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Recommendation ITU-R F.1611
(02/2003)

Prediction methods for adaptive HF system planning and operation

F Series

Fixed service

ITU International Telecommunication Union

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<table>
<tr><td colspan="2" align="center">**Series of ITU-R Recommendations**</td></tr>
<tr><td colspan="2" align="center">(Also available online at http://www.itu.int/publ/R-REC/en)</td></tr>
<tr><td>**Series**</td><td align="center">**Title**</td></tr>
<tr><td>**BO**</td><td>Satellite delivery</td></tr>
<tr><td>**BR**</td><td>Recording for production, archival and play-out; film for television</td></tr>
<tr><td>**BS**</td><td>Broadcasting service (sound)</td></tr>
<tr><td>**BT**</td><td>Broadcasting service (television)</td></tr>
<tr><td>**F**</td><td>**Fixed service**</td></tr>
<tr><td>**M**</td><td>Mobile, radiodetermination, amateur and related satellite services</td></tr>
<tr><td>**P**</td><td>Radiowave propagation</td></tr>
<tr><td>**RA**</td><td>Radio astronomy</td></tr>
<tr><td>**RS**</td><td>Remote sensing systems</td></tr>
<tr><td>**S**</td><td>Fixed-satellite service</td></tr>
<tr><td>**SA**</td><td>Space applications and meteorology</td></tr>
<tr><td>**SF**</td><td>Frequency sharing and coordination between fixed-satellite and fixed service systems</td></tr>
<tr><td>**SM**</td><td>Spectrum management</td></tr>
<tr><td>**SNG**</td><td>Satellite news gathering</td></tr>
<tr><td>**TF**</td><td>Time signals and frequency standards emissions</td></tr>
<tr><td>**V**</td><td>Vocabulary and related subjects</td></tr>
</table>

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R F.1611*, **

Prediction methods for adaptive HF system planning and operation

(2003)

Scope

This Recommendation provides guidance on adaptive HF system planning and operation using prediction methods. This Recommendation addresses frequency planning, power budget and the design process, including many references to other ITU-R Recommendations.

The ITU Radiocommunication Assembly,

considering

a)   that the number of adaptive HF systems in operational use is growing, specifically automatic link establishment (ALE) systems;

b)   that ITU has developed an adaptive HF Handbook which describes the nature of adaptive HF systems and their use;

c)   that frequency-adaptive HF systems are constrained to use the minimum number of active frequency channels in order to limit the potential for interference with other users;

d)   that frequency planning with an accurate HF performance prediction model will reduce the margins over which adaptive HF systems must be designed to adapt, with the result that operational procedures can reduce the potential for interference, and overall cost may be reduced;

e)   that Recommendation ITU-R P.533 (and its software program ITUHFPROP) is the established ITU-R method for HF performance predictions, and is well-suited to be an umbrella for additional (related) prediction methods, some of which are currently used in the control of various quasi-adaptive HF systems and in the design of systems employing forms of ALE;

f)   that other related prediction methods, such as the IONCAP family of programs, are maintained on the same publicly-available Institute for Telecommunication Sciences' (ITS) website as is Recommendation ITU-R P.533;

g)   that all methods downloaded from the ITS website (including Recommendation ITU-R P.533, VOACAP and ICEPAC) have input/output methods that can be reconciled with some additional effort,

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*   This Recommendation should be brought to the attention of Radiocommunication Study Group 3.

