

International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Report ITU-R F.2263
(11/2012)

**Reliability calculations for adaptive
HF fixed service networks**

F Series
Fixed service



International
Telecommunication
Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from <http://www.itu.int/ITU-R/go/patents/en> where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Reports

(Also available online at <http://www.itu.int/publ/R-REP/en>)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management

Note: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.

Electronic Publication
Geneva, 2012

© ITU 2012

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without written permission of ITU.

REPORT ITU-R F.2263

Reliability calculations for adaptive HF fixed service networks**1 Scope**

This Report presents a methodology for reliability calculations of HF (3-30 MHz) transport networks. The HF transport network supports the connections between the different base stations of a network.

2 References

The reader will find additional guidance in the references listed below:

- [Recommendation ITU-R F.339](#): Bandwidths, signal-to-noise ratios and fading allowances in complete systems
- [Recommendation ITU-R F.1110](#): Adaptive radio systems for frequencies below about 30 MHz
- [Recommendation ITU-R F.1611](#): Prediction methods for adaptive HF system planning and operation
- [Recommendation ITU-R F.763](#): Data transmission over HF circuits using phase shift keying or quadrature amplitude modulation
- [Recommendation ITU-R P.533](#): Method for the prediction of the performance of HF circuits
- Other relevant text: “An ionospheric observation network for use in short-term propagation predictions”
ITU Telecommunication Journal,
Charles M. Rush, Vol. 43, issue VIII,
pp. 544-549, 1976

3 List of acronyms

ALE	Automatic link establishment
BER	Bit error ratio
FER	Frame error ratio
FS	Fixed service
GUI	Graphical user interface
ICEPAC	Ionospheric communications enhanced profile analysis and circuit prediction
IONCAP	Ionospheric communications analysis and prediction program (for HF propagation prediction)
QAM	Quadrature amplitude modulation
REC533	Recommendation ITU-R P.533 HF propagation prediction program
REL	Reliability
REQ.SNR	Required signal-to-noise ratio
SSN	Sun spot number

VOACAP Voice of America coverage analysis program (for HF propagation prediction)

4 Introduction

This Report presents a methodology to calculate the availability (or reliability) of HF Automatic Link Establishment (ALE) radio networks. The knowledge of availability and reliability values allows automatic selection of the best channels and routes in a network, thereby relieving the operators from much of the work associated with maintaining information on propagation conditions. In this Report, the assumptions and the methodology are introduced and then an example end-to-end eleven year availability calculation for a hypothetical 4-node network is presented.

5 Computations and assumptions

5.1 ICEPAC computation assumptions

The ionospheric communications enhanced profile analysis and circuit prediction (ICEPAC)¹ program is used to predict the performance of the skywave circuits between the nodes of an HF network. "Propagation reliability or time availability" (REL) is an output parameter in the ICEPAC program and it is defined as the fraction of days in the predicted month that the signal-to-noise ratio (SNR) equals or exceeds the required SNR (REQ.SNR). Reliability is calculated for each of the possible propagation modes predicted for a given circuit hour and specified operating frequency.

The REQ.SNR is a critical input parameter in the ICEPAC program and is the measure of required grade of service. REQ.SNR can range from -30 to 99 dB and is defined as the ratio of the hourly median signal power in the occupied bandwidth relative to the hourly median noise in a 1 Hz bandwidth.

The received signal-to-noise ratio and the reliability values are computed by taking into account the ionospheric propagation conditions, as well as the atmospheric and local man-made site noise levels using the ICEPAC. The various ICEPAC parameters used in the computations are shown in Annex 1. The computations were performed for every third hour of the day, every second month of the year, and at low, median and high sunspot numbers which are considered representative of the performance of the HF circuits over an eleven year period. A total of 144 predictions per radio link were performed. The effects of both atmospheric noise and local man-made site noise were included in the calculations; however the effect of co-channel interference was excluded. The predictions did not take account of ionospheric storm events that can cause blackouts due to unstable conditions which can occur near the peak of the solar cycle lasting several days in duration. Auroral absorption losses were partially taken into account in ICEPAC by the incorporation of excess signal losses for paths propagating through the auroral zone.

