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| **U.S. Radiocommunications Sector**  **Fact Sheet** | |
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| **Purpose/Objective:** This is a Fact Sheet for continued work on the Preliminary Draft Revision to Recommendation ITU-R F.1821 “Characteristics of advanced digital high frequency (HF) radiocommunication systems” with a view towards elevating the document to a DNR at the next ITU-R 5C meeting. | |
| **Abstract****:** This work will consist of completing Tables 2 bis and 3 bis, a final review and, if needed, editorial and language modifications. | |

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| DRAFT REVISION TO RECOMMENDATION ITU-R F.1821  **CHARACTERISTICS OF ADVANCED DIGITAL HIGH FREQUENCY (HF) RADIOCOMMUNICATION SYSTEMS** | |
|  | |

**Introduction**

The United States proposes that ITU-R Working Party (WP) 5C consider the proposed revisions to the ITU-R Recommendation [**F.1821**](https://www.itu.int/rec/R-REC-F/recommendation.asp?lang=en&parent=R-REC-F.1821) **in particular to tables 2 bis and 3 bis. The US proposes to elevate this document to DNR.**

**Attachment:** Draft Revision to Recommendation ITU-R F.1821 “Characteristics of advanced digital high frequency (HF) radiocommunication systems”

The proposed edits are highlighted in yellow.

**attachment**

DRAFT REVISION OF RECOMMENDATION ITU-R F.1821-0

Characteristics of advanced digital   
radiocommunication systems in the 2-30 MHz frequency range[[1]](#footnote-1)

(Question ITU-R 147/9)

(2007-202X)

Summary of Revisions

The proposed revisions to this version of the document include the addition of parameters to Table 2bis and Table 3bis.

Scope

This Recommendation describes emerging advanced digital HF systems and networked protocols, and specifies the typical RF characteristics of wideband modems (single-channel, multichannel and Digital Radio Mondiale (DRM)) used for emerging advanced digital HF systems. Wideband modems include two major systems, multichannel operations and Digital Radio Mondiale operations. Tables of characteristics within the Annex to this Recommendation provide a summary of the values that should be considered for sharing studies.[[2]](#footnote-2)

1. Keywords

AGILE HF, MESH Network*,* Cognitive Radio*,* Automatic Link Establishment

Abbreviations

AGILE-HF: Advanced, Global, Integrated, Low-latency, and Enhanced HF Networks

ALE: Automatic Link Establishment

CSMA: Carrier Sense Multiple Access

DRM: Digital Radio Mondiale

HF: High Frequency

HFTP: HF token passing

HFWAN: High frequency WAN

ISB: Independent sideband

Kbps: kilobits per second

LSB: Lower sideband

MULTICAST: IP Routing protocol technique for data distribution

NVIS: Near vertical incidence skywave

OFDM: Orthogonal frequency division multiplex

OTH: Over the Horizon

PSK: Phase-shift keying

QAM: Quadrature amplitude modulation

SNR: Signal to Noise Ratio

SSB: Single Side Band

TDMA: Time Division Multiple Access

USB: Upper sideband

WAN: Wide area network

WTRP: Wireless token ring protocol

Terms and Definitions

AGILE-HF – An advanced, global, integrated, low-latency HF environment that negotiates the RF environment while mitigating harmful interference to users in or adjacent to desired operational frequencies.

Cognitive Radio – A radio that can be programmed and configured dynamically to use the best wireless channels in its vicinity to avoid user interference and congestion, based on electromagnetic environment measurements or sensing.

MESH Network – A mesh network is a local network topology in which the infrastructure nodes connect directly, dynamically, and non-hierarchically to as many other nodes as possible and cooperate with one another to use/share spectral link space and to efficiently route data from/to clients.

MIMO – A method for multiplying the capacity of a radio link using multiple transmission and receiving antennas.

Related ITU-R Recommendations and Reports

|  |  |
| --- | --- |
| Recommendation ITU-R F.1610 | *Planning, design and implementation of HF fixed service radio systems* |
| Recommendation ITU-R F.1611 | *Prediction methods for adaptive HF system planning and operation* |
| Recommendation ITU-R F.1761 | *Characteristics of HF fixed radiocommunication systems* |
| Recommendation ITU-R F.1762 | Characteristics of enhanced applications for high frequency (HF) radiocommunication systems |
| Recommendation ITU-R F.1778 | *Channel access requirements for HF adaptive systems in the fixed and land mobile services* |
| Recommendation ITU-R F.2061 | *HF Fixed Radiocommunication Systems* |
| Report ITU-R BS.458 | *Characteristics of systems in LF, MF and HF broadcasting* |
| Report ITU-R F.2087 | *Requirements for high frequency (HF) radiocommunication systems in the fixed service* |
| Report ITU-R F.2484 | *Cooperative frequency competition model and the corresponding algorithms and protocols for improving the HF sky-wave electromagnetic environment* |

