Andrzej Hildebrandt

Od Redaktora Naczelnego

Przedstawiamy Państwu kolejny numer naszego kwartalnika, który tym różni się od wszystkich poprzednich, że zamieszczone w nim artykuły zostały napisane przez jednego autora. Autorem tym jest Pan Profesor Ryszard Strużak, a okazją do wydania tego numeru stał się jubileusz Jego osiemdziesiątych urodzin.

Pan Profesor, który jest niewątpliwie wielką indywidualnością w świecie telekomunikacji, rozpoczął pracę w Instytucie Łączności w roku 1956 i po pobytach w wielu instytucjach zagranicznych dziś jest ponownie aktywnym pracownikiem naszego oddziału we Wrocławiu.

Nie muszę w tym słowie wstępnym prezentować sylwetki Pana Profesora, gdyż zrobił to znakomicie dyrektor Wojciech Hałka w wygłoszonej przez siebie laudacji, której tekst zamieszczamy. Z przebiegiem Jego działalności zawodowej i naukowej mogą się Państwo zapoznać czytając dość obszerny życiorys Profesora, również załączony, natomiast obraz zainteresowań i osobowości Profesora Strużaka dopełniają przedruki kilku artykułów pochodzących z różnych okresów Jego działalności.

Pozostaje mi zatem tylko życzyć Szanownemu Jubilatowi, w imieniu własnym i Redakcji TiTI, dużo zdrowia i dalszych osiągnięć dla dobra zarówno Instytutu, jak i całej telekomunikacji, do której rozwoju w tak wielkim stopniu się przyczynił.

A artykuły Profesora czyta się z wielkim zainteresowaniem.

Laudacja [a)]

Profesora Ryszarda Strużaka
z okazji jubileuszu 80. jego urodzin

Szanowne Panie, Szanowni Panowie, Szanowny i Drogi Panie Profesorze,

przypadł mi w udziale wielki zaszczyt, a równocześnie przyjemność i satysfakcja, przedstawienia Państwu, z okazji uroczystego jubileuszu 80. urodzin, sylwetki obecnego tu z nami Jubilata, Pana Profesora Ryszarda Strużaka. Z pewnością większość z nas doskonale zna działalność naukową i organizatorską Profesora, niemniej jednak pozwolę sobie krótko przypomnieć niektóre aspekty jego znaczonej sukcesami pracy, jako dyrektor Instytutu Łączności, w którym Profesor Strużak przez lata pracował i pracuje obecnie i jako, mogę chyba tak powiedzieć drogi Ryszardzie, Twój przyjaciel.

Profesor dr hab. inż. Ryszard Grzegorz Strużak swoje życie zawodowe poświęcił radiotechnice oraz kompatybilności elektromagnetycznej, ich aspektom naukowym, inżynierskim, normalizacyjnym, regulacyjnym i rozwojowym w skali krajowej i międzynarodowej. Studia rozpoczął na Politechnice Łódzkiej w wieku 17 lat. Dyplom inżyniera uzyskał w roku 1954, dyplom magistra inżyniera w roku 1956, obydwa dyplomy na Politechnice Wrocławskiej. Rada Wydziału Łączności Politechniki Warszawskiej nadała mu w roku 1962 stopień doktora nauk technicznych i w roku 1968 stopień doktora habilitowanego. Rada Państwa nadała mu tytuł Profesora nadzwyczajnego w roku 1975 i Profesora zwyczajnego w roku 1988.

Pracę zawodową Profesor rozpoczął w roku 1953 i do dziś jest aktywny zawodowo.

W czasie tych sześćdziesięciu lat 34 lata Profesor Strużak poświęcił pracy w Instytucie Łączności, z oddaniem kierując Oddziałem Instytutu we Wrocławiu, gdzie zorganizował i prowadził pierwszy w Polsce Zakład Kompatybilności Elektromagnetycznej i związane z nim laboratorium. W laboratorium tym zainicjował prace nad propagacją fal radiowych i badania środowiska elektromagnetycznego, celem poznania ich wpływu na wzajemne oddziaływania elektromagnetyczne urządzeń. Był współtwórcą i wielokrotnym przewodniczącym Międzynarodowego Wrocławskiego Sympozjum Kompatybilności Elektromagnetycznej, pierwszego w Europie cyklicznego sympozjum w tej dziedzinie, a w ostatnim okresie zainicjował badania granic rozwoju szerokopasmowego internetu. Wart zwrócenia tutaj uwagi jest niedawny artykuł Profesora opublikowany w roku 2012 w *IEEE Communications Magazine* zatytułowany *Diffusion of broadband services: an empirical study*, w którym przedstawił interesujące uwagi na temat granic wzrostu sieci Internet. Do chwili obecnej Profesor bierze czynny udział w pracach naukowo-badawczych prowadzonych w Zakładzie Kompatybilności Elektromagnetycznej we Wrocławiu, a także w pracach Rady Naukowej Instytutu Łączności, której jest członkiem.

Profesor Ryszard Strużak był i jest silnie związany z Politechniką Wrocławską, ale współpracował także z wieloma uczelniami zagranicznymi. Prowadził wykłady w wielu krajach za granicą: w Szwajcarii, Niemczech, Francji, Japonii, USA, Wielkiej Brytanii, w Meksyku, we Włoszech i w Gruzji.

Od roku 1985 przez 19 lat Profesor Strużak pracował w Genewie. W 1985 roku wygrał międzynarodowy konkurs na kierownicze stanowisko w Sekretariacie Międzynarodowego Związku Telekomunikacyjnego (ITU), gdzie został zatrudniony jako *CCIR Senior Counsellor, Head of Technical Department* i *Acting Assistant Director*. Koordynował wówczas działalność sześciu Grup Studiów CCIR,

[a)] Laudacja została wygłoszona przez Wojciecha Hałkę, Dyrektora Instytutu Łączności, Prezesa Stowarzyszenia Inżynierów Telekomunikacji, w dniu 10 czerwca 2013 r. we Wrocławiu, podczas Krajowej Konferencji Radiokomunikacji, Radiofonii i Telewizji.

zorganizował bibliotekę programów komputerowych zarządzania widmem radiowym, usprawnił proces przygotowań Światowych i Regionalnych Konferencji Radiowych ITU. Po zakończeniu pracy w ITU w 1993 roku działał jako niezależny konsultant, ale już w 1994 roku Konferencja Plenarna Pełnomocników ITU w Kyoto (prawie 2000 delegatów ze 186 krajów) wybrała go do *Radio Regulations Board*, międzynarodowej komisji regulacyjnej i rozjemczej w dziedzinie radiokomunikacji naziemnej i łączności satelitarnej, gdzie pracował przez dwie kadencje, ostatnio jako wiceprzewodniczący tej komisji.

Poza wymienionymi organizacjami Profesor angażował się i pracował w wielu innych instytucjach i firmach krajowych i zagranicznych. Aktywnie uczestniczył w pracach krajowych i międzynarodowych grup ekspertów. Był konsultantem *ITU, IUCAF, UN Office for the Coordination of Humanitarian Affairs, UNESCO, World Bank, PWC* oraz agencji rządowych i przemysłu Wielkiej Brytanii, USA, Szwajcarii, Turcji, Polski i innych krajów. Opiekuje się młodymi naukowcami-stażystami z Afryki we współpracy z *ICTP*, Międzynarodowym Centrum Fizyki Teoretycznej w Trieście i w naszym Instytucie Łączności.

Działalność publikacyjna Profesora obejmuje autorstwo lub współautorstwo 10 patentów, 23 książek i ponad 200 innych publikacji z dziedziny radiokomunikacji, zarządzania widmem i kompatybilności elektromagnetycznej. Należy zwrócić uwagę na wydaną przez *Oxford University Press* książkę *Introduction of Spectrum Management*, w której Profesor przedstawił uporządkowene podstawy zarządzania widmem elektromagnetycznym. Profesor jest także autorem licznych analiz, raportów i projektów włączonych w całości lub w części do oficjalnych dokumentów różnych organizacji krajowych i międzynarodowych.

Za swoją bogatą i wszechstronną działalność Profesor został uhonorowany wieloma odznaczeniami, w tym Krzyżem Kawalerskim Orderu Odrodzenia Polski i Srebrnym Medalem ITU za Szczególne Zasługi dla Rozwoju Telekomunikacji na Świecie (1998), w 1985 roku został mu przyznany tytuł *IEEE Fellow*, w 2003 roku otrzymał dyplom *IEEE Acknowledgement of Gratitude*, a w 2007 roku uzyskał honorowy tytuł *IEEE Life Fellow* oraz specjalne wyróżnienie *IEEE Compatibilty Society* (w 2010 roku).

Intensywna działalność zawodowa Profesora trwa nieprzerwanie 60 lat i zdaję sobie sprawę, że w moim krótkim wystąpieniu wymieniłem tylko nieliczne przejawy jego osiągnięć i dorobku, jako naukowca o szerokich zainteresowaniach, ogromnej wiedzy, pracowitości i aktywności zawodowej. Jako organizatora wyróżnia Profesora dążenie do osiągania celów, przebojowość i umiejętność pozyskiwania utalentowanych współpracowników. Jako człowieka cechuje go prostolinijność, otwartość i życzliwość, chęć niesienia pomocy innym.

Podsumowując, chciałbym stwierdzić. że życiorys Pana Profesora Ryszarda Strużaka dowodzi, w sposób uznany w szerokiej społeczności międzynarodowej, wysokiej jakości polskiej radiokomunikacji, polskich uczelni i instytutów. Jego osobisty wybitny dorobek i osiągnięcia zawodowe, naukowe i organizacyjne, pozwalają stwierdzić, że jest postacią niezwykle zasłużoną dla polskiej i światowej telekomunikacji.

Myślę, że wyrażę intencję wszystkich tu obecnych słowami: dziękuję Ci Profesorze za to, co zrobiłeś dotychczas dla telekomunikacji jako nauki, jako dziedziny techniki i dla ludzi z telekomunikacją związanych, dla nas wszystkich, i życzę Ci wielu dalszych lat owocnej aktywności.

Jubileusz 80-lecia urodzin prof. Ryszarda Strużaka

Profesor dr hab. inż. Ryszard Strużak (ur. 1933) swoje życie zawodowe poświęcił radiotechnice oraz kompatybilności elektromagnetycznej: ich aspektom naukowym, inżynierskim, normalizacyjnym, regulacyjnym i rozwojowym, w skali krajowej i międzynarodowej.

Studia rozpoczął na Politechnice Łódzkiej mając 17 lat. Dyplomy inżyniera (1954) oraz magistra inżyniera łączności (1956) uzyskał na Politechnice Wrocławskiej. Stopień doktora nauk technicznych otrzymał na Wydziale Łączności Politechniki Warszawskiej (1962), a doktora habilitowanego na Wydziale Elektroniki tejże Politechniki (1968). Rada Państwa nadała mu tytuł profesora nadzwyczajnego w 1975 r. i profesora zwyczajnego w 1988 r.

Lata 1953–1985

Pracę zawodową rozpoczął w 1953 r. jako technik w Ośrodku Badawczo-Doświadczalnym Centralnego Zarządu Radiostacji, przekształconym następnie w Oddział Instytutu Łączności we Wrocławiu. W latach 1954–1985 oraz 2008–2010 pracował na Politechnice Wrocławskiej, na różnych stanowiskach, od asystenta do profesora najpierw w Katedrze Podstaw Telekomunikacji i Mikrofal, potem w Instytucie Telekomunikacji i Akustyki, a następnie w Instytucie Metrologii Elektrycznej. Jego głównym miejscem pracy był jednak Instytut Łączności, gdzie pracował w latach 1956–1961, 1964–1985 oraz od 2005 r., zajmując różne stanowiska od kierownika pracowni do kierownika oddziału we Wrocławiu i profesora. Tam zainicjował badania środowiska elektromagnetycznego w celu ograniczania jego niekorzystnych oddziaływań na urządzenia. Zorganizował pierwszy w Polsce Zakład Kompatybilności Elektromagnetycznej. W latach 1961–1963, w ramach obowiązkowej służby wojskowej, pracował jako Oficer Sztabowy ds. Radiolokacji w pułku artylerii przeciwlotniczej.

Jest współautorem pierwszych norm dotyczących kompatybilności elektromagnetycznej. Koordynował Krajowy Problem Węzłowy dotyczący wykorzystania częstotliwości radiowych. Został wiceprzewodniczącym Komisji Normalizacyjnej w zakresie przemysłowych zakłóceń radioelektrycznych (1971–1985). Współpracował z przemysłem podzespołów przeciw-zakłóceniowych i urządzeń pomiarowych przyczyniając się istotnie do zaspokojenia potrzeb kraju i uzyskania specjalizacji eksportowej w ramach wspólnego rynku RWPG. Rozwinął teorię układów Rajskiego o parametrach rozłożonych. Opracował nową metodę planowania częstotliwości w sieciach radiofonicznych, wykorzystaną w Europie Zachodniej. Wraz z zespołem młodszych kolegów opracował unikalną aparaturę pomiarową, pierwszy w Polsce cyfrowy model terenu o dużej rozdzielczości (do obliczeń propagacji fal radiowych), pierwsze w Europie (cywilne) laboratorium pomiarowo-kontrolne na śmigłowcu, oraz jedne z pierwszych na świecie narzędzia symulacji i planowania naziemnych sieci radiowych przy wykorzystaniu komputerów osobistych. Promował kilkunastu magistrów inżynierów i ośmiu doktorów; niektórzy z nich zajmują dziś kluczowe stanowiska w kraju i za granicą.

Został wybrany do Rady Naukowej Instytutu Łączności jak również do innych rad naukowych i technicznych, m.in. działających przy Ministrze Łączności, Wojskowym Instytucie Łączności, Komitecie ds Radia i Telewizji. W latach 1975–1985 przewodniczył Podkomitetowi Kompatybilności Elektromagnetycznej Komitetu Elektroniki i Telekomunikacji PAN.

Uczestniczył aktywnie w pracach krajowych i międzynarodowych grup ekspertów. Na arenie międzynarodowej został zaproszony do międzynarodowego Komitetu Kierowniczego CISPR (1972–1975). Został wybrany wiceprzewodniczącym pierwszej Międzynarodowej Komisji Studiów CCIR *Spectrum Management* (1974–1985); przewodniczącym Grupy Roboczej ISM (1980–1985); wiceprzewodniczącym URSI Międzynarodowej Komisji Naukowej E; współprzewodniczącym Grupy Roboczej E4 (1984–1986, 1993–2003 oraz od 2011). Zapraszany był do komitetów programowych wielu konferencji naukowych. Współorganizował Międzynarodowe Wrocławskie Sympozjum Kompatybilności Elektromagnetycznej (1972–2010), pierwsze tego typu w Europie, pełniąc różne funkcje, m.in. przewodniczącego sympozjum.

Lata 1985–2004

W 1985 r. wygrał konkurs na kierownicze stanowisko w Sekretariacie Międzynarodowego Związku Telekomunikacyjnego (ITU/CCIR) w Genewie i jego działalność krajowa uległa zawieszeniu. W tym okresie także działalność w organizacjach międzynarodowych (poza ITU/CCIR) zostaje przerwana ze względów formalnych i zastąpiona reprezentowaniem CCIR w tych organizacjach. W ITU został zatrudniony jako *CCIR Senior Counsellor, Head of Technical Departament and Acting Assistant Director*. Koordynował działalność sześciu Grup Studiów CCIR. Zorganizował bibliotekę programów komputerowych zarządzania widmem radiowym. Usprawnił istotnie proces przygotowań Konferencji Radiowych ITU. Po zakończeniu kontraktu w ITU (1993) działał jako niezależny konsultant. Na konferencji ITU PP Kyoto 1994 wybrano go do *Radio Regulations Board*, gdzie pracował przez dwie kadencje, ostatnio jako wiceprzewodniczący. Pracował dla organizacji międzynarodowych, agencji rządowych oraz firm prywatnych w różnych krajach, m.in. dla *UN Office for the Coordination of Humanitarian Affairs* (OCHA), World Bank, Teledesic (USA), Thomson CFF (Francja), Noller Comms. (USA), Telecom Strategies (USA) i NoMobile (Szwajcaria). Współpracawał z wydawnictwem *Global Communications* w Londynie m.in. jako redaktor naczelny i przewodniczący komitetu redakcyjnego (1996–2000). Nadal współpracuje z *International Centre for Theoretical Physics* (ICTP), jako wykładowca (od 1988) oraz współdyrektor (od 1993) międzynarodowej szkoły zimowej na temat bezprzewodowych sieci teleinformatycznych.

Od 2004 r. do chwili obecnej

W 2004 r. powrócił do kraju i podjął pracę w Wyższej Szkole Informatyki i Zarządzania w Rzeszowie (2004–2005), w Instytucie Łączności we Wrocławiu (od 2005) oraz na Politechnice Wrocławskiej, gdzie prowadził seminarium z kognitywnych sieci bezprzewodowych (2008–2010). W Instytucie Łączności zainicjował badania granic rozwoju szerokopasmowego Internetu i bierze czynny udział w planowych pracach naukowo-badawczych. Opiekował się młodymi naukowcami-stażystami z Afryki we współpracy z ICTP. Jest promotorem pracy doktorskiej w toku. Został wybrany do Rady Naukowej Instytutu Łączności (2011) i do sekcji KEiT PAN. Został zaproszony do Rady Nadzorczej Grupy HAWE (2008–2010), oraz do *Central European Initiative Task Force on Information Technology* jako *Focal Point* (od 2006).

Publikacje i wyróżnienia

Profesor Strużak jest autorem lub współautorem 10 patentów oraz ponad 200 publikacji, a także licznych analiz, raportów i projektów włączonych w całości lub w części do oficjalnych dokumentów różnych organizacji, także międzynarodowych.

Został dwukrotnym laureatem konkursów międzynarodowych (EMC Montreux 1975, EMC Rotterdam 1977), trzykrotnym laureatem nagród ministrów (Ministra Łączności 1974; Ministra Nauki, Szkolnictwa Wyższego i Techniki 1979, 1983), sześciokrotnym laureatem konkursów Polskiego Towarzystwa Elektrotechniki Teoretycznej i Stosowanej Oddziału we Wrocławiu. Został wybrany na członka *New York Academy of Sciences* (1993) oraz *International Telecommunication Academy* (1997). Wykładał na wszystkich kontynentach (z wyjątkiem Australii), m.in. zaproszony do ETH Zurich (Szwajcaria, 1975), IRT Muenchen (Niemcy, 1982), CNET Paris (Francja, 1983), Tohoku Gakuin University (Sendai, Japonia, 1984), NTIA/FCC Washington (USA, 1992), L'Institut National Polytechnique de Toulouse (Francja, 1994), Oxford University (W Brytania, 1997), Cinevstav/IPN Mexico (Meksyk, 2000), ESF Cagliari (Włochy, 2004), Georgia Technical University (Tbilisi, Gruzja, 2011).

Został uhonorowany wysokimi odznaczeniami międzynarodowymi: Srebrnym Medalem ITU za szczególne zasługi dla rozwoju telekomunikacji na świecie (1998), tytułem *IEEE Fellow* (1985) i *Life Fellow* (2007), dyplomem *IEEE Acknowledgment of Gratitude* (2003) oraz specjalnym wyróżnieniem *IEEE Compatibility Society* (2010). W kraju został m.in. odznaczony Krzyżem Kawalerskim Orderu Odrodzenia Polski (1982), Złotą Odznaka Honorową Stowarzyszenia Elektryków Polskich (1981), Złotą Odznaką Zasłużony Pracownik Łączności (1973).

Biografia prof. Strużaka została opublikowana w *Who is Who in the United Nations and Related Agencies, Who is Who in International Affairs, Who is Who in Engineering, Who is Who in Science in Europe, Who is Who in Switzerland*, oraz w innych publikacjach tego typu.

Źródło: Przegląd Telekomunikacyjny, nr 6/2013, s.160-161.

Microcomputer modelling, analysis and planning in terrestrial television broadcasting [a)]

Digital terrain maps, spectrum-related data banks, and computer simulation help to examine the operation of existing television broadcasting networks and find a place for new stations
by R. STRUZAK*

Ryszard Strużak

ABSTRACT
This article describes a simulation model of a national network of television broadcasting stations. The performance of a station depends on its sitting and its antenna, on its radiated power and frequency, and on surrounding terrain and electromagnetic environment. All these factors can be analysed using the simulation model. Simulation can help in the maintenance of the existing television stations and in the planning of new stations by making "what-if" considerations fast, simple and effective. The simulation model has been developed as an engineering aid in planning the low-power rebroadcasting stations.