**   Radiocommunication Study Group 5 made editorial amendments to this Recommendation in December 2009 in accordance with Resolution ITU-R 1.

noting

a)   that Recommendation ITU-R F.1110 specifies the general characteristics of adaptive HF systems, and specifically recognizes that adaptive HF systems make it possible to achieve the following:

–   higher quality of service by combining the ability to exploit modern radio-frequency technology with advanced real-time control software;

–   reduced transmission times, thereby securing most efficient use of the spectrum, reduced interference between users, and the ability to increase traffic density;

b)   that Recommendation ITU-R F.1337 recommends that automatic and adaptive management schemes be utilized for adaptive HF networks,

recommends

1   that administrations which intend to procure and deploy adaptive HF and ALE systems, based upon the information in Annex 1, should explore the use of HF performance prediction models such as those contained in Recommendation ITU-R P.533 and related models in advance of deployment to establish adaptivity bounds;

2   that the models contained in Recommendation ITU-R P.533, augmented by material such as that contained in the (optional) IONCAP family of programs, are preferred methods for the design of adaptive HF systems and for possible incorporation within software modules for real-time adaptation using recognized real-time channel evaluation (RTCE) technologies (i.e. in-band sounders, advanced channel probes, and out-of-band frequency modulated-continuous wave (FM-CW) sounding).

Annex 1

Adaptive HF system planning and operation using prediction methods

1   Introduction

The ionospheric channel provides the connectivity for the links in an adaptive HF radio circuit or network. To provide proper utilization of this resource the radio system must operate on the ideal frequency or as close to it as practical. This may be the same frequency for a simplex circuit or two different but closely related frequencies for a full duplex circuit. Frequency changes will be dictated by the natural cycles of ionospheric propagation; diurnal, seasonal and sunspot variations. Natural or man-made radio interference may dictate unpredicted changes in the operating frequency. Also solar flares and geomagnetic storms may cause communications disruptions which will also require changes in the operating frequency.

For the most part, the frequency adaptive HF radio system will detect link failure, find another usable frequency, bring the link up on the new frequency and re-establish communications without operator intervention. Several things can create intolerable outages even with the most sophisticated adaptive HF radio system. Equipment failure is one that is unavoidable over the life cycle of the system. It can be mitigated by fault detection, backup power supplies and equipment redundancy in the system design. However, most disruptions are attributed incorrectly to propagation failure. Only

under the most rare of ionospheric conditions should propagation failure occur. Most cases, where the signal power on any frequency across the band is unusable, can be directly traced to improper system design. The areas, which must be considered in the system design, will be discussed in the following paragraphs. Let it suffice to say at this point that the most common areas are:

– inadequate number of frequencies in the authorization list;

– underestimation of radio noise environment at the receive sites;

– antenna radiation patterns which do not match the takeoff and arrival angles of the ionospheric channel; and

– excessive losses in the transmission lines between the transmitter and the transmit antenna or the receiver and its antenna.

2 Frequency planning

Frequency planning begins early in the design phase of the HF radio system. For frequency adaptive HF radio systems, it is essential that the ionospheric model used for making the frequency predictions include as much knowledge as possible concerning the expected variation of the hourly maximum usable frequency (MUF) about the monthly median value (i.e. the MUF) for each of the probable modes on each link in the proposed radio system. The needed accuracy in the prediction model is directly related to the very low S/Ns required for the sophisticated adaptivity techniques employed in the modern radio equipment and their associated modems.

We will now outline a sample procedure by which prediction methods can be used to design and operate adaptive HF systems. The discussion in this Annex is based upon the VOACAP procedure that is used within the United States of America administration, having some experience in its application for adaptive HF systems. It is likely that similar procedures could be developed for other methods such as the preferred ITU method, Recommendation ITU-R P.533. At this time the preferred programs in the IONCAP family are VOACAP and ICEPAC, which, along with Recommendation ITU-R 533, are maintained and available at no cost via the Internet from the US Department of Commerce (i.e. http://elbert.its.bldrdoc.gov/pc-hf/hfwin32.html). The Recommendation ITU-R P.533 computer program predicts the monthly median MUF. It currently does not explicitly give, as an output, the expected distribution of daily MUF values over the days of the month at that hour for the possible modes.

In evaluating an adaptive HF system, each link in the radio net needs to be evaluated using a recommended prediction program. (In this example, we specify VOACAP, which belongs to the IONCAP family of programs.) These prediction methods were originally developed for non-adaptive systems. However they can be utilized for adaptive system planning.

