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Rationalization for a Better Management of the Radio Frequency Space Allocated to Radiocommunications between Specified Fixed Points and Mainly to Point to Point Microwave Links [and Discussion]

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Rationalization for a better management of the radio frequency space allocated to radiocommunications between specified fixed points and mainly to point to point microwave links

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The frequency spectrum for radio services is physically limited and cannot be arbitrarily extended, whereas in industrialized countries radio services develop particularly fast and exert pressure leading to the fact that a radio station no longer has the exclusive right to its own frequency.

The elements of this paper are to look at spectrum management, especially for microwave relay systems.

In their national preparations for the 1979 I.T.U. conference, civil administrations will probably receive many competing demands for more frequency space.

Two classical problems appear likely to have a significant impact upon frequency allocation: frequency bands allocation to services, and geographical assignment and frequency channel arrangements for each service.

The overall aim is to assemble a picture of the frequency requirements. We have to take into account three main aspects: (i) technical – relative to the frequencies (propagation data); (ii) geographical; (iii) functional – relative to the services.

The objective of such a regulation will be: to increase and improve the proposed services; to achieve a high degree of bandwidth efficiency; to enhance spectrum management by making easier the checking of recommendations; to facilitate the development of new technology (by, for example, the use of s.s.b. in microwave relay systems or s.s.m.a. in v.h.f. band).

Radio relay links form a considerable part of the entire public telecommunications network. With television, and in particular because of the need for large groups of circuits for subscriber-dialled trunk calls, the demand for radio relay links and consequently for frequencies increases tremendously.

Therefore planning which makes the most economical use of the available frequencies is more than ever necessary.

1. INTRODUCTION

The frequency spectrum available for radiocommunications is physically limited and cannot be arbitrarily extended, whereas in industrialized countries communication needs are developing very quickly and the saturation effect is such that a radio station can no longer claim exclusively its own frequencies.

Radio relay links now form a considerable part of the public communication network and often the whole of the television network.

These links are characterized by the necessity of providing adequate clearance between successive stations and by the high directivity of the antennas which, in addition to the coupling with the propagation space, play an essential part as directional filters. However, this filtering action is not perfect.

Over 400 different sites are used on the French post and telecommunication network, excluding the television network stations, which yields one station, on an average, per 1599 km^2.

To cope with the need for large groups of circuits for subscriber-dialled trunk calls, the demand for radio links and consequently for frequencies has increased tremendously.

The setting up of very high capacity radio links (1800 channels and 2700 channels), although it improves the occupation of the spectrum, results in specific problems related to distortions and a lower immunity to noise.

While 900 channels can be transmitted with 1 W, a transmission power of 10–20 W is required for 2700 channel equipment. These high power levels further aggravate the interference and jamming problems.

The introduction of space services which are dependent on the same frequency bands results in significant restrictions in radio relay frequency planning. The very high coordination distances (over 400 km) on the reception frequencies of Earth stations impose severe constraints to frequency allocation.

Moreover, mention should be made of the new data transmission systems using radio links. They operate on much wider frequency bands than those of the analogue systems. In spite of this handicap, these digital systems are less susceptible to interference and each frequency may be used more often.

The growth of the radio link network has led the French Post and Telecommunication Administration to study the problems of frequency with a special care, in order to draw up an overall, coherent and estimated plan for their use.

The circuit requirements are directly related to the increase of the number of subscribers, and the first step of a prospective study consists in determining the traffic trend, the chronological steps and then the methods for developing the transmission capacities.

This development may take four different forms:

1. Addition to an existing trunk of radio channels of the same type as those already in service: the problem should be solved easily for this addition, made with the same type of equipment, because it suits the lengths of the hops and the infrastructure. Of course, this implies that channels of the same system are still vacant and that these channels can be used with sufficient isolation from the other trunks of the same system, terminating in the same centre or crossing the trunk considered. Difficulties appear at the nodes, in some stations close to the borders or in the coordination areas of Earth stations.

2. The addition to an existing trunk of radio channels in another frequency band than that of existing channels or the substitution of new, higher capacity equipment operating in the same frequency band: experience has shown that these additions or substitutions are often difficult. New equipment has to comply with the construction characteristics of the trunk (length of hops, length of waveguide, interference with other systems, space available for new antennae, etc.).