1. Introduction

1.1 Background

Our society places increased demands on television. There are more television receivers in use throughout the world than there are telephones.[1] Broadcasting networks involve thousands of television transmitters. Without careful co-ordination, they would all dissolve in a chaos of mutual interference. High-power transmitting stations are coordinated at international conferences, [2] but many low-power television stations only require national co-ordination. Such stations, of less than 1 W and up to 1000 W, can operate unattended and are more and more popular. For only a fraction of the cost of high-power stations, they provide services complementary to the main broadcasting network, for example, local information, local market advertisement, services for special interest groups, clubs, minority communities, ethnic groups and church communities. In the United States, a local broadcast station is seen as a basic cultural force in the community it serves. [3]

Another application of low power stations is the delivery of television programmes to small communities in remote areas. Still another application is the filling of coverage gaps. Such gaps in the coverage by terrestrial and satellite transmitters are due to shadowing and reflections by terrain obstacles and man-made structures: although the signal can be delivered by cable, low-power rebroadcasting is often more practical. In spite of a spectacular growth of cable and satellite technology, terrestrial broadcasting remains the principal means for delivery of television to the home, and heavy investment in the

[a)] *Od redakcji TiTI: Niektóre rysunki zostały ponownie narysowane.*

* *The opinions expressed in this article are the author's personal views, and do not necessarily reflect those of the International Radio Consultative Committee (CCIR) or the International Telecommunication Union (ITU). The following pages have been scanned from the original article published in Telecommunication Journal Vol. 59-X/1992 p. 459 – 492 and 453. Advertisement pages have \been omitted. Some formatting details of the original have been lost and some diagrams have been redrafted.*

equipment indicates that it will continue for a number of years to come. The number of low-power stations is growing fast both in large cities and in small localities in remote areas. According to the statistics of the European Broadcasting Union (EBU), about 95% of all television transmitting stations in Europe are low power.[4] In Australia, about 80% of all television transmitting stations are translators.[5]

With the privatization of the broadcasting sector, a great demand for additional transmitters is to be expected. For example, some 6000 applications for such stations were registered in the United States during a period of one year. [6] However, to find space for a new station is not an easy task in regions with well-developed television broadcasting networks. Each application requires a detailed evaluation to ensure that the proposed station will neither suffer nor create interference. Often an existing station also requires an evaluation. A new transmitter, even distant, can modify signal environment, and man-made structures can modify the signal propagation conditions.

Ultimately, any evaluation of a station, existing or planned, is based on field measurements. From these measurements, one determines the station coverage and identifies any coverage deficiency. The volume of such measurements increases with the number of transmitters and with the coverage area. In the measurements, test transmitters must often be used to generate a test signal. [7, 8] As such experiments are expensive, weather-dependent and time-consuming, one avoids them as much as possible, especially in inaccessible areas.

1.2 Development of automated tools

Automated tools have been developed to reduce the labour and cost of the field experiments. [9] Signal levels can be predicted instead of being measured, and computers can do the job, if supplied with propagation models and data. In order to have accurate predictions, propagation models involving detailed topographic data must be used. [10-12] Manual extraction of the data from source maps for each propagation path is a time-consuming task that can be automated by converting these maps into computer-readable form. [13, 14] The data of transmitting and receiving stations, however, must still be prepared and introduced manually. The ultimate step is, therefore, to integrate all relevant models and data into one system that can simulate the operation of the complete transmitter network. [15] This article discusses the implementation of such a simulation system.

Computer simulation can radically reduce the number of the required "real life" experiments and offer substantial gains in cost and in time. What is, however, even more important is that such an approach can help in an economic use of the radio-frequency spectrum, as more decision variants can be examined within the imposed time and cost limits. The essential characteristic of simulation is the use of models for experimentation. A simulated experiment is less expensive and avoids all risks and difficulties of the "real world". It is easier to prepare, to perform, to control, to modify and to repeat. Another important characteristic of the simulation is its ability to examine systems that exist only in conceptual form, or are intractable to experimental manipulation and/ or exact mathematical treatment. Having a simulation model of a system, it is quite easy to alter the parameters of the model and observe how it operates with these changes. The conclusions drawn from these observations are applicable to the original system if the model and input data are correct. [16] The simulation can only give an estimate of the actual performance of the station, and an experimental verification in the field is usually required, but the volume of field measurements is minimized.

Underlying the software advances is the steady rise in hardware performance. The first automatic systems required large computers and highly qualified professional staff. The high hardware cost and complex user's interface limited their application to a few moneyed centres. The progress in computer technology has opened new perspectives. As recently as 1970, nearly 100% of the world's computer power was concentrated in large computers. By 1990, such machines held less than 1% of the world's computer power. Personal microcomputers, available at everyone's desk, became as powerful as an early 1970s mainframe, for a fraction of its price. Therefore, the interest in microcomputer-aided spectrum engineering has been fast growing.[17] The demand for microcomputer software is great, but only a few minicomputer spectrum engineering systems have been described in the literature [18, 19], possibly because firstly, frequency-spectrum engineering tasks are computing-intensive and involve huge collections of data (until recently, they exceeded the capabilities of microcomputers), and secondly, the spectrum-engineering software market is limited. [20] These factors do not encourage software developers.

1.3 Organization of the article

The rest of the text is organized as follows: section 2 describes the databases, among which, in particular, are digital terrain maps. The following section describes how the model can be used to analyse the performance of an existing television network, for example to identify the coverage gaps. Section 4 discusses the planning process of a new television station and its harmonization with the existing television network and topographic environment. Section 5 discusses the overall performance and limitations of the model and gives results of its verification. Section 6 contains concluding remarks. The presented system was demonstrated at seminars of the International Frequency Registration Board (IFRB) [21] and at other occasions. It is a new, simplified version of the software developed earlier for a large computer and described in reference [14].

2. The databases

The main aim of the simulation model is to imitate a network of television broadcasting stations. Another objective is to facilitate the storage, retrieval, and analysis of the information that is needed to evaluate the operation of the stations. The model integrates several elements, discussed below and shown in figure 1. It incorporates data banks, radio-wave propagation algorithms and electromagnetic compatibility (EMC) criteria. These are based, as much as possible, on the CCIR texts.

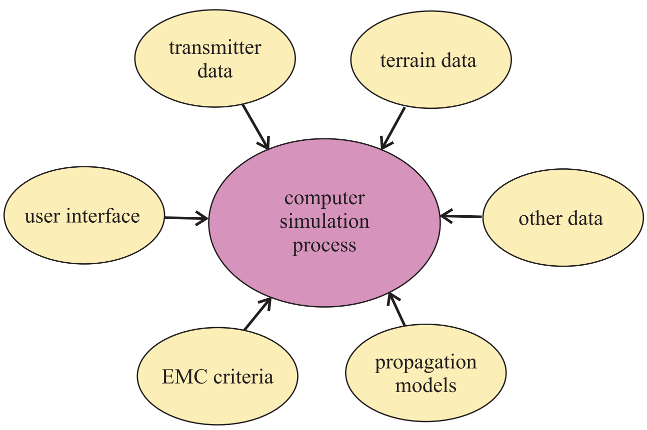
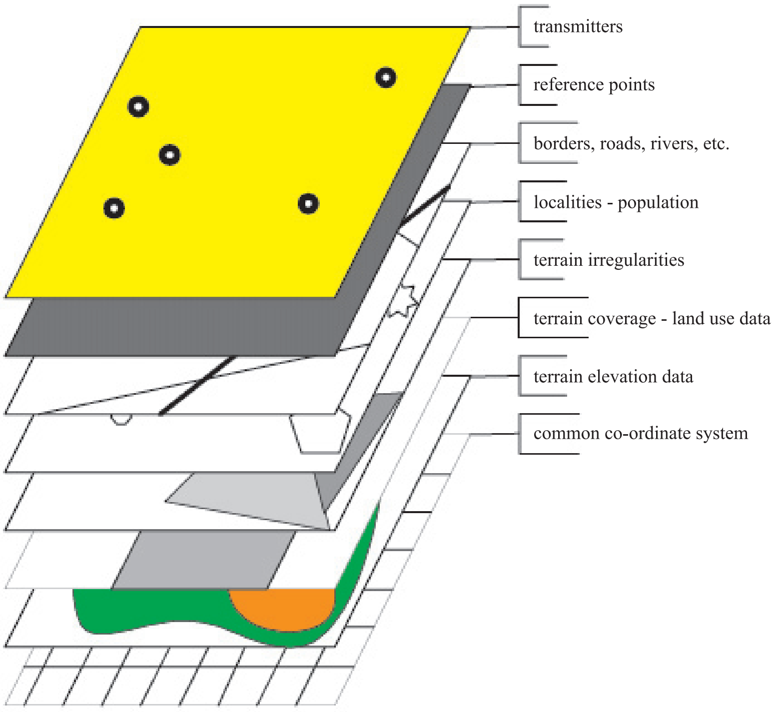


Figure 1*-Simulation model (simplified diagram)*

2.1 Geographical database

Numerous geography-related data are necessary to evaluate the effects of VHF/UHF signal propagation. In addition to the terrain relief, information is required about administrative boundaries, population distribution, roads, power line networks, etc. Usually, that information is extracted from various sources. Since no common standards exist, rarely the same scale, projection and co-ordinate systems are used. The data must be made mutually consistent and converted to a digital form before they can be used in a computer system. All geography-related data are thus referred to the Earth ellipsoid, independently of the projection system adopted in the source maps, and the points on the Earth surface are identified by their geographic coordinates (figure 2).



Object	Resolution/ Cell size
Individual terrain points	50 m
Lines (roads, borders, etc.)	100 m
Terrain elevation (regular points)	250 x 250 m
Terrain coverage/ land use	250 x 250 m
Terrain irregularity (“Delta h”)	25 x 25 km

Figure 2-*Geography-related data use common co-ordinate system. Data from maps in various scales can be automatically adjusted and superimposed*

2.1.1 Data representation

The way the geographic data are stored in a computer depends on the required accuracy and available computer memory. Table 1 compares the approximate resolution of various maps. A 1:50000 map offers about 50 m of the surface resolution and about 1m of the height resolution. Usually, such a precision is quite sufficient for planning UHF/ VHF television broadcasting. There are two methods of computer representation of geographic data. The first one uses regularly spaced discrete data, and the other irregularly spaced data, with interpolation between the discrete data points. In our simulation model, we use both methods. Such a combination results in the increased accuracy of terrain representation and economic use of the computer memory.

Table 1. Approximate resolution of various maps

Map scale	Surface resolution* (m)	Height resolution** (m)
1:1000000	1000	20
1:500000	500	10
1:250000	250	4
1:100000	100	2
1:50000	50	1
1:25000	25	0.5
1:10000	10	0.25

** The surface resolution is defined here as the distance (in terrain) between two points that spaced by 1 mm on a given map.*
*** The height resolution is defined here as one-tenth of the basic height-contour interval on a given map.*

- **Regularly spaced data**

The basic topographic data are the terrain elevations at regularly spaced points with implicit co-ordinates. Each point represents a terrain cell, in the form of a square. The location of an individual point is not specified but is calculated using its row number, column number and cell size. The data are stored in the matrix form. The regular structure assures a quick access to the data by its address derived from the geographical co-ordinates. The cell size must be small enough to reflect the terrain details with required accuracy. According to our experience, in hilly and undulated regions, the maximum cell size is about 250 m. In flat areas, larger cells of about 500m give practically the same elevation accuracy. On the other hand, the smaller the cell size, the greater is the number of cells for a given territory. Table 2 shows the approximate relationship between the cell size and cell number. For example, a territory of 1000 x 1000 km needs 4 million 500-m cells, or 400 million 50-m cells. In our simulation model, various scales of map and cell sizes can be used. The capability of automatically combining different map scales is one of the most important features of the system.

- **Irregularly spaced data**

In addition to the data just described, our digital terrain model also contains irregularly spaced data with explicit co-ordinates. These are terrain elevations at specific points that are important for the radio wave propagation, like mountain peaks or passes. In hilly regions, the number of such points reaches up to a few percent of the regular lattice points. Figures 3A and 3B show fragments of the topographic data bank.

Table 2. Cell size and cell number for an area of 1000 x 1000 km

Linear cell size [m]	Angular cell size on the Equator [arc-second]	Number of cells
1000 m	32.3"	1 million
500 m	16.2"	4 million
250 m	8.08"	16 million
100 m	3.23"	100 million
50	1.62"	400 million
25	0.81"	1.6 billion
10	0.32"	10 billion
1	0.03"	1000 billion

Table 3 compares cell sizes of digital terrain maps used in various countries. Many of these maps have been created for the purposes of the mobile radiocommunication service in the VHF/ UHF frequency bands.[22, 23] Digital maps with cell size of the order of 20 m are now in preparation in several countries.

Table 3. Cell size of various digital maps in use

Country	Cell size [m]	Notes
Canada	~500	Whitteker J. H.: Propagation prediction from a topographic data base, IEEE International CommunicationsConferenCe-ICC'83 (Boston, Massachusetts, 19-23 June 1983), Vol. 1, pages 44-48
Czech & Slovak Federal Republic	~100	Bak P.: private communication (1991)
Finland	~200	Karjalainen J.: private communication (1991)
France	~100	Meyer S. and Pihan J.: Coverage prediction for rural telephony systems, IEEE International CommunicationsConference-ICC'83 (Boston, Massachusetts, 19-23 June 1983), Vol. 1, pages 72-76
Germany	~100	Loew K. and Lorenz R. W.: Determination of service areas for mobile commu-nication with a topographical data base, IEEE International Communications Conference-ICC '83 (Boston, Massachusetts, 19-23June 1983), Vol. 1, pages 54-58

Table 3 (cont.) Cell size of various digital maps in use

Ireland	1000	EBU: Planning parameters and methods for terrestrial television broadcasting in the VHFIUHF bands (Tech. 3254,1988)
Italy	~230	Del Duce V., Isola C. and Virgadamo G.: Interactive graphic procedure for broadcasting frequency management making use of terrain data bank on high-definition CAD workstations, Telecommunication Journal, September 1990, Vol. 57, No. IX, pages 620-629
Italy	~400	Freni A., Giuli D. and Fossi M.: Simulation models for meteorological radar siting, Alta Frequenza, 1989, Vol. LVIII, No.4, pages 419-426
Japan	~500	CCIR: Handbook on spectrum management and computer-aided techniques, ITU (Geneva, 1987)
Japan	~250	Niimi H., Hirabayasi T. and Kajiyama M.: Computer aided analysis of propagation characteristics using topographical mesh-data basis, IEEE International Communications Conference-ICC '83 (Boston, Massachusetts, 19-23 June 1983), Vol. 1, pages 49-53
Netherlands	~100	Mawira A. and Stortelder B.: The development of propagation models and CAD tools for the planning of mobile communication networks, Alta Frequenza, February/March 1988, Vol. LVII, No.2, pages 83-88
Poland (since 1950s)	~1000	Struzak R. G.: Radio frequency spectrum management; Telecommunication Journal, July 1981, Vol. 48, No. VII, pages 410-413-250
Poland	~250	Since 1975
South Africa	400	In rural flat areas, Koffeman A.; private communication (1992)
South Africa	200	In urban areas and mountainous terrain; Koffeman A.: private communication (1992)
Sweden	~50	Wieweg L.: private communication (1992)
Switzerland	~250	Kartachoff P.: private communication (1991)
United Kingdom	~500	Ibrahim M. F. A., Parsons J. D. and Dadson C. E.: Signal strength prediction in urban areas using a topographical and environmental database, IEEE International Communications Conference-ICC '83 (Boston, Massachusetts, 19-23 June 1983), Vol. 1, pages 64-67
United States	~100	Spies K. P. and Paulson S. J.: TOPOG: a computerized worldwide terrain elevation data base generation and retrieval system, NTIA-Report 81-61 (1981)
Yugoslavia	~100	Starcevic D.: Production of digital model of topographic map for radiocommunication planning, Proceedings of the Fifth International Wroclaw Symposium on Electromagnetic Compatibility--EMC 80 (17-19 September 1980), Part 2, pages 477-485

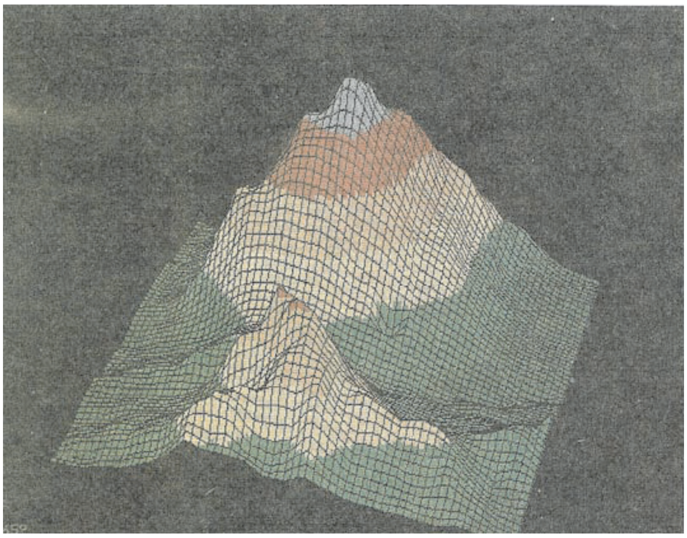


Figure 3A*- Terrain elevation data bank: pseudo-three dimensional visualization. A fragment of the terrain surface displayed on the screen. Terrain elevations at line intersections are stored in the computer memory. False colours and visual perspective are added to create a realistic appearance of the terrain. The scale of the picture and position of the observation point can be modified. Such a representation can be used for error detection in the database, as errors tend to give rise to unnatural-looking features*

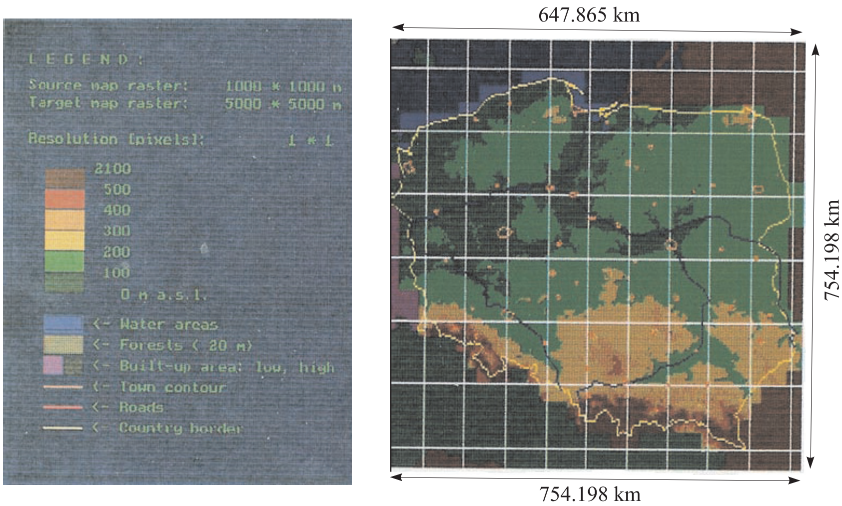


Figure 3B*- Terrain elevation data bank: two-dimensional visualization*

Right window*: physical map of the country derived from the topographic data bank, as displayed on the screen. A colour scale is used to differentiate terrain elevation classes, the scale can be modified. The horizontal and vertical lines on the map are the meridians and parallels. The country borders, main rivers and major cities are visible*

Left window*: each pixel on the map represents an area of 5 x 5 km, derived from a digital working map with a resolution of 1 km. The source digital map has the resolution of 50/50 m*

- **Terrain irregularity data**

For fast propagation predictions in accordance with the relevant CCIR Recommendation, [24] there is a map of terrain irregularity factor "Delta h" provided in digital form. The country is divided into geographic rectangles of approximately 25 x 28 km, and 12 numbers are stored for each rectangle. These are the ~h values at 12 azimuths taken every 30°.

- **Other data**

Associated with each cell is the information about the terrain coverage within the cell. The coverage is ranked in eight categories that include forests, built-up areas of various intensity, open area, sea, etc. Other information stored deals with the administrative borders, roads, contours of cities and localities, power lines, etc. These were coded by digitizing the co-ordinates of selected points along each line.

2.1.2 Data organization

The total area of the country has been divided into 60 "pages" or geographic rectangles of one degree latitude by one degree longitude. Each page of the digitized map is kept in a separate file, identified by the geographic co-ordinates of the south-west corner. Within the file, data are organized as a matrix $[h_{c,r}]$ where column index c = 0...287 and row index r = 0...443 for the smallest cells:

$$\begin{bmatrix} h_{0,0} & \dots & h_{0,287} \\ \dots & \dots & \dots \\ h_{443,0} & \dots & h_{443,287} \end{bmatrix}$$

Digital maps with larger cells are also possible. These are represented by smaller matrices. Each element of the matrix is 16-bit long. Twelve bits represent terrain elevation, covering the elevation span from the sea level up to more than 4000 m. Three bits describe the terrain coverage, allowing for a differentiation among eight coverage classes. One bit contains information on whether or not there exists an associated file with the specific terrain points. Such files are also identified by geographic co-ordinates. The data are record-structured, and each record contains three co-ordinates (x, y, z) of a point. The linearly-related geographical data are also record-structured. Each record contains (x, y) co-ordinates (6-bit real numbers), interpreted as the geographic longitude and latitude in radians. The terrain information covering the whole territory of Poland occupies about 20 megabytes disk space.