For conventional HF radio links, the optimum working frequency (OWF) would be determined by finding the most reliable frequency at each hour, season and for high and low sunspot activity. However, for frequency adaptive HF radio systems, the highest probable frequency (HPF) needs to be found. This is the frequency which would not be exceeded more than 10% of the days in the month at that hour and sunspot number; whereas the OWF is the frequency which is exceeded on

approximately 90% of the days per month. The frequency adaptive system using ALE should have the capability of operating on frequencies above the monthly median MUF on half of the days per month. The frequency authorization list for such a system should include frequencies above the MUF but not to exceed the HPF. This feature of frequency adaptivity demands the use of accurate prediction programs in the systems design of the radio circuit or network.

It is essential in the planning for an adaptive HF radio system that the equipment be designed to work over the full range of usable frequencies including those below the MUF but above the lowest usable frequency (LUF). When possible, the system should operate at the highest usable frequency which permits error-free connectivity. The higher frequencies will experience less atmospheric and man-made radio noise and provide higher S/Ns for less transmitter power and antenna gain. By designing the adaptive system to take advantage of the highest possible frequency usage, cost savings can be made in the power capacity of the transmitter and the size of the transmit and receive antennas. At the same time, it should be recognized that practical circumstances may require operation of individual links at less than optimal frequencies to avoid self-interference or to avoid harmful interference to other users in a shared environment. Frequency predictions provide an *a priori* capability for assessing groups of sub-optimal channels to provide the best possible system reliability under specified conditions. Also care must be taken in the system design to assure that the signal-plus-noise power delivered to the receiver is meets the sensitivity requirements of the proposed receiver.

Another frequency consideration which will be important in the operation of the frequency adaptive system is that the frequency assignment should be several times per day and for seasonal and sunspot number changes. Ideally the frequency sampling should not exceed more than half a dozen frequencies at a given time epoch. This allows the adaptive system to perform link establishment more rapidly and reduces the needless interference caused by sounding on useless frequencies. Also a priority of frequency sampling should be established so that during a given time epoch the most reliable frequency is sampled first in the link establishment process. If there is a frequency which is 90% reliable, then on 27 days out of the month at that hour the system should lock up on that frequency and on the first try. Short term forecasting or now-casting techniques can further assure the success of finding the best operating frequency in the shortest time possible. The advantage of using predicted frequencies for first priority is that they are more likely to remain stable over the entire hour than a frequency of opportunity found by random sampling of the spectrum.

In short, there are two levels of frequency steering in a frequency adaptive HF system. At the first level, frequency predictions can be used to reduce the range of frequencies to be sampled or sounded in a real-time scenario. The second level of steering is defined by channel properties best derived from sounding or equivalent RTCE schemes, supplemented by a knowledge of the expected trends in frequency availability obtained from an appropriate prediction procedure. In-band channel soundings (e.g. ALE sounding), full-band FM-CW soundings (i.e. chirp sounding), or parameters derived from the modulation in use may be used. (See Chapter 6 of the Handbook on Frequency

adaptive communication systems and networks in the MF/HF bands, on sounding and RTCE technologies.) Still, the use of frequency predictions is essential for the development of requisite lists of the most likely frequencies to be used during the day and night path conditions by an adaptive HF radio system.

3   Power budget

The next phase in the design for a frequency adaptive HF radio system is to establish the power budget for each of the ionospheric links in the circuit or network. The power budget may be considered as the means of finding the most cost-efficient design which will permit for acceptable service over the life cycle of the system. Again for adaptive HF system design, performance prediction models with the highest degree of accuracy in modelling the signal and noise variations should be used. Programs should employ the full statistics of the expected variation in transmission loss by mode and the time variation of the atmospheric and man-made radio noise.

The reason for needing this sophistication in the prediction model is that adaptive HF radio systems operate at very low S/Ns. In order to be certain that the selected transmitter power and antennas for each of the links are adequate, great care must be taken in the calculation of the time- and frequency-variant signal and the noise power delivered to the receiver. Errors in this design step will result in needless cost in over-design or communications failure when the signal power is below the detection threshold of the receiver.

