Electromagnetic Spectrum Allocation: Wireless Networks

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Abstract

A wireless network has limited capacity to provide information transactions (finite bandwidth), making it a common-pool resource. The usage of the bandwidth in a wireless network is not restricted, promoting free-riding as an attractive strategy of appropriation of the bandwidth leading to an eventual saturation. A congested bandwidth may cause delays in the information traffic and might lead to eventual system collapse and the loss of wireless signal for everyone. The key governance challenge is given by the lack of restriction in the use of the new technologies (like fisheries), allowing a selected group of users exploit the system causing spectrum scarcity for the rest.

1 What is the Electromagnetic Spectrum?

The Electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation. These frequencies represent the amounts of radiant energy released by certain electromagnetic process, consisting of synchronized waves of electric and magnetic fields that propagate at the speed of light through a vacuum. Figure 1 gives examples of different types of electromagnetic radiation according to their frequencies.

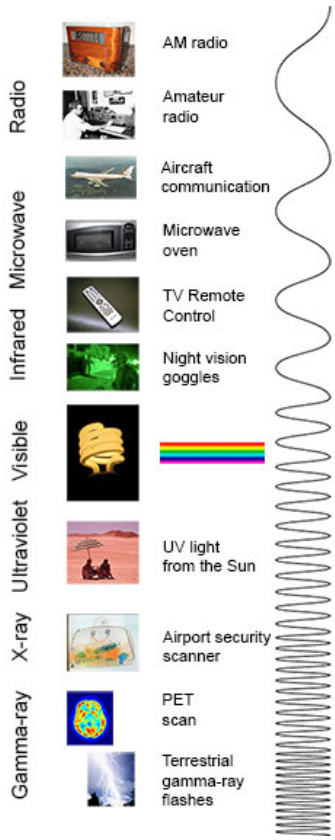

Figure 1: Electromagnetic radiation by type

The Radio spectrum is a part of the electromagnetic spectrum allocated to about 40 different telecommunication services. Some of the most prevalent examples include radio, television broadcasting, cellular phones, Wi-Fi, Bluetooth, broadband wireless Internet access, GPS, radar, weather satellites, and military/government/public safety communications, etc. Even thought, the radio spectrum is finite, it is an exceedingly valuable natural resource that facilitates a tremendous variety of applications and services. As a direct result of its value, the use of the radio spectrum has intensified and expanded enormously during the past two decades. Wireless systems have proliferated and new applications have emerged, becoming a major productivity tool for every sector of the world economy since they have been integrated into our everyday lives creating an ever-greater demand for spectrum resources.

2 Spectrum Appropriation

Electromagnetic spectrum is one of our most valuable natural resources, yet our interaction with wireless technology is both recent and relies on a trust system just like most common-pool resource systems creating the opportunity for over-appropriation. Taking into account that the first wireless transmission took place in 1897, spectrum sharing is a rapidly evolving field. As in other common-pool resources, the need for action and new rules are often the result of a resource over-exploitation crisis.

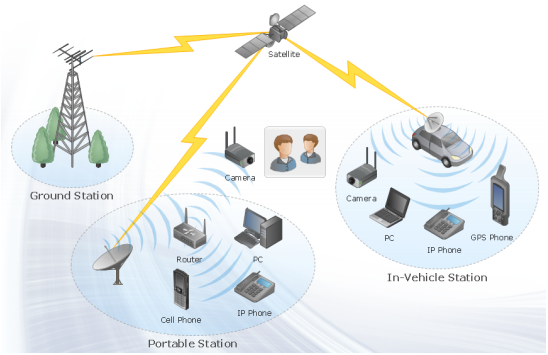

Figure 2: Wireless networks from different scales.