¹ The ICEPAC program is part of a suite of HF prediction programs based on IONCAP. The programs included in the suite are ICEPAC, VOACAP and REC533 software implementation of Recommendation ITU-R P.533. Each program has an instance that will calculate circuit reliability for point-to-point links. Any one of these programs can be used for reliability predictions. ICEPAC is available for public download from the NTIA Institute for Telecommunication Sciences ITS website at the following address: <http://elbert.its.blrdoc.gov/hf.html>.

5.2 Equipment assumptions

Several important assumptions have been made in the analyses based on the use of modern HF radio systems. For the computations of signal levels at the receiver sites, a rosette of directional log-periodic antennas is assumed at both transmitter and receiver sites. The antennas are arranged as a rosette of antenna arrays to cover 360° of azimuth. The log-periodic antenna is set to cover the 6 to 30 MHz range and a horizontal dipole is utilized for the 2 to 6 MHz range. In all computations, it is assumed that directional information is available to select an antenna in the rosette in which the main lobe is directed towards the transmitter or receiver. It is also assumed that automatic link establishment (ALE) is available on all HF links, enabling the selection of the optimum frequency out of a complement of frequencies available in the HF band.

5.3 Reliability computations

The reception reliability (R) is defined as the probability that a specified signal-to-noise ratio is achieved by taking into account all of the transmitting frequencies for an HF circuit. It is assumed that at any specified time, the optimum frequency is used for communications and parameters such as the ionospheric losses and noise levels occurring at the various frequencies are correlated. For each location, month, hour and sunspot number, the reception reliability R is computed as follows:

$$R = \text{maximum of } B_1, B_2 \dots B_k$$

$$k = \text{number of frequencies}$$

$$B_k = \text{reliability (REL in Method 20) for the } k^{\text{th}} \text{ frequency computed by the ICEPAC.}$$

The service reliability (S) is the probability for all times, months and sunspot numbers that a specified performance is achieved by taking into account all transmitted frequencies. Service reliability is computed as follows:

$$S = \frac{\sum R_i}{n}$$

where:

R_i is the reception reliability for the i^{th} month, hour and sunspot number

$i = 1 \dots n$ and n is the number of combinations of months, hours, and sunspot numbers used in the computations.

5.4 Network assumptions

It is assumed that all the stations in the network have ALE systems and adaptive network controllers. The network of stations operates with network controllers that perform the network-layer functions related to traffic routing and relaying. The controller routes the traffic through the nodes that have the best path to the destination. All the nodes in the network have network connectivity data supporting adaptive routing and a path quality matrix. This matrix is assumed to be organized to provide information on data path quality to any reachable destination or via intermediate stations. These path quality estimates are based on link quality measurements reported by the link controllers. The route selection function routes data traffic through links using direct or indirect paths as required. While accomplishing this, it uses and maintains the routing table. The link selection function simply chooses the best data link available to each destination selected by the route selector.

5.5 Network reliability

For each circuit, the reception reliability is computed for a specified month, hour and sunspot number. An estimate of the probability that a specified performance is achieved over one or more HF circuits connected in series, and taking into account of all transmitted frequencies, is computed as follows:

$$N_s = \prod_{c=1}^n R_c$$

where:

N_s = is the reliability of the circuits connected in series

R_c = is the reception reliability for the c^{th} circuit at the same specified month, hour and sunspot number; and

n = is the number of circuits.

Similarly, an estimate of the probability that a specified performance is achieved over one or more HF circuits connected in parallel, and taking into account all transmitted frequencies, is computed as follows:

$$N_p = 1 - \prod_{c=1}^n (1 - R_c)$$

where:

N_p is the reliability of the circuits connected in parallel.