3. Creation of a new trunk when the above solutions 1 and 2 cannot be adopted for the following reasons: saturation of existing infrastructure; inadequate lengths of hops or waveguide lines; excessive interference. Planning is necessary to meet both present needs and foreseeable future development.

4. Construction of new trunks by making optimal use of existing sites, essentially modulation and demodulation nodes, in order to limit the creation of new repeating centres. The stations

reused must have a sufficient handling capacity, and interference risks have to be carefully assessed.

In order to cope with the traffic increase over several decades, one could imagine an increase in the number of radio segments in order to remedy the overcrowding of present spectra. However, the allocation of new frequency bands under 10 GHz cannot be reasonably expected.

The technology is subject to very rapid changes. Within a few years new transmission techniques may offer new possibilities. One even approximately correct prediction for a period of 20 years is difficult. The studies in France lead to reservation of the frequencies below 10 GHz to analogue transmissions with increasing capacities of each radio frequency channel.

The required band width, referred to as the telephone channel, is narrower than for digital transmission and decreases from 20 kHz for equipment with 960 telephone channels to 15 kHz for equipment with 2700 telephone channels.

The necessary high transmitter power can be obtained more easily for lower frequencies.

Digital radio relay systems, particularly suited for regional trunk networks and suburban networks, will gain ground considerably. Above the 10 GHz band, capacities of about 7500 channels are to be expected. Such digital systems require wider bands but much lower transmitter power. For a future p.c.m. system based on path lengths of 10–15 kHz, a great demand of radio links is estimated by 1990. It is therefore imperative to exploit also the higher frequency bands around 40 GHz.

The problems raised by the economical development of high quality radio links will increase with the development of the network. To meet this purpose, it is necessary to reform the frequency planning and management more rationally.

2. Major constraints of frequency allocation

The frame of frequency allocation problems is determined by two well known constraints, namely the frequency band distribution between the various services, and the necessity of a geographical assignment of frequencies and radio channel arrangement in each segment.

Since the final aim is to satisfy the requirements relative to these frequencies, three major objectives have to be taken into account:

technical aspects relating to these frequencies (propagation data);
geographical aspects (more precise definition of coordination areas, network layout);
functional aspects (suitability for the contemplated uses).

2.1. *Frequency bands reserved for radio links*

The frequency band allocation tables drawn up by the I.T.U. and the relevant C.C.I.R. recommendations set the frequency ranges and segments allocated to radio links as well as the radio channel arrangements in each segment allocated. Other C.C.I.R. recommendations set the types of modulation, interconnection levels, impedances and modulation indexes. Some segments are shared by ground links and space links.

These recommendations constitute a basis for the plans of the French post office and the radiobroadcasting and television office.

The frequencies used for radio link requirements extend to approximately 15 GHz. In view of the network density and development projects, frequencies lower than 1700 MHz are practically unused for radio links. Directional antennae are of large size but their gain remains low. Moreover, there are high risks of incorrect propagation due to diffraction, and the coordination distances are very extensive. It would be preferable to reserve these frequencies to mobile installations.

At the other end of the frequency spectrum, from about 10 GHz, propagation losses are enhanced by climatic absorption effects. At these frequencies, to maintain permanent transmission qualities on analogue links, it is necessary to reduce significantly the length of radio hops, much below the usual length of 45–50 km. So short sections may be used essentially to connect urban communities to the main trunks and for the connections between large cities (urban and suburban networks).

The frequency bands used in the French post and telecommunication radio link network are:

2100–2300 MHz;	7125–7725 MHz;
3800–4200 MHz;	7725–8275 MHz;
5925–6425 MHz;	8200–8500 MHz;
6430–7110 MHz;	11700–13250 MHz.

The French administration now possesses slightly more than 100 pairs of frequencies and the number of uses of these pairs of frequencies is over 4000. It follows that each frequency couple is used 40 times on an average in the French post and telecommunication radio link network.

The high number of frequency repetitions is a measure of the difficulties encountered for planning the extension of a trunk or creation of new trunks.

