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SECOND ICTP - URSI - ITU/BDT SCHOOL ON THE USE OF RADIO FOR DIGITAL COMMUNICATIONS IN DEVELOPING COUNTRIES, INCLUDING SPECTRUM MANAGEMENT

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Spectrum Management / Utilization and Wireless Telecommunications

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SPECTRUM MANAGEMENT/ UTILIZATION AND WIRELESS TELECOMMUNICATIONS

Chairman's report at the URSI Commission E Open Meeting,
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Abstract: *Radio has become indispensable for our society to function, but spectrum scarcity hampers its development. This text discusses various aspects related to the use and management/ regulation of the radio frequency spectrum resources. It gives an insight into field of research of Working Group E1 "Spectrum Management/Utilization and Wireless Telecommunications" of International Union of Radio Science (URSI).*

Note: *The opinions expressed are the author's personal views, and do not engage any entity.*

1 Background

1.1 Renaissance of radio

Hundred years after its invention, radio is entering a new era. The development of communication and computer technologies and their convergence generate applications that were hard even to imagine a few years ago. Radio has become indispensable for our society to function. Areas, in which the radio waves have become invaluable, are numerous. National defense, disaster warning, public safety, air-traffic control, and weather forecasts, are only few examples.

The 1969 Moon Landing, the most spectacular illustration of the conquest of the Space by humans, would never be possible without the radio[2]. Remote-sensing satellites are irreplaceable in discovering natural resources of the Earth and in monitoring the climate changes[3]. A meter-resolution they offer allows for identifying, quantifying, monitoring and mapping agriculture and water resources and land cover.

The world has been kept away from major war conflicts thanks to "spy satellites" that have continuously monitored military activities from space. Radio astronomy has opened new windows on the Universe and contributed to the better understanding of nature[4]. Radio and television broadcasting have become the main source of everyday information for most people of the world. There is more radio receivers than telephones over the world. The recent Olympic Games, for instance, were watched by two billion people or so.

Radio and television play a principal role in meeting information needs of illiterate people unable to read: about two-thirds of the world population. Non-communication applications of radio waves have become indispensable, too, as evidenced by millions of household microwave ovens in daily use. Many industrial processes and scientific experiments have been improved, or even made possible, by ingenious usage of radio waves[5].

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1 This text is based on a talk given at the University of Oxford on 8 April 1997.

2 Dooling D.: A quarter century after the Apollo Landing; IEEE Spectrum, July 1994, pp.16-29

3 Bell T.E.: Remote sensing; IEEE Spectrum, March 1995, pp.25-31

4 Zorpette G.: Radio astronomy new windows on the Universe; IEEE Spectrum, February 1995, pp.18-25

5 Struzak R.: Vestigial radiation from industrial, scientific and medical radio-frequency equipment; in Nonlinear

Radio became crucial for security and economy, nationally and world wide, like the nervous system in a living organism. The uses of radio waves create businesses. In spite of economic fluctuations, the telecommunication sector alone has been one of the most profitable industries, after pharmaceuticals and diversified financials[6]. In the USA only, 1991 shipments of radiocommunication equipment were of 55 billion USD[7]. In 1994, a cellular operator in the UK made alone a yearly profit of 350 million BP[8].

As a whole, the economic impact of the use of radio is estimated for about 2% of the Gross Domestic Product[9]. One can argue whether or not it is sufficient to describe the impact of the spectrum use on the society in economic terms only. Certainly, it would be unacceptable oversimplification to judge about the value of the nervous system in human organism based on its weight only, which is less than 2% of the total weight of the body.

Anyway, it is widely accepted that the convergence of wireless telecommunications and information technologies will be a major engine of economic growth and improvement of the standard of living in the next decades. The enormous impact of radio on our life continues to increase, although we still do not fully realize all consequences of that development.

1.2 Three examples

This section gives three examples of applications of radio waves that could change significantly our life in the next century. One of them is the Global Positioning System (GPS). It is a space-based navigation, positioning and time-transfer system completed in 1993 and offering unsurpassed accuracy, reliability and availability. Now open for civilian applications at no cost, it was developed for military purposes for an amount of over 10 billion USD. GPS is American; its Russian equivalent is named GLONASS. With a hand-held receiver, you may determine your position with the accuracy of 30 meter or so. (With special equipment, software, and access to the decryption key, that accuracy may be much greater[10]). In 1997 such receiver was priced for 250 USD or so, and a year later a two-chip GPS receiver was offered for 25 USD[11].

The operating principle is remarkably simple, and refers to the ancient art of navigation when our ancestors followed the stars on the sky. The difference is that GPS uses man-made "talking stars" - a constellation of 24 satellites. Each satellite carries a precise onboard atomic clock. The exact position of each satellite is monitored by the GPS Master Control Station that maintains also a GPS time standard which, in turn, is synchronized with Coordinated Universal Time.