Sample expressions for the reliability computations for the Vancouver to Ottawa HF FS network in Canada are shown in Fig. 1. In these expressions, ‘+’ and ‘x’ signs represent series and parallel link arrangements, respectively.

In this Report, the term “network reliability” is an average of the reliabilities N_s , N_p or their combination over all months, hours and sunspot numbers.

5.6 Discussion of assumptions

The assumptions made in calculations and their implications on computed values of reliability are discussed below:

- a) In the computation of the reception reliability for a specified time period, the maximum reliability from a complement of available frequencies is selected as indicated in § 5.3. The selection of the maximum value assumes that a combination of several frequencies does not increase the reliability, and poor or good performance on one frequency is generally associated with a similar performance on most other frequencies. The similar performance on the frequencies can be explained by variations in atmospheric noise levels at the receiver site, occurring over the complete range of operating frequencies and by various radio paths propagating through similar areas of D-region absorption.
- b) The network reliability estimate for two or more circuits connected in series or in parallel, assumes that the reception reliabilities for various circuits are completely independent of each other. The assumption of independence is considered more realistic than the assumption of dependence since uncorrelated variations in propagation conditions between the circuits are expected due to different circuit terminal locations and lengths used in the study. The spatial correlation of ionospheric structure is reported in reference Rush 1976.

5.7 Sample calculation of reliability for a hypothetical digital HF fixed service network

Figure 1 displays a network of HF stations and possible message routes analysed to demonstrate the end-to-end availability calculation. Note that Fig. 1 does not show all possible routes or optimum routing; it only provides an example to demonstrate the calculations of series and parallel connections of several message routes. Table 1 summarizes the geographic information of the stations used in the calculations. The coordinates of the stations are selected from default latitude and longitude values given in ICEPAC and they do not represent real HF stations. The input parameters listed in Annex 1 are used for sample calculations, and it is assumed that all the stations are operating with the same parameters.

The data waveforms used in this Report are described in Annex 6 of Recommendation ITU-R F.763-5 – Data transmission over HF circuits using phase shift keying or quadrature amplitude modulation. The digital data waveform parameters considered for this study are 64-QAM modulation data rate of 9 600 bit/s, 32-QAM modulation data rate of 8 000 bit/s and 16-QAM data rate of 6 400 bit/s, in a 3 kHz bandwidth with long interleaver. Recommendation ITU-R F.339-7 – Bandwidths, signal-to-noise ratios and fading allowances in complete systems, is used to determine the required SNR for the ICEPAC performance objective in fading channels. The values obtained from Recommendation ITU-R F.339-7 were used in the prediction of system performance calculations.

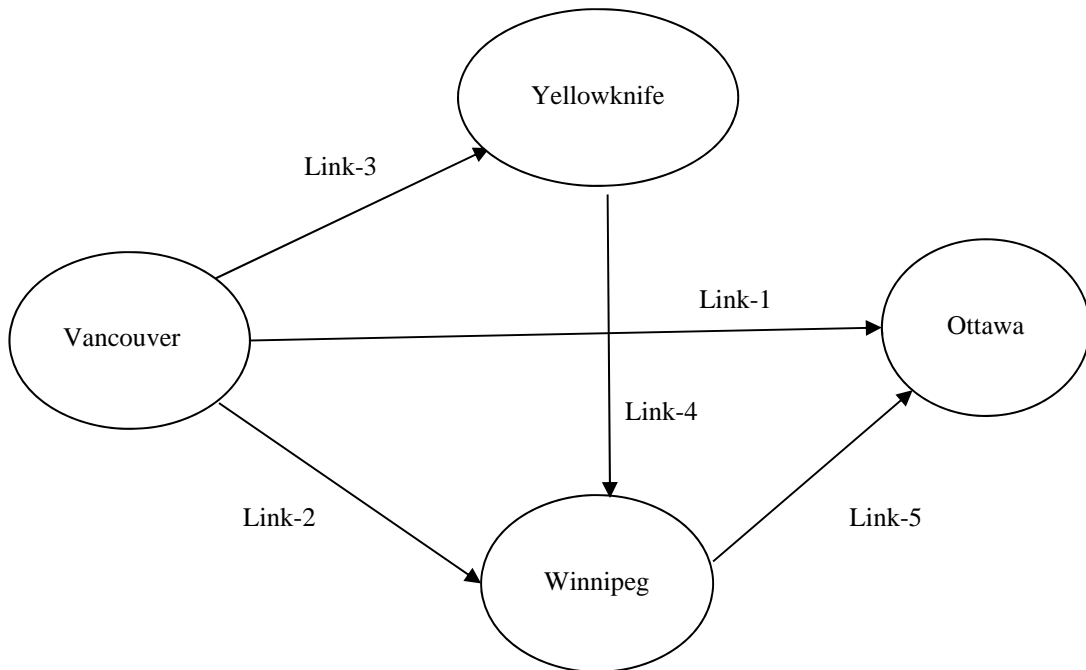
A BER of 1×10^{-5} is selected as the desired operating point of an IP packet network and the following assumptions were made.