The ITU-R Radiocommunication Assembly,

considering

*a)* that there is an increasing use of advanced digital systems in the HF bands;

*b)* that such advanced systems are not standardized and may have different operational technical characteristics;

*c)* that the lack of uniformity, in the arrangement and designation of the channels in multichannel transmitters for long-range circuits operating on frequencies below about 30 MHz, may give rise to certain difficulties when one transmitting station has to work with several receiving stations;

*d)* that the increasing use of spectrum in the HF bands for Wideband High Frequency (AGILE-HF) applications, such as e-mail (with and without attachments), internet access, large file transfer and live video streaming, which provide a communications path for exchanging these enhanced digital information, should be considered;

*e)* that such AGILE-HF systems are not standardized in use and may have different operational and technical characteristics,

recognizing

that the frequency range 2 to 30 MHz is also allocated to several other services on a primary basis,

recommends

that the technical and operational characteristics of advanced digital HF systems described in Annex 1 should be considered representative of those systems operating in the HF frequency bands from 2 MHz to 30 MHz for use in sharing and compatibility studies.

Annex 1  
  
TABLE OF CONTENTS

[Editor’s note: Table of contents to be updated.]*Pages*

[Annex 1 5](#_Toc135905512)

[1 Introduction 5](#_Toc135905513)

[2 Wideband modems 6](#_Toc135905514)

[2.1 Multichannel approach 7](#_Toc135905515)

[2.2 Digital Radio Mondiale (DRM) 9](#_Toc135905516)

[3 Networked systems 10](#_Toc135905517)

[3.1 AGILE HF Networks 10](#_Toc135905518)

[4 Multicast technologies 12](#_Toc135905519)

[4.1 Time Division Multiple Access (TDMA) 12](#_Toc135905520)

[4.2 Carrier Sense Multiple Access (CSMA) 12](#_Toc135905521)

[4.3 Token passing protocols 12](#_Toc135905522)

[5 Summary 16](#_Toc135905523)

Attachment to Annex . [HF, advanced Digital HF, and AGILE-HF, technical characteristics 17](#_Toc135905525)

# 1 Introduction

HF systems have specific attributes that make them a viable solution for many radiocommunication objectives. They provide highly versatile means of radiocommunications to a broad base of users and such equipment can be easily transported to remote and lightly populated areas. There are two technologies that are examples of advanced digital HF systems. This Recommendation specifies the characteristics of these systems.

Overall, the maturation of system configuration, advanced technology, and enhanced capabilities afford AGILE-HF (Advanced, Global, Integrated, Low-latency, and Enhanced HF Networks) the ability to operate in environments not traditionally allocated for wider bandwidth operations.

For the purpose of this Recommendation, spectrum efficiency is defined as an objective with three parts. The first one is to achieve maximum throughput (bits/Hertz/s), the second one is to maximize the number of users per frequency net, and the third one is to maximize the ability of fixed communications operations to achieve performance and mission goals. Several approaches can be sought to accomplish this objective.

Recently, several wideband approaches have been proposed to increase the capability of HF radio communications. These approaches use contiguous (up to 48 kHz), and non-contiguous (within up to 200 kHz) signalling test bandwidths exceeding the SSB voice channel bandwidth of 3 kHz, in some cases by as much as a factor 16.

This Recommendation contains an Attachment that provides technical characteristics of typical HF, digital HF and AGILE-HF Systems operating within the 2-30 MHz frequency band (see Attachment).

While the HF band is advantageous for long-distant communication applications, it is also a critical and affordable option together with satellite communications. The challenge with these emerging advanced digital HF networks is to seek increased bandwidth while not impeding incumbents within the frequency band or countries dedicated legacy frequency needs. Advanced HF technologies can support digital HF networks that can enable a shared environment while maximizing utilization of HF frequency band from 2 to 30 MHz.

# 2 Wideband modems

RF characteristics are presented in tables of attachment of Annex 1.

HF waveform designed to optimize data movement in varying spectral environments is as old as modulation and demodulation (MODEM) itself. Standards for different modulation methods and patterns have centered either on best effort, high-reliability or spectrally noisy situations. Recently interest in waveforms that compensate for natural and unnatural jamming or detection have been called for and technology groups have assembled to create them. Academies and Technologists have offered some of the most innovative approaches to high *Eb*/*N*o <-> low detection techniques, typically based on a spreading the waveform across wideband HF (WBHF) that in field trials shows a responsive and resilient extensibility with high transmission reliability.

## 2.1 Direct Sequence Spread Spectrum (DSSS) approach

Some of these new offerings are based in Direct Sequence Spread Spectrum (DSSS) spectrum techniques whereby the original data signal is multiplied with a pseudo random noise spreading code. This spreading code has a higher chip rate (this is the bitrate of the code), which results in a wideband time-continuous scrambled signal. Spread spectrum using DSSS gives high immunity to interference which sustains links better in contested frequency bands.