2.1.3 Data capture

The data were extracted manually from the 1:50000 source map, as automated tools were unavailable at the time of the data bank creation. Special temperature-insensitive transparencies were used for that purpose. A precise grid of geographic lines was drawn on each transparency, defining cell borders every 12.5 seconds in the north-south direction and roughly 8 seconds in the east-west direction. It is about 5 mm on the map, or 250 m in terrain, the same in both directions. The grid was then superimposed on the map, and the terrain height was coded at the intersections of the grid lines. The elevation values were estimated by visual interpolation from adjacent isarithms. Over flat regions it was sufficient to read the elevation every second line.

Conversion of data from the source map to the computer introduces inaccuracies, and special precautions were undertaken to minimize errors (figure 4). The elevations were read by well-trained professionals, recorded on magnetic (audio) cassette and then typed independently on two sets of perforated cards. Typing errors were identified by the computer and checked against the master map. To identify read-out errors, the elevation gradient between adjacent cells was examined. In case of inconsistency, the data were checked again. The inevitable random errors in elevation are estimated to be in the order of one-tenth of the terrain irregularity [25] ~h, or one-tenth of the contour interval over flat areas.[26] The uncertainty in reading the x, y position on the map is in the order of 1 mm (50 m in terrain).

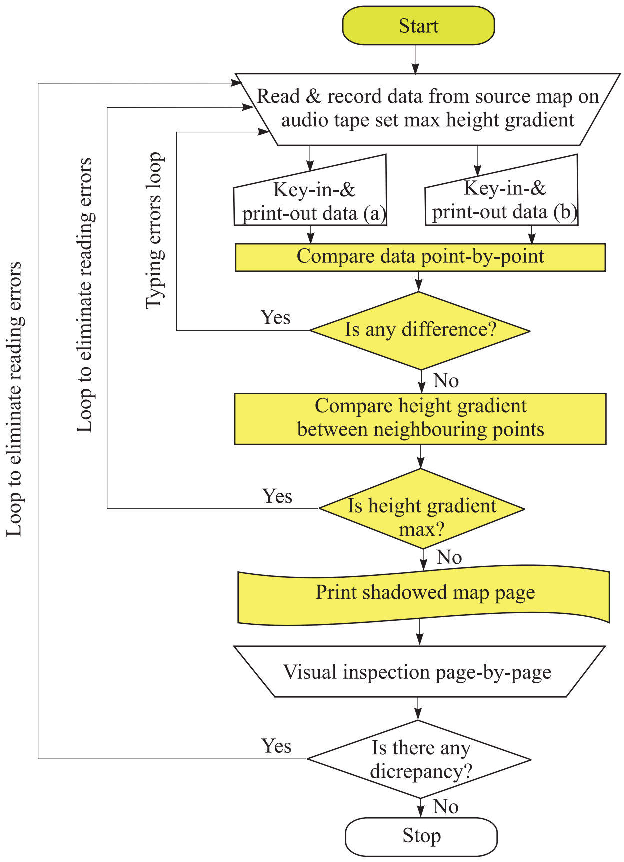


Figure 4 *– Extracting data from the source map (simplified diagram). The yellow-marked tasks are performed automatically*

2.2 Transmitter database

The transmitter database incorporates all needed information about television transmitting stations. The technical information includes the geographic co-ordinates, frequency channel, offset, polarization, effective antenna height and power radiated at various azimuths. The data format is compatible with the CCIR Recommendations and ITU/IFRB standards. The administrative data include the country, name and status of the station. There are three status categories foreseen. All legally operating stations belong to the first category. Their data must remain intact. The second category includes the stations that do not physically exist but are notified, or coordinated. Their data should not be changed, except for minor modifications allowed. The third category embraces all planned or tested stations whose data can be modified at will when alternative solutions are to be examined.

3. Analysing station operation

3.1 Tasks performed

With the simulation model, the manager can analyse the operation of an existing television broadcasting network and assess its performance. He can quickly identify all wanted and unwanted signals at any given location, and answer questions such as:

- what is the coverage area of the station? is there any coverage gap?
- what is the interference threat?
- what television programmes can be received at a given location?

Table 4 contains a non-exhaustive list of tasks that are facilitated by the simulation model. These are discussed in the following sections.

3.2 How it works

The simulation model is interactive with a user-friendly graphical interface. Such a visualization provides the most efficient way of man-machine communication, keeping in mind the large band of the human visual system and the computer speed. Relevant information is presented in the form of colour maps and diagrams on the screen in various scales, depending on the user's selection. All operations previously carried out on paper maps are performed on the cathode ray tube display with the computer aid. Special windows and cursors help to communicate with the computer. The results of simulation can also be presented in numeric form and/or written into computer files for further reviewing, processing, or printing. The model involves all major parameters of television rebroadcasting stations, shown in table 5.

3.3 Coverage analysis

In order to estimate the extent of the station coverage area at VHF and higher frequencies, visibility tests are usually performed. The classic approach involves the performance of such tests in the field in "real life" conditions, on a suitable topographic map, or on a scaled "physical" relief terrain model. [27] The terrain relief is analysed and the line-of-sight (LOS) coverage maps are produced. Such maps identify "shadow" areas (with excess attenuation due to terrain shielding) and "visible" areas. In our approach, the tests are accomplished in the computer memory, using the digital terrain data bank.[28] To produce a LOS map, the region considered is divided into small cells. The size of these cells is independent of the dimension of the cells of the digital terrain map. Each cell is represented by a point. The position of the transmitting antenna, borders of the region to be analysed and receiving antenna height are determined by the user. Two heights of receiving antenna are provided, maximal and minimal. The software simulates the displacement of the receiving antenna from one point to another, over the entire region. For every point, the terrain elevation profile between the transmitting and receiving antennas is produced, and the LOS is constructed. An alternative is to construct and examine the first Fresnel zone ellipse. (The elevation profile is discussed in the following section.) Then the relative position of the line against the terrain elevation profile is analysed (figures 5A, 5B and 5C).

Table 4. Examples of tasks performed automatically with the simulation model

• Determination of equipment characteristics
• Determination of signal environment at a given location
• Determination of the coverage area of transmitting station
• EMC examination
• Extraction and analysis of terrain elevation profile
• Extraction of terrain coverage data
• Field-strength prediction of wanted signals
• Field-strength prediction of unwanted signals
• Great circle computations of distance and bearing
• Maintenance of signal environment documentation
• Maintenance of technical documentation of stations
• Production of documents for frequency co-ordination/notification
• Production of various extracts, reports and maps
• Simulation of field-strength measurements
• Simulation of various experiments in the field
• Spectrum analysis

Table 5. Main characteristics of television rebroadcasting stations

• Power radiated by transmitter
• Transmitter frequency
• Transmitting antenna: height directive radiation pattern polarization
• Transmitting station site
• Minimum signal level
• Receiving antenna height directive radiation pattern polarization
• Reception frequency
• Receiving station site
• EMC scenario

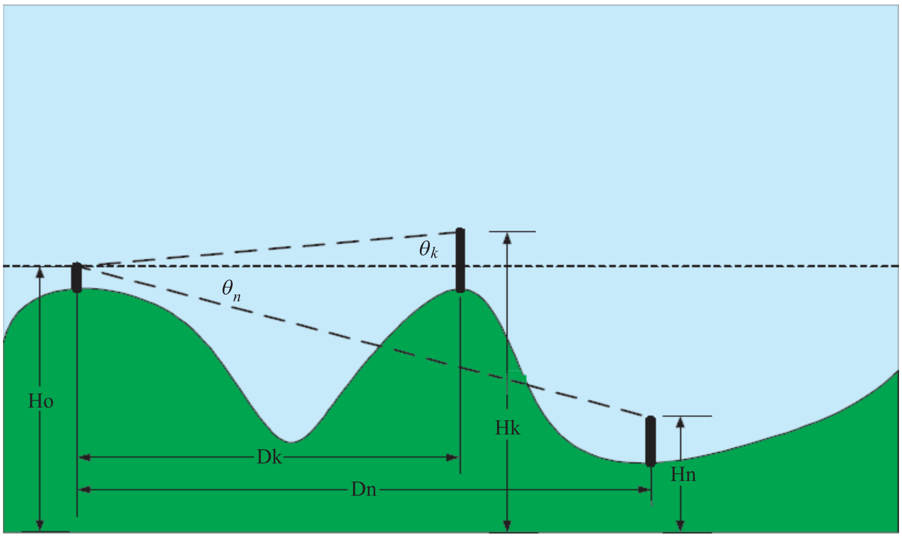


***Figure 5A**. LOS-maps: visibility test (principle). Indexes "0" and "n" indicate the endpoints of the propagation path. H0, H1, H2, ..., Hn are the elevations and D1, D2, ..., Dn are the distances of successive points from the point "0" along the path.*

Let $\theta_k = \arctan\left(\frac{H_k - H_0}{D_k}\right)$, *k = 1, 2, ..., n. If* $\theta_i < \theta_n$, *i = 1, 2, ..., (n –1) then the n-th point of the path is visible from point "0".*

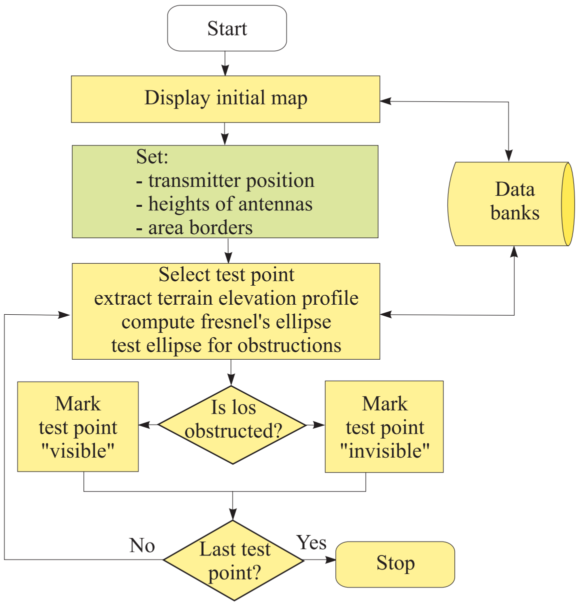


***Figure 5B**-LOS maps: production process (simplified diagram). The yellow-marked tasks are performed automatically. Instead of the LOS, the first Fresnel zone may be produced and examined for terrain obstructions*

3.4 Terrain elevation profile analysis

Terrain elevation profiles are automatically generated by the software, given the transmitter and receiver locations. For that purpose, a geographic map with two cursors is provided on the screen. One cursor symbolizes the transmitter and the other represents the receiver. Each can be moved freely by the user. Their current geographic co-ordinates are displayed in separate windows on the screen, together with the local terrain elevation, antenna height and terrain coverage symbol. The software extracts the terrain profile from the database along the great circle path connecting the transmitting and receiving antennas. The effective Earth's radius is introduced to allow for the tropospheric refraction of electromagnetic waves. To accelerate computations, the great circle path is approximated by a number of loxodromes.

The great circle is the shortest path between two points on a sphere. The loxodrome, or rhumbline, is the path of constant heading between two points on the Earth's surface; it intersects all lines of longitude at the same angle. On the Mercator projection, it is represented by the straight line between the two points. The software generates co-ordinates of 400 uniformly spaced points along the path, and determines the terrain elevation at each point. For points not included in the terrain database, linear interpolation between the nearest four database points is applied. If there is a specific terrain point (peak) in the vicinity, the result is corrected by taking the elevation of that point into account. In addition to the terrain elevation profile, the computer determines the terrain coverage, bearings and distance between the antennas, the first Fresnel zone, and parameter Delta h. Figures 6A and 6B illustrate the process.

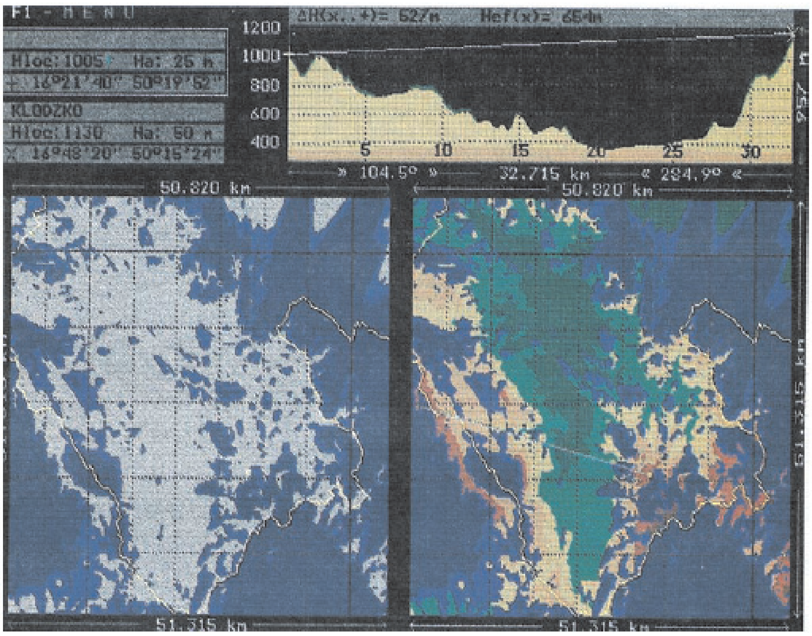


Figure 5C*-LOS maps: example*

Lower-left window*: map showing visible (grey) and invisible areas (blue and dark blue) of the region. The blue colour means that the LOS between the transmitting and receiving antennas is obstructed. The blue and dark-blue colours correspond, respectively, to the minimum and maximum receiving antenna height above the ground. These heights are selected by the user. Visible are: the position of the transmitting antenna (yellow point), geographic coordinates (vertical and horizontal black dashed lines), border of the country (yellow line) and distances (white lines outside the window)*

Lower-right window*: the same as the lower-left window but with more details. The visible additional elements are: one position of the receiving antenna (the left end of the LOS), the transmitting antenna position and LOS (grey line from the transmitting antenna), and terrain elevation (various colours)*

Upper-right window*: terrain profile between the two antennas. Visible are: distance and elevation markers, LOS connecting the antenna centres, direction angles and distance between the antennas (the bottom line), and propagation information specific to the path (the top line). The Earth curvature is corrected for diffraction effects*

Upper-left and middle-left windows*: terrain elevation, antenna height and geographic co-ordinates of the transmitting (x) and receiving (+) antennas*

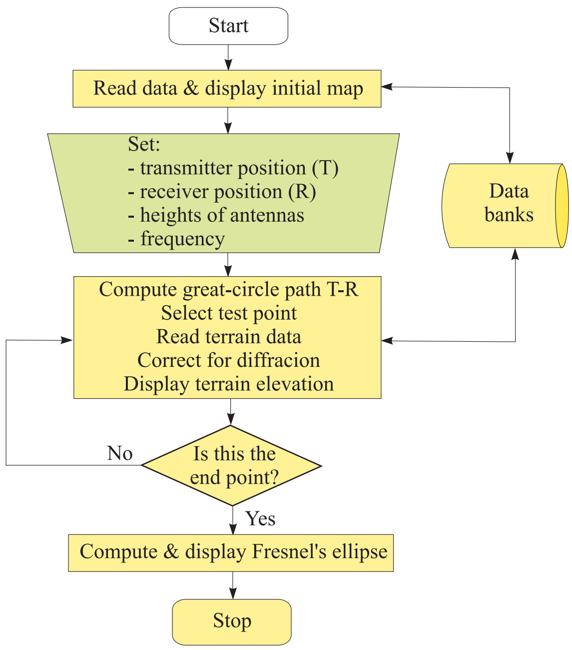


Figure 6A*- Terrain elevation profile: production process (simplified diagram). The yellow-marked tasks are performed automatically*

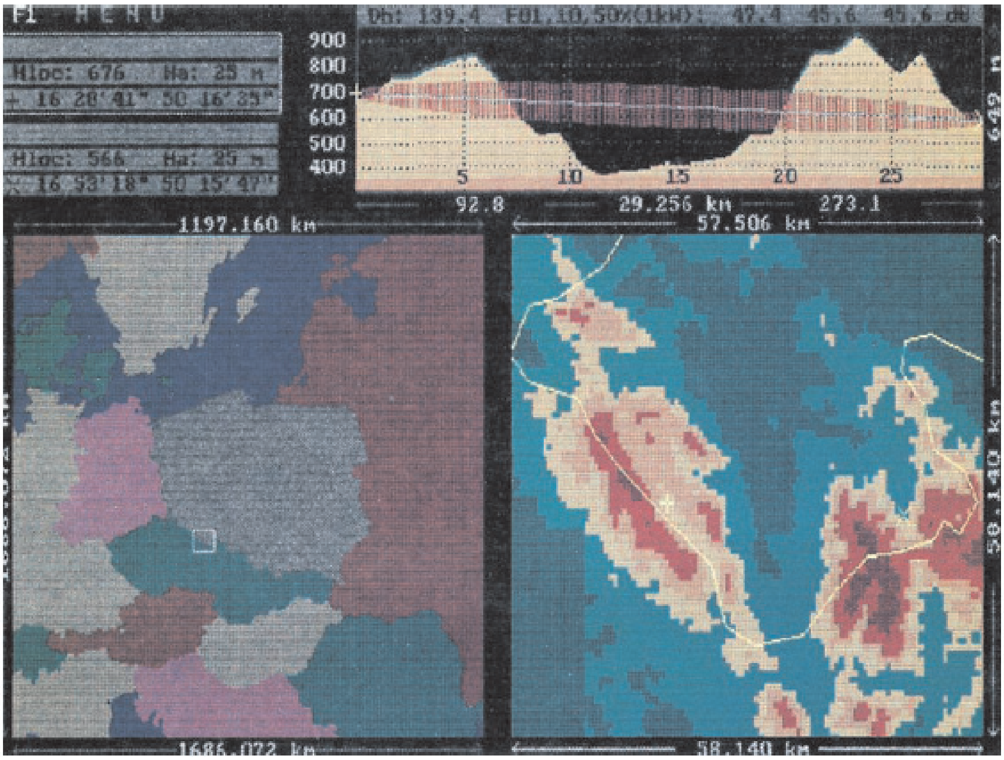


Figure 6B *- Terrain elevation profile: visualization*

Lower-left window*: administrative map of Central Europe (status of 1989). Visible are various countries and seas. The small (white) square near the centre marks the region displayed in the adjacent window. The distances are indicated outside the window*

Lower-right window*: a more detailed physical map of the region displayed in the adjacent window. The markers (+, x) indicate the positions of the transmitting and receiving antennas, respectively. Their co-ordinates are shown in separate windows in the left upper-side of the screen. The terrain elevation profile between the antennas is displayed in a separate window in the upper part of the screen. The user can move the antenna positions freely. Visible are the border of the country (yellow line), terrain elevation (represented by coloured pixels), and distances (white lines outside the window)*

Upper-right window*: terrain elevation profile between the transmitting and receiving antennas (+, x) automatically extracted from the data bank. Visible are: the distance and elevation markers and scales, LOS connecting the antenna centres and first Fresnel zone. The Earth curvature is corrected for diffraction effects. The direction angles and distance between the antennas (the bottom line) and propagation information (the top line) are also shown*

Upper-left and middle-left windows*: transmitting and receiving antennas data. Shown are: the terrain elevation, antenna height and geographic co-ordinates*

Note*: The interrelated information displayed in various windows is automatically updated.*

3.5 Field-strength prediction

The software automatically performs the propagation predictions necessary for the analysis of station operation. There are two approaches to field-strength prediction. The first is based on the analysis of many thousands of measurement results. It uses a set of curves indicating how the field strength changes with distance, without involving details of the path between the transmitter and receiver. The second approach employs calculations based on optical theories. It takes account of the unique terrain characteristics of the propagation path involved. The second method is generally more accurate than the first, but requires a large amount of detailed data. The software incorporates both. The first one is automatically selected if the propagation path is not covered by the digital map. In such a case, CCIR propagation curves are used (see reference [23]). The second approach is automatically applied if detailed terrain elevation and coverage along propagation path data are available in the computer memory. The field strength is determined for 1%, 10% and 50% of the time. Corrections for attenuation by forests and built-up areas are included, as appropriate. These models are described in reference [29]. Figure 7 shows the results as they appear on the screen.