The target BER is selected to be 1×10^{-5} . For a typical frame size of 300 bytes or 2 400 bits, it is assumed that this BER will result in approximately an FER of 2.3×10^{-2} , which will degrade the net throughput by only a small amount. When the BER is 1×10^{-5} and the frame length is 300 bytes, the FER is estimated as:

$$\begin{aligned}
 \text{FER} &= 1 - (\% \text{ Number of frames received correct}) \\
 &= 1 - (1 - \text{BER})^{\text{FrameSize (bits)}} \\
 &= 1 - (1 - 10^{-5})^{(300 \times 8)} \\
 &= 0.023 \\
 &= 2.3\%.
 \end{aligned}$$

The target BER of 1×10^{-5} is chosen and corresponding required SNR values for data rates of 9 600, 8 000 and 6 400 bit/s are shown in Annex 1, Table 4. These values correspond to required SNR values in fading channels in Recommendation ITU-R F.339-7.

FIGURE 1
Example of a 4-node HF network



Network reliability Vancouver to Ottawa = $1 \times (5 + 2 \times (3+4))$

+: series connection

x: parallel connection

TABLE 1
Distances of the HF network in Canada for Fig. 1

Name of the link	Connection between	Distance (km)
(1) Link-1	Vancouver to Ottawa	3 538
(2) Link-2	Vancouver to Winnipeg	1 864
(3) Link-3	Vancouver to Yellowknife	1 560
(4) Link-4	Yellowknife to Winnipeg	1 745
(5) Link-5	Winnipeg to Ottawa	1 674

The link predictions were performed only for the directions as shown in Table 1 and the final network reliability was calculated for the “Vancouver to Ottawa” direction. Predictions for the reverse direction were not performed. Note that reverse direction reliabilities cannot be assumed the same as the forward direction reliabilities due to different receiver site noise levels. Table 2 shows the result of average reliability calculations for each link of the network depicted in Fig. 1. Table 2 columns display reliability calculations for data rates from 6 400 to 9 600 bit/s. Lower data rates for the same grade of service require lower SNR values resulting in higher reliability values.

