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| **U.S. Radiocommunications Sector****Fact Sheet** |
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| **Purpose/Objective:** This is a Fact Sheet for a Working Document Towards a Preliminary Draft Revision to Recommendation ITU-R F.1821 “Characteristics of advanced digital high frequency (HF) radiocommunication systems “. The update includes characteristics of networking systems (Mesh Networks) that could be used to provide advanced high-speed network-based applications within the 3 to 30 MHz frequency range.  |
| **Abstract:** This document provides updates to typical RF characteristics and Mesh Network configurations that can be used to deploy advanced digital HF systems. An updated table of characteristics will be included in an Annex to this Recommendation. |

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| WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT REVISION TO RECOMMENDATION ITU-R F.1821 CHARACTERISTICS OF ADVANCED DIGITAL HIGH FREQUENCY (HF) RADIOCOMMUNICATION SYSTEMS |
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**Introduction**

The United States proposes to update the Recommendation ITU-R F.1821 “Characteristics of advanced digital high frequency (HF) radiocommunication systems “to include typical RF characteristics of advanced digital HF systems and networked system (Mesh networks) configurations that could be used to provide advanced high-speed network-based applications within the 3 to 30 MHz frequency range.

Attachment: Working Document Towards a Preliminary Draft Revision to Recommendation ITU-R F.1821 “Characteristics of advanced digital high frequency (HF) radiocommunication systems

RECOMMENDATION ITU-R F.1821

Characteristics of advanced digital high frequency (HF)
radiocommunication systems

(Question ITU-R 147/9)

(2007)

Scope

This Recommendation specifies the typical RF characteristics of advanced digital HF systems for use in sharing studies. It includes descriptions of network configurations (HF Token Ring, HF Token Mesh and HF ALE Mesh Networks) ,broadband HF data waveforms and wideband módems. Wideband modems are further subdivided into two major systems, multichannel operations and Digital Radio Mondiale operations. A table of characteristics within the Annex to this Recommendation provides a summary of the values needed for sharing studies.

**Summary**

(TBD)

**Background**

(TBD)

Acronyms and Abbreviations

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

ALE – Automatic Link EstablishmentDRM Digital Radio Mondiale

HF – High Frequency

HFTP HF token passing

HF MESH HF MESH Network

HFWAN High frequency WAN

ISB Independent sideband

kpbs – kilobits per second

LSB Lower sideband

NVIS Near vertical incidence skywave

OFDM Orthogonal frequency division multiplex

OTH – Over the Horizon

PSK Phase-shift keying

SNR – Signal to Noise Ratio

QAM Quadrature amplitude modulation

USB Upper sideband

WAN Wide area network

WTRP Wireless token ring protocol

**Terms and Definitions**

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.

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

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.

Automatic Link Establishment – A technique for digitally initiating and sustaining HF radio communications.

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 frequencys.

**Related ITU Documents**

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](https://www.itu.int/pub/R-REP-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 the spectrum in the HF bands by advanced digital systems;

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 provides a communications path for exchanging information; should be considered.

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

*noting*

(TBD)

recommends

1. **1** 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 up to 30 MHz for use in sharing studies.

Annex 1

# 1 Introduction

HF systems have specific attributes that make them a viable solution for many radiocommunication requirements. They provide a 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 types of 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 two parts. The first is to achieve maximum throughput (bits/Hertz/s), the second is to maximize the number of users, per frequency net and the third is to maximize the ability of fixed communications to achieve performance and mission goalsSeveral approaches can be used to accomplish these objectives.

In recent years, wideband approaches have been proposed for increasing the capability of HF radio communications. These approaches use contiguous and non-contiguous (across 48 kHz) signaling bandwidths exceeding the traditional SSB voice channel bandwidth of 3 kHz, in some cases by as much as a factor 16. (48 kHz contiguous bandwidth). This Recommendation contains an Appendix that provides technical characteristics of typical HF, digital HF and AGILE-HF Systems operating within the 3-30 MHz frequency band. (Appendix 1)

While the HF band is advantageous for long-distant communication applications, it is also a critical and affordable option for the commercial sector in lieu of satellite communications. The challenge with emerging advanced digital HF networks is seeking increased bandwidth while not impeding incumbents within the frequency band or countries dedicated legacy frequency needs. Advanced technology enables advanced digital HF networks that can support a shared environment while maximizing utilization of the 3 to 30 MHz frequency band.

# 2 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 in 3 kHz circuits.. 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 when using the traditional 3kHz channels presently allocation by the ITU.

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 and even faster when wider HF bandwidths are used

# 3 Wideband modems

HF waveform design for optimized 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/No <-> low detection techniques, typically based on a spreading the waveform across wideband HF (WBHF) that in field trials shows a responsive and resilent extensibility with high transmission reliability.

FIGURE 1

 **Typical DSSS Waveform Design**



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 give high immunity to interference which sustains links better in contested frequency bands

## 4.1 Multichannel approach

### 4.1.1 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.

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

When contiguous channels are not available in sufficient quantity to support 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.

#### 4.1.3 Single-channel Independent sideband (ISB) HF equipment

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

#### 4.1.4 Multichannel HF equipment

Multiple channelling 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 centre 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



## 4.2 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 requirements 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 signalling. 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.”