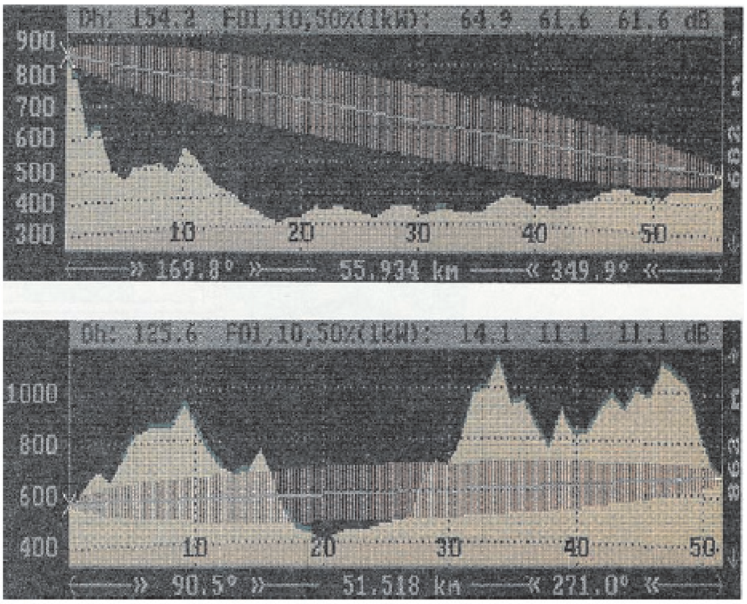


***Figure** 7-Point-to-point propagation prediction: visualization of the results.*

***The top line** indicates the terrain irregularity factor Delta h of the propagation path and field strength in dB(uV/m) for 1 kW e.r.p. exceeded for three different percentages of time (1%, 10%, and 50%). Visible is the terrain elevation profile along the propagation path.*

***The bottom line** shows the bearing angles and distance between the transmitting and receiving antennas.*

***The right scale** indicates the elevation in meters above the sea level.*

***The bottom scale** shows the distance in kilometres, and the right scale the elevation span in meters*

***Upper window**: case of the first Fresnel zone free; note the signal level about 60 dB*

***Lower window**: case of the first Fresnel zone obstructed; note the signal level about 10 dB*

3.6 Signal environment analysis

The model simulates two kinds of signal measurements, one using a field-strength meter, and another using spectrum analyser. In both cases it assumes an ideal equipment, i.e. a directive antenna without side- and back-lobes and spectrum analyser without spurious responses. For that purpose, tile model uses a transmitter working data file, terrain data bank and propagation models described in previous sections. The working file may contain all transmitters, or only transmitters pre-selected in accordance with specific criteria, in order to accelerate the process. The user fixes the position of the test point, and the software identifies all signals that would be observed there. The frequency, magnitude, polarization and direction of arrival are determined for each signal together with the distance to its transmitter. The software identifies, channel by channel and transmitter by transmitter, all signals that exceed a given threshold value (in our case 20 dB above 1 uV/m) and disregards signals below that level (figure 8A). The maximum signal is also identified for each frequency channel and offset category. Figure 8B shows the results.

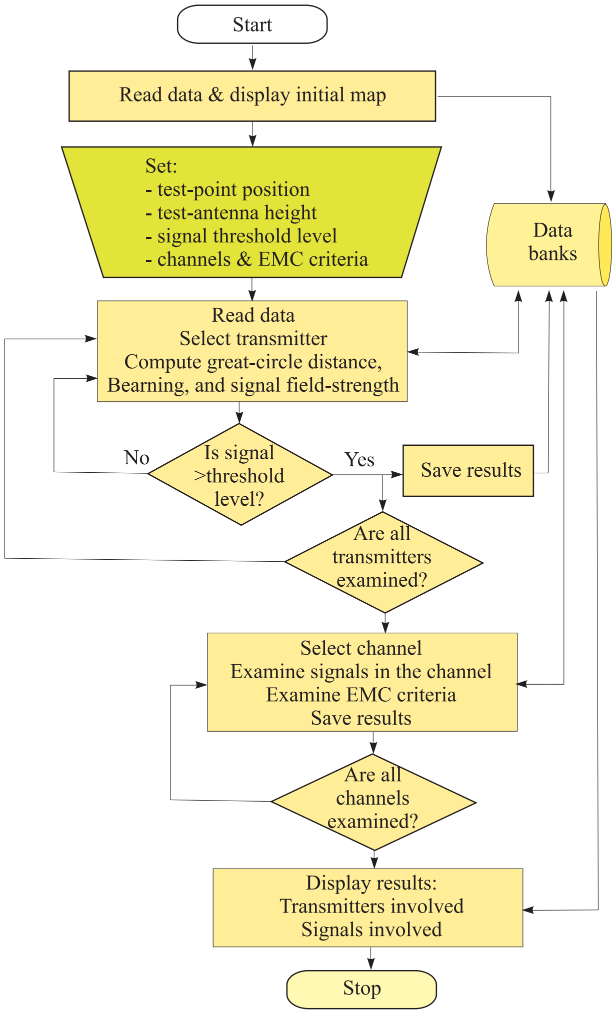


Figure 8A-*Signal environment: flow diagram (simplified).*

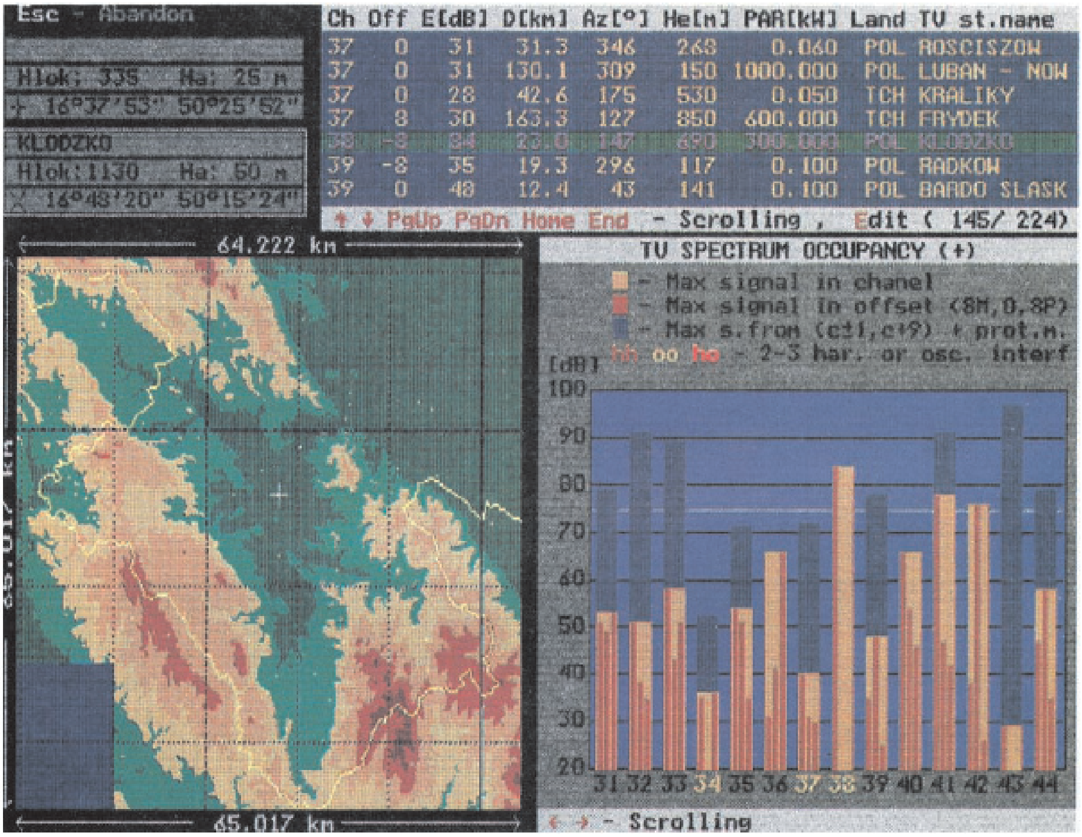


Figure 8B-*Signal environment: visualization*

Lower-left window: *a physical map of a region showing the position of the receiving test station (+). Visible are: the positions of the transmitting stations (yellow points), geographic co-ordinates (vertical and horizontal black dashed lines), border of the country (yellow line) and distances (white lines outside the window)*

Upper-right window: *list of television transmitting stations which produce, at the location of the receiving test station, signals equal to, or greater than, the fixed minimum level. Indicated are: the radio-frequency channel number and offset (Ch, Off), level (E) in dB(t fl Vim), distance from, and bearing to, the transmitting station (0, Az), effective antenna height and e.r.p. of the transmitting station (He, PAR), and name of the country and of the transmitting station (Land, TV st. name)*

Lower-right window: *an imitation of the screen of a "smart" spectrum analyser. The horizontal and vertical axes represent the radio frequency channels and the signal level observed at the station, respectively. The horizontal white line is the required minimum usable signal level. The orange bars are the maximum signal levels within the channels. The red lines are the maximum signal levels with specific offsets. The dark-blue bars indicate the signal level required to overcome potential adjacent- and image-channel interference. They involve signals in the adjacent and image channels and minimum acceptable interference margins. Channel numbers marked in red or orange are warnings about potential oscillator interference*

Upper-left window: *terrain elevation, antenna height and geographic co-ordinates of the receiving test station (+)*

Middle-left window: *The name, terrain elevation, antenna height and geographic co-ordinates of the selected transmitting station (x)*

3.7 EMC analysis

3.7.1 EMC models

EMC is the ability of a device or system to function satisfactorily in its electromagnetic environment without introducing intolerable disturbance to that environment. There are several possible mechanisms of incompatibility in television broadcasting. These fall in two categories: the co-channel interference and interference due to equipment imperfections. Limited receiver selectivity, limited linearity and local oscillator radiation are examples of imperfections. They are discussed below.

- **Co-channel interference**

If the wanted and unwanted signals fall in the same frequency channel and the two signals are commensurate, horizontal bars appear on the television screen, moving slowly up and down. The effect does not depend on the receiver design. It can be reduced by increasing the wanted-unwanted signal margin at the receiver input and/or by offsetting the carrier frequencies of the wanted and unwanted stations. For instance, with a frequency difference of about 10kHz, the required protection margin can be reduced by about 18 dB (table 4).

- **Interference due to limited selectivity**

Due to the limited selectivity of the receiver, the energy from the two channels adjacent to that to which the receiver is tuned can cause interference. Similarly, the signal that is separated from the received channel by twice the intermediate frequency of the receiver can cause the image-channel interference. To reduce the interference threat, adjacent and image signal levels have to be limited. Table 6 lists the limits incorporated in the model.

Table 6. Minimum tolerable wanted-unwanted signal margins

Unwanted signal type	Channel No.	Margin [dB]	Remarks
Co-channel	c*	45 27 22	No offset Offset (non-precision) Precision offset
Adjacent channel	c + 1 c - 1	-12 -6	Upper adjacent channel Lower adjacent channel
Image channel	c + 9	13	

** Channel No. "c" is the channel to which the receiver is tuned in.*

- **Interference due to local oscillator**

Radiation from the local oscillators of nearby receivers can interfere with the wanted signal. The radiation at the oscillator fundamental frequency and at each harmonic frequency can affect one channel. It means that reception in frequency bands 3,4 and 5 may suffer interference from the harmonics of the local oscillator of receivers tuned to lower bands.

- **Interference due to limited receiver linearity**

If two stations deliver strong signals into the receiver and use channels separated by the intermediate frequency, they can mix due to the nonlinearities in receiver circuitry. The product can ride through into the IF amplifier and produce interference beat. The worst case is when these two strong unwanted signals are located around a relatively weak wanted television signal. Intermodulation interference may also appear with strong input signals. Usually, it is the two-signal, third-order intermodulation, involving twice the frequency of one station minus the frequency of the other. A non-linearity in the front of the receiver may produce two spurious signals, one above the higher and a second below the lower of the two channels involved.

3.7.2 Analysis

All signals are analysed above the specified threshold and potential conflicts are signalized. The recognized conflicts are co-channel, adjacent channel and image channel. The signal level required to overcome the interference is suggested, taking into account the required protection margins. The software signalizes also local oscillator conflicts. At UHF it is the fundamental oscillator frequency, and at VHF it is the second or third harmonic. Figure 8A illustrates the process. The results of the EMC evaluation and signal environment analysis are displayed together (figure 8B).

3.8 Reference points

The results of simulations can be stored in the computer memory. There are two reasons to save the results. Firstly, they may be used as a reference to identify any change or anomaly in the operation of stations. Secondly, if the parameters of a station do not change, the results of simulations of that station can be reused as many times as needed, offering a significant economy. For that purpose, a set of some 3600 reference points has been selected and signal environment at these points has been determined. There is at least one point for each transmitting station and for each locality. These are distributed over the whole territory, one reference point per 10 km x 10 km area on average. The frequency, level, polarization, azimuth of arrival and source of every signal that can be received at each reference point have been stored in the computer memory. Only signals above a threshold level are taken into account, and the information occupies about 60 megabytes of disk space. The results of simulation kept in memory can be complemented by the results of the field measurements. With this in mind, the control points are located in such places that are not only significant but also easily accessible and easily identifiable in the terrain.

3.9 Transmitter data visualization

The access to the information on transmitting stations is possible by the name of station, frequency channel, or location. The inter-related data from different files can be displayed simultaneously, as shown in figures 9A and 9B. The transmitter database includes all television transmitters existing and planned over the country and all foreign television transmitting stations that have been notified internationally and are situated within about 600 km distance from the country border.

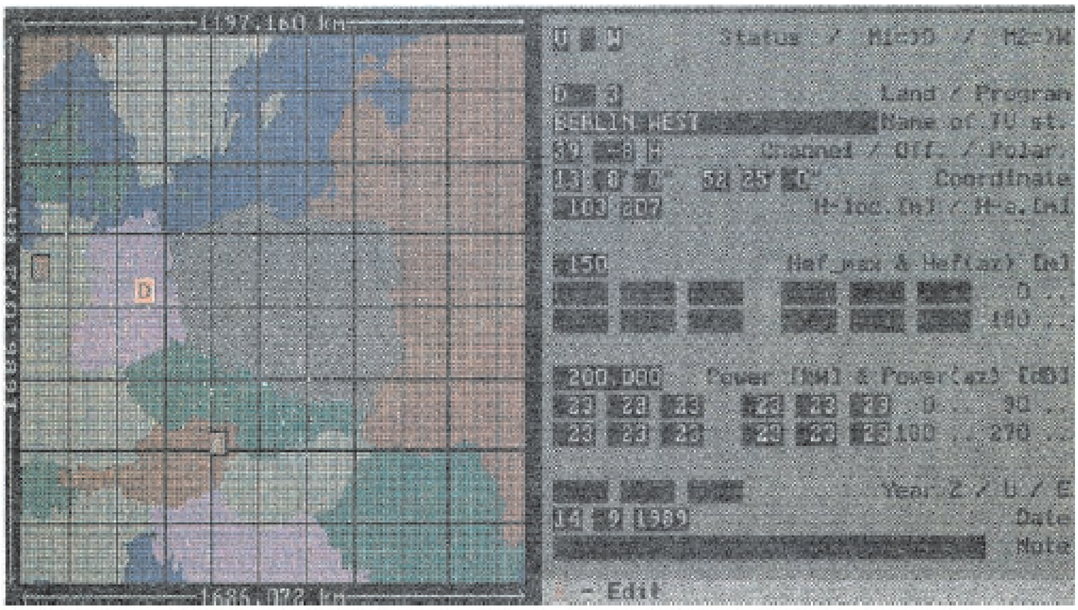


Figure 9A*:Transmitter data visualization with large scale map (example)*

Left window*: administrative map of Central Europe (status of 1989) showing the position of the television transmitting stations over a territory in a trapezoidal form of 1686 km x 1686 km x 1197 km. The horizontal and vertical lines represent the meridians and parallels. Distances are indicated outside the window. Different colours are used to distinguish between countries. Letters indicate positions of the transmitting stations. Note the position of station D*

Right window*: standard form listing the main technical characteristics of station D*

Note*: The interrelated information displayed in various windows is automatically updated.*

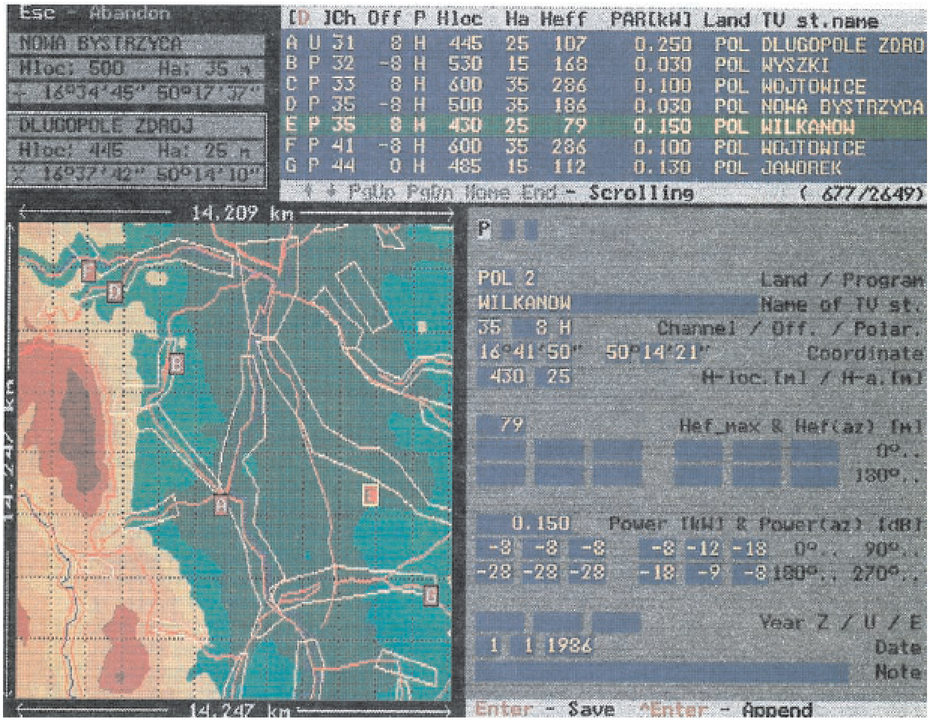


Figure 9B*- Transmitter data visualization with detailed map (example)*

Left window*: physical map of selected region about 14 x 14 km. Visible are: geographic co-ordinates (vertical and horizontal black dashed lines), roads (red lines), contours of built-up areas (orange lines), rivers (blue lines), terrain elevation above the sea level (areas in various colours), positions of selected television transmitting stations (framed letters), distances (white lines outside the window). Note the highlighted station E*

Upper window*: (partial) list of television transmitting stations displayed in the left window. Indicated are: the position on the map and formal status (D), number of frequency channel, offset and polarization (Ch, Of~ P), terrain elevation and actual and effective antenna heights (Hoc, Ha, Heff), effective isotropically radiated power (PAR), name of the country and station (Land, TVstname).*

Note the highlighted station E. The lowest row lists commands available, and, on the right side, the identification number of the highlighted station divided by the total number of the stations in the transmitter working database

Right window*: the form listing the characteristics of the station E highlighted in the other windows (the form is not completely filled in). It serves to view, add, modify, or delete the station characteristics Note: The interrelated information displayed in various windows is automatically updated.*

4. Planning new stations

This section deals with planning applications, with emphasis on the rebroadcasting.

4.1 Planning tasks

The computer simulation model can be used as a tool to examine effects of various planning decisions and/or project alternatives. With this tool, the planner can quickly answer such questions as:

- what is the distance from the planned transmitter to the nearest transport road?
- what signal will be the best for reception?
- what frequency channel will be the best for transmission?
- will the proposed radio link be obstructed by terrain obstacles?
- will the proposed station disturb the existing television network?
- will it suffer interference from the existing stations?
- what will be the coverage area of the proposed station?

To plan a new broadcasting station is a major undertaking. With an overcrowded radio-frequency spectrum, any new installation must be harmonized with all existing and planned stations. Each signal must be examined in detail to ensure that the investment is successful and the new station will neither suffer, nor produce, harmful interference. At VHF and higher frequencies, "terrain shielding" or "site shielding", that is the diffraction losses caused by the intervening terrain, can often be deliberately used to reduce the intensity of unwanted signals.[30] Thus, the likelihood of interference to, or from, another system can significantly be reduced. The station design depends on the geography of the country, the population distribution and the availability of broadcast frequencies, and a careful design and positioning of the antenna and selection of frequency channels are required. In addition to the signal coverage and EMC considerations, the selection must also accommodate such factors as physical access to the site, cost, legal aspects, and other limitations.

To select a feasible variant from the variety of possible deployment scenarios, many analyses and comparisons have to be made. The station siting, working frequency, power radiated, and antenna radiation pattern are among the parameters that can be varied to achieve the best cost performance ratio. In order to reach a practicable solution, it might be necessary to examine many combinations of these parameters. To select a station siting, Hufford [25], for example, examined some 80 potential locations. Such examinations may require a million of calculations or more.[31] To reduce the related labour to manageable proportions, computer-aided tools are indispensable.