It should be pointed out that these pairs of frequencies are obtained from interlaced plans and that they cannot be used without restriction on a given radio link section.

2.2. *Propagation features of these frequencies*

Under normal conditions, the refraction index of the atmosphere decreases with height since the radiations propagate more slowly towards the Earth. The reduction in the refraction index may be such that the Earth's curvature and the radiation curvature are the same. A far-off propagation of the radiation is then observed and is the source of jamming through interference.

The line-of-sight propagation at the frequencies allocated to radio links is characterized by variation in the level of the signal received through a multi-path effect (ground reflection, different propagation paths in the atmosphere).

Variations in the radiation beam curvature, resulting from undue refraction index variation in the lower layers of atmosphere, also entail fluctuations in the signal level. The effect of any jammer will be increased at the output of receivers in the same ratio as thermal noise when fading occurs on the useful signal. Diffraction also results in propagation beyond the line-of-sight range, which is the more perceptible, at a given distance from the obstacle, the greater the wavelength. Non-visibility does not guarantee absence of jamming.

The application of electronic computation methods to the determination of free-space transmission attenuation between given points, is a well established practice. Radio link designers are mostly interested in supplementary, very low probability, attenuations. The disturbing fields then become highly important.

The various asymptotic laws proposed, involving the fading occurrence probability p, the depth of such fading m, the frequency f and length of the hop d, are all expressed by the formula

$$p = f^A d^B K/m.$$

The values of parameters A, B and K obtained in France are

$$A = 1, \quad B = 3.5, \quad K = 2.5 \times 10^{-8} \quad \text{(Boithias–Battesti–Misme)}.$$

So far the coordination area has been evaluated by empirical methods.

2.3. *Importance of geographical aspects and physical layout*

As mentioned before, there are over 400 stations in the French post and telecommunication radio link system, evenly scattered over the territory. Almost all of the natural high points are already integrated into the system and the sites are often occupied by other users. The construction of new trunks leads to the use of existing sites which become crossing or termination points where the problem of the co-location of radio link systems is very acute.

Moreover, in order to achieve the transmission quality recommended by the C.C.I.R., trunks have to approximate the organization proposed for the 2500 km hypothetical reference circuit and in particular consist of hops whose length is approximately 45 km. Shorter sections provide lower fadings but the increase in the number of sections and, hence, the number of transmitter/receiver assemblies result in a greater equipment noise for analogue links.

The limitation of sections to an optimum length (lengths for which equipment has been designed by manufacturer) is therefore an additional constraint. The high buildings in the city outskirts raise other problems (reflexion, multipath and other difficulties, which may result from buildings now in construction or projected).

Indeed, the first Fresnel area will have to be kept free from obstacles on each hop of a new trunk and the following have to be evaluated for each site retained: perturbing radiation which may affect the receivers on the new path, and the effect of new transmitters on the existing links.

One can calculate the considerable number of geographical contours which have to be obtained to determine the power level of the interfering signal as soon as the radio link system reaches a given meshing density. The practical rule of alternate frequencies on the successive sections of a link also makes it necessary to check the protection level between non-adjacent stations. The terrain configuration and the route of the links are fundamental factors.

2.4. *Suitability of equipment and infrastructure for the contemplated services*

2.4.1. *Quality characteristics of radio links*

All the C.C.I.R. recommendations, especially the recommendations relating to the required performance on the hypothetical reference circuit, have to be taken into account by the manufacturers in the design of their equipment.

For telephony on analogue links (f.d.m./f.m.) the objectives for the permissible noise power on each telephone channel are given for

(*a*) High percentages of time (80 %): 7500 pWo.w. (pWo weighted);
(*b*) Low percentages of time (10^{-3} %): 47500 pWo.w.;
(*c*) Very low percentages of time (10^{-4} %): maximum noise level 10^6 pW.

For television, the objective is given as a limit of the ratio of the peak-to-peak value of the video signal to the weighted r.m.s. value of non-periodic random noise integrated over one second. The value proposed varies with the television standard between 52 and 57 dB.