FIGURE 1

Typical DSSS Waveform Design

Graphical user interface

Description automatically generated with medium confidence

## 2.2 Multichannel approach

### 2.2.1 Independent sideband (ISB) operation

There are modems that convey data in multiple independent sidebands simultaneously. Such modems contain independent PSK/QAM modulators for each audio channel (for information on modulation see Recommendation ITU‑R F.763‑5, Annex 6), but employ a single forward error correction encoder, whose output bit stream is distributed over the individual channels for transmission. When these channels are carried by contiguous frequencies, the *S*/*N* of the channels tend to be similar, although channel errors are not perfectly correlated. Thus, some improvement in output is achieved using receiver diversity.

#### 2.2.1.1 Independent sideband (ISB) operation in non-contiguous channels

When contiguous channels are not available in sufficient quantity to support operational data requirements, operation in non-contiguous channels is necessary. In this case, channel *S*/*N* values may vary significantly so the distribution of a single coded bit stream over the complete set of channels is not optimal. Instead, separate coded bit streams are generated for each set of channels. Flow control operates independently for each set of channels so that overall data throughput is maintained near the maximum possible for the frequencies in use.

#### 2.2.1.2 Single-channel HF equipment

One nominal 3 kHz channel USB or LSB (selectable).

[Editor’s note: This paragraph on single-channel HF is not related to multichannel and should be reorganised in the document.]

### 2.2.2 Contiguous multichannel HF equipment

Multiple channeling arrangements are possible as shown below:

– Two nominal 3 kHz channels in the USB or LSB (two independent channels in the same sideband – sideband selectable).

– One nominal 6 kHz channel in the USB or LSB (selectable).

– Two nominal 3 kHz channels in the USB and two in the LSB (four independent 3 kHz channels – two in each sideband).

– One nominal 6 kHz channel in the USB and one in the LSB (two independent 6 kHz channels – one in each sideband).

– One nominal 12 kHz channel in the USB or LSB (selectable).

– One nominal 3 kHz channel in the USB and one in the LSB (two independent 3 kHz channels – one in each sideband).

When four-channel independent sideband operation is required, the four individual 3 kHz channels should be configured as shown in Fig. 2, which also shows the amplitude response for these four channels. Channels A2 and B2 should be inverted and displaced with respect to channels A1 and B1 as shown in the figure. This can be accomplished by using subcarrier frequencies of 6 290 Hz above and below the center carrier frequency, or by other suitable techniques that produce the required channel displacements and inversions.

The suppression of any subcarriers used should be at least 40 dB below the level of a single tone in the A2 or B2 channel modulating the transmitter to 25% of peak envelope power as shown in Fig. 1. The RF amplitude versus frequency response for each ISB channel is within 2 dB between 250 Hz and 3 100 Hz, referenced to each channel’s carrier (either actual or virtual). Referenced from each channel’s carrier, the channel attenuation should be at least 40 dB at 50 Hz and 3 250 Hz, and at least 60 dB at 250 Hz and 3 550 Hz.

Group delay distortion should not exceed 1 500 μs over the ranges 370 Hz to 750 Hz and 3 000 Hz to 3 100 Hz, and 1 000 μs over the range 750 Hz to 3 000 Hz and 150 μs for any 100-Hz frequency increment between 570 Hz and 3 000 Hz. Absolute delay should be less than 10 ms over the frequency range of 300 Hz to 3 050 Hz. Measurements are from end-to-end (transmitter audio input to receiver audio output) with the radio equipment configured in a back-to-back configuration.

Figure 2

Four-channel independent sideband operation



### 2.2.3 Non-contiguous Multichannel HF equipment

Some systems permit to reach data rate requirements by simultaneous use of up to 16 non-contiguous traditional SSB channels arranged in an (non-overlapping) arbitrary way.

The modulation of such an equipment consists in a set of elementary 3 kHz wide modulators, arranged in a frequency division multiplex. Any elementary modulation is processed and applied to a subcarrier whose frequency value is chosen according to the allocated channels.

All channels shall be contained within a working bandwidth of up to a maximum of 200 kHz.

Each of the channels shall be modulated independently with a common modulation rate of 2 400 bauds. The transmit data clocks for all channel shall be synchronized so that there is no drift.

The frequency of the suppressed carrier shall be the reference frequency, noted f0.

The amplitude versus frequency response of the transmitter or the receiver over the frequency range (f0 + 300 Hz) to (f0 + 3 050 Hz) shall be within 3 dB for all types of equipment. The attenuation shall be at least 20 dB from f0 to (f0 – 415 Hz), at least 40 dB from (f0 – 415 Hz) to (f0 – 1 000 Hz), and at least 60 dB below (f0 – 1 000 Hz). Attenuation shall be at least 30 dB from (f0 + 4 000 Hz) to (f0 + 5 000 Hz) and at least 60 dB above (f0 + 5 000 Hz).