Two characteristics of rebroadcasting stations are of major importance: the coverage area and EMC. The LOS coverage, approximating the potential coverage, is one of the decisive parameters for the selection of the station site. In this context, the coverage area (of a terrestrial transmitting radio station) means the area associated with the station within which, under specified technical conditions, the intended communication is feasible. The EMC decides about the frequency selections. Coverage area predictions and EMC evaluations require data about the local terrain and signal environment. The more precise the data, the better the selections.

Each rebroadcasting station needs two frequency channels, one for reception and one for transmission. These should be compatible between themselves and with the signal environment. Ideally, the transmission channel should be free from any other signal, and its use should not interfere with the actual and planned use of frequency channels. The reception channel should contain only the wanted signal, strong enough and interference-free. The simulation tool helps to make such a selection. In a preliminary planning stage, if the number of appropriate frequency channels is insufficient, only the transmitting channel is determined. The signal for retransmission must then be delivered by cable or microwave link. In more critical situations, special selection techniques may be required.[32] These, however, are beyond the scope of this article.

4.2 Planning through simulation

One of the main aims of our simulation tool is to help to select technical characteristics of television rebroadcasting stations listed in table 5. It covers only technical elements and figure 10 illustrates the approach. The user has to input the instructions. The software automatically extracts and processes all additional data needed and performs the analyses described in previous sections. The results of simulated experiments and examinations are displayed on the screen for the interpretation, analysis and evaluation of the user, who is to decide whether the current characteristics are satisfactory, or another variant should be examined. In the latter case he introduces new instructions, and simulation is repeated with new data.

This cycle can be repeated as many times as needed, until an acceptable version is selected, or the iteration process is discontinued. Ideally, this process would be automated to optimize the system for the wanted behaviour. The station planning is, however, too complex, and human reasoning is necessary. The final selection is based on a comparative analysis of several alternatives possible. The larger the number of alternatives analysed, the better the final solution. Extensive interaction between the planner and simulation model is necessary to tune parameters before embarking on experimental verification in the field.

To restrict interference effects, co-sited transmissions and overlapping coverage areas should avoid conflicting frequency channel combinations, and levels of the unwanted signals should be kept within the tolerable limits. Table 6 lists the minimum requirements built in the model. There are three measures to follow these requirements. Firstly, the attenuation of the unwanted signal over the LOS propagation path may be used. It means that minimum separation distances between the stations must be observed.[33] Secondly, additional attenuation due to terrain obstacles may be exploited. Finally, the required amount of attenuation may be obtained by the directional antenna design.

5. Verification, performances and limitations

This section discusses the overall performances and limitations of the model. It also gives results of the verification of the data banks and propagation models.

5.1 Verification

5.1.1 Terrain data verification

The terrain elevation profiles derived automatically from the digital map were verified against those extracted manually from the source (paper) map.[34] About 100 randomly selected paths in various regions were used for that purpose. A sample of about 6000 points at intersections of the paths with contour lines was tested, and table 7 summarizes the results. The mean difference did not exceed 1 m, the correlation coefficient was above 0.99, and the standard deviation of the difference did not exceed 15 m in mountainous terrain. It seems fair to conclude that our topographic data bank contains nearly all the elevation information one could reasonably expect to extract from the source map.

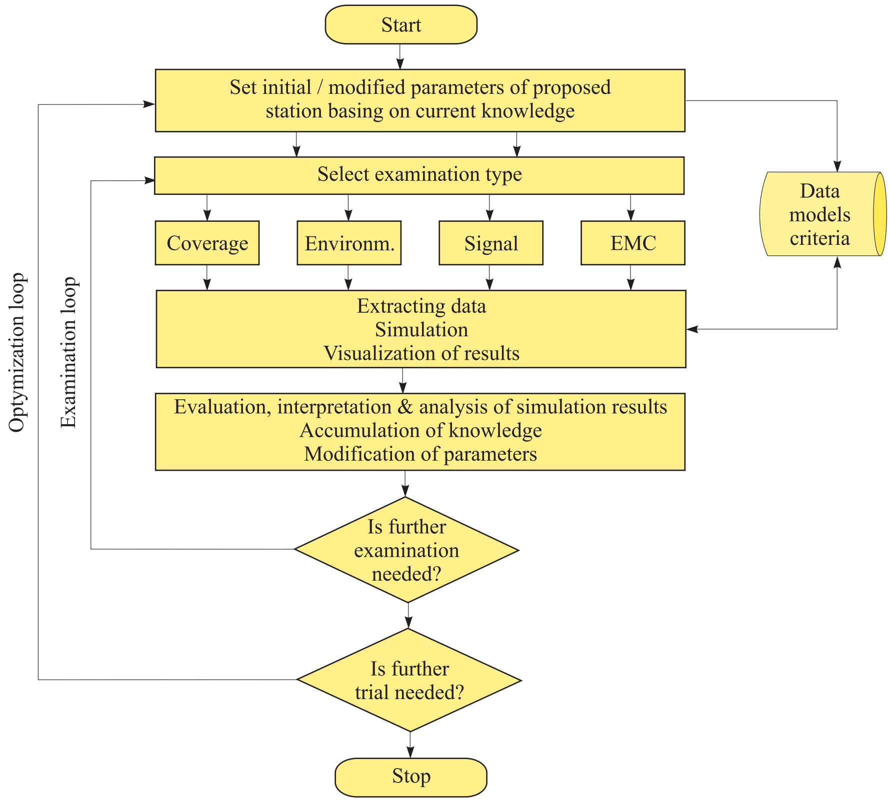


Figure 10*-Planning through simulation: the process (simplified diagram). The double-framed tasks are performed automatically*

5.1.2 Transmitter data verification

Transmitter data were checked against the master copies of notifications submitted to the national authority and to the I FRB. A part of the data was verified against the actual installations. Some discrepancies were discovered on that occasion.

5.1.3 Signal predictions verification

As the field-strength prediction models have already been verified by other authors, the software was checked only against errors. For that purpose, a comparison was made between the signal levels measured in the field and predicted by the simulation model. The test sample was limited to 36 transmitter-receiver links in a hilly region (400 to 1000 m above sea level). The mean difference between the measured values and predicted ones was 3 dB, the mean-square difference 5 dB and the correlation coefficient 0.87. These results correspond to the accuracy of the field-strength measurements [35] and are similar to those published in the literature.[36-38]

Table 7. Results of comparison of the measured and predicted values

Item		Sample size	Mean difference	Standard deviation	Correlation coefficient	Maximum difference	Minimum difference
Terrain elevation*	All terrain types (135-1300 m)	6117	0 m	12 m	0.998	143 m	-75 m
	Flat terrain (135-255 m)	1242	0 m	4 m	0.996	19 m	-30 m
	Undulated terrain (200-840 m)	1524	-1 m	10 m	0.994	40 m	-47 m
	Mountainous terrain (260-1300 m)	3351	0 m	15 m	0.996	67 m	-75 m
Field strength**		36	3dB	5 dB	0.875	12 dB	-8 dB

* Difference between the terrain elevation above sea level at the same points derived automatically from the digital terrain data base and extracted manually from the source map by skilled persons.

** Difference between the measured and predicted field strength levels.

5.2 Performances

Table 8 illustrates the overall performance in terms of time required to perform the specific task. Rows 1 to 3 of the table list the tasks relevant to the analysis of the station operation. Rows 4 to 9 list the tasks relevant to the planning of a new station. These performances were observed with the personal computer Compaq 386/20e with a mathematical co-processor, EGANGA graphic card, 4 megabytes RAM, 80 megabytes hard disk and OOS.5 operating system. Better performances may be expected with faster microprocessors and larger memory.

5.3 Limitations

The computer hardware limits the speed of simulation computations and the maximum number of transmitters processed within a reasonable time. The simulation model described in this article has been running successfully on a personal microcomputer type IBM-A T or compatible. The system allows to simulate a network of about 10 000 transmitters over a territory of about 1500 x 1500 km. At present, the simulation model is limited to Secam D/K television systems. The propagation prediction models refer to VHF/UHF frequency bands, land paths, standard atmosphere and temperate climate (the main-frame version includes four different propagation models). As they are based on measurements within some 500 km distance, the predictions for greater distances are less reliable. The model restricts the signal propagation path to the vertical plane connecting the transmitting and receiving antennas. Multipath propagation, effects of reflection from terrain obstacles, buildings, etc., as well as ducting phenomena, are disregarded.

Table 8. Simulation model performances

No.	Task	Time* (seconds)	Remarks
1	Transmitter-file search and data extraction	< 1	500 transmitters
2	Signal environment and spectrum occupancy estimation	< 10**	500 transmitters
3	EMC analysis and interference threat evaluation	< 10**	500 transmitters
4	Transmitter-receiver distance and bearing computing	< 1 ***	50 km distance
5	Terrain-profile extracting	< 1 ***	50 km distance
6	Terrain irregularity (Delta h) evaluation	< 1***	50 km, 400 points
7	First Fresnel zone determination	< 1***	50 km, 400 points
8	Point-to-point propagation predicting	< 1***	50 km, 50%, 10%, 1% of time
9	LOS coverage area predicting	< 20	50 km x 50 km, 90000 points

* The time required to perform the task; the task volume is defined in the column "Remarks".
** The total time of performing tasks 2 and 3 together.
***The total time of performing tasks 4 through 8 together.

6. Conclusion

6.1 Summary

The growing demand for frequencies can be satisfied by improving the control over interference among stations and by reducing the spectrum wasted due to interference. The interference reduction involves analyses of huge amounts of spectrum- and geography-related data. Without automation, the job would be hopeless. This article shows how the task can be facilitated by a computer system that integrates the analysis, design and documentation. The strength of the described system lies in its precision, efficiency, simplicity of use and low cost. As its earlier main-frame version, it has been used to analyse the operation of thousands of television transmitters and to plan several hundreds of new low-power rebroadcasting stations. It offered substantial economies:

- -in the time spent for technical examinations and analyses;
- -in the frequency spectrum used through tighter "packing" of stations;
- -in energy and in cost.

6.2 Future development

The experience indicated its possible further development, and appropriate work has already been initiated. This section contains some remarks in this connection. Two independent directions are being considered: to make the simulation tool more universal and to make it more accurate.

6.2.1 Other services

Our simulation model is restricted to a specific country and a specific radiocommunication service. Could it be applied to other services and other countries? The answer is: yes, but data banks, propagation models and criteria have to be modified as appropriate. Cellular mobile radio, rural radiotelephony, microwave links and sound broadcasting applications at VHF and higher frequencies could use the digital terrain elevation data banks and other elements of the model.

6.2.2 More accuracy

A better imitation of the real world requires more accurate propagation models and data. Three comments can be made in this connection. Firstly, more accurate digital maps are not a technical problem today. Digital maps of some regions are available on compact disks (CD-ROM). Microcomputer tools exist to convert conventional maps into digital format. In addition, satellite technology offers digital maps from the sky.[39] The ITU publishes various maps, [40, 41] but digital terrain elevation maps are not available within that organization. On an international scale, the Food and Agriculture Organization of the United Nations (FAO) is developing a worldwide geographic information system (see FAO: Geographic information systems in FAO (Rome, 1988). Unfortunately, FAO's terrain data cannot be used in VHF/UHF radiocommunication applications.

The resolution of generally available digital maps from satellites reaches about 10 m. A 1-m resolution or less is possible with today's technology. However, to collect and maintain these data with the corresponding degree of reliability might be difficult. Many man-made structures of such dimensions would have to be included in the data banks. As the structures can be created, destroyed, modified, or displaced, the data would need frequent updating. Otherwise, the data bank would be inaccurate. Secondly, in order to improve propagation predictions, multiple propagation modes should be included and a three-dimensional propagation model would be required for that purpose. Various ray-tracing techniques are possible here. Unfortunately, all of them are computing-intensive and require huge amounts of data. The existing personal computers are unable to cope with such tasks, and we have to wait for the next generation.

Finally, it seems unreasonable to require from simulation results more precise than field-strength measurements. It is the measuring uncertainty that defines the accuracy required from the computer simulation.

6.2.3 Wider application

The EMC examinations require data about the transmitting stations and terrain within the range of approximately 1500 km. With small countries, such distances spread outside the country's territory, so that the same data are used in two or more countries. An exchange could eliminate the need to duplicate data collection and maintenance. A common co-ordinate system, and common data structure would make such an exchange easier. The ITU maintains data banks on radiocommunication stations that seek international recognition, and it could also maintain digital terrain data banks and simulation models, similar to that presented in this article.

Many time-consuming technical examinations could be then automated and made more accurate. The system would be accessible for consultations and trial examinations by all those interested. Its operation would resemble an air-ticket reservation network, where a client can consult flight schedules, select connections, reserve seats and buy tickets in his local travel office. In our case, it would be the assignment of the frequency and position of a station, rather than the airplane seat, and the local spectrum management office rather than the travel office, but the concept is the same.

The results of the examinations could be available at the user's desk almost instantaneously. In the case of a positive finding, formal notification could be done automatically. Otherwise, potential conflicts would be identified and necessary negotiations among the involved parties could begin without delay. Facsimile and videoconferencing, complementing the computer communications, could facilitate the negotiations and consultations. A group of highly qualified experts would maintain the system at headquarters and be available for consultations. Such a group might also help in solving those spectrum management problems which result from the lack of sufficiently experienced professional staff, especially in developing countries. The border between national and international spectrum management would be blurred. The spectrum management would be more efficient not only in terms of the involved cost and time, but also in terms of spectrum conservation, which is even more important.

6.3 Acknowledgement

The software presented in this article, including the databases, has been developed and tested at the Institute of Telecommunications, Wroclaw Branch (Poland). Collaboration with the Institute of Telecommunications and Acoustics (Politechnika Wroclawska) and the Institute of Geography (Uniwersytet Wroclawski) is acknowledged. Several people collaborated with the author, and it is not possible to list all of them here.

The first working version of the software was developed by Messrs W. Sega and W. Waszkis in the 1970s, as a part of their doctoral dissertation. The topographic data were extracted under Mr. P. Adamczyk. For this work, the author's team was honoured by the Award of the Minister of Telecommunications of Poland (1984) and by other awards. Later, Mr. A. Marszalek converted the software to a personal microcomputer, and prepared an original graphic interface.[42] It brought him the "MicroLaur" award in a computer software contest in 1989. Messrs Z. Janek, J. Sobolewski and T. Stromich also collaborated. The Polish Administration has offered the software to CCIR, under CCIR Resolution 88. According that resolution, copies of the software are available on an "as is" basis directly from the Polish Administrations, Institute of Telecommunications, Wroclaw Branch, or from the CCIR Director, with a handling charge. The author also wishes to express his gratitude to Messrs P. Balz, K. Bjornsjo, P. Kartachoff, J. Karjalainen and L. Wieweg, for their comments during the preparation of the manuscript, and to Mr R. C. Kirby, CCIR Director, for his encouragement to publish the article.

(Original language: English)

References

[1] Waters G. T.: *The evolution of broadcasting in Europe, Proceedings of the 1991 International Symposium on Broadcasting Technology-ISBT '91*, Zhuhai (China), 29-31 August 1991, pages 33-42

[2] Eden H.: *Frequency planning methods for sound and television broadcasting*, Telecommunication Journal, January 1986, Vol. 53, No. I, pages 30-47

[3] Flaherty J. A.: *HDTV systems and applications: the U.S. position, Proceedings of the 1991 International Symposium on Broadcasting Technology-ISBT '91*, Zhuhai (China), 29-31 August 1991, pages 232-233

[4] EBU: *Planning parameters and methods for terrestrial television broadcasting in the VHF/UHF bands* (Tech. 3254,1988)

[5] Blair R. H.: *The rebuilding of Australia's regional television stations*, Telecommunication Journal of Australia, 1991, Vol. 41, No.2, pages 67-72

[6] Jacobs G.: *Low-power television*, IEEE Spectrum, June 1982, pages 54-59

[7] Massucci M.: *Choix de I'emplacement d'un reemetteur de television en O.dm avec essai d'emission en vraie grandeur*, Radiodiffusion television, 1980, No. 61, 1/5, pages 6-14

[8] Vujasinovic M., Mirkovic M., Pavic B. and Tadic V.: *Mobile TV system as a powerful tool for designing and locating a stationary TV transmitter*, Proceedings of the 1991 International Symposium on Broadcasting Technology-ISBT '91, Zhuhai (China), 29-31 August 1991, pages 492-495

[9] CCIR: *Handbook on spectrum management and computer-aided techniques*, ITU (Geneva, 1987)

[10] Causebrook J. H.: *Computer prediction of UHF broadcast service areas*, BBC Research Department Report 1974/4

[11] Dadson C. E., Durkin J. and Martin R. E.: *Computer prediction offield strength in the planning of radio systems*, IEEE Transactions on Vehicular Technology, February 1975, Vol. VT-24, No.1, pages 1-8

[12] Longley A. G. and Rice P. L.: *Prediction of tropospheric radio transmission loss over irregular terrain. A computer method*, ESSA Technical Report, ERL-79-ITS67 (Boulder, Colorado, 1968)

[13] Scheihing C., Jablinske R. and Scott J.: *Topographic considerations in environmental predictions*, IEEE EMC Symposium Record, Washington, DC, 18-20 July 1967, pages 106-125

[14] Isola C. and Riccardi M.: *Computer-aided VHF/UHF fieldstrength predictions*, EBU Review-Technical, April 1988, No. 228, pages 68-77

[15] Sega W., Struzak R. G. and Waszkis W.: *Interactive computer simulation system for analysis of television broadcast networks (in Polish),* Przegl. Telekom., 1982, No. 2/3, pages 35-40

[16] Struzak R. G.: *Simulation model for evaluating interference threat to radiocommunication systems*, Telecommunication Journal, December 1990, Vol. 57, No. XII, pages 827-839

[17] Ibid.: *Computer-aided spectrum engineering, Proceedings of the 9th International Zurich Symposium on Electromagnetic Compatibility-EMC 91*, (12-14 March 1991), pages 193-198

[18] Beck R. and Kruger M.: *GRAND-A program system for radio network planning,* Philips Telecommunication Review, September 1991, Vol. 49, No.3, pages 18-22

[19] Del Duce V., Isola C. and Virgadamo G.: *Interactive graphic procedure for broadcasting frequency management making use of terrain data bank on high-definition CAD workstations*, Telecommunication Journal, September 1990, Vol. 57, No. IX, pages 620-629

[20] Cesky T.: *Applicability of engineering models in frequency pianning*, Proceedings of the Tenth International Wroclaw Symposium on Electromagnetic Compatibility-EMC 90 (26-29 June 1990), Part 2, pages 1011-1013

[21] Struzak R. G.: *Low-power TV stations planning on PC using terrain data bank*, IFRB Seminar on Frequency Management and the Use of the Radio Frequency Spectrum and the Geostationary-Satellite Orbit, (Geneva, 8-12 October 1990), pages 123-127. *Use of topographic data bank*, Regional Seminar on Frequency Management and the Use of the Radio Frequency Spectrum and Geostationary-Satellite Orbit (Athens, 9-13 September 1991), organized by the Telecommunications Development Bureau (BOT) and the IFRB (Document No. 23). *Utilisation de la banque de donnees topographiques*, Cycle d'etudes regional sur la gestion des frequences et I'utilisation des frequences radioelectriques et de /'orbite des satellites geostationnaires (Praia, Cap-Vert, 28 octobre-1er novembre 1991), organized by the IFRB and the BOT (Document No.6, Addendum No.1)

[22] Bonfatti F., Bonora S., Falciasecca G. and Frullone M.: *Structure and use of a geographic data base for mobile radio propagation prediction*, IEEE International Communications Conference-lCC '83 (Boston, Massachusetts, 19-23 June 1983), pages 77-81

[23] Damosso E. and Lingua B.: *A computer prediction technique for land mobile propagation in VHF and UHF bands*, IEEE International Communications Conference-lCC '83 (Boston, Massachusetts, 19-23June 1983), pages 59-63

[24] CCIR: *XVIIth Plenary Assembly (Dusseldorf, 1990), Recommendation 370-5 (VHF and UHF propagation curves for the frequency range from 30 MHz to 1000 MHz*)

[25] Hufford G. A.: *Techniques for the evaluation of proposed VHFTVdrop-ins*, OT Report 77-112, US Office of Teiecommunications (July 1977)

[26] MacDougall E. B.: *Computer programming for spatial problems*, Edward Arnold Publ. Ltd. (1976)

[27] Kaltbeitzer K. H.: *Site selection for VHF and UHF transmitting stations* (Tech. 3104, 1965)

[28] Sega W., Struzak R. G. and Waszkis W.: *Computer prediction of VHF/UHFtransmitting station coverage area*, Proceedings of the Fifth International Wroclaw Symposium on Electromagnetic Compatibility-EMC 80 (17-19 September 1980), Part 2, pages 497-505