For digital data links, no precise values have yet been proposed by the C.C.I.R. (see Report

378-2, Geneva 1974). Two sets of provisional values have been stipulated by the French Post and Telecommunication Administration in a CNET note EST-5:

(*a*) error rate on bits for high percentages of time: for national links: $10^{-8}\ L$ km/2500; for local links: 10^{-8}.

(*b*) error rate for low percentages of time: 10^{-5} (whatever the type of link).

These results allow for the total noise: thermal noise, intermodulation, interference due to jamming. The very high noise levels are associated with the concept of good or bad operation of switching sections (main to standby channel changeover). Below this threshold, the effects are very disturbing: application of excessive noise to telephone circuits; disturbance of adjacent ratio channels; substitution by transfer of adjacent channels.

2.4.2. *Causes of transmitted signal degradation*

These causes may be classified into two groups:

Distortions essentially due to the radio link elements which do not feature ideal amplitude and phase characteristics; owing to their repetitivity along a trunk, filters bring about a reduction in bandwidth, and hence systematic distortions. Of course, the greater the filtering, the lower the risk of interference but the higher the cross-talk risks.

Noise produced in the radio link trunk; this group includes the noise resulting from interference with adjacent radio channels or with more remote jammers. The fading distortion laws allow determination of the risks relating to the jamming levels which may then become perceptible. As regards the digital data links, these effects are considerably reduced by regenerating.

TABLE 1. DESIGN CAPACITY IN TELEPHONE CHANNELS

	1800	2700
bandwidth at 3 dB of s.h.f. filters/MHz	56	77
number of resonators per filter	5	4
number of filters per transmitter-receiver	4	4
i.f. filtering characteristics/MHz:		
maximally flat band	± 13	± 17
points at 15 dB	± 21.6	± 27.5
points at 40 dB	± 29.65	± 40

2.4.3. *Suitability of equipment and infrastructure for the contemplated services*

The state of the art consists in reducing the perturbations specific to the equipment: spurious radiation, echoes in antenna feeders. A greater efficiency in the use of the spectrum can be secured only by a substantial improvement in the interference protections. These protections are provided by filtering of radio channels, microwave infrastructure, and selection of a diversity system.

As regards digital data links, the modulation and, mostly, the demodulation method plays an essential part.

The conflicting characteristics of filtering components can be optimized by processing on a computer. The results relating to 1800-channel and 2700-channel equipment used on the French system are given in table 1.

To improve infrastructure it is necessary to replace the old metal towers with reinforced concrete towers with a capacity compatible with foreseeable extensions of the network over 20 or 30 years.

Owing to the network density, very high performance antennae have to be used (reduced sidelobes and back scattering) in an ever increasing number. The capabilities of old towers are limited. Moreover, the provision of new directions raises a delicate problem, considering that existing antennae had not been designed to this end.

For this purpose, the French Post and Telecommunication Administration has sponsored the development of a very high performance, multi-band antenna covering the 3.8–7.2 GHz band, with an efficiency greater than 55% and allowing communications in directions at 45° to originate from the same tower. This antenna can be fed by the complete 960-channel frequency plan in the 4 GHz band and at the same time by the C.C.I.R. 1800-channel half plan in the 6 GHz band and by the C.C.I.R. 2700-channel half plan in the 6.7 GHz band.