The data on current satellite position and time, updated periodically, are uploaded to each satellite to be broadcast continuously in a coded form[12]. A GPS receiver extracts the data, and compares its own time with the time sent by a satellite. The difference between the two times and the velocity of the radio wave are used to calculate the distance from the satellite to the receiver. The satellite clocks are exact to a billionth of a second (which corresponds to 0.3m distance uncertainty), but the receiver's clock is simple, to keep its weight and cost low. It introduces an unknown time offset, or error. Thus, to calculate its longitude, latitude, altitude, and the time offset, the four unknown variables, a GPS receiver must use data from at least four satellites. For this purpose, the satellites are orbiting in a formation that ensures that every point on the planet is always in radio contact with at least four satellites.

The precise signals from the GPS satellites create a worldwide time and frequency reference, easily accessible from any point on the Earth, for the first time in the history[13]. They are used to synchronize various processes and networks, including telecommunication and power supply networks. However, it is only a part of benefits offered. GPS system provides a unique address

6 ITU WTDR: World Telecommunication Development Report ITU 1998

7 NTIA: U.S. Spectrum management policy- agenda for the future, 1991, p.1

8 Goddard M.: private communication, 1994

9 NERA/ Smith: Economic impact of the radio spectrum in the UK; Radiocommunications Agency, May 1997

10 Trimble Navigation Ltd., manufacturer information, 1997

11 Mattos P., Complete GPS receiver fits on two chips; Electronic Design, July 16, 1998, pp. 50-56.

12 The Global Positioning System, GPS News, August 1996

for each point on the Earth, instantly available in electronic form, setting a new standard for locations and distances.

Its applications appear to be virtually unlimited. GPS enables drivers, mariners and pilots to navigate safely and efficiently in all weather conditions, day and night, and to save fuel by traveling the most efficient route at optimal speed. It provides data for mapping and surveying tasks, lay roads, bridges, foundations and utilities, quickly and precisely. Once gathered, GPS data can automatically be transferred to a Geographic Information System (GIS). According to some predictions, GPS receivers may become as ubiquitous as watches, and GPS coordinates may eventually replace a street address to define the location of home or business. GPS created new industries. The worldwide GPS market estimated for three billion USD in 1997 will grow to eight billion by the year 2000, according to a recent report[14]

The second example discussed here is the satellite communication services. Several constellations of low-orbiting satellites are planned, and have so far absorbed about eight billion USD. Among them, "Teledesic" system, whose tests started in 1998, is the most refined[15]. It will provide an affordable two-way communication services, such as broadband Internet access, videoconferencing, high-quality voice, and other digital data exchange, offering access speed up to 2000 times faster that today's standard analog modems.

The Teledesic Network is designed to support millions of simultaneous users at any time, offering the same services everywhere on the planet: in London, in the center of the Gobi desert, or in the Amazonian jungle. Privately funded, and costing nine billion USD, it will be in service in 2002. Originally, it was planned as a constellation of 840 satellites in 21 polar orbits some 700-km above the earth. Later, the number of satellites was reduced to 288.

The significance of these new communication systems cannot be overestimated. Information exchange for a multitude of computer applications become increasingly essential to economic development, education, health care, public services, and to many other activities. However, there is increasing "information gap" and most of the world does not have access even to the most basic telephone service. Even where this basic service is available, most of the networks over which it is provided are antiquated and inappropriate for computer communications. Inadequate telecommunication means block the applications of computers. The cost and time required to upgrade these facilities through conventional or fiber-optic lines would be prohibitive for much of the world.

The new satellite systems create complete telecommunication infrastructure in the sky, accessible from any place, 24 hours a day. They are capable of providing the needed services at a low cost, indifferent to distance or location. Because satellites in polar orbits move in relation to the Earth, the cost of continuous coverage of any <u>one</u> point on Earth is the same as the cost of covering of <u>all</u> points on the Earth's surface. It radically transforms the economics of telecommunications and enables leapfrogging earlier stages of telecommunication technology development to gain immediate access to the most advanced information infrastructure. The value of such systems lies in the number of people getting access to advanced communication services and who otherwise will never have such access at all.

The third application example has nothing common with communications, except for potential interference. The project, known as the Satellite Power System (SPS), was developed for the US government to satisfy the increasing energy demand. A constellation of 60 or so satellites would collect energy from solar radiation above the earth atmosphere, beam it to the Earth, and inject into the existing power distribution system. Each satellite would carry a solar array, 10 km long and 5 km wide, to intercept approximately 70 gigawatts of solar energy.

With conversion efficiency of 7%, this solar array would provide 5 gigawatts of dc power for conversion to microwave power by thousands of klystron generators. This power would then be beamed to Earth via a 1-km diameter phased array microwave antenna. A special pilot beam would be transmitted from earth to the satellite for dynamic phasing of the transmit antenna. Radio waves would transport the energy from the geostationary-satellite orbit to a terrestrial receiving antenna array.