## 2.3 Digital Radio Mondiale (DRM)

The DRM system is a narrow bandwidth orthogonally coded digital data transmission system that has the capability to tailor its transmission characteristics to match the service objectives and radio propagation factors. Each of the various subcarriers is modulated using quadrature amplitude modulation (QAM) in order to carry the information content, which also incorporates forward error correcting code elements. Two primary QAM constellations are used: 64‑QAM and 16‑QAM. In addition, a quadrature phase-shift keying (QPSK) modulation mode is available for highly robust signaling. The data is also interleaved in time over the subcarriers in order to counter time and frequency selective fading. The European Telecommunications Standards Institute has published the DRM option in its “Data Applications Directory” which can be accessed at <http://pda.etsi.org/pda/queryform.asp>. In the search function for this webpage enter “data application directory.”

# 3 Networked systems

Different types of networking protocols could be implemented to support advanced HF systems, such as, and not limited to, Token ring, Time Division Multiple Access (TDMA) and Carrier Sense Multiple Access (CSMA).

The purpose of this chapter is to describe some networking capabilities that could apply.

## 3.1 AGILE HF Networks

AGILE-HF Systems will operate across portions of the 2 to 30 MHz frequency band to support digital voice (point-to-point and point to multi-point), data transfer and database replication (e.g. financial transactions, logistics, medical records, law enforcement data, etc.), remote sensor reporting (e.g. tsunami or meteorological buoys, ice shelf diagnostics, seismic monitoring, etc.), emergency management and disaster relief applications along with many other applications such as email, FTP file transfer, chat rooms and video calls across thousands of miles.

Deployment of AGILE-HF (Figure 3) networks can be accomplished through the use of Mesh Networks. A mesh network is a group of devices that act as a single Wi-Fi network; and can provide real-time video, high speed data transfers, email, internet access and other network-based services. Within this network all of the devices (points) act as a single network. AGILE-HF systems use RF as the means of connecting the points within the AGILE MESH network providing global connectivity.

An AGILE-HF ALE Mesh Network provides for sensing the occupancy of a frequency and has a-priori knowledge programmed information with regional operational restrictions on channel use; it can calculate and select a frequency based on availability and then release it when finished and select another later.

FIGURE 3

Global AGILE-HF Network Example

Diagram

Description automatically generated

“Sub-nets” within an AGILE-HF Mesh network provide extensibility of the “local” mesh into a farther ranging Wideband HF Mesh (WHFM) with durability of data transport by having layers of single frequency “subnets” to route or reroute information on. The first premise in this description is that all members with emission capacity (radio silence disabled) in any WHFM have a common capacity to receive, catalog and report local configuration of their node, including spectral conditions – to all other enabled nodes. The second premise is that some number of nodes have more than one AGILE-HF radio and therefore can participate in more than one Mesh “subnet.”

Each “sub-net” in an AGILE-HF Mesh is on a particular frequency for a specific period of time and can adapt its channel bandwidth to reach nodal members of its “subnet” based on their configuration (both hardware and spectral conditions) and that those nodes with dual AGILE-HF radios can gather and re-report this same data from other “subnets” that are on a different frequency.

Any node can be aware of other nodes it can connect through either directly-link or neighbored-link within its frequency “subnet;” and it can identify and use those nodes within it “subnet” that have two or more AGILE-HF radios to extend connections to nodes on other “subnets” which are on a different frequency than its own. And since it has configuration knowledge of nodes on that extended “sub-net” the originating node has record of “sub-net” time-to-live parameters either pre-set or real-time calculated based upon frequency occupation and spectral conditions.

Many AGILE-HF nodes are constantly manoeuvring, so they can join a “subnet” of the network and make use the extensibility as described above. At some time later they can switch frequencies and join the secondary “sub-net” (or even a tertiary, should the second subnet also have dual connection to a third “sub-net”). This capability provides a persistent connection within the AGILE-HF Mesh Network with a high degree of “link durability.”

Descriptions of HF Token Ring, HF multicast, HF Token Mesh and HF ALE Mesh can be found in the corresponding following sections.

# 4 Multicast technologies

Sharing data access within an HF network can be achieved using a range of multiple access technologies.

Multicasting is an efficient mechanism for disseminating messages through HF Wireless Networks, Multicast IP Routing protocols are used to distribute data (for example, audio/video streaming broadcasts) to multiple recipients. Using multicast, a source can send a single copy of data to a single multicast address, which is then distributed to an entire group of recipients. Multicasting can provide a potentially bandwidth efficient transfer capability, especially when there are many recipients of a message in the same radio network.

Moreover, as a consequence of the broadcast nature of HF propagation, many nodes are in direct connectivity with each other, which favors the application of multicast principles.

## 4.1 Time Division Multiple Access (TDMA)

Time-division multiple access (TDMA) is a frequency channel access method.