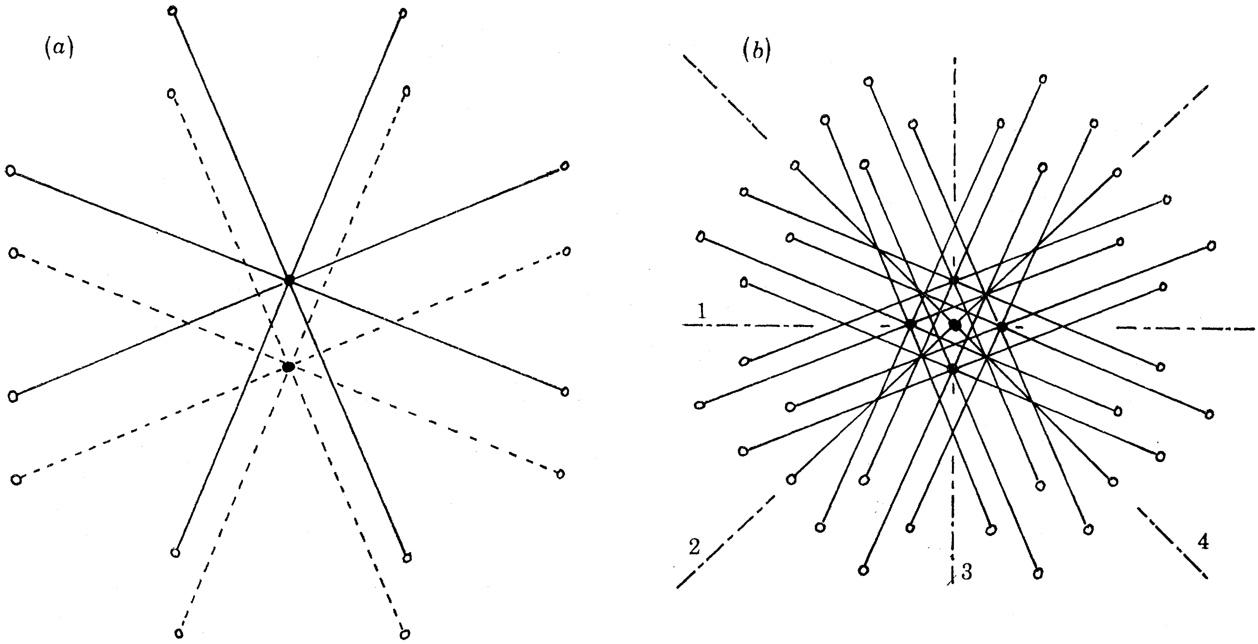

FIGURE 1. (*a*) A typical structure of two node centres. (*b*) A structure with five node centres; the numbered lines are axes of symmetry.

The studies of the Radio Link Department of the D.T.R.N. (Direction des Télécommunications du Réseau National) concerning the maximum use of radio channels in the bands 5925–6425 MHz (7+1 analogue r.f. channels, 1800 telephone channels, plan 6A) and 6425–7110 MHz (7+1 analogue r.f. channels, 2700 telephone channels, plan 6B), led to the definition of an 8-way node centre with a capacity of 252000 circuits.

Figure 1 (*a*) shows a typical structure of two node centres (applicable to large cities). These two centres do not interfere with each other.

Figure 1 (*b*) shows a more complex structure with five node centres (applicable to very large cities) with a total of 36 directions and providing 1134000 circuits of very good quality.

The fading amplitude, which is known from its distribution function, allows selection of the transmitter power which limits the risks of overshooting the noise threshold to a very low percentage of the time. This method is still applied systematically for very high capacity equipments. However, it involves the radiation of excessive powers for a high percentage of the time.

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The results recorded on the existing links evince the sensitivity of the fading effects to the frequency and path. The frequential sensitivity is currently used in the frequency diversity actually provided by the standby channel. Formulas were proposed by Barnett (*Bell Syst. tech. J.*, October 1970) and Vigants (*Bell Syst. tech. J.*, January 1975) to give the improvement brought about by frequency diversity and space diversity. This comparison shows that a frequency diversity with a difference $\Delta f/f$ of 3% is the equivalent of a space diversity with antennae 150 λ apart. The second solution allows the saving of a pair of frequencies, subject, however, to duplication of antennae and receivers.

Moreover, the probability for a given fading to occur is reduced and, for a given probability, the fading amplitude would be reduced. The power levels and radio 'pollution' could then be reduced.