[29] Sega W. and Waszkis W.: *Zastosowanie symulacji komputerowej do analizy i prognozowania dzialania ultrakrokofalowych systemow radiodyfuzyjnych (in Polish),* Politechnika Wroclawska, Raport 128/PRE-019/79 (1979)

[30] Dougherty H. T. and Dutton E. J.: *Quantifying the effects of terrain for VHF and higher frequency application*, NTIAReport 86-200 (1986)

[31] Commission of the European Communities: *COST Project 210-Influence of the atmosphere on interference between radiocommunication systems at fr~quencies above 1 GHz*, EUR 13407 EN;ECSC-EEC-EAEC (Brussels, Luxembourg, 1990)

[32] Struzak R. G.: *Optimum frequency planning: a new concept*, Telecommunication Journal, January 1982, Voi. 49, No. I, pages 29-36

[33] Dixon J.: *UHF- TV taboos: the FCC electromagnetic compatibility plan for UHF television*, IEEE Transactions on Electromagnetic Compatibility, January 1964, Vol. EMC6, No.1, pages 29-32

[34] Sega W.: *Digital terrain map for television and land mobile radio*, Proceedings of the Seventh International Wroclaw Symposium on ElectromaQnetic Compatibility-EMC 84, Part 2, pages 949-955

[35] CCIR: *XVlth Plenary Assembly (Dubrovnik, 1986), Vol. V (Propagation in non-ionized media*), Report 227-3 (General methods of measuring the field-strength and related parameters)

[36] Krank W. and Stocker F.: *The use of a topographical data bank for field-strength forecasting in the SOdwestfunk service area, (in German)* Rundfunktechnische Mitteilungen, July/August 1982, No.4, pages 162-179

[37] Grosskopf R.: *Comparison of field-strength prediction methods in the UHF range*, EBU Review-Technical, June1988, No. 229, pages 102-110

[38] Sandeil R. S.: *VHF/UHF field-strength prediction*, EBU Review- Technical, August 1991, No. 248, pages 184-192

[39] Westwell-Roper A. and Beckow S.: *Mapping from space*, Space, March-April 1987, Vol. 3, No.1, pages 24-28

[40] CCIR: *Report 340-5 (CCIRAtlas of ionospheric characteristics*) , ITU (Geneva, 1988)

[41] Ibid. Report 717-2 (*World atlas of ground conductivities*), ITU (Geneva, 1988)

[42] Marszalek A.: *Mapki TV* (in Polish), Report of the Institute of Telecommunications (Wroclaw, 1989)

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*On future information system for management of radio frequency spectrum resource**

Ryszard Strużak

SUMMARY
This article attempts to outline an information system that will provide data for decision-making by governments, their contractors, international consortia, private companies, and other entities interested in radiocommunications. The proposed system will harmonize national and international radio frequency spectrum management, and will integrate the existing computer resources within one computer network. It will contain the complete data on current use of radio frequencies around the world and offer specialized computer tools to facilitate the technical coordination analyses required when a new radio station is proposed. The system will help to manage the radio frequency spectrum resources and to satisfy the increasing frequency demand for new radio services and systems. It will affect strongly the spectrum management, independently of any other reform such as simplification of the International Telecommunication Union (ITU) Radio Regulations. The new system will be the expected "next step"after the decisions of the recent Additional Plenipotentiary Conference (APP-92). After presenting the background, we discuss current problems in radio frequency spectrum management such as the role of new partners, fragmentation and inefficiency. Section 3 outlines the concept of the system. Comments on implementation are given in section 4 and concluding remarks in section 5.

1. Background

Limits to growth

Mutual interferences among radio stations impose limits on radiocommunications. Suitable frequency bands are already occupied, and finding a place for a new radio service or radio station is more and more difficult. To continue and develop further radiocommunication services, an efficient radio frequency spectrum management system is necessary. It is the responsibility of each government to eliminate and prevent harmful interference to and from the stations under its authority. As a consequence, most countries have introduced the radio interference issues into their legal systems and developed national radio frequency spectrum management structures.

National developments

National spectrum managers are responsible for the satisfaction of conflicting frequency requirements and coordination of the domestic use of the radio frequency spectrum resource. An evaluation of the interference threat to and from a new radio station is an integral part of their function that requires an

* *Editor's note: The opinions expressed in this article are the author's personal views, and do not necessarily reflect those of the Radiocommunication Bureau (BR) or the International Telecommunication Union (ITU).*

examination of detailed characteristics of the station and its environment. Many countries have found it necessary to develop computer tools and databases for these purposes.[1]

The market approach to radio frequency spectrum, introduced in some countries and contemplated in others, involves extra tasks, in comparison with the traditional spectrum management, in response to requests from trade and business. In New Zealand, 'for example, computer services play an integral role in the government's sale by tender of radio frequency rights, in assuring fast, objective, secure and transparent processing of tenders, The computer-based Register of Radio Frequencies serves not only to store technical and operational information on radio stations, but also to register property rights and legal documentation. The computer services, available to the public, offer an immediate client access to up-to-date licensing and other information.[2]

The degree of computerization of national spectrum management is increasing rapidly. Recently, even the least developed countries were offered about one hundred personal computers for spectrum management applications,

International aspects

Many countries have to coordinate domestic radio stations with the neighbouring countries, within the coordination ranges reaching thousands of kilometers. Only few countries have such a geographical position that the probability of interference conflicts across the borders is low, but even they have to coordinate all short-wave, satellite and other radio stations that use the global radio wave propagation modes. When an international recognition of a station is sought, its frequency and orbital position assignments have to be coordinated, notified and registered at the ITU headquarters, in accordance with the Radio Regulations.

Computer impact

Personal computers and workstations have revolutionized the spectrum management. Due to the technological progress their speed and computing power is increasing continuously whereas prices are falling. In the 1970s, a PDP-11/70timesharing system with 15 terminals might have cost 150000 United States dollars. In the 1980s, a comparable microprocessor-based system could have been installed for about 25% of that sum. These factors, the cost, speed and power, contribute to fast proliferation of computers and computer networks.

Mainframes are giving way to networks of personal computers served by a mid-range computer, while workstation clusters are substituting for supercomputers. Multi-user systems allow several people at different terminals to use the common computer resources at the same time. Multitasking systems allow one user to run several computing jobs simultaneously. Multi-user and multitasking environment is increasingly popular, offering user-friendly and timesaving tools that improve productivity. UNIX is one of operating systems that offer such an environment.

More than 300 000 UNIX-based installations around the world are supporting over one million users, and their number increases rapidly, Decreasing prices contribute to proliferation of computer networks at international business, universities, libraries, airlines, insurance companies, banks, research centres and travel agencies. One of such networks, for instance, interconnects as much as 15 000 travel agencies distributed over 190 countries and territories with the network availability of 99.98% and response time of 2.1 seconds.[3]

[1] *See Karjalainen J.: National Frequency Management Experience from Finland, Telecommunication Journal, Vol. 59, No. V, 1992, pp. 240-247.*

[2] *See: Radio Frequency Service Communication Division: Corporate Profile, New Zealand Ministry of Commerce, 1990.*

[3] *See: SITA: Activity Report 1991.*

2. Problems and solutions

The existing international spectrum management system has been created in 1947 to satisfy the basic needs of all ITU Member countries. These needs change, following the technological, economic, political and social development, and the system has to change accordingly. With a renaissance of wireless technology, the number of radio stations, operating and planned, is growing.

Growing also is the complexity of the coordination process and the volume of coordination data required to ensure their interference-free operation. Management of the radio frequency spectrum becomes increasingly difficult and expensive. On the other hand, we witness economic difficulties, shrinking budgets and competition. As a result, there is increasing pressure on all governments, and on the ITU, to use better the existing resources. The proposed information system will contribute to that aim mainly through a better harmonization and integration of the existing resources, national and international.

New partners

Non-governmental multinational consortia, service providers, equipment manufacturers, consultants and other entities are the new partners in radio frequency spectrum management issues. With liberalization and privatization of the telecommunication sector in many countries, the role of these partners is increasing. We witness continuing development of trans-national exchange of goods and services, increasing regional cooperation and blurring border between national and regional spectrum management.

The existing spectrum management structures were created when State monopoly was prevailing, and a limited role has been foreseen for non-governmental entities. While this approach was justified in the past, it has not been adapted to the new environment. The new partners require more transparency in the radio frequency spectrum management and decision taking processes, vital for their activities. The future system will offer them an easy access to exact information on the current usage and management of radio frequencies, including data, and models.

Efficiency

In the absence of an automated system, the manual treatment of required examination and the follow-up actions in the International Frequency Registration Board (IFRB) were time-consuming operations, which delayed other activities of the Board. This was criticized on several occasions. In 1959, for instance, the following comments were made:

> "...***when an analysis is made of the work carried out by the IFRB over the last ten years, it must be admitted that the Board was in a position to carry out only one duty more or less satisfactorily. ...With regard to registration procedure itself, ...technical examination is exceedingly theoretical and is far removed from actual conditions. ...Moreover, ...if a technical examination is carried out, the registration of frequencies is unjustifiably delayed...."*** [4]

Many attempts were undertaken in the past to improve that situation. Organizational changes, application of computers at the ITU headquarters, provision of data on magnetic tapes, diskettes and CD-ROMs, and recent attempts to simplify the ITU Radio Regulations, are examples. Almost all possibilities have been explored, but all these efforts did not seem to meet the expectations of ITU Members.

[4] *See Doc. No. 153, Plenipotentiary Conference (Geneva, 1959).*

Recently, APP-92 decided to merge the IFRB and the International Radio Consultative Committee (CCIR) Secretariats into the Radiocommunication Bureau (BR), and we have to wait to see whether or not this merging will meet the expectations. There is also another possibility for improvements, not fully explored until now: harmonization and integration of the existing spectrum management information systems and automatic exchange of data. It is the view of this author that the CCIR-IFRB merging per se cannot produce any practical effect, as long as the existing working arrangements among the national spectrum managers and with the ITU remain unchanged. The key element is the data exchange. Substantial improvements in the way the data are exchanged among administrations (and with the ITU headquarters) are necessary. The aim of the proposed system is to improve that exchange.

Complexity

Radio frequency spectrum management on the international scale is based on negotiations, coordination, and the consensus principle. In the early stages of radiocommunications, bilateral negotiations were practical, as an administration was generally required to coordinate with one administration only. Later, the increased number of radiocommunication systems resulted in a necessity to coordinate among three and more administrations. The negotiations with one may lead to modifying the characteristics of the network. This, in turn, may necessitate renegotiations with the other, and even the involvement of a third party, new in the processing, may be required.

Such iterative coordination and search-for-agreement process, especially for satellite systems, absorb much effort and time. A key element is to identify the parties with which coordination is required. In the proposed system, all parties that have to be involved in the negotiation process will be identified automatically, taking into account technical issues. This will allow to limit the coordination meetings to those parties that are involved due to technical reasons only. By applying the system software and data with respect to contemplated frequency assignments, it will be possible to investigate effects of varying system design parameters and select the alternative that involves minimum negotiations. This may decrease the total number of bilateral and multilateral coordination conferences.

Fragmentation

The approach to computerization of spectrum management has been different in various countries. National spectrum management has historically been tailored to the specific needs and conditions of the country and was developed separately in each country. As a consequence, in many countries, domestic regulations, frequency allocations, radio wave propagation models, interference criteria, etc. do not necessarily coincide with one another and with the internationally agreed compromise standards. This creates additional barriers to exchange of goods and services across the borders.

All parties concerned agreed on the need to maintain and follow certain common standards to facilitate interchangeability of data, but the direct interworking of the national systems within the ITU has not been foreseen. As a consequence, the data elements required for the bilateral and multilateral coordination have to be extracted from the domestic databases, re-formatted, printed out, and re-entered again into computer in a new format. Repetition of work and multiple verifications to eliminate human errors are unavoidable.

This resembles the early days of telegraph, when a message was sent out and transmitted by wire up to the border of the country. Here, it had to be printed out and carried across the border by a special messenger. On the other side of the border, the message had to be re-entered again into the wire system because interworking of national telegraph networks was impossible. Although all parties agree that interchangeability of data between different countries will facilitate their tasks, and some studies have already been undertaken in the Radiocommunication Sector, still much has to be done in that area.

Many thousands of man-years have been spent to develop specialized computer programs for spectrum management. About a hundred of them have been offered for free use within the ITU. These programs, however, are not portable and most of them are mutually incompatible.

As the number and complexity of radiocommunication systems grow, spectrum managers must not only employ a larger number of diverse computer tools but they must also work in teams to accomplish their task and communication and integration issues are becoming key elements. Desktop and portable computers, telephones, facsimile machines, and other devices can all be connected globally by wire and fibre optic cables and radio waves, but to interwork seamless they must "speak the same language". The proposed system addresses that issue through harmonization, automation and greater integration of the existing systems.

Technology gap

With the introduction of computers to spectrum management, a technology gap appeared and is increasing between the developed and developing countries. This is a serious problem for the whole radiocommunication community, not only for developing countries as the radio frequency spectrum is shared by all nations. If a portion of the spectrum is wasted or used wrongly by a country, it is damaging for another country. It is like on a street: pedestrians, cyclists and lorry drivers, all are involved and have to move in a coordinated way to avoid accidents. The issue is addressed in the proposed system by offering the administrations of developing countries the same access to common computer resources as to anybody else.

Data reliability

We witness continuing development of radiocommunications. New radio stations are being put into operation, others continue with modified characteristics, and still others cease. In many countries, the national databases follow these changes fast, but it may take a long time to submit the modifications to the ITU central registers. As a result, there is a difference between the data on spectrum usage stored in the international (ITU) and national databases.

The ITU register, with about one million entries, contains a rather unknown proportion of records that are invalid. The need for its maintenance is, therefore, questionable. The proposed system addresses that issue by an automatic relationship between the system database and the national databases. This will guarantee that international and national data are consistent and equally reliable.

3. System concept

Integration

Information exchange is an integral part of the ITU's mission. The future information system for the radio spectrum management will integrate within one computer network the existing resources available in administrations, ITU and other organizations. It will be a network of national and regional computer networks used for the spectrum management purposes. Video communication and other auxiliary equipment will be added to facilitate further spectrum management tasks.

The system will evolve following the changing requirements, technological developments and available budget. It will allow for the incorporation of new users, new data, new services and new tools, as required. The system will be maintained by the ITU and will serve as a framework for spectrum management in a national, regional and worldwide scale.

Functioning

The functioning of the proposed system will resemble the well-known air-ticket reservation network, where a client can consult flight schedules, select connections and carriers, reserve a seat and buy a ticket at his local travel agent's office. In our case, it will be the frequency and/or orbital positions instead of airplane seats, but the concept is the same.

Automatic examination

The technical examinations defined in the Radio Regulations will be automated. Additional automatic analyses will be possible, as well as trial analyses to investigate effects of varying system design parameters. The results and complete documentation will be available at the user's desk within seconds.

Automatic warning

If a potential conflict is detected, the victim parties can automatically be identified. The system will determine who, where, when and how is threatened, and the complete documentation of the interference analyses performed by the system will be available. The necessary coordination/ negotiation between the involved parties could begin without delay. Or the characteristics of station can be modified and the examination process repeated with the new data. The victim parties can be warned automatically as soon as the threat is discovered.

Automatic notification

If the results of the examination are positive, and there are no interference threats to third parties, the data of the station can automatically be submitted for the international notification and registrations in accordance with the agreed rules. There will be no need for any further re-examination.

System organization

The system resources will be structured into territorial (sub-national), national, regional, and world centres, to limit data transfer and system reaction time. They will be logically integrated and physically distributed, and will serve as a worldwide extension to the existing (or planned) national and regional radio frequency spectrum management centres. The maintenance of the system will be centralized at ITU headquarters. The source data will be entered and maintained directly by the source organizations. It could also be done at ITU field offices, or headquarters, if so required.

System resources

The proposed system will allow for use of distant computers and databases connected to the network. These will contain administrative information and statistical, geographic and technical data and engineering models and tools. The existing resources will serve as the kernel of the system and new data, models and tools will be added as required. Table 1 shows possible content of the system databases.

Table 1. Sample of data accessible within the information system

International agreements
Final Acts of Radio Conferences, ITU Convention, Constitution, etc. ITU Radio Regulations and Rules of Procedure Lists of coast stations, ship stations, call signs, etc. Recommendations of ITU and other organizations relevant to radiocommunications Records of the frequency and satellite orbit assignments World and Regional Frequency Allocation Plans World and Regional Frequency Assignment Plans
Administrative data
Addresses of national spectrum management authorities Frequency allocation plans (national) Frequency assignment plans (national) Monitoring stations data National Radio Regulations and relevant legal documents Other data
Spectrum engineering models and data
Electromagnetic compatibility (EMC) criteria Frequency planning and frequency assignment tools Frequency sharing analysis models Propagation models for various regions, applications and frequency bands Radio equipment data (including antenna characteristics)
Geographical data
Ground conductivity maps Maps of administrative (political) borders Maps of ionospheric characteristics Maps of radio climate Population density maps Radio noise distribution maps Road map Topographic (terrain elevation) maps

Users

The system is intended to be used by all authorized parties according to the terms and conditions established by the competent body. This embraces the national spectrum managers, international organizations, governmental contractors, service providers, equipment manufacturers, scientific organizations, universities and training centres, private consultants, ITU staff (at headquarters and field offices).

Access

The system will offer an equitable access to the system resources and will guarantee data security. The access to the resources will be under control. The domestic, or "private", data and the data intended for a common use will be separated. Each authorized user of the system will have the "read-only" access to the shared data. To guarantee the sovereign rights of each country, only the national spectrum manager will be authorized to enter, modify, or delete its national data. He also will decide which data are to be "private" and which to be "public".

Data exchange

An automatic exchange of technical and operational data, including graphics and computer programs, is required for the spectrum management. The exchange will be possible among various users within a country, between neighbouring countries and among countries, worldwide. The information will be available directly from the system databases, through the communication network, 24 hours a day, or on CDROM and computer printouts.

Function separation

Technical examinations, and all tasks that are performed repetitively following the agreed criteria, rules and algorithms, will be separated from the management and decision-taking functions. The repetitive functions will be done automatically without human intervention. In this way, once the criteria, rules and algorithms are agreed, the results will be free of human errors and human intervention. The proposed system will thus offer a full transparency.

International coordination

The technical coordination of radio stations will be simplified and more effective. The direct cooperation of the parties involved will be facilitated and regional cooperation will be enhanced. The entering of the notification data will be done by each national spectrum manager, and technical examinations will be automated. The workload imposed on the BR will change. The weekly circulars and associated correspondence will be superfluous. The ITU staff will focus on the maintenance and further development of the system and on users' assistance and training, taking into account special needs of developing countries.

Domestic

In some countries, radio frequency spectrum management tools and data will require modifications to harmonize them with others. Each authorized entity will have the equitable "read-only" access to the common resources. The existing technology gap in spectrum management will disappear. Administrative barriers and restrictions imposed on non-governmental entities will disappear.

4. Remarks on implementation

Creation of a network of interworking computer networks devoted to convey strategic information on radiocommunications as proposed in this article is not an easy task. Several barriers may be expected and some are listed below. In addressing the interworking question, it is not surprising that many non-technical questions are more difficult to solve than purely technical problems.

Table 2. Possible implementation scenario

phase 1	read-only access to the existing ITU data bases
phase 2	standard data structures for selected services agreed read-and-write access to the existing ITU data bases for selected services automatic submission of notifications for selected services automatic submission of modifications to selected frequency plans
phase 3	standard structure of electronic maps agreed electronic maps for selected regions created
phase 4	standard models and criteria for selected services agreed automatic trial examinations allowed with the existing ITU data bases
next phases	harmonization and integration of national data bases new system data bases created automatic exchange of data and updating of the system data bases further development of the system

Step-by-step

The proposed information system will probably be implemented in an evolutionary way, step-by-step, in close collaboration with all potential users. One may expect that the initial costs of the system will be limited to the costs of the necessary modifications of the existing software and data banks and of implementation of the relevant standards recommended by the Radiocommunication Study Groups and developed further accordingly. The cost of the hardware may be disregarded because, in any case, the existing hardware has to be re-placed by a new one every few years or so, due to technological progress. Table 2 shows a possible scenario of implementation. The read-only access to the existing ITU databases is the easiest phase. Other phases may be more difficult.

The partial automation in phase 2 will probably be limited to the satellite and short wave services, and majority of the frequency plans. The implementation of the proposed system can also be initiated in an individual country or region, where conditions are favourable and specific problems need to be solved without delay. European countries may wish to interconnect directly their national systems, as they are well developed and have much in common. The South American countries may prefer to begin with the electronic maps of the region, as they need them urgently. In any case, it is extremely important to avoid the further fragmentation as discussed in section 2.

