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Dynamic Spectrum Allocation in Composite Reconfigurable Wireless Network

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Abstract:
Over time wireless networks has evolved into more complex systems. And all of these systems depend on static and/or licensed Spectrum allocation without which signal interferences will be unavoidable. This static nature of spectrum allocation has left some wireless networks less of useful frequency/spectrum while others have it in excess. With the increasing convergence between composite networks, static allocation approach is no longer appropriate, since greater spectrum efficiency can be gained from the use of excess spectrum from different radio systems for other systems at different times and probably locations too. This paper assumes the reader to be new to wireless technology, and therefore introduces briefly Wireless Communication, Spectrum Allocation and types, and Concept of Dynamic Spectrum Allocation (DSA) and its benefits in a composite reconfigurable wireless network.

Keywords: Composite Networks, Dynamic Spectrum Allocation, Frequency Allocation, OSI Layers, Reconfigurable Networks, Spectrum, Wireless.

I. INTRODUCTION

Wireless Communication is the transfer of information or power between two or more points (nodes or network devices) that are not connected by an electrical conductor. The most common wireless technologies use radio waves and this include: Cellular Telephone Systems, Cordless Phones, Wireless LANs, Wide Area Wireless Data Services, Fixe Wireless Access (which provides wireless communications between a fixed access point and multiple terminals, Paging Systems, Satellite Networks, Blue Tooth, Home RF, and others like Remote Sensor Networks, Satellite for car tracking, et.c.
The flexibility involved in connecting different devices without the use of physical media like wires or cables; gave rise to and has increased the success of wireless communication technologies in electronic industry. Wireless communication can be found both in consumer electronics and industrial electronics. Presently wireless communication systems are almost everywhere around us ranging from the home electronics remote control systems that use infra-red, to advanced wireless technology found in GSM systems, and Satellite Communications. Wireless technology has found its applications in sectors such as Aviation, Security, Land and Rail Transportation Systems, et.c.
Another application is in industrial process monitoring and control, where process variables like; Pressure, Temperature, Flow, Level, Humidity, Density, Viscosity, vibration intensity and several other parameters can be collected through sensing units (Sensors) and transferred (through transmitters) wirelessly to a control system for processing, operation, monitoring, control, and management.

II. METHODOLOGY

SPECTRUM ALOCATION

Spectrum Allocation also called ***Frequency Allocation*** is the process of regulating the use of the electromagnetic spectrum. This involves sharing it among various and sometimes competing organizations and interests. This practice ensures that there is little competition when using specific frequency bands. Some Common Frequency Allocations by International Telecommunication Union (ITU) can be seen in the Fig. 1.

Table.1. International Telecommunication Union (ITU) Frequency Allocations [7]

Band name	Abbreviation	ITU band number	Frequency and Wavelength	Example Uses
Extremely low frequency	ELF	1	3–30 Hz 100,000–10,000 km	Communication with submarines
Super low frequency	SLF	2	30–300 Hz 10,000–1,000 km	Communication with submarines
Ultra low frequency	ULF	3	300–3,000 Hz 1,000–100 km	Submarine communication, communication within mines

Very low frequency	VLF	4	3–30 kHz 100–10 km	Navigation, time signals, submarine communication, wireless heart rate monitors, geophysics
Low frequency	LF	5	30–300 kHz 10–1 km	Navigation, time signals, AM long wave broadcasting (Europe and parts of Asia), RFID, amateur radio
Medium frequency	MF	6	300–3,000 kHz 1,000–100 m	AM (medium-wave) broadcasts, amateur radio, avalanche beacons
High frequency	HF	7	3–30 MHz 100–10 m	Shortwave broadcasts, citizens band radio, amateur radio and over-the-horizon aviation communications, RFID, over-the-horizon radar, automatic link establishment (ALE) / near-vertical incidence skywave (NVIS) radio communications, marine and mobile radio telephony
Very high frequency	VHF	8	30–300 MHz 10–1 m	FM, television broadcasts, line-of-sight ground-to-aircraft and aircraft-to-aircraft communications, land mobile and maritime mobile communications, amateur radio, weather radio
Ultra high frequency	UHF	9	300–3,000 MHz 1–0.1 m	Television broadcasts, microwave oven, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS and two-way radios such as land mobile, FRS and GMRS radios, amateur radio, satellite radio, Remote control Systems, ADSB
Super high frequency	SHF	10	3–30 GHz 100–10 mm	Radio astronomy, microwave devices/communications, wireless LAN, DSRC, most modern radars, communications satellites, cable and satellite television broadcasting, DBS, amateur radio, satellite radio
Extremely high frequency	EHF	11	30–300 GHz 10–1 mm	Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner, wireless LAN (802.11ad)
Terahertz or Tremendously high frequency	THz or THF	12	300–3,000 GHz 1–0.1 mm	Experimental medical imaging to replace X-rays, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, remote sensing,

