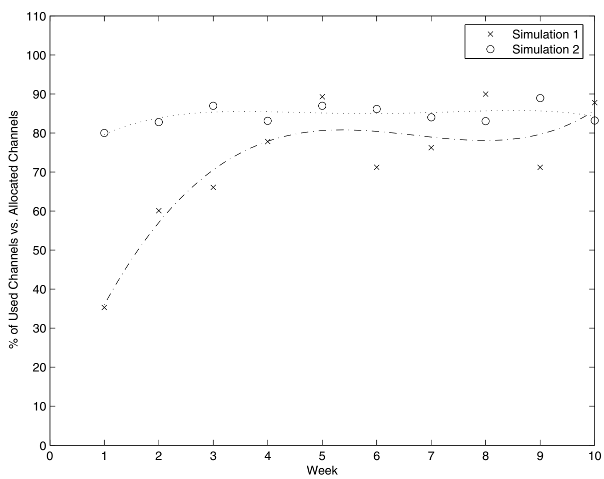

Fig. 6. RANs channel usage percent

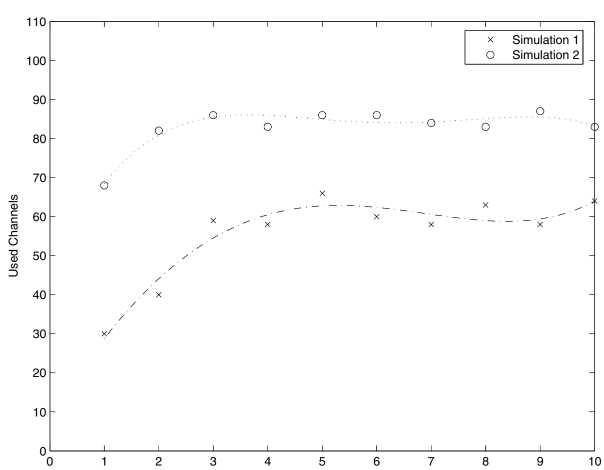

Fig. 7. RANs channel usage

spectrum allocations. The results showed that the broker algorithm is effective in reducing the fragmentation of the spectrum, thus increasing the efficiency.

In order to have a more mature broker system, several improvements can take place and these may include: i) creation of a hierarchy structure to facilitate communication and cooperation between brokers; ii) additional set of parameters in modeling the spectrum allocation; iii) consideration of the effects of the irregular terrain on the transmission of wireless signals; iv) designing a security component for the communications between brokers and RANs. Necessary authentication of RANs must be completed before communication lines may be opened with a broker. Information integrity must be verified as wireless communications are vulnerable to various attacks such as intrusion, denial of service, and so on.

ACKNOWLEDGMENT

The authors would like to thank Brent Horine for suggestions on the architecture, Mohammad Z. Ahmad and Nikos Peppas for their review comments.

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