In 1927, congress passed the Radio Act to respond to a broadcasting crisis. In 1934 the Radio Act was absorbed by the Communications Act, most of the premises relating to the electromagnetic spectrum were applied on railroad regulations to communications. Despite that these acts were passed long before modern technologies were even considered possible, many of the basic premised of the Radio Act are still in place today. In fact, it seems obvious that recent advances in technology will force government agencies to evolve the rules and regulations of electromagnetic spectrum allocation. It is not enough to account just for current technologies but on the other hand, we need to account for ways to monitor spectrum usage in order to make sure it is not over-appropriated. Even thought, there have been modification in the way the electromagnetic spectrum has been used, it is obvious that the rules in place are prone to be outdated soon since the telecommunication industry is rapidly evolving. The fact that facilities are limited and not all the people is able to use the resource (lack of hard human made infrastructure) the electromagnetic spectrum available is not enough to accommodate everybody's needs without causing extreme amounts of interference.

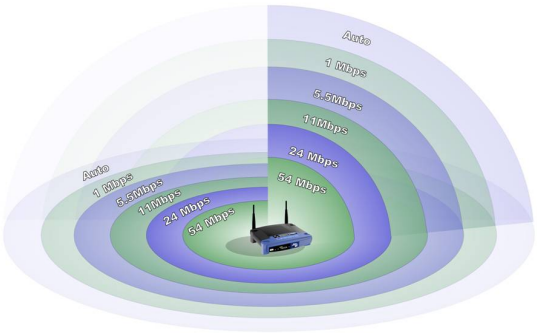

Figure 3: User ranges in a local wireless network.

In short, a wireless network has limited capacity to provide information transactions to all users due to a finite bandwidth. The bandwidth usage in a wireless network is not restricted; neither the number of users allowed nor the amount of consumed spectrum per user. Bandwidth over consumption may saturate the system and eventually collapse it. A congested bandwidth is a very common phenomena that cause delay in the information traffic and sometimes collapse the system, leading to the loss of wireless signal for all the users.

3 Wireless Network Community

Wireless network is a network set up by using radio signal frequency to communicate among computers and other network devices, due to its easy setup feature and no cabling involved, it have become an important tool in the construction of modern society. New emerging technologies allow users to perform more and more complex tasks, driving an increasing mean bandwidth consumption per user. However, a wireless network has limited capacity to provide information, that is, finite bandwidth; despite that neither, the number of users allowed to connect nor the amount of consumed spectrum are restricted. In order to guarantee an optimal performance is necessary to avoid signal traffic saturation and, at the same time, be able to reach an optimum usage of bandwidth even with a dynamical configuration of users and consumption. In order to accommodate the needs of all users, a systematic analysis is needed before proposing and establishing amendments to rules and protocols currently in use. The recommended approach is to use the same structure used for the development of new environmental law for the allocation of natural resources since the electromagnetic spectrum is as valuable as any other natural resource and should be reasonably allocated in order for the public to enjoy its full potential.

3.1 Biophysical Context (IAD)

Natural infrastructure (NI)

The electromagnetic spectrum or bandwidth available for information traffic consisting of the range of all possible frequencies of electromagnetic radiation. These frequencies represent the amounts of radiant energy released by certain electromagnetic process, consisting of synchronized waves of electric and magnetic fields that propagate at the speed of light through a vacuum.

Hard human infrastructure (NI)

The “bandwidth” is available by different types of private hard human communication infrastructure i.e, electronic devices that have antennas as transmitters and wireless network cards for signal reception.

Attributes of the Community (IAD)

The community in a wireless network system works as a non-cooperative society in which each individual is looking for its own benefit, sometimes following behavioral protocols or sometimes acting improperly.

Social Infrastructure

The structure of a wireless network provides the capability of connection with any user whenever an appropriate electronic device is used. However, communication among users does not shows the attributes of users in terms of bandwidth consumption.

Human Infrastructure

Consist of a user as administrator of the network and the rest of users able to connect to the network.

3.2 Rules in Use (IAD)

Position rules

The administrator of the network has the ability to displace a user to improve the performance of the network or remove the user and prevent re-connection definitely if the user is incurring into illegal actions.