Electronic maps

The creation of new computer tools and databases, especially for terrain elevation data, is an-other issue. To automate technical coordination and planning of radio stations, terrain data and other geographic data must be available in a computer-readable form of electronic maps. Such maps have already been in use in almost all developed countries, and in some international organizations, such as, for example the Food and Agriculture Organization of the United Nations (FAO).[5] Although this technique is more and more popular and electronic maps of some regions are available on compact disks

[5] *See Geographic Information Systems in FA 0, United Nations Food and Agriculture Organization (Rome, 1988).*

(CD-ROM),[6] many countries do not have access to such maps and cannot benefit from automation. It will be a great opportunity and challenge for the ITU to follow FAO's example and create a framework within which electronic maps of individual countries and regions could be created and used for the benefit of each Member.

Alternatives

Organizations that have more money than manpower often find more practical to purchase a turnkey system with an out-of-house support staff that provides all the services a system user might desire. Such a solution has many benefits but the purchase of a commercial software often initiates a long-term dependence on the software vendor. Organizations that have significant talent but less purchasing power prefer a public-domain option instead of a single software vendor. In this approach, the system is developed by the self-supporting user community exchanging ideas and software. The results of such common efforts are available to the public, nominally without charge. In our case, a combination of both approaches might be the best solution.

Previous attempts

There were proposals in the past to allow for an external access to the ITU (formerly the IFRB) data files, but they were premature and have never been realized. The pectrum management issues have always been separated into national and international, and data security and national sovereignty problems have been raised. Today, the situation is different. In the meantime, not only the view on the role of government has changed,[7] but also dramatic progress has been made in computer networking and data security and data compression.

The necessary infrastructure has been created in many countries and in the ITU. Practical experience has been gained with the ITU Telecom Information Exchange Services (TIES). TIES provides a set of computer-based information services to about 700 external users from 83 countries and to 300 ITU staff.[8] The services are accessible through the public telecommunication networks and Internet (with no charge for the use of most TIES services if accessed via Internet). There are thousands of computers used for the national radio frequency spectrum management purposes, worldwide. More than 50% of them are interconnected in local and national networks. The proposed system will take the full advantages of that infrastructure and experience gained till now.

Proprietary barriers

Almost each organization has its own set of application software and data banks and might not want to abandon them for that provided by another organization. Such arguments as "not invented here" or "not under my control" might hamper any attempt to create a common spectrum management information

[6] *See Struzak R. G.: Microcomputer modelling, analysis and planning in terrestrial television broadcasting, Telecommunication Journal, Vol. 59, No. X, pp. 459-492. 7 See The changing role of government in an era of telecom deregulation, ITU, 1993*

[7] *See The changing role of government in an era of telecom deregulation, ITU, 1993*

[8] *The users are: representatives of the ITU Member States (ministries, embassies, missions, ITU Council Members, national administrations' staff); officials of international organizations involved in telecommunications (e.g. the International Telecommunications Satellite Organization (INTELSAT), standardization (e.g. the European Telecommunications Standards Institute-ETSI and the International Organization for Standardization-ISO), development (e.g. the United Nations Development Programme-UNDP) and finances (e.g. World Bank); representatives of telecommunication operating agencies (e.g. AT&T), industrial organizations (e.g. SIEMENS), research organizations (e.g. the Centre national d'e'tudes des telecommunications-CNET), libraries and training institutes; field project officers, telecommunication planners and other ITU staff. See: What is TIES?, ITU TS SG2, Inf. Doc. 4, Geneva, 1-11 June 1993.*

system. Some software and data are proprietary, and intellectual property issues may create additional obstacles. There might be a lack of willingness to give access to the "monopolized" data. A computer network might be seen as a mean to import and export computer resources without physically moving the equipment across the borders. In some countries, it might fall under the regulations restricting the export of technological "know-how".

Technological barriers

Each country has its own list of priorities and in many countries, the radio frequency spectrum issues are not at the top of that list. Some developing countries might be unprepared to take immediately full advantage of the proposed system. Unreliable telecommunication networks and lack of qualified human resources may be the obstacles. Many countries will have to start to organize their databases, which needs time and money. Joining efforts, combining resources from several similar projects and, finally, special programs can be envisaged to overcome these difficulties.

Standardization barriers

The proposed system, like any other network, requires some common standards to be applied by all parties. Unfortunately, there are many standards, and not all them work together. The system should provide applications and data portability, but portability can be achieved now only across a limited set of platforms and often after significant conversion efforts. The available spectrum management software has not been designed with the portability and reuse in mind.[9] Their harmonization, or provision of appropriate interface software, is needed.

5. Conclusions

Development of radiocommunication services creates new requirements for radio frequency spectrum management. Trends towards liberalization, privatization and exchange of goods and services across the borders add new dimension to the problem. An improved management is needed to satisfy the increasing demand for new frequencies and to make a better use of the frequency resources, and the proposed information system is the key element. Spectrum managers and radio services planners will be allowed to analyse, store, update, model, display and exchange data they need quickly and easily.

Data files can be developed for various frequency bands and for large or small geographic regions at any scale desired within the limits of original source documents and the storage capacity of the hardware. Time savings due to automation are additional advantages. It will be a major project, which will change dramatically the way ITU Members solve the radio frequency management problems. In this article, we have attempted to outline the system concept and to point out some issues that must be addressed before the proposed system can be implemented. It is quite evident that the path to network interconnection of national systems is difficult, and that the main obstacles are not technical or economic, but political.

To fulfil its task, the proposed system must be well understood and accepted by all those involved in its creation and use. Its concept, or “vision”, has to be agreed upon as soon as possible, to avoid further problems in the management of the spectrum resources. We hope that this article will contribute to acceptance of such a common vision, that practical solution to the problems mentioned can be found within a not so far future and that ITU will play here the “catalytic role”, postulated by the High Level Commission.[10]

Original language: English

[9] *See: Struzak RG and Olms K: Software for radio spectrum management, Telecommunication Journal, Vol. 59, No IV, pp. 168-174*

[10] *See Tomorrow’s ITU: the challenges of change, Geneva 1991.*

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Spectrum Management
Part 1

Ryszard Strużak

As preparations for the Year 2000 World Radiocommunication Conference continue in earnest, ITU News will bring you in-depth analyses of what is at stake in the complex radio world. Indeed, how the spectrum/orbit resources are used and managed has a profound impact on society, its prosperity, security, culture, and education. This article takes you back in history on the use, management and regulation of the radio frequency spectrum resources. It then discusses current trends.

What is the spectrum?

The answer to this question is not as simple as one may expect, as spectrum has more than one meaning in the context of wireless communications. 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.

It was not until Peter Dirichlet (1805-1859) and Georg Riemann (1826-1866) resolved these doubts, that the spectrum concept was generally accepted and has now become a powerful tool used in signal processing, communications, computers and many other fields. In the meantime, experimental science and instrumentation were being developed and the spectrum soon became a measurable physical object. Then came radio engineering; and now the concept of radiofrequency spectrum is in everyday use.

The ability to carry energy and messages at a distance, at no cost and at the speed of light, made the spectrum of radio waves a valuable resource from which everybody could benefit. 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 concept has been associated: invisible lines in the space-satellite orbits. Three elements added new dimensions to the spectrum concept:

- the market demand and pressure of wireless service providers, 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 or groups of countries may have equitable access to both ..."[1] Radio waves and satellite orbits are now treated as a common heritage of humanity. No one nation can operate it alone, ignoring the others. It is subject to misuse and pollution by manmade radio noise and interference that decreases its utility.

[1] *ITU Constitution and Convention (Geneva, 1992), Article 44, No. 196.*

Sharing

Sharing common resources, such as radio frequencies and satellite orbits, has its intrinsic benefits and drawbacks. The evident benefits are that all shareholders can draw profits from the access to the resources; disadvantages are not so evident. The main disadvantage is often referred to as the "tragedy of commons", after Hardin published his paper under this title[2]. He considered a simplified model of common pasture exploited by a group of herdsmen. He made a few 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 possible. At the beginning, when the total number of animals is small, such an arrangement works well. The herds grow fast and the wealth of the herdsmen follows.

However, a 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 about the utility of adding one more animal to his herd.

Two components are to be taken into account, one positive and the other 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. However, the effects of overgrazing are shared by all, so that 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 common heritage.

The result is that what was 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 ... ".

Regulation

Hardin's model portrayed that the concept of a free, unregulated access to a limited resource does not work if the number of its users exceeds certain 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 at sea. Soon, however, military secrets were abandoned under the pressure of business rushing to exploit the "no man's land" of civilian radio.

Two opposite forces appeared, one diverging and the other converging. The diverging force was due to the competition among the equipment manufacturers and service providers. They wanted no sharing, no control, no regulations and no common standards imposed. They also did not want to cooperate as this would result in disclosing their know-how secrets. Such an attitude can often be seen also today. The converging force came from the market, from the customers. The users of radio wanted to communicate freely, one with another, independently of the service provider or equipment supplier. Moreover, in a liberal environment, without any regulation, mutual interference often paralysed the operation of wireless systems, whereas the users wanted interference-free communications.

[2] *Hardin G.: The tragedy of commons, Science, December 1968, pages 1243-1248.*

Finally, all interested parties came to the conclusion that the regulation, coordination and management of the uses made of the spectrum are an unavoidable necessity. Such management started on a national scale. However, 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 a few years after Marconi received his patent on wireless telegraphy, the first international conference was held in Berlin in 1903 to regulate and manage the use of the spectrum.

That conference marked the end of the first period of uncontrolled rivalry and unregulated radiocommunications. The spectrum resources consisted at that time of only two frequency bands (one near 500 kHz and another about 1 MHz) and were used to help in marine disaster relief off the coast.

The use of the spectrum has been regulated by necessity to prevent mutual interference, and to allow for intercommunication. In the early days of radio, with few radio stations operating, the probability of interference was low and the inter-communication issues were more important.

In 1902, Prince Henry of Prussia attempted to send President Theodore Roosevelt of the United States a courtesy message while crossing the ocean after his visit to that country. He was refused the service because the shore station, operated by the Marconi Company, would not deal with a ship station of its German competitor.

Not without the influence of that incident, the Berlin Conference ruled that a communication service with ships must be provided regardless of the system used. However, international treaties are all part of a worldwide game which nations agree to play following certain rules - 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 the first operational standards on radiocommunications were agreed, only nine years later, at the London Conference in 1912. To a large degree, it was under the pressure of public opinion, shocked by the *Titanic*[a)] disaster.

The "Titanic" was the most luxurious and largest ship at that time, claimed as being unsinkable. During its maiden voyage, it hit an iceberg and sank on the night of 14-15 April 1912. About 1500 passengers lost their lives and the recent film, "Titanic", revived the event. Inquiries alleged that another liner was nearby and could have helped had its radio operator been on duty to receive the distress signals of the "Titanic".

Today, the uses made of the spectrum are internationally coordinated through the International Telecommunication Union (ITU). This specialized agency of the United Nations has, among its major purposes, to ensure that radio interference is avoided and that the spectrum/orbit resources are used in a rational manner, taking into account the special needs of developing countries.

The Radio Regulations, appended to the ITU Convention and Constitution, have the status of an international treaty. Each government warrants that the Radio Regulations are respected by everybody under its jurisdiction.

To keep pace with technological, political, and economic changes, the Regulations are periodically reviewed at competent world radiocommunication conferences. However, experience has shown that 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.

[a)] *Od Redakcji TiTI: Dwa zdjęcia z filmu „Titanic" w reż. Jamesa Camerona zostały w tej edycji pominięte.*

Evolution

It is interesting to note that, in dealing with the spectrum/orbit resources, we are following the same approach 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 for a long time as inexhaustible, have become scarce.

After a period in the past when there was an abundance of "no man's land", there is no free farmland now. Open pastures and free hunting and fishing areas have been restricted. Regulations have been imposed on the disposal of sewage and are now widely accepted throughout the world. The concept of the environment and its protection has been developed and restrictions have been imposed on the pollution of land, water, and air.

Radio frequencies and satellite orbits are therefore no exception. The issue of rational use, sharing, and protection of the limited common resources has become a serious problem on the 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 ...".[3]

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

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 saleable, auctionable, rentable piece of real estate. J. D. Bedin, a French jurist, defined it in a few words: "the frequency spectrum is technology, industry, money, culture, and power".

A matter of preference

Which of the possible approaches is the best? It all depends on the criteria applied. The final answer lies with 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, experience, and investments may play a significant role here. Of all the possible ways in which the resource can be used or shared, the one to be adopted will be that which is valued most by a given 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 population, however superior it may be by other criteria. "[4]

[3] *Op. cit.*

[4] *Firey W.: Man, mind and land, a theory of resource use, Greenwood Press (1977).*

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. It means that progress towards realization of one value or goal is destructive to another value or goal held by the same individual or group, and the lack of consistency may not be 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. Sooner or later, however, the rest follow that example and accept, more or less voluntarily, the approach, "mode of life" and hierarchy of values of the leader.

Source: ITU News 3/99, pp. 27-31.

Spectrum Management Part 2

Ryszard Strużak

Particular situation, interests, goals and views

National spectrum management began in the early 1920s with record keeping – logging out frequencies to applicants essentially on a first come, first served basis. The 1947 Atlantic City Radio Conference made foundations for today's international spectrum management by copying, to some degree, the United States national spectrum management system of the 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 embrace sound spectrum engineering, monitoring and enforcement mechanisms.

Three objectives shape any spectrum management system: conveying policy goals, apportioning scarcity, and avoiding conflicts, with due regard to social, political, economic, ecological, and other aspects. The society is composed of various groups, each with its particular situation, interests, goals and views.

As a consequence of spectrum scarcity, conflicts arise between those who have access to the spectrum resource and those without it. Conflicts also arise between the proponents of competing uses of the spectrum as well as between those who manage the spectrum and those who use it. These conflicts may be of various natures: commercial, political, physical interference, and so on.

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 from entering the competition. What is seen as the best for one group is not necessarily good for the other. Since the very beginning, spectrum management rules and regulations have tended to reflect the relative balance of powers of the competing interest groups.

Dual approach

Traditionally, the uses made of the spectrum/orbit resources have 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, others 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 the so called *ad hoc* coordination or frequency distribution method. The alternative is known as a priori frequency distribution, or planning. 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 are agreed at competent radio conferences for specific applications, geographic regions, and frequency bands that are subject to *a priori* frequency planning. A frequency plan is a table, or more generally, a function that assigns appropriate characteristics to each radio station (or group of stations) at hand.

The name "frequency planning" is a remnant of the early days of radio, when only the operating frequency of a radio station and its geographic location could vary. International plans are general and contain a 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 1997 World Radiocommunication Conference (WRC-97) that established another 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 a plan for feeder links for the broadcasting-satellite service in the fixed-satellite service in the frequency bands 14.5-14.8 and 17.3-18.1 GHz in Regions 1 and 3. Both plans are annexed to the Radio Regulations.

Advocates of the *a priori* approach indicate that the *ad hoc* method is not fair because it transfers all the burden to latecomers who must accommodate their requirements with those of the existing users. Opponents, on the other hand, point out that *a priori* planning freezes the technological progress and leads to "warehousing" the resources. Here, warehousing means not using but keeping in reserve. However, when not used, no resource can offer benefits.

Although all usable frequency bands have been allocated to services, only a small portion of them is subject to 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. Instead, it blocks frequencies and freezes development.*

Indeed, technological progress is very fast, and the plan may become outdated before it is implemented. We have to note that in fact, the *a priori* and *ad hoc* approaches differ only in the time horizon taken into account. Finally, one may argue that 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: "... 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 ... ".[1]

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

Trends

The current spectrum management policies and practices are inherited from the times when radio was mainly under State monopoly and access to spectrum resources was free. However, the world has changed in the meantime and the role of governments is still changing. State monopoly is being abandoned in many countries and the importance of the private sector and non-governmental international corporations is increasing. A single market is being created and a competitive worldwide market economy is developing.

New satellite constellations and stratospheric stations are being planned. New wide-band spread-spectrum systems based on a new concept of spectrum sharing are becoming more and more popular. Digital signal processing offers new possibilities for the integration of services, which are not yet fully exploited.

> *New satellite and stratospheric station technologies are being planned. All of this does not fit well into the framework of the present Radio Regulations. Redistribution, and better use of radio waves, is felt necessary by many.*

Although the present spectrum management system has been criticized almost from its introduction, nothing better has been agreed. Developing countries are afraid that there will be no spectrum to satisfy their future needs. They would also like to exploit their old equipment for as long as it works. Developed countries are afraid that they cannot implement new technologies and develop new applications because of warehousing and regulatory barriers.

In the past, all the Radio Regulations were criticized as being too complicated and excessively rigid. The new regulations, which provisionally came into force on 1 January 1999, were expected to solve the problem, but it is too early to assess the results and we have to wait and see to what degree these expectations were justified.

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 others! 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 States, their needs and their interests. In spite of large differences between, say, China, representing a billion people, 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. Similar disparity exists in the telecommunication infrastructure.

[1] *Robinson G. O.: Regulating international airwaves: the 1979 WARC, Spectrum Management and Engineering, IEEE Press (1985), pages 43-69.*

Another reason is the national sovereignty and consensus-based decision process – the two most sacred principles in 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 State to the Union's common budget is voluntary and without any correlation to the number of radio stations or satellites that that Member State uses. Consumers or users, service providers and equipment manufacturers are represented by governments in ITU's decision-making 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 have introduced a fee system for access to spectrum/orbit resources at the national level.

If introduced internationally, "spectrum occupation fees" could limit excessive demand and 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 WRC-97. The majority of ITU Member countries have preferred to continue with the administrative "due diligence" approach that focuses on bureaucratic aspects.

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. For the time being, that action has been limited to a few countries and to selected frequency bands.

Its advocates indicate that market forces automatically match the demand to the available resource capacity and that the market-based management is inexpensive. 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. However, market forces could make wireless applications more expensive and influence the existing balance between the further developments of wired and wireless communication services.

The spectrum-market concept was implemented in a few countries, but the real break through was the series of spectrum auctions conducted by the United States Federal Communications Commission (FCC) in 1994 and 1995. Earlier, licences to use radio frequency to offer wireless communication services were awarded on a "first come, first served" basis, by lottery, or by comparative hearings ("beauty contests"), almost for free.

Now the FCC is granting the licences to the highest bidders. The first auction in the United States (held in 1994) ended with the assignment of three bands of 1 MHz around 900 MHz for a total of about USD 650 million. In 1995, two pairs of bands of 15 MHz around 1900 MHz for personal communication services were assigned for a total of USD 7.74 thousand million[2].

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 centre of New York or Tokyo will cost much more than somewhere in the middle of a desert. However, one thing is clear: the consumers will pay the final bill.

[2] *Bell T. E.: Main event: spectrum auctions. IEEE Spectrum, January 1996, page 28.*

It should be noted here that the creation of an international spectrum market would be the next logical step after the introduction of national spectrum markets. It would be a real revolution and – in view of a large inertia of the ITU mechanism and many open questions – it seems improbable that it will happen soon.

No evidence has been published that selling the spectrum on the global market will solve the scarcity problem in a way acceptable to all parties involved. The market approach, combined with sovereignty, still an indisputable principle in ITU, may increase further the existing fragmentation in spectrum management.

Source: ITU News 5/99, pp. 20-23.

Spectrum Management Part 3

Ryszard Strużak

Renaissance of radio

One 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 to the functioning of our society. Areas in which the radio waves have become invaluable are numerous. National defence, disaster warning, public safety, air-traffic control, and weather forecasts, are but a few examples.

The 1969 moon landing, the most spectacular illustration of the conquest of space by humans, would never have been possible without the radio. Remote-sensing satellites are irreplaceable in discovering natural resources of the Earth and in monitoring the climatic changes.

> *Radio astronomy has opened new windows on the universe and contributed to a better understanding of nature. Radio and television broadcasting have become the main source of everyday information for most people. There are more radio receivers than telephones worldwide. The 1996 Olympic Games, for instance, were watched by some two billion people.*

Radio and television play a principal role in meeting information needs of illiterate people unable to read: about two-thirds of the world's 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 the ingenious usage of radio waves.

Radio became crucial for security and economy, nationally and worldwide, 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.[1] In the United States alone, radiocommunication equipment shipped in 1991 is said to have reached USD 55 billion. In 1994, a cellular operator in the United Kingdom made a yearly profit of GBP 350 million.

As a whole, the economic impact of the use of radio is estimated at about 2 per cent of the gross domestic product. 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 an unacceptable oversimplification to judge the value of the nervous system in the human organism based on its weight alone, which is less than two per cent of the total weight of the body.

[1] *ITU: World Telecommunication Development Report (1998).*

At any rate, 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. A recent publication of the European Community[2] is the best evidence of this fact. The enormous impact of radio on our lives continues to increase, although we still do not fully realize all the consequences of that development.

Examples of applications of radio waves that could change our lives significantly 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 over USD 10 billion.