It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using their own time slot. This allows multiple stations to share the same radio frequency channel while using only a part of its channel capacity.

Fixed TDMA protocols are based on static time slot allocation and will be generally inefficient in the context of HF networks to achieve a satisfactory trade-off between latency and link capacity. To improve that, adaptive TDMA principle would be preferred, due to the fact that it permits variations in the time slot allocation to adapt to variations in the traffic generated by the nodes.

## 4.2 Carrier Sense Multiple Access (CSMA)

Carrier-sense multiple access (CSMA) is also a frequency channel access method.

The Carrier-Sense Media Access (CSMA) is based on a node’s ability to listen to the channel in order to detect another transmission, before initiating a transmission on a shared frequency channel.

If a carrier is sensed, the node waits for the transmission in progress to end before initiating its own transmission. Using CSMA, multiple nodes may, in turn, send and receive on the same frequency channel. Transmissions by one node are generally received by all other nodes connected to the channel.

CSMA provides simple yet effective access sharing mechanism for a limited number of nodes in the HF network, and for a limited traffic load.

## 4.3 Token passing protocols

Robust token management schemes are conducive for sharing data channels in HF networks where packet loss rates can be driven to extreme levels due to unforeseen variations in propagation. Network performance can be seriously degraded if nodes are out of contact. Data rates are degraded under these circumstances. Propagation perturbations can reduce efficiency in spectrum usage by HF networks.

Token passing can provide efficient medium access control in heavily loaded networks. However, it has been perceived to be too fragile for use in networks with non-negligible packet loss rates. In this Recommendation, a token management approach is presented that quickly recovers from common token loss and duplication scenarios, and deals efficiently with changes in network connectivity and membership.

Token passing protocols generally provide mechanisms for nodes to enter and leave the network. When token passing is to be used in a WAN, the characteristics of the wireless medium introduces additional token management issues:

– The node holding the token may lose connectivity to its successor, which can result in a lost token.

– The node holding the token can lose connectivity to the rest of the network. The network loses the token.

– A network may become partitioned. One subnetwork must create a new token.

– A node may be reachable only by one other node, so a ring topology is not possible if that node is to be included.

– Nodes from two or more rings using the same channel may come within range of each other. This results in interference unless the rings merge or change channel(s).

– Merging of rings or recovery from a lost token may result in multiple tokens in a ring.

The approach to recovery from connectivity problems places nodes that are not members of an active token-passing ring into a disconnected or floating state in which they either wait to be invited to join the remaining ring or periodically solicit other connected nodes to join with them.

The long link turnarounds inherent in fielded HFWAN technology result in token rotation times on the order of a minute. For example, if link turnaround times are 2 s and we allow each of *N*nodes to transmit for up to 8 s when it receives the token, we achieve a throughput efficiency of at most 80% with a token rotation time (latency) of up to 10*N*s.

If we limit solicitations to join the ring to one per token rotation, and rotate the authority to solicit among the nodes, each node will solicit once in *N* token rotations.

With ten nodes in a ring, use of the (non-HF oriented) wireless token ring protocol (WTRP) would result in disconnected nodes remaining out of the network for around 10 min (if there are no colliding responses to the eventual SOLICIT\_SUCCESSOR); this is not an attractive mode of operation for a dynamic network in the fixed and mobile service.

The time required for WTRP to reform a new ring from the disconnected remains of two colliding rings would be at least that long: a small ring might emerge quickly, but the remaining nodes would then go silent and wait to be invited to join.

The recovery times for HFTP are more attractive. In the case of a lost link, HF requires *N* slots (whose duration equals a packet plus a turnaround time) to identify a relay. Thereafter, one additional packet time and turnaround time are required *in each token rotation*. In an example ten-node network, this amounts to a pause of less than 30 s while identifying the relay, and lengthening the token rotation time by a bit over 2%.

In the case of colliding rings, HFTP networks will experience packet collisions until one of the nodes initiates the ring merger, while WTRP nodes will go silent as soon as they detect the foreign ring. However, once a MERGE\_RINGS request is received and accepted, the merging rings will resume normal data transfers after (*N*+ 1) packet + turnaround times (i.e., after the SET\_SUCCESSOR and the fast token rotation of the DOUBLE\_TIME\_TOKEN). This amounts to less than 30 s in an example ten-node network, even faster [data transfers?] when wider bandwidths are used.

### 4.3.1 HF Token Ring

A Token Ring Network[[3]](#footnote-3) (also known as 802.5) is a data link for a local area network (LAN) in which all devices are connected in a circular or closed loop and pass tokens from host to host (Figure 4). A token is a frame of data that is transmitted between network points. Within the Token Ring only a host that holds a token can send data.