4   Design process

The first step in the design process is to evaluate the predicted required power gain (RPWRG) on each link of the radio circuit or network. It is defined as the additional or excess power, expressed in dB, required to achieve the required S/N at a specified reliability. A value of 0 dB at 90% reliability would mean that the required S/N would be achieved or exceeded 90% of the days of the month at that circuit hour.

Generally, the prediction program is set up with an assumed transmitter power of 1 kW and isotropic (0 dBi) antennas. To prevent modes from being considered at unreasonably low take-off or arrival angles, the minimum take-off angle to be considered is set at 3° above the horizon.

At this time a revised frequency list (up to 11 frequency bands between 2 and 30 MHz can be specified in one run of the Recommendation ITU-R P.533 and VOACAP-family of programs) needs to be established for this phase of the system design. The goal is to select frequencies which fall between the lowest usable frequency and the highest probable frequency needed over the hours, seasons and sunspot numbers representing the expect life cycle of the system. In other words the performance prediction should be made for only those frequencies for which we expect ionospheric support. The LUF is not predicted as such in the IONCAP-family or the Recommendation ITU-R P.533 programs. Instead, the reliability expected at various frequencies is predicted, which may be compared with the service requirement. (For design purposes the LUF is defined as the lowest frequency which will provide 90% reliability of meeting the required S/N or as approximately 90% of the MUF.) The next step is to decide upon the minimum required S/N density

ratio needed to allow the adaptive system to provide a minimum acceptable grade of service. The value of the required *S/N* is not well established this time for adaptive HF radio equipment. However, there are several guidelines we can apply before actually selecting the radio equipment for the desired service.

Analogue voice communications can be greatly enhanced using compression and expanding techniques to increase the amount of power expended in the transmission of the voice signal. Typically, a *S/N* of 50 dB in a 1 Hz noise power bandwidth will provide commercial quality voice reception using a state of the art compression/expanding equipment.

Digital systems used for voice or data transmission have a considerable range in required *S/N* density ratios. The reason for this is they may incorporate time, space (path) and frequency diversity. The cost of the modems generally increases with the greater the degree of diversity employed in the design. Another factor maybe that the customer will tolerate slow rates of data transfer during periods of poor propagation. Generally, we can assume that link establishment can be achieved at 40 dB in 1 Hz noise power bandwidth. Little to no digital traffic can be sent at this level, however. Slow to moderate speed digital transmission is possible at *S/N* density ratios of 55-65 dB. High speed data usually requires 65-75 dB in 1 Hz noise power bandwidth.

The required *S/N*s are closely related to the ones in Recommendation ITU-R F.339. In the IONCAP-family of programs care must be taken to express the *S/N* density ratio needed in 1 Hz noise power bandwidth including the short term fade protection (usually 8 dB for Rayleigh fading). The values are those required at the RF stage of the receiver.

Based upon experience of the United States of America administration, system performance predictions should be made using one of the IONCAP-family of programs or an equivalent program. It would be highly desirable to include the appropriate aspects of this family and of Recommendation ITU-R P.533 into an optimum set of procedures. Then, irrespective of the application, the user community would have a clearer choice. Having made the model choice, the analysis should be done for all critical links, and the analysis should cover the expected life cycle of the system. In the case of systems that are expected to operate for over five years the analysis should be made for the hours of operation, four seasons and years having a sunspot number of 10 and of 130. The critical links may be all of the links in the network or those that are known to be inferior. In radio nets involving a fixed base station and mobile units in the field, the critical link will most likely be the mobile station with less power and small antenna contacting the base station. The reverse could be the case if the environment of the remote station is extremely noisy, such as on aircraft, etc.

The output of the prediction analysis should be reviewed to find the smallest RPWRG needed for each of the candidate frequencies specified at the input to the program. A review of the take-off/arrival angle requirement associated with the smallest RPWRG should also be made at this time. The tabulated results of the smallest RPWRGs and their take-off/arrival angles provides the power budget for the life cycle of the system at the required *S/N* for the minimum acceptable grade of service.