TABLE 2
Average reliability of the network of Fig. 1

Link	From	To	Average reliability data rate 9 600 bit/s	Average reliability data rate 8 000 bit/s	Average reliability data rate 6 400 bit/s
1	Vancouver	Ottawa	0.29	0.40	0.51
2	Vancouver	Winnipeg	0.66	0.73	0.80
3	Vancouver	Yellowknife	0.83	0.90	0.94
4	Yellowknife	Winnipeg	0.59	0.67	0.74
5	Winnipeg	Ottawa	0.76	0.83	0.89
	Vancouver to Ottawa Network reliability =		0.74	0.84	0.92

6 Conclusions

The output of the ICEPAC files for each communication link is analysed and the maximum reliability is selected from the set of results for each time slot from the prediction results to simulate an ALE system. The average of each link's reliability is presented in Table 2 for an eleven year period to cover operation in one sun spot cycle for this network. This analysis does not take into account any blackout periods due to ionospheric storm conditions and interference events. The HF frequencies are shared worldwide and there will be a high probability of interference from other transmitters which will degrade the net reliability calculated for a HF network. The effect of these factors will reduce the performance that is estimated by prediction tools.

The reliability of a direct connection from Vancouver to Ottawa (link-1) is very low for all the data rates. When a network configuration with alternate routes is analysed, the reliability of 0.74 is achievable for the 9 600 bit/s system, which can provide reasonable connectivity. The reliability can be increased to 0.92 if lower data rates can be tolerated by the network services.

Some guidelines for evaluation of network availability of adaptive HF systems are presented. Specific adaptive systems may require modified approaches. The performance of adaptive HF systems can be improved by networked HF systems. A networked system may provide economical solutions compared to adding more transmitter power into the network budget to improve a direct link's reliability.

Annex 1

ICEPAC parameters

(Version 100123W)

The ICEPAC input parameters used in the sample calculations are listed in this Annex². Annex 2 is a listing to demonstrate how ICEPAC was used to predict the link reliabilities.

- 1) Method: 20
- 2) Year: 2011
- 3) Coefficients: CCIR
- 4) Time: 0100, 0400, 0700 ----- 2200 UT
- 5) Months: 01, 03, 05 ----- 11
- 6) Sunspot numbers: 10, 60, 120 and effective Q-index = 0 (geomagnetic activity quiet)
- 7) Fixed site locations, same geographic coordinates assumed for hypothetical transmitter and receiver sites:

TABLE 3

Geographic details of the network in Fig. 1

City	Latitude	Longitude
Vancouver	49 27 N	123 12 W
Yellowknife	62 45 N	114 35 W
Winnipeg	49 88 N	97 15 W
Ottawa	45 42 N	75 70 W

- 8) Short or long path: Short
- 9) Frequencies: 3.1, 4.5, 5.4, 6.9, 8.5, 10.5, 12.5, 14.9, 17.4, 20.5 and 24.0 MHz
- 10) Noise power at 3 MHz: The man-made noise level at the receiver in –dBW (decibels below 1 Watt) in a 1 Hertz bandwidth at 3 MHz, all sites: –156 dBW
- 11) Minimum take-off angle: 3 degrees
- 12) Required signal/noise per Hz:

TABLE 4

BER for 1×10^{-5} and required SNR in fading channels

User data rate (bit/s)	Modulation	Required SNR (dB/Hz)
9 600	64-QAM	67
8 000	32-QAM	63
6 400	16-QAM	59

- 13) Multipath power tolerance: 3 dB

² The parameters in this Annex are shown in the same format as in the ICEPAC program.

- 14) Maximum tolerable time delay: 5 ms
- 15) Absorption: Normal
- 16) Fprob variables: $1.0 \cdot f_{oE}$, $1.0 \cdot f_{oF1}$, $1.0 \cdot f_{oF2}$, $0.5 \cdot f_{oEs}$
- 17) Transmitter antennas and transmitter power:
Rosette array of antennas with main beam of transmitting antenna always directed toward receiver site, transmit antennas:
 - Frequency range 2-6 MHz sample type 23 ITSA-1 horizontal dipole antenna
 - Frequency range 6-30 MHz horizontal log periodic REC705 sample 5 antenna
 - Antenna input power = 0.4 kW
- 18) Receiving antennas:
Same as transmit antennas with main beam of receiving antenna always directed toward transmitter site.
- 19) Electrical properties of the ground:
All computed radiation patterns for antennas located on land is on poor ground (conductivity = .001 mS/, dielectric = 4).