FIGURE 4

TOKEN Ring

Shape

Description automatically generated

Wireless Token Ring protocol is the base protocol of HF Token Ring Protocol. Which is a robust, self-healing, self-coordinating, and distributed MAC layer protocol for ad-hoc networks. The MAC protocol through which mobile stations can share a common broadcast channel is essential in an ad hoc network. Due to the existence of hidden terminals and partially connected network topology, contention among stations in an ad-hoc network is not homogeneous. Some stations can suffer severe throughput degradation in access to the shared channel when load of the channel is high, which also results in unbounded medium access time for the stations. This challenge is addressed as quality of service (QoS) in a communication network.

### 4.3.2 HF Token Ring Mesh Networks

An HF ALE Mesh[[4]](#footnote-4) does not need to be as rigidly structured as HF token ring Mesh. A HF Mesh would share its pool of frequencies using a listen before transmit channel access protocol. ALE sounding would be used to provide the connectivity information.

An HF Token Ring[[5]](#footnote-5) or an HF Token Ring Mesh Network[[6]](#footnote-6) could be formed by incorporating a routing protocol with either a network of ALE radios or one or token-passing fixed-frequency rings:

– ALE inherently uses multiple frequencies, although only a subset of the ALE frequency pool will be usable for each link in a network.

– Each token-passing ring will normally operate on a single frequency so achieving multiple-frequency operation will require the linking of multiple rings to form the mesh.

Multiple radios per node would be required in a multi-ring token mesh so that relay nodes could simultaneously listen in all of their connected networks (which operate asynchronously).

An example token mesh is shown in Figure 6. The arrows show the successor-predecessor relationships in each ring. Note that one node acts as a gateway between rings A and B, and B and C.

FIGURE 6

Mesh TOKEN Ring

Diagram

Description automatically generated

Token passing rings are formed on the fly and re-formed as necessary. To avoid interference, each ring operates on a distinct frequency. Each node is assumed to have a separate radio for each ring in which it participates. A clear advantage of a mesh of HF token LANs over LOS mesh networks is that neighboring nodes would not interfere with each other.

### 4.3.3 HF ALE Mesh Network

An HF ALE Mesh[[7]](#footnote-7) does not need to be as rigidly structured as HF token ring Mesh. A HF Mesh would share its pool of frequencies using a listen before transmit channel access protocol. ALE sounding would be used to provide the connectivity information normally obtained by the routing protocol. ALE sounding can include statistics from the nodal token passing process[[8]](#footnote-8).

An HF ALE Mesh Network relays traffic through an ad-hoc network of HF nodes as shown in Figure 5. Connectivity in HF networks is not necessarily governed by the geographic location of the nodes. Distant stations that are farther away can be easier to reach than those that are nearby. In Fig. 5 the dark blue nodes are within NVIS range of each other; skywave links have been established between other pairs of nodes (green, white dark blue and light blue.) by pairwise usable frequency) to form indirect routes.

FIGURE 5

HF ALE Mesh Network

Chart, scatter chart

Description automatically generated

[Editor’s note: Table 1 moved to Attachment.]

# 5 Summary

HF radio offers beyond-line-of-sight wireless radiocommunications for applications ranging from extended line-of-sight within a small region to global coverage supporting commercial aviation and maritime distress and e-mail messages. The long-haul links available using transportable HF equipment also provide quick communications into disaster areas where the terrestrial infrastructure may have been severed or destroyed.

Despite this ability to communicate beyond line-of-sight, vagaries of propagation and other environmental effects can sometimes produce outages on some HF links while leaving others intact. Thus, reliability in HF networks is enhanced when indirect routing is supported. Most routes in an HF network usually require only a single link. However, in cases where multiple routing options are necessary to maintain quality of service, a single-relay routing mechanism should be useful.

When multiple HF nodes wish to share a channel for efficient one-to-many as well as one-to-one communications, a channel access protocol is needed. Token Ring Mesh, TDMA, CSMA and ALE Mesh Networks can support this capability. One approach uses a token passing protocol. The narrow-bandwidth, high-delay, and high-loss characteristics of the HF channel place especially stringent operational requirements on token passing protocol.

When operational data transmission requirements exceed the rates that can be achieved in nominal 3 kHz allocations, mechanisms that spread the data transmission over a multitude of such channels may be employed. Wideband modems are available which significantly increase data throughput of a network. Independent sideband operation can support multichannel operation to increase bandwidth while maintaining spectral efficiency.