The frequency bands can cause interference if they are used for different and unregulated purposes.
This regulation is controlled and standardized by various governmental and international organizations such as [8];
• International Telecommunication Union (ITU).
• European Conference of Postal and Telecommunications Administrations (CEPT).
• Inter-American Telecommunication Commission (CITEL)

Spectrum allocation is being used extensively now that there is emergence of more complex wireless telecommunications technologies.These technologies have created huge demands on the radio frequency spectrum for various services such as high-speed data transfer and communication. The purpose of various spectrum policies and laws is the management and regulation of the electronic spectrum for the benefit of everyone that make use of it. Spectrum allocation is therefore done to prevent major interference and chaos in the air waves.

TYPES OF SPECTRUM ALLOCATION

Spectrum allocation can be grouped under the following;

- **No One May Transmit** – Spectrum band that fall within this category is reserved for a specific use such as radio astronomy so that there is no interference with radio telescopes.
- **Anyone May Transmit**–Anyone may transmit using the frequency bands that fall in this category as long as transmission power limits are respected.
- **Only Licensed Users/Organisations of the Specific Band may transmit** – Examples of spectrum/users that belong to this category are Cellular and Television Spectrums as well as Amateur radio frequency allocations.

STATIC SPECTRUM ALLOCATION

Radio spectrum is being allocated with static licensing to a particular radio standard and eventually to specific

organisations/users. Network operators own their spectrums, which are of fixed size and protected from interference by Guard Band. These licenses remain solely for the use of the licensed owners until the licenses expire. This method makes it simple to design hardware for use at a known frequency band.
The wireless networks converge and **composite networks** emerge, which is the resultant network when the boundaries between the services offered over different systems slowly disappear. The old spectrum allocation (Static) as a result of the emergence of the more complex and dynamic systems will make the resource utilization seize to be efficient.

Put differently, with the increasing convergence between composite networks, static spectrum allocation is no longer appropriate, since greater spectrum efficiency can be gained from the use of spectrum being used by other radio systems at different times or different locations. To enhance the benefits from this diversity of spectrum usage in the systems, some new spectrum allocation concepts are being investigated, namely [1];

- Open Spectrum
- Dynamic Spectrum Allocation (DSA)

This paper however discusses Dynamic Spectrum Allocation (DSA) concepts in a composite reconfigurable wireless network.

DYNAMIC SPECTRUM ALLOCATION (DSA)

As against static spectrum allocation, Dynamic Spectrum Allocation involves allocation of frequencies to users dynamically and on demand basis. Most wireless networks are subject to time and regional variations in the degree to which spectrum is utilized.

That is traffic may vary with time and location. The waste of spectrum happens when traffic in one place is low while in another place is high. An arrangement for dynamic account allocation is achieved by pooling together Spectrum and network availability, as well as congestion information, from different Service providers in a central database. Also by the purchase of wholesale Volume of network capacity or accounts with predetermined monthly usage. The purchased network capacity is dynamically allocated to devices of different origin and ownership. The central System operator handles the rebilling and reconciliation of any fractional usage to each device.

Unlike other proposed Solutions that require the carriers to bet on proprietary technologies and involve changes to the network and high capital expenditures to build and operate the network, the present invention requires no changes to the carrier's network and no investment in a proprietary Solution but only reconfiguration.

The Dynamic Spectrum allocation schemes have the goal of increasing the spectrum efficiency, which is achieved by exploiting temporal and spatial variations in the traffic demands that are seen on disparate types of radio systems, such as cellular and broadcast networks. When these networks are operating in composite multi-radio systems, then it provides the ideal environment for operating a Dynamic Spectrum Allocation (DSA) scheme. The goal is to allocate the spectrum dynamically to the radio access technologies (RAT) over space and/or time, as required, while at the same time managing or preventing any resulting interference.

Previous work by Leaves P., et al. has investigated the use of both;

- Continuous DSA – For use with two RANs (Radio Access Network)
- Fragmented DSA – For use with more than two RANs

CONTINUOUS DYNAMIC SPECTRUM ALLOCATION

In continuous DSA as demonstrated by Fig. 2. & Fig. 3., only contiguous blocks of spectrum are assigned to different RANs. The width of the spectrum block assigned to a RAN varies to allow for changes in demand.

The RANs can only use the adjacent RANs spectrum resource. If a RAN wishes to increase its spectrum, it will not be able to do so if the spectrally adjacent RAN does not release its spectrum. This is a simple way to implement dynamic spectrum allocation but will not be efficient if more than two (2) RANs are to share spectrum[1].