Annex 2

ICEPAC running the prediction

The graphical user interface of ICEPAC has some limitations; this Annex provides a sample listing to demonstrate how ICEPAC can be executed to perform all the predictions for one link with one batch file. The GUI of ICEPAC program allows a maximum of ten month/SSN value pairs and a total of five antennas (four transmit antennas and one receive antenna to be used in one prediction). Here it is shown how it was specified for two transmit and two receive antennas and 18 month/SSN values for the Vancouver to Ottawa link.

The ICEPACW.EXE is the calculation engine for ICEPAC GUI that accepts a data file as input. This input data file is composed of a number of “control cards”, or labelled lines. ICEPACW.EXE can be found in the C:\itshfbc\bin_win\ directory (provided the user has accepted the default ICEPAC installation options). The predictions are performed by the execution of the following command, assuming that the ICEPAC is installed to C: drive and itshfbc directory:

```
C:\itshfbc\bin_win\icepacw C:\itshfbc VAN2OTT.DAT VAN2OTT.TXT
```

The input parameters are provided in the VAN2OTT.DAT file and prediction output is directed to VAN2OTT.TXT and they are both located in the C:\itshfbc\run directory.

The listing of VAN2OTT.DAT is below:

```
LINEMAX 55      number of lines-per-page
COEFFS  CCIR
TIME    1 24 3 1
LABEL  VANCOUVER      OTTAWA
CIRCUIT 49.27N 123.12W 45.42N 75.70W S 0
SYSTEM  1. 156. 3.00 90. 67.0 3.00 5.00
```

FPROB 1.00 1.00 1.00 0.50
 ANTENNA 1 1 2 6 0.000 [samples\SAMPLE.23]78.5 0.4000
 ANTENNA 1 2 6 30 0.000[samples\SAMPLE.05]78.5 0.4000
 ANTENNA 2 3 2 6 0.000 [samples\SAMPLE.23]294.3 0.0000
 ANTENNA 2 4 6 30 0.000[samples\SAMPLE.05]294.3 0.0000
 FREQUENCY 3.10 4.50 5.40 6.90 8.50 10.50 12.50 14.90 17.40 20.50 24.00
 METHOD 20 0
 MONTH 2011 2.00
 SUNSPOT 120. 0.00
 EXECUTE
 MONTH 2011 4.00
 SUNSPOT 120. 0.00
 EXECUTE
 MONTH 2011 6.00
 SUNSPOT 120. 0.00
 EXECUTE
 MONTH 2011 8.00
 SUNSPOT 120. 0.00
 EXECUTE
 MONTH 2011 10.00
 SUNSPOT 120. 0.00
 EXECUTE
 MONTH 2011 12.00
 SUNSPOT 120. 0.00
 EXECUTE
 MONTH 2011 2.00
 SUNSPOT 60. 0.00
 EXECUTE
 MONTH 2011 4.00
 SUNSPOT 60. 0.00
 EXECUTE
 MONTH 2011 6.00
 SUNSPOT 60. 0.00
 EXECUTE
 MONTH 2011 8.00
 SUNSPOT 60. 0.00
 EXECUTE
 MONTH 2011 10.00
 SUNSPOT 60. 0.00
 EXECUTE
 MONTH 2011 12.00
 SUNSPOT 60. 0.00
 EXECUTE
 MONTH 2011 2.00
 SUNSPOT 10. 0.00
 EXECUTE
 MONTH 2011 4.00
 SUNSPOT 10. 0.00
 EXECUTE
 MONTH 2011 6.00
 SUNSPOT 10. 0.00

EXECUTE
MONTH 2011 8.00
SUNSPOT 10. 0.00
EXECUTE
MONTH 201110.00
SUNSPOT 10. 0.00
EXECUTE
MONTH 201112.00
SUNSPOT 10. 0.00
EXECUTE
QUIT