Attachment TO ANNEX 1

Characteristics for ISB, Contiguous and Non-Contiguous SSB channels

{Editor’s note: This attachment of Annex 1 is focusing on technical radio characteristics for ISB, contiguous and non-contiguous SSB channels. The title of the attachment should reflect that and may be, the reference to Agile HF which is more a mean of networking is not appropriate in this attachment.}

TABLE 1

Characteristics of advanced digital HF radiocommunication systems (ISB and Contiguous channels Systems)

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Propagation mode | | |
| Ground wave | Sky wave | |
| NVIS | Oblique incidence |
| Frequency band (MHz) range | 2-10 | 2-10 | 3-30 |
| Approximate service area | Up to 80 km | Between 80 and 200 km | Greater than 200 km |
| Antenna polarization | Vertical | Horizontal | Vertical/horizontal |
| Transmitting antenna gain (dBi) | 1-3 | 1-6 | 6-15 |
| Maximum e.i.r.p. (dBW) | 1-29 | 10-32 | 16-55 |
| *S*/*N* (dB)1 | SSB 17 DRM 18 | SSB 25 DRM 26 | SSB 26 DRM 26 |
| Necessary bandwidths and types of emission2 | SSB/ISB: 3, 6, 9, 12 kHz, 18, 24, and 48 kHz 3K00J2D, 6K00J2D, 9K00J2D 12K0J2D, 18K0J2D, 24K0J2D and 48K0J2D | | |
| DRM: 3, 4.5, 5, 9, 10 and 20 kHz 3K00J2D, 4K50J2D, 5K00J2D, 9K0J2D, 10K0J2D, 20K0J2D | | |
| NOTE 1 – More detailed information on required *S*/*N*s can be found in Recommendation ITU-R F.339.  NOTE 2 – For emission type the last letter (D) refers to data transmissions. If emission is not data (D), substitute (E) for voice, (C) for facsimile, (W) combination or (X) for cases not otherwise covered. | | | |

TABLE 1*bis*

Characteristics of advanced digital HF radiocommunication systems (non-contiguous multichannel systems)

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Propagation mode | | |
| Ground wave | Sky wave | |
| NVIS | Oblique incidence |
| Frequency band (MHz) | 2-12 (TBC) | 2-12 (TBC) | 3-30 (TBC) |
| Approximate service area | Up to 80 km (ground)  Up to 200 NM (sea) | Up to 300 km | Greater than 300 km |
| Antenna polarization | Vertical | Vertical/horizontal | Vertical/horizontal |
| Transmitting antenna gain (dBi) | 1-3 | 1-6 | 1-15 |
| *S*/*N* per channel (dB)1 | 17 | 25 | 25 |
| Necessary bandwidth and | SSB: 3 kHz | | |
| Type of modulation per channel2 | 3K00J2D | | |
| Sensitivity for 10 dB SINAD in 3 kHz (dBm) | -111 | | |
| Receiver IF filter bandwidth (kHz) | > 200 kHz | | |
| NOTE 1 – 1 second interleaver, 16 channels.  NOTE 2 – For emission type the last letter (D) refers to data transmissions. If emission is not data (D), substitute (E) for voice, (C) for facsimile, (W) combination or (X) for cases not otherwise covered. | | | |

TABLE 2

Typical RF characteristics of AGILE-HF systems (transmitter for ISB and contiguous channels systems)

| AGILE advanced HF transmitter parameters | Groundwave / Skywave | NVIS / Groundwave | Skywave / NVIS / Groundwave | Skywave |
| --- | --- | --- | --- | --- |
| Frequency band (MHz) range | 3-30 | 3-30 | 3-30 | 3-30 |
| Channel bandwidth (kHz) | Variable 3-48 | Variable 3-48 | Variable 3-48 | Variable 3-48 |
| Transmitter power (dBW) | 36 | 26 | 36 | 27 |
| Feeder loss (dB) | 2.2 | 1.5 | 2.6 | 1.1 |
| Antenna gain (dBi) | 14.15 | 4.15 | 11.15 | 2.15 |
| Antenna height (m) | 64 | 3.65 | 28.04 | 1.21 |
| Antenna polarization | Vertical | Vertical | Vertical | Horizontal |
| Antenna type | Broadband omni | Narrowband monopole | Broadband dual fan-wire | Narrowband dipole |
| Maximum e.i.r.p. (dBW) | 34.2 | 24.2 | 35.7 | 26.7 |
| Modulation | AM/FM | AM/FM | FM | FM |
| Typical Minimum Path Length (km) | 161 | 48.2 | 38.6 | 19 |

TABLE 2*bis*

Typical RF characteristics of AGILE-HF systems (transmitter for non-contiguous multichannel systems)[[9]](#footnote-9)

[Editor’s note: To be completed.]

| AGILE advanced HF transmitter parameters | System supporting Groundwave | System supporting Skywave / NVIS | System supporting Skywave / Oblique incidence |
| --- | --- | --- | --- |
| Frequency band (MHz) range | 2-12 (TBC) | 2-12 (TBC) | 3-30 (TBC) |
| Individual SSB Channel bandwidth (kHz) | 3 | 3 | 3 |
| Number of simultaneous use of non-contiguous SSB channels | Up to 16 | Up to 16 | Up to 16 |
| Aggregated non-contiguous bandwidth (kHz) | Up to 200 | Up to 200 | Up to 200 |
| Transmitter power (dBW) | 10-30 | 10-30 | 10-40 |
| Feeder loss (dB) | 2-4 | 2-4TBD | 2-4TBD |
| Antenna gain (dBi) | 1-3 | 1-6 | 1-15 |
| Antenna height (m) | 64 | 28 | 1.21 |
| Antenna polarization | Vertical | Vertical/Horizontal | Vertical/Horizontal |
| Antenna type | Monopole | Omni | Dipole |
| Maximum e.i.r.p. (dBW) | 33 | 26 | 23 |
| Modulation | PSK/FSK/QAM/OFDM | PSK/FSK/QAM/OFDM | PSK/FSK/QAM/OFDM |
| Typical Minimum Path Length (km) | 161 | 48 | 19 |