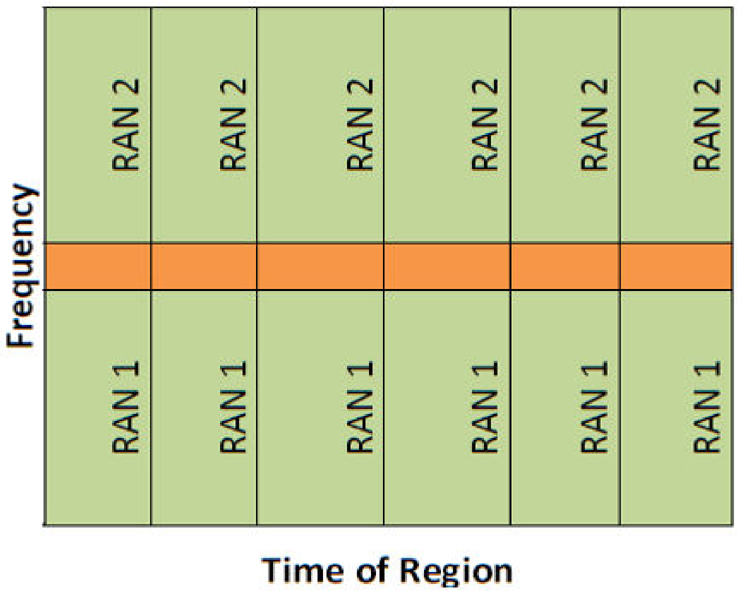

Figure.2. Fixed DSA

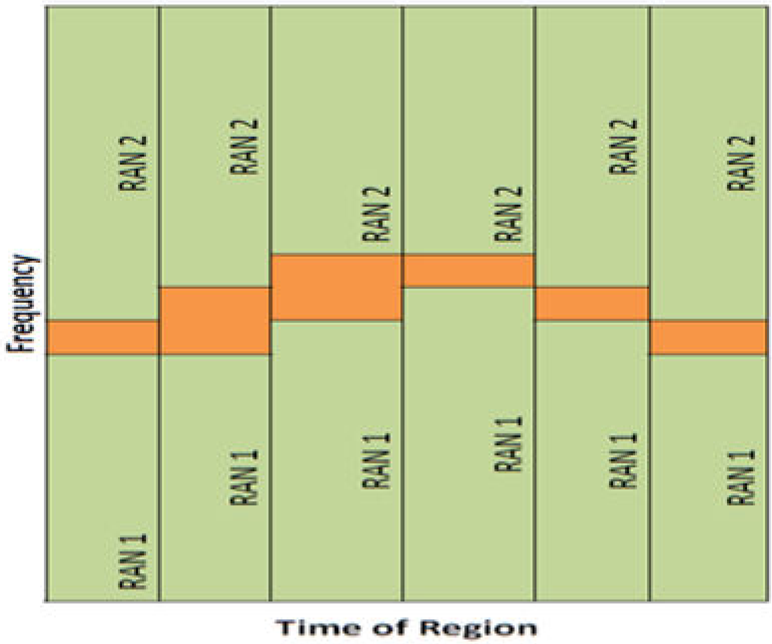

Figure.3. Continuous DSA

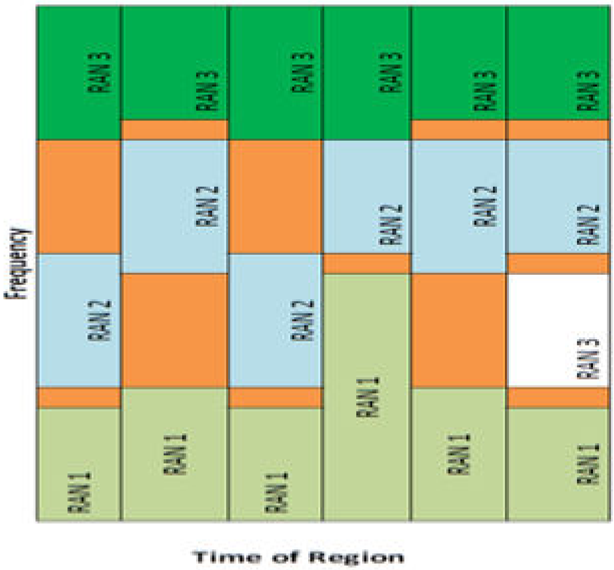

Figure.4.Fragmented DSA

Fragmented Dynamic Spectrum Allocation

In Fragmented DSA demonstrated in Fig. 4., spectrum is treated as a single shared block. Any RAN can be assigned an arbitrary piece of spectrum anywhere in this block. It will be of advantage if more than two RANs are sharing the spectrum. More guard bands are required since it is more difficult to control interference.