The next step is to evaluate the take-off/arrival angles and select the antenna or antennas needed to satisfy the angle requirement for each of the critical links and over all of the required frequencies. It is convenient to graph the RPWRG versus take-off angle and then plot various candidate antenna patterns over the requirement taking into account both the transmit and the receive pattern. The shortfall in gain at the various angles will have to be made up by increasing the transmitter power by that many dB relative to the assumed 1 kW. If the RPWRGs are negative after applying the antenna gains, then the transmitter power can be reduced by that many dB relative to 1 kW.

If the RPWRGs are so large that the antennas and transmitter power become unreasonable, then the required S/N must be reduced; but not below 40 dB in 1 Hz noise power bandwidth. This can be done in several ways. The type and grade of service can be degraded or the adaptivity of the equipment can be enhanced.

The final step is to calculate the power gain patterns for the candidate transmit and receive antenna being careful to take into account whether or not the main beam of the pattern is off-azimuth from the actual great circle route for each of the links. In many cases, the needed power gain pattern can be computed using the antenna pattern calculation program, HFANT, which is inherent with the IONCAP-family of programs. The antenna patterns are then specified for use in the performance prediction program, the transmitter power is adjusted to the value determined above, and the required S/N is adjusted, if need be. The output from this analysis should provide the expected performance capability of the proposed design.

The first thing to look for are the hourly reliability values at each of the frequencies, hours, months and sunspot number combinations. The goal is to have at least one frequency at each hour which meets or exceeds the minimum required S/N at 90% reliability. If a minimum required S/N that is representative of being able to establish link connectivity has been used, then the system should be able to link up on 27 days out of the month over the life cycle of the system. This assumes that a frequency close to the one in the prediction analysis is provided in the frequency allocation for the system and that ionospheric conditions are not severely disturbed.

Next, the median S/Ns in the prediction output should be reviewed. At each hour over the life cycle of the system, there should be at least three to five frequencies which have predicted median S/Ns which meet or exceed the desired required S/N. This will allow the system to make maximum use of the ALE feature. For example, if there are four frequencies with adequate S/Ns on 50% of the days per month (i.e. the median), then the combined probability that one of those frequencies should be available at that level or higher is 93%, assuming that the distributions are independent of each other. This may be an overestimation on days when the MUF is lower and the LUF is higher, such as occurs during severe geomagnetic disturbances. However, it is a reasonable estimate of the design robustness in that there is sufficient bandwidth at each hour so that the ALE feature can find a usable frequency in as little search time as necessary.

The concluding step is to review the predicted signal power at the three to five best frequencies at each hour in the prediction analysis. Although the S/N and the predicted reliability may appear to meet the system requirements, it does not assure that the signal power meets the sensitivity

requirement of the receiver. In future upgrades of the prediction models it would be useful to include receiver thermal noise in the noise power computation. That would preclude having to make this final step in the proposed design process.

5 Conclusions

Some guidelines for evaluation of quasi-adaptive HF systems are presented. They are not intended to be applied universally. Specific adaptive systems may require modified approaches. The performance of adaptive HF systems can be improved by following these guidelines. The guidelines have been exercised by using VOACAP in this example. The model within the current version of Recommendation ITU-R P.533 (i.e. the REC533 model) could certainly be examined in the same manner.

6 List of acronyms and abbreviations

ALE: automatic link establishment

FM-CW: frequency modulation and continuous wave

HFANT: antenna pattern calculation program

HPF: highest probable frequency

ICEPAC: ionospheric communications enhanced profile analysis and circuit prediction

IONCAP: ionospheric communications analysis and prediction

ITS: United States Department of Commerce NTIA/ITS Institute for Telecommunication Sciences

LUF: lowest usable frequency

MUF: maximum usable frequency

OWF: optimum working frequency

RPWRG: required power gain

RTCE: real-time channel evaluation

VOACAP: Voice of America communication analysis prediction