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14 Hemisphere Report, Forbes, 22 September 1997

15 Struzak R.: Internet in the sky - tests have started; Global Communications Asia '98, pp. 156-158, also ITU

The receiving antenna would be a 10-km by 13-km array. The array would be built of multiple half-wave dipole elements feeding diodes for the conversion of RF energy into direct current. Filters would be inserted between the dipole and diodes to suppress re-radiation of harmonics generated in the rectification process. The system would cover a significant portion of national energy consumption and would cost few billion USD. The project has not been implemented as the price of power from satellites would not be competitive and also because the environmental and EMC problems were inadequately addressed. If, however, the price of oil or carbon will increase, the project may be revived[16].

1.3 Spectrum scarcity

Due to the laws of nature, various applications of radio waves can interfere with each other and nullify the benefits they offer if incorrectly designed or operated. To avoid such interference, each application requires some amount of radio frequency spectrum for exclusive use, unless special arrangements are made[17] [18]. We use interchangeably the terms "radio waves", "radio frequency spectrum" and "spectrum", that have, in the context of this paper, the same meaning.

The capacity that can be provided by any communication system to any single user, or to any group of users, is ultimately limited by the spectrum available to that system. The number of radio systems in operation worldwide is enormous and continues to increase. Liberalization and deregulation trends encourage the introduction of new services and new technologies, which generates demand for radio frequencies without precedence. The ITU has recorded more frequency assignments in the last few years than during the whole previous history of radio.

Most of suitable frequencies have already been occupied and, within the existing arrangements, the demand exceeds what can further be assigned. In some frequency bands and geographical regions there is no place for new radio stations. Spectrum scarcity is observed in VHF/UHF frequency bands if the population density exceeds 200 people per square km and GNP - 10.000 USD per capita per annum, according to some experts. Similarly, the geostationary satellite orbit becomes congested and there may be no place for new satellites in some areas. That scarcity hampers further development of telecommunications[19]. The issue is critical for the future of services and applications, and deserves serious consideration.

The scarcity of radio spectrum is not a new problem. It was a US Secretary of Commerce who first declared: "There is no more spectrum available." The Secretary was Herbert Hoover. The year was 1925[20]. In the meantime a multitude of applications of radio waves have been invented and successfully implemented. Is therefore the spectrum congestion real? And, if so, is there any way to solve the problem? Is the spectrum/ orbit scarcity due to the law of nature or, perhaps, due to our mismanagement? The problem of the shortage of radio frequencies was repeatedly raised at international conferences and at other occasions. This would indicate that the spectrum shortage has a periodic or chaotic character. Today, we are seeking new solutions to an old problem that depends strongly on the progress in science and technology, on development mechanisms, and on a mixture of competition and cooperation.

To solve spectrum scarcity and spectrum congestion problems, numerous conferences and symposia gather thousands of experts every year. The seriousness of the issue is evidenced by the number and caliber of international organizations involved. Their list includes specialized UN Agencies such as the International Telecommunication Union (ITU), International Civil Aviation Organization (ICAO), International Maritime Organization (IMO), World Meteorological Organization (WMO), World Health Organization (WHO), World Trade Organization (WTO), and the World Bank. In Europe, involved are the European Commission (EC), Conference of

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16 Kirby R., Struzak R.: Radio Astronomy in the radio environment, in McKelly D. (Ed.) The Vanishing Universe. Adverse environmental impacts on astronomy, Cambridge University Press, 1994, pp. 85-93

17 Berry L.A.: Spectrum metrics and spectrum efficiency; in Matos F. (Ed.): Spectrum management and engineering, IEEE Press, 1985, p. 171-176

18 Struzak R.: Vestigial radiation rom industrial, scientific, and medical radio-frequency equipment; in Nonlinear and environmental electromagnetics, Kikuchi H. (Ed.), Elsevier 1985, pp.223-252

19 Struzak R.: Key issues in spectrum management; Pacific Telecommunication Review, No. 10, Vol. 18, Sep.1996, pp. 2-11; also Global Communications Asia 97, Hanson Cooke Ltd., London, pp. 342-349

20 Dougan D.L.: Somewhere over the technology rainbow: spectrum in perspective; in The spectrum

European Posts and Telecommunications Administrations (CEPT), European Radiocommunications Committee (ERC), European Radiocommunications Office (ERO), and International Union of Radio Science (URSI), among others.

2 Spectrum management

2.1 What is the spectrum?

The answer to question "What is the spectrum?" is not as simple as one may expect, as "spectrum" has more than one meaning in the context of wireless communications.[21] Originally, "spectrum" was only an abstract mathematical idea introduced by Jean-Baptiste Fourier (1768-1830) to solve differential equations. At the beginning, the idea was strongly criticized and considered as a curiosity of doubtful value.