SPATIAL DSA

Spectrum allocation can be adapted to the regional demands on networks for a given time. The area must be divided into DSA areas, which are regions with relatively constant traffic demands. Spatial DSA allocates spectrum to RANs according to traffic demands in each DSA area. Spectrum Allocation between adjacent DSA areas will be coordinated to avoid interference.

DSA OBJECTIVE

The key objective of Dynamic Spectrum Allocation is to manage spectrum in a converged radio system and share it among all participating radio networks over space and time, to increase overall spectrum efficiency. This is because in Dynamic Spectrum Allocation, greater spectrum efficiency can be achieved by the use of spectrum under-used by other radio systems at different times.

POTENTIAL ENABLERS OF DSA

These include;

- Composite networks (which allows seamless delivery of services through the most appropriate access network)
- Re-configurability

WIRELESS NETWORK RECONFIGURABILITY

A reconfigurable network is such that possess the ability to reconfigure and adapt its hardware and software components and architecture, enabling flexible delivery of wide range of services, as well as well as sustaining robust operation under highly dynamic conditions [2]. This characteristic is important due to the fact that wireless networks are steadily evolving into profoundly more complex and dynamic systems. Application requirements for wireless networks continue to expand in both range and diversity, while user demands increase progressively increase at the same time. Reconfiguration can be performed at all OSI Layers as shown below [2];

Table.2. Open System Interconnection (OSI) Layers.

LAYERS	POSSIBLE RECONFIGURATIONS
APPLICATION	Context Information
	User Requirements
	User Interface
Transport	Number of retransmissions
	Congestion Control
Network	Routing
	Admission Control
	QoS Management
MAC	Transmission and Sleep Scheduling
	Content/Sensing window
	Transmission rate
PHY	Transceiver and Antenna Reconfiguration

The concept of wireless network re-configurability is however not discussed in full detail here, because that is not the main focus of this paper.

REGULATORY SUPPORT FOR DSA

Regulation policies in use currently, for both spectrum management and equipment certification do not allow the rollout of DSA schemes. Although some regulatory efforts are currently being carried out to enable more flexible spectrum practices [1]. Also some new market-based tools enabling spectrum sharing are being discussed. Active discussions are also on going by FCC in the USA on the need to relax some important constraints on current spectrum use. It should also be known that spectrum is a national resource and therefore currently national regulators have the responsibility to ensure economical use of spectrum resources in addition to its use without interferences.

DSA INFRASTRUCTURE AND ARCHITECTURE REQUIREMENT

The implementation of a DSA scheme together with its required support mechanisms pose challenges comparable to those encountered for re-configurable systems [1]. This complex technology needs some kind of minimum support infrastructure, supporting decision-making as well as implementing the mechanisms for both the actual spectrum re-allocation and reconfiguration processes.
Multiband and integrated narrow/wideband antennas with miniaturized constraints for small-sized devices are needed. Flexible frequency carrier tuning will be involved together with flexible receiver signal filtering.
The architecture envisaged might be such that an additional infrastructure/hardware handles both reconfiguration and DSA separately, combined, or a Hybrid of the two scenarios depending on the system.

III. RESULTS & ANALYSIS

Dynamic Spectrum allocation when eventually secures all needed regulatory backing and infrastructure requirement will find its application in different types of Radio Systems such as cellular and broadcast networks e.g. Universal Mobile Telecommunication System (UMTS) and Digital Video Broadcasting (DVB-T).The objective is to allocate spectrum dynamically to the Radio Access Technologies (RAT) over space and time in order to achieve high spectrum efficiency. While achieving this, any resultant interference will be appropriately managed or prevented.
Configurability readiness of the network infrastructure is a key pre-requisite to having DSA achieved in steadily emerging complex wireless networks. Hence the hardware and software designs of network infrastructures will be seriously considered e.g. Antenna, Reconfiguration controllers/support, et.c.

IV. CONCLUSION

This paper has investigated/introduced in summary the concept of Dynamic Spectrum Allocation (DSA) in a composite Re-configurable wireless network. It attempted to carry a reader who is new to this concept from the basics of spectrum and its allocation. Before the DSA concept proper was discussed wireless networks, Spectrum Allocation, Static Spectrum Allocation, and few other terms that will ensure fast comprehension of the topic of this paper was briefly introduced. In as much as the DSA concept is a futuristic idea, it will sure come to implementation stage as discussions on it are already on at the appropriate standardisation and licensing organisations level. This is however so much summarised and presented such that the reader who is new to this concept will not struggle to grasp what the DSA is all about and its objectives. Further studies and some technical details can be found on the articles referenced in this work.

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