**4.3 AGILE-HF Networks**

AGILE-HF Systems will operate across the entirety of the 3 to 30 MHz frequency band and will provide, on a global basis, digital voice (point-to-point and point to multi-point), data transfer and database replication ( financial transactions, logistics, medical records, law enforcement data, etc.), remote sensor reporting (tsunami or meteorological buoys, ice shelf diagnostics, seismic monitoring, etc.) , emergency management and disaster relief services along with many other services and applications such as email, FTP file transfer, chat rooms and video calls across thousands of miles

Implementation of AGILE-HF (Figure 3) networks can be accomplished through the use of Mesh Networks[[1]](#footnote-1) 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 into it of regional 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**



 “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 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 maneuvering, so they can join a “subnet” of the and use the extensibility described above and then later 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 to heighten it persistent connection within the AGILE-HF Mesh Network provides a high degree of “link durability.”

To help in understanding the depth of this Mesh network utility, consider that all the cellular towers near you are interconnected and “talking” to each other - sharing configuration and status of the device in your hand. As you move and change position from one tower geometry to another, these towers collaborate to hand-off your call/text/email/video/movie to the next tower that has best service for your cell phone; and often direct or negotiate with your cell phone to switch frequencies and channel bandwidths. So the AGILE- HF Mesh network is not that much different than what keeps your informed and connected every day – except the AGILE-HF Network is spanning hundreds or thousands of miles between nodes (a.k.a. towers) .

Some potential applications of AGILE-HF communication and data systems include: safe SeaNet reporting (ISPS);fishery catch reporting, fishing boat position and movement reporting, real-time weather maps; general electronic mail; messages to the ship’s agent, the pilot or harbor authorities; banking terminals (especially on passenger ships), safety-related information, telemetry information, updating of electronic maps, .ship to ship communication, ship to shore communication, ship to aircraft, aircraft to ship, aircraft to shore, aircraft location and telemetry, emergency services and disaster management. AGILE-HF Networks can also l provide, on a global basis, digital voice (point-to-point and point to multi-point), data transfer and database replication ( financial transactions, logistics, medical records, law enforcement data, etc.), remote sensor reporting (tsunami or meteorological buoys, ice shelf diagnostics, seismic monitoring, etc.) , emergency management and disaster relief services along with many other services and applications such as email, FTP file transfer, chat rooms and video calls across thousands of miles.

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

**4.4 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.

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– 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 10N 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.

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.

**4.4.1 HF Token Ring**

A Token Ring Network [[2]](#footnote-2)(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**

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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.

**4.4.2 HF Token Ring Mesh Networks**

An HF ALE Mesh[[3]](#footnote-3) 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.

A HF Token Ring[[4]](#footnote-4) A token ring Mesh Network [[5]](#footnote-5) 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 inall 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**



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.

**4.4.3 HF ALE Mesh Network**

An HF ALE Mesh[[6]](#footnote-6) 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.5

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**



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# 5 Conclusions

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 and ALE Mesh Networks can provide this capability.. The narrow-bandwidth, high-delay, and high-loss characteristics of the HF channel place especially stringent requirements on token passing protocols.

When 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.

**Appendix 1**

**Typical** **HF, Digital HF and AGILE-HF Technical Characteristics**

TABLE 1

**Characteristics of Advanced digital HF radiocommunication systems**

|  |  |
| --- | --- |
| **Parameter** | **Propagation mode** |
| **Ground wave** | **Sky wave** |
| **NVIS** | **Oblique incidence** |
| Frequency band (MHz) | 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) | SSB 17DRM 18 | SSB 25DRM 26 | SSB 26DRM 26 |
| Necessary bandwidths and types of emission2  | SSB/ISB: 3, 6, 9 ,12 kHz, 18, 24 and 49 kHz3K00J2D, 6K00J2D, 9K00J2D 12K0J2D, , 18K0J2D, 24K0J2D and 48K0J2D |
| DRM: 3, 4.5, 5, 9, 10 and 20 kHz3K00J2D, 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. |

High Frequency radio waves can propagate to a distant receiver ) via the: ground wave: near the ground for short distances, up to 100 km over land and 300 km over sea.

TABLE 2

Example RF Characteristic of AGILE- HF Systems (Transmitter)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **AGILE Advanced E HF Transmitter Parameters** | Groundwave / Skywave | NIVS/ Groundwave | Skywave/NVIS/ Groundwave | Skywave |
| Frequency band (MHz) | 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 3**

RF Characteristic of AGILE-HF (Receiver)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| AGILE HF Receiver Parameters | Groundwave / Skywave | NIVS/ 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 10dB SINAD | -113 | -113 | -113 | -113 |
|  ISB for 10dB SINAD | -97 | -97 | -97 | -97 |
|  CW for 10dB SINAD | -116 | -116 | -116 | -116 |
| Signal-to-noise ratio (dB)[[7]](#footnote-8) |   |   |   |   |
|  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 |
| Protection Criteria | TBD | TBD | TBD | TBD |

1. 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.) [↑](#footnote-ref-1)
2. “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-2)
3. HF Radio Mesh Networks; Eric E. Johnson; MILCOM 2006 - 2006 IEEE Military Communications conference, 23-25 Oct.. 2006

5 Cognitive Radio Outside The Radio, Mahan, Rockway, Luong; Whitepaper published by US Navy, 2022 [↑](#footnote-ref-3)
4. “Third-Generation and Wideband HF Radio Communications”; Johnson, Koski, Furman, Jorgenson and Nieto; 2013 Artech House [↑](#footnote-ref-4)
5. “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-5)
6. HF Radio Mesh Networks; Eric E. Johnson; MILCOM 2006 - 2006 IEEE Military Communications conference, 23-25 Oct.. 2006

5 Cognitive Radio Outside The Radio, Mahan, Rockway, Luong; Whitepaper published by US Navy, 2022 [↑](#footnote-ref-6)
7. The SNR’s listed here are given in a waveform’s necessary bandwidth Additional more detailed information regarding SNR can hbe found in ITU-R F.339 and MIL-STD-188-110D. [↑](#footnote-ref-8)