Only when Peter Dirichlet (1805-1859) and Georg Riemann (1826-1866) resolved the doubts, it was generally accepted to become now a powerful tool used in many branches of theoretical sciences, signal processing, communications and computer technology. In the meantime, experimental science and instrumentation have been developed and the spectrum has become a measurable physical object. Then radio engineering was developed and now concept of radio frequency spectrum is in everyday use, with RF spectrum analyzers as basic instruments in radio laboratories.

The ability to carry energy and messages at a distance, at no cost and with the speed of light, made the spectrum of radio waves a valuable resource from which everybody could profit. Free access to it, from any place and at any time, added much to its attractiveness. The radio spectrum has become a natural resource, with which another abstract has been associated: invisible lines in the space - satellite orbits. Three elements added new dimensions to the spectrum concept:

(The market demand associated with the pressure of wireless service providers and users and equipment manufacturers,

(The development of international wireless services,

(The threat of cross-border radio interference.

An international treaty, signed by all governments, confirms that *"...radio frequencies and the geostationary-satellite orbit are limited natural resources [...] that must be used [...] so that countries and group of countries may have equitable access to both..."*[22]. Radio waves and satellite orbits are now treated as a common heritage of the humanity[23]. No one nation can operate it alone, ignoring the others. It is subject to misuse and pollution by man-made radio noise and interference that decreases its utility.

2.2 Sharing

Sharing common resources, such as the radio frequencies and satellite orbits, has its intrinsic benefits and drawbacks. The benefits were discussed earlier in this text. The main disadvantage of shared resources is known as "*tragedy of commons*", after Hardin published his paper under such a title[24]. He considered simplified model of a common pasture exploited by a group of herdsmen. He made four assumptions. First, he assumed that herdsmen are "rational". It means each herdsman seeks to maximize his gain from the sale of animals, and there are no other aims or rules regulating the use of the pasture. Second - the pasture is common and each herdsman pays nothing for feeding his herd there. Third - the pasture is limited.

Under these assumptions, the scenario develops following the inherent logic of the commons, says Hardin. As each animal offers a unit gain, each herdsman tends to maintain as many cattle as

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21 Struzak R.: Key issues in spectrum management; Pacific Telecommunication Review, No. 10, Vol. 18, Sep.1996, pp. 2-11

22 ITU Constitution and Convention, Geneva 1992, Art. 44, item 196

23 Fleming D. et al.: State sovereignty and the effective management of a shared universal resource: observations drawn from examining developments in the international regulation of radiocommunication; Annals of air and space law, 1985, pp.326-352

possible. At the beginning, when the total number of beast is small, such an arrangement works well. The herds grow fast and the wealth of herdsmen follows.

However, at same time a critical moment comes when the population of animals approaches the carrying capacity of the pasture. When this critical point is reached, adding more animals leads to the degradation of the pasture. Then, each herdsman asks himself what is the utility to him of adding one more animal to his herd.

Two components are to be taken into account, one positive and one negative. The positive component reaches +1, since the herdsman receives all the proceeds from the sale of the additional animal. The negative component results from the increased overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all, the negative utility for any particular decision-making herdsman is only a fraction of -1. Adding together these partial components, the herdsman concludes that the only reasonable course for him to pursue is to add another animal to his herd. And another, and another, and this is the conclusion reached by every rational herdsman sharing a commons.

The result is that once rich pasture is being transformed into a desert. Hardin concludes: "*Therein is a tragedy. Each man is locked into a system that compels him to increase his herd without limit - in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons...*"

2.3 Regulation

The Hardin's theory shows that the concept of a free, unregulated access to a limited resource does not work if the number of the resource users exceeds some limits. With radio waves, that conclusion has been reached very early from practical experience. The first uses of radio were military, to communicate with warships on the sea. Soon, however, military secrets were abandoned under the pressure of the business rushing to exploit the "nobody land" of civilian radio.

Two opposite forces appeared, one diverging and another converging. The diverging one was due to the competition among the equipment manufacturers and service providers who wanted no sharing, no control, no regulations and no common standards imposed. They also did not want to co-operate as it would result in disclosing their know-how secrets. The converging force came from the market. The customers/ users of radio wanted to communicate freely one with another, independently of the service or equipment supplier. Moreover, in a liberal environment, without any coordination and control, mutual interference paralyzed the operation of wireless systems. The users wanted interference-free communications.

Finally, all parties interested came to the conclusion that the coordination or management of the uses made of the spectrum is an unavoidable necessity. Such coordination/ management started on a national scale but, as radio waves do not recognize political borders, the global nature of the problem required international cooperation. Only two years after the first transatlantic transmission astonished the world, and just few years after Marconi received his patent on wireless telegraphy, the first international conference was called to Berlin in 1903 to regulate and manage the use of the spectrum. That conference marked the end of the first period of uncontrolled rivalry in radiocommunications. The spectrum resources consisted at that time of only two frequency bands (one near 500 kHz and another about 1MHz) and were used to aid in marine disaster relief off the coast[25].