| AGILE HF receiver parameters | Groundwave / Skywave | NVIS / Groundwave | Skywave / NVIS / Groundwave | Skywave |
| --- | --- | --- | --- | --- |
| Frequency band (MHz) | 3.0-30 | 3.0-30 | 3.0-30 | 3.0-30 |
| IF filter bandwidth (kHz) | 48 | 24 | 48 | 48 |
| Sensitivity (dBm) |  |  |  |  | |
| SSB for 10 dB SINAD | −113 | −113 | −113 | −113 | |
| ISB for 10 dB SINAD | −97 | −97 | −97 | −97 | |
| CW for 10 dB SINAD | −116 | −116 | −116 | −116 | |
| Signal-to-noise ratio (dB)[[10]](#footnote-11) |  |  |  |  | |
| PSK | 5 | 12 | 8 | 14 | |
| FSK | 8 | 18 | 12 | 18 | |
| QAM | 14 | 24 | 20 | 24 | |
| OFDM | 16 | 26 | 26 | 30 | |
| Feeder loss (dB) | 2.2 | 1.5 | 2.6 | 1.1 | |
| Antenna gain (dBi) | 14.15 | 4.15 | 11.15 | 2.15 | |
| Antenna height (m) | 64 | 3.65 | 28.04 | 1.21 | |
| Antenna polarization | Vertical | Vertical | Vertical | Horizontal | |
| Typical minimum path length (km) | 161 | 48.2 | 38.6 | 19 | |

TABLE 3*bis*

Typical RF characteristics of AGILE-HF systems (receiver of non-contiguous multichannel systems)

|  |  |  |  |
| --- | --- | --- | --- |
| AGILE HF receiver parameters | System supporting Groundwave | System supporting Skywave / NVIS | System supporting Skywave / Oblique incidence |
| Frequency band (MHz) | 2 -12 (TBC) | 2-12 (TBC) | 3-30 (TBC) |
| IF filter bandwidth (kHz) | 200 | 200 | 200 |
| Sensitivity (dBm) | -110 | -110 | -110 | |
|  |  |  |  | |
| Signal-to-noise ratio (dB) | 17 | 25 | 25 | |
| Modulation TBD | 3K00J2D | 3K00J2D | 3K00J2D | |
| Feeder loss (dB) | 2 | 4 | 3 | |
| Antenna gain (dBi) | 14 | 28 | 4 | |
| Antenna height (m) | 64 | 28 |  | |
| Antenna polarization | Vertical | Vertical/Horizontal | Vertical/Horizontal | |
| Typical minimum path length (km) | 161 | 38 | 19 | |

1. Some systems described in this Recommendation are operated from 2 MHz with reference to RR. [↑](#footnote-ref-1)
2. Recommendation ITU-R F.1762 addresses characteristics and applications of HF systems that operate in a non-networked environment. This document is focused on HF systems operating in HF MESH networked environments. [↑](#footnote-ref-2)
3. Analysis of Multiple Frequency HF Networks Versus Single Frequency Toke Ring Networks”; Gillespie, Trinder; 2006 10th IET International Conference on Ionospheric Radio Systems and Techniques; IRST 2006. [↑](#footnote-ref-3)
4. HF Radio Mesh Networks; Eric E. Johnson, <http://tracebase.nmsu.edu/hf/papers/hf_mesh.pdf>. [↑](#footnote-ref-4)
5. “Third-Generation and Wideband HF Radio Communications”; Johnson, Koski, Furman, Jorgenson and Nieto; 2013 Artech House. [↑](#footnote-ref-5)
6. “Analysis of Multiple Frequency HF Networks Versus Single Frequency Token Ring Networks”; Gillespie, Trinder; 2006 10th IET International Conference on Ionospheric Radio Systems and Techniques; IRST 2006. [↑](#footnote-ref-6)
7. HF Radio Mesh Networks; Eric E. Johnson. [↑](#footnote-ref-7)
8. Cognitive Radio Outside The Radio Whitepaper, Mahan, Rockway, Luong. [↑](#footnote-ref-8)
9. The parameters listed in Table 2bis are typical for systems using the given propagation modes. [↑](#footnote-ref-9)
10. Signal-to-noise ratios listed here are given in a waveform’s necessary bandwidth for systems that operate under the indicated propagation modes. [↑](#footnote-ref-11)