Boundary rules

Depending of the technology in the used of electronic device a user can have different boundaries for bandwidth consumption. Users with novel technologies are able to perform more complex task than users with old technology.

Choice rules

Users decide their availability of spectrum within certain ranges by paying fees to the network provider. Other way that users have a choice is in the technology implemented in the electronic device and the type of device used.

Aggregation Rules

When a user is trying to connect, the user has to have the authorization of the network administrator (password).

Scope Rules

Depending of the type of network the administrator can allow or prohibit the use of certain technologies. The administrator is also able to restrict proprieties of the wireless network in order to maintain the system under its control, such as passwords.

Information Rules

Commonly when a user connects to a wireless network is informed of the appropriate use of the resource in terms of allowed activity and restrictions of usage.

Payoff Rules

When an improper act is detected, the administrator can remove the user and restrict re-connection definitely.

3.3 Summary

The lack of well implemented design principles as: clearly defined boundaries, collective-choice arrangement, monitoring, graduated sanctions and conflict-resolution mechanisms; incentives the users to incur in a free-riding strategy. Thus leading to an over-harvested spectrum and at the end incurring in a commons dilemma.

4 A new approach to wireless paradigm

In 2010, the President of the United States issued the memorandum "Unleashing the Wireless Broadband Revolution," which, called on the Federal Government to identify 500 MHz of spectrum to be made available for wireless broadband use for non-government entities, and specifically called on the NSF to work with the Department of Commerce and other federal agencies to "create and implement a plan to facilitate research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies." In the American Recovery and Reinvestment Act, the United States Congress directed the Federal Communications Commission to devise a plan "to ensure that all people of the United States have access to broadband capability." The resulting National Broadband Plan was released in 2010 and, among many other recommendations, calls on the NSF to fund wireless research and development that will advance the science of spectrum access. In 2012, the President's Council of Advisors on Science and Technology (PCAST) released a report that recommended sharing of up to 1,000 MHz of federal government radio spectrum with non-government entities. NSF seeks to help reach the nation's broadband goals and the larger objective of alleviating growing pressure on limited spectrum resources through innovative approaches, technologies, and policies that will be required to enable more flexible and efficient access to the radio spectrum. The particular interest is in a combination of three of the ten key research areas: spectral efficiency, re-configurable wireless platforms and security of wireless signals and systems in the context of spectrum sharing.

There are two ways to improve spectral efficiency: on an instantaneous basis, such as mitigation of unwanted emissions, improvements in filter technology, interference cancellation, etc.; and improvements on a system-wide basis, such as dynamic spectrum access, frequency re-use, and innovative millimeter wave and THz frequency devices and systems. Advanced spectrum sensing techniques are needed to quickly and accurately identify transmission opportunities over a very wide spectrum pool that may host a large number of different wireless services. Re-configurable wireless platforms, such as cognitive radio, will implement dynamic incentive mechanisms and spectrum policy, facilitating the coexistence of multiple dynamic spectrum access networks, and optimize network performance.

Wireless communication provides individuals worldwide with flexible and seamless services. However, the limited radio spectrum resources constrain the development of wireless systems that can cope with the exponentially increasing data traffic demand. Opportunistic spectrum access enables the use of idle resources, which is essential to meet the growth of digital traffic demand. Traditionally, such reuse of idle portions of the licensed spectrum is allowed if the transmissions of secondary users do not cause harmful interference to primary users. In parallel to the network capacity bottleneck, the issue of privacy and security in wireless networks has taken a fundamental role in wireless applications development such that mostly of novel research has been focusing on this issue and neglected the electromagnetic spectrum problem of the commons. Limited bandwidth, constrain the possibility of coexistence only in certain network configurations. We expect that future wireless networks will be mostly ad-hoc and cognitive, where each node accesses the resources according to the amount of data to be transmitted, the quality of the communication link, and the cost of the resources. Therefore, networks will become complex adaptive systems capable of self-organization.