The use of the spectrum has been regulated *by necessity:* to prevent mutual interference, and to allow for inter-communication. In the early days of radio, with few radio stations operating, the probability of interference was low and the inter-communication was more important. In 1902, Prince Henry of Prussia attempted to send President Theodore Roosevelt a courtesy message while crossing the ocean after his visit to the United States. He was refused service because the shore station, operated by the Marconi Company, would not deal with a ship station of its German competitor.

The Berlin Conference ruled that communication service with ships must be provided regardless of the system used. However, international treaties are all part of a worldwide game nations agree to play following certain rules, and consensus is an inevitable ingredient here. Great Britain and Italy, where Marconi was exploiting his system, did not agree and made reservations. Such reservations were removed, and first operational standards on radiocommunications were agreed, only nine years later, at London Conference in 1912. To a large degree, it was under the pressure of public opinion, shocked by the Titanic disaster. Titanic was the most luxurious and largest ship at that time, considered unsinkable. During its maiden voyage, it hit an iceberg and sank on the night of April 14-15,1912. About 1,500 passengers lost their lives and recent film "Titanic" revived the event. Inquiries alleged that another liner was nearby and could have aided had its radio operator been on duty and thereby received the Titanic's distress signals.

Today, the uses made of the spectrum are internationally coordinated in the framework of the International Telecommunication Union. This Specialized Agency of the United Nations has, among its major purposes, the avoidance of radio interference and assurance of rational use of the spectrum/ orbit resources, taking into account the special needs of developing countries[26]. Its mission is accomplished by:

(Ensuring meeting the specific needs of countries through mechanism of the World and Regional Radio Conferences, Radio Regulations, Agreements and Plans.

(Coordinating the efforts to eliminate harmful interference between radio stations of different countries,

(Studies and recommendations on technical and operational matters by Radiocommunication Study Groups and Assemblies.

The Radio Regulations have the status of International Treaty; each government warrants that they are respected by everybody under its jurisdiction[27]. To keep pace with technological, political, and economic changes, the Regulations are periodically reviewed at competent World or Regional Radio Conference. Usually, however, only minimum modifications are agreed at each conference, leaving fundamental principles essentially untouched. One reason is that the process of intergovernmental conferences is often more about the art of politics and public relations than an exercise in economics and engineering.

2.4 Evolution

It is interesting to note that, in dealing with the spectrum/ orbit resources, we are following the same way as with other common resources. Our past confirms that the approach to such resources changes, as does our understanding of their value and social role. In our uncontrolled growth, we have discovered with surprise that many resources, considered long time as being inexhaustible, have become scarce.

Firstly, the commons in food gathering were abandoned. Farmland has been enclosed, and there is no free farmland now. Later, open pastures and free hunting and fishing areas have been restricted. Then, using the commons as a place for waste disposal has been abandoned and regulations on the disposal of sewage are now widely accepted throughout the world. Finally, the concept of the environment and its protection has been developed and restrictions have been imposed on the pollution of land, water, and air. The radio frequencies and satellite orbits are thus not exceptions.

The issue of rational use, sharing, and protection of the limited common resources has become a serious problem on national and international scale. We believe all these regulations to be necessary for the common benefit of humanity. Several approaches to scarce resources are possible.

"We might sell them off as private property. We might keep them as public property, but allocate the right to enter them. The allocation might be on the basis of wealth, by the use of an auction system. It might be on the basis of merit, as defined by some agreed-upon standards. It might be by lottery. Or it might be on a first-come, first-served basis... "[28].

For the time being, on the international scene the spectrum/ orbit resources are still treated as public. No access fee mechanism has been envisaged, but the access is controlled following the Radio Regulations negotiated by all ITU member countries at the competent conferences. However, on the national scene, most countries have introduced a system of fees.

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26 ITU Constitution and Convention, Geneva 1992, Art. 44, item 196

27 Radio Regulations, International Telecommunication Union, Geneva

A few countries even created a spectrum market, but the market approach has not been universally accepted. There is a continuing debate over whether spectrum is to be treated as a free common heritage of humankind, a scarce natural resource, a renewable and reusable commodity, or a salable, auctionable, rentable piece of real estate. J. D. Bedin, a French jurist, defined it shortly: "the frequency spectrum is technology, industry, money, culture, and power"[29].

2.5 Preferences

Which of the possible approaches is the best? Each can be questionable, dependent on the criteria applied. The final answer results from the human preferences of goals and hierarchies of values. In practice, it is often impossible to separate technical aspects of resource sharing from their economical, social and political contexts, and from the interests affected by them.