GPS is American; its Russian equivalent is known as GLONASS (global navigation satellite system). With a handheld receiver, you can determine your position with an accuracy of 30 m or so. If you have special equipment, software, and access to the decryption key, that accuracy may be much greater. In 1997, this type of receiver was priced at some USD 250, and a year later a two-chip GPS receiver was available at 25 dollars.

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

The data on current satellite positions and time, updated periodically, are uploaded to each satellite to be broadcast continuously in a coded form. 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 a 0.3-m 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 orbit 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 Earth, for the first time in history.[3] These signals are used to synchronize various processes and networks, including telecommunication and power supply networks. However, this is only a part of the benefits offered. GPS provides a unique address for each point on Earth, instantly available in electronic form, setting a new standard for locations and distances.

The applications of the GPS appear to be virtually unlimited. They enable drivers, mariners and pilots to navigate safely and efficiently in all weather conditions, day and night, and to save fuel by travelling the most efficient route at optimal speed. They provide data for mapping and surveying tasks, as well as for laying roads, bridges, foundations and utilities, quickly and precisely.

[2] *Green Paper on Radio Spectrum Policy in the Context of European Community policies such as Telecommunications, Broadcasting, Transport and R&D; Commission of the European Communities, Brussels, 9/12/1998 [COM(1998)596).*

[3] *Martin K. E.: Powerful connections, GPS World, March 1996, pages 20-36.*

Once gathered, GPS data can automatically be transferred to a geographic information system. 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 a home or a business. GPS has created new industries. The worldwide GPS market, estimated at USD 3 billion in 1997, is expected to grow to 8 billion by the year 2000, according to a report by Forbes.[4]

The second example is the satellite communication services. Several constellations of low-orbiting satellites are planned, and have so far absorbed about USD 8 billion. Among them is the *Teledesic* system, whose tests started in 1998 (see *ITU News*, No. 6/98, pages 22-26).

It will provide affordable two-way communication services such as broadband Internet access, videoconferencing, high-quality voice, and other digital data exchange, offering access speeds of up to 2000 times faster than today's standard analogue 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 middle of the Gobi desert, or in the Amazonian jungle. Privately funded, and costing USD 9 billion, this network will be in service in 2002. Originally, it was planned as a constellation of 840 satellites in 21polar 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, the "information gap" is growing and most of the world does not have access to even 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 facilities block computer applications. The cost and time required to upgrade these facilities through conventional or fibre-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, regardless of distance or location. Because satellites in polar orbits move in relation to the Earth, the cost of continuous coverage of anyone point on Earth is the same as the cost of covering all points on the Earth's surface.

These systems radically transform the economics of telecommunications and enable leap-frogging 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 would never have such access.

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. We use interchangeably the terms "radio waves", "radio frequency spectrum" and "spectrum", that have the same meaning in the context of this article.

[4] *Hemisphere Report, Forbes (22 September 1997).*

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 International Telecommunication Union (ITU) has recorded more frequency assignments in the last few years than during the whole previous history of radio.

Most of the suitable frequencies have already been occupied and, within the existing arrangements, the demand exceeds what can be assigned further. 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 kilometre and the gross national product is USD 10 000 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. 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 the United States Secretary of Commerce, Herbert Hoover, who first declared: "there is no more spectrum available." The year was 1925. In the meantime, a multitude of applications of radio waves have been invented and successfully implemented. Is the spectrum congestion real? 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 own mismanagement?

The problem of 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 largely on the progress in science and technology, on development mechanisms, and on a mixture of competition and cooperation.

To solve spectrum scarcity and orbit congestion problems, numerous conferences and symposia gather thousands of experts every year. In particular, ITU holds a World Radiocommunication Conference every two years or so (the next one is planned for the spring of 2000).

The seriousness of spectrum scarcity is evidenced by the number and calibre of international organizations who participate in these events.

Apart from ITU, other specialized agencies of the United Nations include: the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), the World Meteorological Organization (WMO), the World Health Organization (WHO), the World Trade Organization (WTO) and the World Bank.

In Europe we can count, among others, the European Commission (EC), the European Conference of Postal and Telecommunications Administrations (CEPT), the European Radiocommunications Committee (ERC), the European Radiocommunications Office (ERO) and URSI.

Source: ITU News 6/99, pp. 22-25

Flexible Spectrum Use and Laws of Physics [a)]

Ryszard Strużak

This note refers to flexible-use spectrum rights that would allow the radio frequency spectrum to be traded, aggregated, divided and freely used for a wide range of user-selected services. So far, discussions on that approach have largely focused on economic aspects, without due consideration of physical realizability. We argue here that additional spectrum management rules are required to assure compatible coexistence of radio systems in congested environments.

Background

Various proposals to improve management of the radio frequency spectrum resources have been around since long time1[①,②,③]. Among these, the flexible spectrum use doctrine has enjoyed particular popularity. Its two rules: *"(1) Transmit within signal power restrictions inside your licensed electro-space region and (2) Keep your signals below 'X' outside that region"*[④] are expected to assure the quality of service and to protect other services nearby. The idea is appealing. It sounds simple and refers to well-known concepts. For instance, when you own or rent a house, you are free in arranging the furniture at will, or in replacing it by new models. The doctrine is supposed to assure similar freedom in using the radio frequency spectrum.

Unfortunately, it is not as simple as it might look at first glance. Discussions on this matter have largely focused so far on economic aspects. Some questions have been left open, without due consideration of physical realizability and inherent constraints. This text aims at filling this gap. The next two sections focus on radio wave propagation and unintended interactions among radio systems. Then, a few open questions are indicated. Finally, we conclude that additional spectrum management rules are necessary to assure compatible coexistence of densely packed radio systems. In principle, these rules can be built-in in the device hardware and software.

[a)] *Od Redakcji TiTI: Niektóre rysunki zostały powtórnie narysowane.*

① *See e.g. Struzak R: Introduction to International Radio Regulations (ed. by Radicella S); The Abdus Salam International Centre for Theoretical Physics 2003; ISBN 92-95003-23-3*

② *For a review of literature, see e.g. Ting C, Wildman SS, and Bauer JM: Comparing Welfare for Spectrum Property and Spectrum Commons Governance Regimes; Telecommunications Policy 29 (2005) pp. 711-730.*

③ *Nekovee N: Dynamic Spectrum Access – concepts and future architectures; BT Technology Journal, Vol. 24, No 2. April 2006, pp.111-116*

④ *Matheson RJ: Flexible Spectrum Use Rights. Tutorial. International Symposium on Advance Radio Technologies (ISART) 2005*

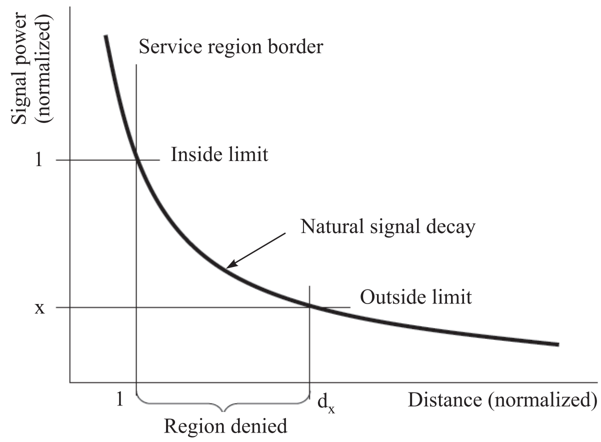

Figure 1. *Natural signal decay in free space and signal limits inside and outside the licensed (covered) region imply that neighboring service areas must be at some distance one from another. The service extends up to (normalized) distance 1, whereas the area denied to neighboring systems extends up to distance d_x.*

Propagation

Rules (1) and (2) mentioned above impose signal limits that are different within the licensed region and outside of it. On one side of the region's border, the signal must be strong (as required by the service offered) whereas on the other side it must be weak (not to disturb services that might be licensed there). However, the radio wave signal propagating in a continuous medium decays gradually and cannot change abruptly, as Figure 1 illustrates.

The power of the radio wave falls naturally below level 'X' at some distance d_x from the transmitter. In case of two systems, d_x determines the range of the region denied to neighbors that can share the same frequency resources in a compatible way. It is known as the frequency reuse distance. (The minimum distance concept can be extended over other dimensions, see the following section.) With such a constraint, only a small part of the space is usable, which evidently limits flexibility in using and managing the radio frequency spectrum resources. The flexible spectrum use doctrine disregards that fact.

Unintended interactions

The service coverage and quality, as well as other features, depend on the intended signals, as well as on unintended interactions among radio systems[5]. Transmission of messages via radio can be considered as a series of mappings in signal hyperspace, see Figure 2.[6,7] The transmitter first maps the original message (m_i) into the radio wave that is radiated in the direction(s) of the intended receiver(s). The propagation-process maps the radiated wave into the incident wave at the receivers (s_{ij}). The propagation process introduces noise, distortions, reflections, latency, fading, Doppler Effect, etc.

[5] *Definition of spectrum use and efficiency of a radio system; REC. ITU-R SM.1046-2; (Question ITU-R 47/1-- 1994-1997-2006).*

[6] *Struzak R: Evolution of Spectrum Management Concepts; Electromagnetic Compatibility 2006. Proceedings of the Eighteen International Wroclaw Symposium on Electromagnetic Compatibility, June 28-30, 2006, pp. 368-373*

[7] *Such a hyperspace might be created by any set of orthogonal variables by which one radio signal can be distinguished from another. Frequency, power, polarization, direction, modulation, coding, spreading etc. are examples.*

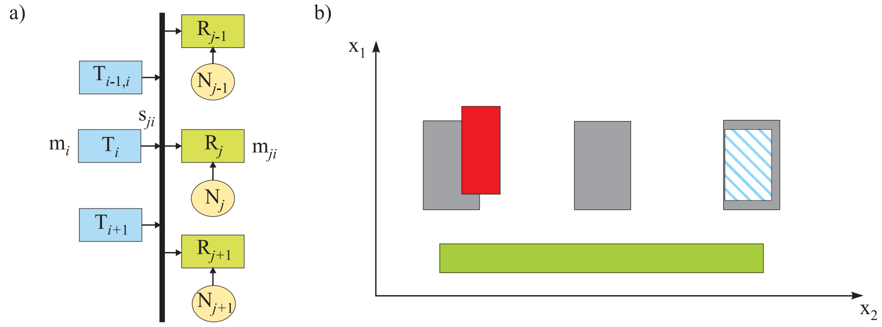

Figure 2. *a) Schematic diagram of multiple radio links. b) Projection of incident signal hyperspace on plane (x1, x2). The dark rectangles represent the receiver's reaction window.*

Many of these effects are uncontrollable. Due to physics of radio wave propagation, the radiated wave is received not only by the intended receiver(s), but also – unintentionally – by a number of other receivers, where it is unwanted. Thus, at each receiver, the incident wave is a combination of the wanted signal, a number of unwanted signals and noise.

The receiver applies communication protocols, algorithms and signal processing to map that wave into the recovered message (m_{ij}). Normally, the recovered wanted message is as close to the original message as required and all unwanted messages carried by radio waves are null and void at the receiver output. In that process, the receiver responds only to those components of the incident wave that fall into its reaction window. Other components e.g. those that appear at wrong time, at wrong frequency, etc. are considered unwanted and are rejected.

Figure 2b is a projection of the signal hyperspace on plane (x1, x2). Variables "x1" and "x2" may be interpreted as e.g. frequency and time. Actually, it may be any pair of orthogonal variables used to distinguish the wanted signal from unwanted ones. A projection is used here because it is impossible to show more than two orthogonal variables on a sheet of paper. Note that the receiver reaction window may consist of a single opening (analog systems) or a series of non-contiguous openings (digital systems). For an unwanted signal to be rejected, it must be sufficiently distant from the receiver's reaction window in at least one variable. The "sufficient" distance is system dependent. It might be the geographical distance, frequency-difference, power-difference (as in ultra-wideband systems sharing frequencies with narrow-band systems), time-difference, distance between the spreading functions (in spread-spectrum systems), etc., or their combination

Figure 3 illustrates the effect of environment (computer simulation). The scenario assumes an omnidirectional radio system first operating alone. Then, without any other change, one, two or six identical systems are put into operation nearby in such a way that their original coverage areas touch each other. The outer (blue) line is the border of service coverage in the case when the system operates alone. The inner (red) line is the coverage border when signals from neighboring co-channel transmitters are taken into account. It is easy to notice that each new transmitter in the neighborhood reduces the coverage of our system under consideration. One transmitter added nearby reduces its original coverage area by 35%. Two transmitters result in the coverage loss of 50%, and six -- 75% (the numbers are scenario-specific). Referring back to our household analogy it is as if the house walls were made of a rubber membrane rather than built from rigid materials. Under the neighbors' pressure, its rooms change size and form, so that the owner's flexibility in the furniture arrangement is reduced.

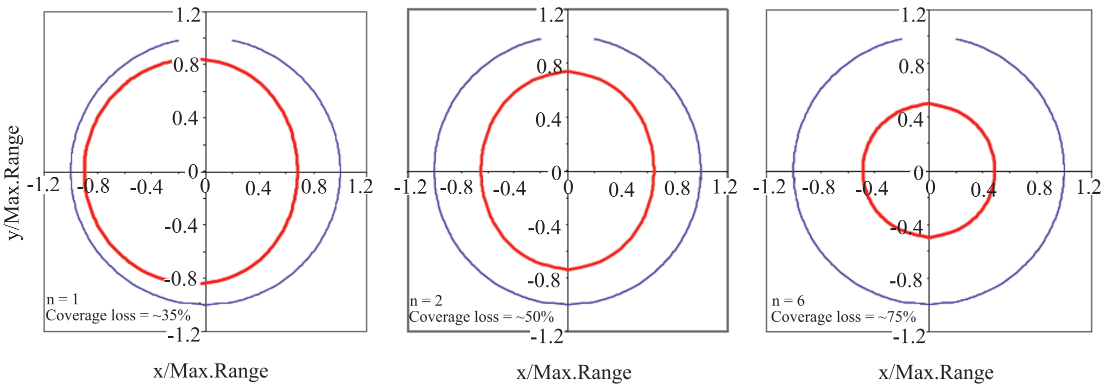

Figure 3. *Illustration of environmental impact on the system coverage. Explanations in the body text.*

Note that consequences of such influences depend not only on the characteristics of individual systems around, but also on their number and spatial deployment. Unintended electromagnetic interactions play critical role in congested radio environment and their significance increases with the growth of radio.[8] That is the reason why a lot of effort is spent to study these interactions within the ITU-R Study Groups and elsewhere and to set necessary regulations at the ITU Radio Conferences. There exists a multitude of ways and means to control unwanted effects of these interactions. Unfortunately, each of them restricts the flexibility in setting system technical and operational characteristics.

One of popular methods consists in balancing the powers of transmitters operating nearby[9]. Frequency coordination is another method. In the frequency domain, to protect licensed regions against intolerable service degradation, specific constraints are imposed on the frequencies used by neighboring transmitters[10]. In their simplest formulation, the constraints can be written as matrix $[\theta_{ij}]$, where θ is a 'distance', and indexes i and j denote radio systems. If f_i is frequency used by system i, then any two frequencies must be sufficiently distant one from another: $|f_i - f_j| > \theta_{ij}$. Such constraints have been named "binary" as each constraint involves exactly two systems. Other physical interaction processes involve three and more systems and additional constraints. For instance, to eliminate third-order intermodulation effects, frequency combinations $2f_i - f_j \neq f_k$ among any three neighboring systems are forbidden. Similar constraints might be required in the time domain. Mathematical theory of graphs is often useful in solving such interaction problems.

[8] *Delogne P and Baan W: Spectrum Congestion; Modern Radio Science 1999 ed. by M Stuchly; Proceedings of the International Union of Radio Sciences (URSI) General Assembly held in Toronto. ISBN 0-19-856569-0, pp. 309-327*

[9] *See e.g. Struzak R: Frequency Reuse and Power Control In Wireless Networks; Global Communications – Wireless, Nr 11, 1999, pp.92-104, ISBN 1 902221 27 3*

[10] *See e.g. Leese R and Hurley S: Methods and Algorithms for Radio Channel Assignment; Oxford University Press, 2002, ISBN 0 19 850314 8*

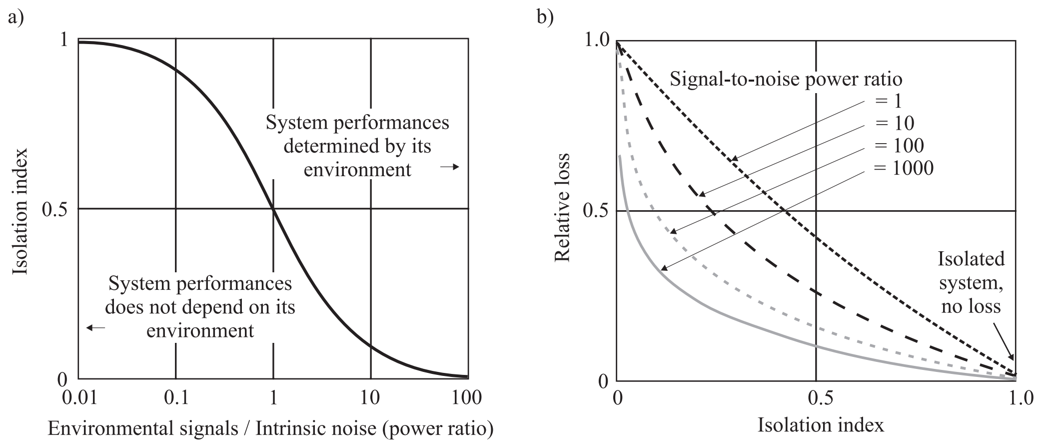

Figure 4. *a) Isolation index vs. unintended signal-to-noise ratio. '1' represents perfect isolation. b) System capacity loss vs. isolation index* for various *wanted-signal-to-noise ratios.*

To allow quantitative examination of unintended interactions in a general way, "isolation index" has been proposed[11]. That index is the power ratio of the system noise and all the unwanted signals and does not depend on the technology used. Its value is confined between one and zero (Figure 4a) with '1' representing a hypothetical autonomous system whose features are environment-independent. Zero represents the opposite situation, when system performances are determined by unwanted signals (and the wanted signal, of course). All practical cases fall between these two extremes. Figure 4b shows the relation between the system capacity and isolation index. The capacity falls down if the system is insufficiently isolated from the environment. All practical cases fall between zero loss, when system performances are determined by the system noise, and one, when they are limited by unwanted signals. Other system features show similar tendencies.[12]

Open questions

Consequences of unintended interactions indicated above may be significant. Imagine, for instance, a paid radio service. With the service users uniformly distributed, the income of the service provider is proportional to the service coverage area. As the coverage decreases with each new transmitter added, so does the provider's income (Figure 3). Similar decrease may happen when the technical or operational characteristics of the systems nearby change. Should that decrease be quietly accepted or should compensation be demanded for the income loss? Will this depreciate the market value of the business? Will this influence the investment decisions? It seems that so far such questions have not been suitably clarified, which leads to uncertainties in contractual rights and responsibilities at the secondary spectrum marked, should it be introduced. Another problem arises with the necessary protection of passive services, where natural phenomena impose unavoidable constraints (e.g. in radio astronomy service)?

[11] *Struzak R: Spectrum Congestion – a Voice in Discussion. The Radio Science Bulletin 291, December 1999 pp. 6-7; March 2000 p. 3-4; June 2000 p.3.*

[12] *Struzak R: On Spectrum Congestion and Capacity of Radio Links; Annals of Operations Research 107, 2001 (2002), pp. 339-347*

Conclusions

We have reviewed some aspects of the coexistence of radio systems. Except for the case of isolated systems, the service coverage, range, and other system features, depend on interactions among the systems. These interactions are ruled by laws of physics and are not negotiable, do we like it or not. They do not depend on spectrum management regime and are the same when the spectrum resources are treated a private property or as a commons.

When a number of radio systems co-exist, they mutually interact and behave as linked together into a common network. In the network, the operation of neighboring systems must be coordinated to avoid problems indicated in previous sections. Until now, such coordination has been ruled by the radio regulations, enforced by local and national spectrum managers and sanctioned by bilateral agreements and the ITU radio conferences. Once the system operation is coordinated within the network, a little flexibility exists, if any, to modify it.

New ‘intelligent’ radio systems offer an elegant solution to the problem. These systems have the policy, coordination, negotiation and regulations rules built-in (in the system hardware and software). They monitor the signal environment and apply these rules to coordinate their operations as needed. In such a way, they automatically ensure compatible co-existence with the neighbors, in a dynamic signal environment. It seems that only such systems can offer a real flexibility in the use of the radio frequency spectrum resources. However, enormous investments in the existing ‘classic’ systems may postpone their mass introduction for a number of years.

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Source: ITU/FUB Workshop on Market Mechanisms for Spectrum Management. International Telecommunication Union, Geneva 22-23 January 2007, pp. 1-6.