3. Frequency management and planning

The objective is an intensive and economical use of the spectrum to meet the requirements and it assumes:

(i) Suitability of radio equipment for such requirements: channel capacity; type of modulation; transmission quality; use of a minimum of pairs of frequencies; maximum occupancy of the spectrum. It should be remembered that whereas the spectral occupancy per telephone channel decreases to 16 kHz in the 1800-channel systems and even down to 15 kHz for a 2700-channel system, the provision of a too high capacity trunk compared with actual needs would be an illusory advantage. The interference risks increase with the growth of the network and the resultant effect on receivers increases in the same ratio as thermal noise when fading occurs on the useful signal. Frequency planning requires: detailed information on the frequency bands and on the r.f. channel arrangement; information on the fine characteristics of the radio equipments and infrastructures; analysis of electromagnetic compatibility related to propagation, spectra for the various systems, antenna radiation pattern, filtering; indications regarding the spectrum occupancy status with all relevant geographical and technical data. It should allow correct frequency assignment, spectrum management and drawing up of specifications for new equipment and the associated infrastructure. This activity implies the setting up of several specific systems; these systems are of course connected to one another via the transmission network.

(ii) Spectrum monitoring and data collection system on existing links.

(iii) Electromagnetic compatibility monitoring system consisting of terrain configuration data subsystem; radio characteristic subsystem representing the existing network; subsystem relating to equipment characteristics, specific characteristics, and characteristics relating to the operating conditions, radiation patterns, geometrical features of antennae, polarization; propagation data subsystem; application subsystem combining the above-mentioned subsystems and causing a message to be edited in case of incompatibility.

(iv) System intended for frequency assignment and management from data basis exchanging data with the above systems.

3.1. *Spectrum monitoring and data collection system*

This work is still carried out manually. The file is supplied with data transmitted often with some delay. The main radio link node centres are covered by specific studies, but there is no accurate, real time information regarding the occupation status of all the pairs of frequencies.

To achieve this result, a system of sensors should be distributed over the territory for spectrum monitoring purposes (processing, recording, storage, locating). Thereafter, a synthesis between the measured values and the data bank of the existing equipment in use should enable anomalies, as to presence and value, to be determined: pairs of frequencies in service; average width of associated spectra; reception level; geographical location of each emission.

3.2. *Electromagnetic compatibility monitoring system*

The aim sought is to review the possible sources of interference due to existing or projected systems, to evaluate the levels of the perturbation at the input of receivers, and the resultant disturbance. It does not seem possible yet to perform all these operations in a fully automatic way. The difficulty lies in the volume of the required information and in the uncertainty of the selection criteria.

As a matter of fact, the noise, transmission attenuation and interference levels have to be evaluated in an automatic and reproducible manner, which argues in favour of a systematic use of the digital presentation of the terrain in the above-mentioned operations.

When the provision of a new radio link trunk is contemplated, the energy radiated by the transmitters has to be described in two dimensions. The new transmitters have to be located with respect to the receivers of the trunks in service, the orientation of the antennae has to be determined, as well as the response of each receiver in its environment. The same studies have to be carried out for new receivers.

The extent of this task is such that data processing has to be resorted to, but this can be done only with a harmonization of the description of equipment performance and the associated situations.

The availability of a limited number of standard equipments allows reduction of the number of models. Some factors are known from their statistic distribution, which results in a certain degree of uncertainty, but a good approximation should be achieved by storage and processing of results.

3.3. *Frequency assignment and management system*

This system uses the results obtained by the above-mentioned systems, in order to quickly meet the requirements of the spectrum users.

The methods of interchange with this centre have still to be defined according to the technical capabilities and the administrative organization.

4. Conclusion

The limitation of radio link development as a result of frequency saturation is no longer to be feared, when a good management of the frequency spectrum is provided. There are certainly real and more numerous jammers, but permanent research work on a rational occupancy of the spectrum leads to finding appropriate routes or acceptable radio channel arrangements while limiting perturbing effects.

This work also facilitates the design of new generations of equipment.

Automation of frequency monitoring and planning (which is not yet fully accomplished in France), through reproducibility of the results, enables multiple, consistent computations to be carried out and the manufacturers to be provided with essential information for the development of constantly improved equipment.

Discussion

H. M. Barlow (*Penrith, 13 Hookfield, Epsom, Surrey, U.K.*). As the problem of frequency-space in the ether becomes more acute, as indeed it must, a policy should, I suggest, be applied deliberately restricting the use of radio between fixed points, whenever that is economically feasible. Thus, free-space waves should be reserved, as a rule, for telecommunications links in which one or more terminals are mobile, including of course satellites in stationary orbit.

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