The problem of sharing scarce resources cannot be solved by technical means, without involving systems of human values, convictions and ideas. Tradition, past experience, and investments made play a significant role here. Of the all possible ways in which the resource can be used/ shared, adopted will be that one which is valued most by some population in terms of that population's own system of values and beliefs.

"*Where a resource process involves beliefs and techniques that are incongruous with a people's system of activities, it will not be adopted by that people, however superior it may be by other criteria.*"[30].

However, in a pluralistic society the goals and hierarchies of values are often inconsistent and conflicting. First, the hierarchies of values and preferences of each individual or group may be inconsistent among themselves. It means that progress toward realization of one value or goal is destructive of another value or goal held by the same individual or group, and the lack of consistency may be not obvious to the individual or group concerned. Second, different individuals and groups may have different hierarchies of values and preferences. And these values and preferences may be partially in conflict with those of other groups and individuals. Conflicting goals or values cannot be served by the same policies: what enhances one will degrade the other. Finally, the capacities of different groups to implement their preferences may be different.

Our experience shows that the way in which the spectrum/orbit resources are used and managed follows the technological, economic, political and social changes in the world. These changes usually begin in one leading or dominating nation or region. The rest, earlier or later, follows that example and accept more or less voluntarily the approach, "mode of life" and hierarchy of values of the leader.

2.6 Objectives

National spectrum management began in the early 1920's with the record keeping - logging out frequencies to applicants essentially on a first come, first served basis. The 1947 Atlantic City Radio Conference made foundations for the present international spectrum management by copying, to some degree, the US national spectrum management system of that time. Today, the concept of spectrum management embraces all activities related to regulations, planning, allocation, assignment, use, and control of the radio frequency spectrum and the satellite orbits. To be effective, any spectrum management system should include sound spectrum engineering, monitoring and enforcement mechanisms. [31]

Three objectives shape any spectrum management system: conveying policy goals, apportioning scarcity, and avoiding conflicts, with due regard to social, political, economic, ecological, etc., aspects. The society is composed of various groups, each with its particular situation, interests, goals and views. As a consequence of the spectrum scarcity, conflicts arise between those who have access to the spectrum resource and those who have not. Conflicts arise also between the proponents of competing uses of the spectrum as well as between those who manage the

29 Dougan, op. cit

30 Firey W: Man, Mind and Land a theory of resource use; Greenwood Press, 1977

31 Struzak R.: Key issues in spectrum management; Pacific Telecommunication Review, No. 10, Vol. 18,

spectrum and those who use it. These conflicts are of various natures: commercial, political, physical interference, etc.[32]

For those whose needs have already been satisfied, spectrum management should assure the continuation of the existing status. Any modification would threaten their acquired benefits. On the other hand, the newcomers have no access to the spectrum they need. For them, the principal aim of spectrum management is to change the way the spectrum is assigned and to eliminate obstacles that prevent them to enter the competition. What is the best for one group is not necessarily good for the other. Since the very beginning, the spectrum management rules and regulations tend to reflect the relative balance of powers of the competing interest groups.

2.7 Dual approach

The uses made of the spectrum/ orbit resources has been based on frequency allocation principles, as given in the Table of Frequency Allocations of the Radio Regulations. *Allocation* means the distribution of a frequency band to a wireless service, *allotment* - to a country or area, and *assignment* - to an individual radio station. Some allocations are worldwide, other are regional, i.e. uniform throughout a particular region. A country can make an assignment to an individual station or to a group of stations when needed. This is co-called *ad hoc* frequency distribution method.

An alternative is *a priori* frequency distribution. For services subject to a priori planning, an assignment in accordance with the plan receives protection from any other assignment. In the case of *ad hoc* managed services, the protection is given in accordance with the priority of registration dates - a system frequently described as *first-come, first-served.*

International frequency plans for specific applications, geographic regions, and frequency bands that are subject to *a priori* frequency planning are coordinated at competent radio conferences. A frequency plan is a table, or more generally, a function that assigns appropriate characteristics to each radio station at hand. The name "frequency planning" remained from the early days of radio, when only operating frequency of radio station and its geographic location could vary. International plans are general and contain minimal number of details. In contrast, design and operational frequency plans include all the details necessary to operate the station.

In *a priori* frequency plans, specific frequency bands and associated service areas are reserved for particular application well in advance of their real use. The distribution of the spectrum resource is made on the basis of the expected or declared needs of the parties interested. That approach was used, for instance, by the World Radiocommunication Conference, Geneva, 1997, that established Plan for the Broadcasting-Satellite Service in the Frequency Bands 11.7 - 12.2 GHz in Region 3 and 11.7 - 12.5 GHz in Region 1 and Plan for Feeder Links for the Broadcasting-Satellite Service in the Fixed Satellite Service in Frequency Bands 14.5 - 14.8 GHz and 17.3 - 18.1 GHz in Regions 1 and 3. Both Plans have been annexed to the Radio Regulations[33].

Advocates of the *a priori* approach indicate that *ad hoc* method is not fair because it transfer all the burden to the latecomers which must accommodate their requirements to the existing users. Opponents, on the other hand, point out that *a priori* planning freezes the technological progress and leads to "*warehousing*" the resources. Although all usable frequency bands have been allocated to services, only a small part of them is subject of international *a priori* planning. In this connection, many countries currently lacking the necessary financial resources are afraid that they will never have access to unplanned frequency bands or positions on the geostationary satellite orbit. These bands and positions might already be occupied when the countries will be ready to use them.

Critics of *a priori* planning indicate also that it is impossible to predict future requirements with a degree of accuracy, and any plan based on unrealistic requirements has no practical value, blocks frequencies, and freezes the development. Indeed, the technological progress is very fast, and the plan may become outdated before is implemented. The *a priori* and *ad hoc* approaches differ only in the time horizon taken into account. Finally, one may argue that the access to services does not require the ownership of, or control over, the spectrum/ orbit resources.

What is important, is that there is no mechanism to limit the requirements, as the spectrum/ orbit resource is available at no cost at international planning conferences. Although the ITU Convention calls for minimizing the use of spectrum resources,

32 Huang D.C.: Managing the Spectrum - Win, Lose, or Share; Harvard University, 1993.

"*...each country has an incentive to overstate its requirements, and there are few accepted or objective criteria for evaluating each country's stated need. In fact, the individual country itself may have only the dimmest perception of its needs over the time period for which the plan is to be constructed. ... Under these circumstances, it is easy to make a case that allotment plans are not only difficult to construct, but when constructed will lead to a waste of resources as frequencies and orbit positions are "warehoused" to meet future, indeterminate needs...*"[34].

These remarks, however, do not concern the frequency planning at the design stage of wireless systems, when all requirements are "real" and "immediate".

2.8 Trends

The current spectrum management policies and practices are inherited from the times when radio was mainly under the state monopoly and the access to the spectrum resources was free. However, the word has changed in the meantime and the role of governments is still changing. The state monopoly is being abandoned in many countries and the importance of private sector and non-governmental international corporations is increasing. A single market is being created and competitive worldwide market economy is developing. New technologies are being created and introduced in the market with accelerated rate. Digital signal processing offers new possibilities for integration of services, not exploited yet fully. New satellite and stratospheric station technologies are being planned. All that does not fit well into the framework of the present Regulations. Redistribution, and better use of radio waves, is felt necessary by many.

Although the present spectrum management system has been criticized almost from the very beginning, nothing better has been agreed. The developing countries are afraid that there will be no spectrum to satisfy their future needs. They would also like to exploit their old equipment until it is still working. The developed countries are afraid that they cannot implement new technologies and develop new applications because of regulatory barriers. All users complaint that the Radio Regulations are too complicated and excessively rigid[35].

Every radio conference makes the participants equally unhappy with the results achieved. But, this equal dissatisfaction of all parties involved indicates in fact that the best compromise possible has been reached; otherwise some parties would be more satisfied than the others would! Over the years, various improvements have been proposed, but few have been implemented and the fundamental rules remain unchanged.

One of the reasons of slow adaptation of the ITU process to the changing environment is fragmentation and disparity among the member countries, their needs and their interests. In spite of large differences between, say, China, representing a billion population, and that of Tonga, representing a hundred thousand people, the ITU constitution warrants a single vote to each of them, as to any other member country.

Another reason is the national sovereignty and consensus-based decision process - the two most sacred principles in the ITU. These principles imply that common decisions are possible only if acceptable to the weakest and most conservative members. Still another reason is the separation of the decision making process from economic mechanisms. The financial contribution of each member to the common budget is voluntarily and without any correlation to the number of radio stations or satellites it uses. The consumers/ users, service providers and equipment manufacturers are represented by the governments in the ITU decision process.

The experience gained in dealing with other resources indicates that economic incentives could be used as an instrument to rationalize the use of scarce resources. As mentioned earlier, most countries introduced nationally a fee system for access to spectrum/orbit resources. If introduced internationally, "*spectrum occupation fees*" could limit excessive demand and make free the frequencies and orbital positions that are now "warehoused". The income could be used to develop telecommunication infrastructure where needed. Such an idea was formally proposed (among others by this author), but did not receive substantial support at the World Radiocommunication Conference Geneva 1997. The majority of ITU member countries have preferred to continue with the administrative "due diligence" approach.

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34 Robinson G.: Regulating International Airwaves in Matos F. (Ed.), Spectrum management and engineering, IEEE Press, 1985, pp. 43-69

35 Bellchambers W.H.: Incorporating flexibility into spectrum allocations; in The spectrum mundwrestle-

The concept of spectrum management through market forces, put forward in some countries, has found as many supporters as opponents. The idea is to replace the regulatory and fee system by a competitive market economy mechanism[36]. For the time being, that action has been limited to few countries and to selected frequency bands[37]. Its advocates indicate that market forces automatically match the demand to the available resource capacity and that the market-based management is inexpensive[38]. Moreover, relying upon administrative decision-making is inferior to relying on market forces because decisions are arbitrary and often mistaken in determining what is the best interest of users[39]. However, marked forces could make wireless applications more expensive and influence the existing balance between the further developments of wired- and wireless communication services.

The breakthrough event in recent years was a series of spectrum auctions conducted by the US Federal Communication Commission. These auctions mark a break with tradition. Earlier, licenses to use radio frequency to offer wireless communication services were awarded on the basis "first come - first served", by lottery, or by comparative hearings ("beauty contests"), almost for free. Now the federal agency is granting the licenses to the highest bidders.

The first auction in the USA held in 1994 concluded in assigning three 1-MHz bands around 900 MHz for a total of about 650 million USD. In 1995, two pairs of 15-MHz bands around 1900 MHz for personal communication services were assigned for a total of 7.74 thousand millions USD[40]. On top of this, the successful bidders have to pay expenses for relocating thousands of microwave transmission facilities that were already using that portion of the spectrum. These numbers, however, should not be generalized as the price depends on the demand and supply. Spectrum in the center of New York or Tokyo will costs much more than somewhere in the center of desert. However, one thing is clear: the consumers will pay the final bill.

It should be noted here that creation of an international spectrum market is the next logical step after the introduction of national spectrum markets. No evidence has been published that selling the spectrum on global market will solve the scarcity problem in a way acceptable for all parties involved. The market approach, combined with sovereignty, still an indisputable principle in the ITU, may increase further the existing fragmentation in spectrum management.

3 Conclusions

How the spectrum/ orbit resources are used and managed, has profound impact on the society, on its prosperity, security, culture, and education. Following the tradition originated at the turn of the century, the use and management of the spectrum/ orbit resources on the international forum is based on two general principles, maintained until the present time with minor changes only:

⟨ The spectrum/ orbit resources are public, and each country has equitable and free access to it.

⟨ The uses of the spectrum/ orbit resources are based on administrative regulations and allocations of frequency bands (and orbital parameters).

⟨ The regulations and allocations are set through the mechanism of international consultations, negotiations, and consensus in the framework of the International Telecommunication Union, a Specialized Agency of United Nations.

⟨ Each sovereign country decides about its uses freely, as long as the electromagnetic compatibility[41] principles and international agreements in force, including the Radio Regulations, are respected.

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36 Goddard M.: The Role of Pricing in Spectrum Management; in: Developments in Spectrum Management, ITU Radiocom. Regional Seminar, Wroclaw, 6-8 July 1994.

37 Kalman Z.E., Nunas M.K.; Study on spectrum pricing, ITU, 1994.

38 To give a rough idea of the costs involved: the US Army alone spends nearly 40 million USDa year in frequency compatibility investigations necessary in the spectrum management process, see Dougan, op. cit.

39 Webbing D.W., The value of the frequency spectrum allocated to specific uses, IEEE Trans. Vol. EMC-19, 1977, pp. 343-351.

40 Bell T.E.: Main event: Spectrum auctions; IEEE Spectrum, Jan. 1996, p.28.

41 Electromagnetic compatibility is the ability of a system to operate correctly in its environment without

The development of wireless services depends strongly on how the radio spectrum and orbit resources are managed. There is growing opinion that the spectrum/ orbit scarcity is in a great part due to a combined effect of our inadequate approach, simplistic models, tools and methods, inappropriate regulations, and lack of reliable data.[42].

Eventually, technology may remove the need for some functions now included in spectrum management. Future radio systems would be able to coordinate automatically among themselves the use of spectrum resources to avoid interference and assure inter-communication. However, in view of enormous investments in the "old" equipment, it would not happen soon[43].

Before this happens, scientific approach and wider application of advanced mathematical methods and computers could improve the management and use of the available spectrum resources.[44] [45]

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42 Struzak R.: Computing tools in support of RF spectrum management; Proceedings of XIV International Wroclaw Symposium on Electromagnetic Compatibility, Wroclaw, Poland, 23-25 June 1998, pp. 648-653.

43 RA DTI: The future management of the radio spectrum, UK Radiocommunications Agency, 1994.

44 Struzak R.: Microcomputer modeling, analysis and planning in terrestrial television broadcasting; Telecommunication Journal, Vol. 59, X/1992, pp. 459-492.

45 Struzak R.: Spectrum management for wireless services of the 21st century; Global Communications -