CHAPTER 2
REQUIREMENTS FOR AUTOMATIC AND ADAPTIVE HF RADIO

2.1 Automatic and adaptive HF radio

The introduction (Chapter 1) introduced HF radio transmission as a communications medium. This introductory chapter gives us the first look at some of the problems associated with HF radio communication, and it introduces us to the concepts of automation and adaptivity. These features have been added to make HF radio a more reliable communications medium and less prone to problems.

In Chapter 2, we explain why the automatic and adaptive techniques have improved HF radio. In later chapters we will show how these techniques advance as the technology advances from generation to generation. The approach used in this chapter is to describe the radio system in terms of layering. The lowest level is the transmission level, which is responsible for physically moving the message from point to point. Table 2.1 shows how this layer is related to other layers. Above this layer is the link level where the heart of the radio transceiver resides. It is in this layer that the concepts of Automatic Link Establishment (ALE) are primarily added. Above this layer is the network layer, which is responsible for bringing a series of radios together into a network. The uppermost layer is the operator or the higher level system function responsible for generating and receiving the messages or data traffic. Using this concept of layers, the fundamentals of taking a basic radio and adding the features and functions of automation and adaptivity can more easily be understood.

HF radio has been used for decades for long-distance communications. HF radio communication has a number of positive characteristics that can be enhanced—and drawbacks that can be minimized—through the use of automatic and adaptive techniques. The positive attributes for communication in the HF band include long-distance transmissions and the potential for better recovery from ionized effects in a nuclear environment [Galanos, *et al.*, 1987]. The negative aspects include: labor-intensive operation, variable propagation, much lower overall reliability and limited data bandwidth. Communicating in the HF radio band requires the optimization of conditions to make it reasonably reliable. The reliability of HF radio transmissions is dependent on a large number of factors such as:

a. operating frequency,
b. the degree of ionization of the ionosphere,
c. the distance between stations (number of hops),
d. overhead procedures (*i.e.*, error checking, handshaking, *etc.*)

In manual operation—a procedure used until recent years to optimize HF radio communication between points—the operator must adjust the parameters of the system for maximum performance. He/she must monitor the conditions of the ionosphere, track the variable propagation conditions, and select the operating conditions (*i.e.*, frequency) that will allow the signal to propagate best. Because of the intensive labor required, HF radio communication was an easy target for justifying adding automation and adaptive techniques. Present-day, automation techniques reduce the burden on the operator by adding subsystems for frequency management, link establishment, link maintenance, etc. These techniques can be used to reduce the skill-level demands and duty requirements of the HF radio operator or communicator. Typically, automation can be added to make the radio appear to be "push-to-talk on the best channel," while actually the radio is a multichannel communication device performing many underlying functions.

Beyond these automation techniques are the "adaptive" techniques, which also can reduce the burden on the operator while making the radio more responsive to changing HF radio propagation conditions. The definition of adaptivity might be: *the process associated with automatically altering operating parameters and/or system configuration in response to changes in the time-varying channel propagation conditions and external noise.*

The functional parts of the radio system can be represented using the model of the International Organization for Standardization (ISO) called the Open System Interconnection—Reference Model (OSI—RM). Adaptivity techniques exist that can be added to various levels of the radio system (see Table 2.1). At the *transmission level*, adaptive characteristics might include: data rate, waveform, error coding, power, and antenna type and pattern procedures as well as performance assessment characteristics unique to the transmission level. At the *link level*, adaptive characteristics might include frequency management, ionospheric sounding, channel probing, and occupancy/congestion monitoring in addition to performance-assessment details. At the *network level*, adaptive characteristics might include: adaptive routing, flow control, protocol management, data exchange, and network reconfiguration, as well as performance-assessment details. At the *system level*, adaptive characteristics might include: system-level system management, system-level frequency management and control, in addition to performance assessment details.

TABLE 2.1
Adaptivity techniques and associated levels

Level	Adaptivity technique that can be added
System Level	System-level frequency management and control
Network Level	Adaptive routing Flow control Handshaking Data exchange
Link Level	Frequency management and control
Transmission level	Data rate Waveform Error coding Power Antenna type Antenna pattern

2.1.1 Transmission adaptivity level

The lowest level of adaptivity (see Table 2.2) is concerned with the characteristics associated with a communication over a single transmission path at one or more frequencies. Such characteristics include data rate, transmission waveform, coding scheme, transmitted power, antenna pattern, and performance assessment [Goodman, 1992].

Data Rate

It may be possible to boost the communication data rate to the maximum rate that the ionospheric channel will support. However, when unfavorable conditions exist, the data rate will necessarily be adjusted to a lower rate. Adaptive systems can be conceived that will try communication at the maximum rate, then if the bit error ratio becomes excessive, the system will try a lower rate in an attempt to complete the transmission sequence.

Adaptive Transmission Waveform

The choice of modulation format is critical with HF communication because of the precarious nature of the propagation channel [Goodman, 1992]. The transmission waveform should be chosen that will give the system maximum throughput while maintaining acceptable error characteristics.

Adaptive Coding Schemes

Error detection and correcting coding methods provide varying degrees of protection for data integrity and transmission security. It seems only natural, therefore, to visualize the development of coding schemes which are adaptive in nature. Use of the adaptive schemes can be selectable depending on the state of the channel. Some schemes are more robust in the face of channel disturbance but they carry with them a significant overhead burden. Other methods require less burden and can be relatively fast, provided the channel is only moderately disturbed, but may fail under conditions of virulent disturbance.

Adaptive Power Control

Adaptive power control is a very important control technique. Adaptive power control concepts can assure that adequate power is used to achieve maximum range without creating interference beyond the desired coverage area. Adaptive power control is also useful to the military when use of minimum power is desired to prevent detection of critical communications.

TABLE 2.2
HF communications adaptivity levels

Level	**Function**
System Adaptivity Level - (Multi-Media)	Higher level system management System level frequency management Stress environment assessment Performance assessment—System
Network Adaptivity Level - (Multi-Mode)	Message routing schemes Adaptive routing Flow control Protocol management Data exchange Network reconfiguration Performance assessment—Network
Link Adaptivity Level - (Point-to-point)	Frequency management procedures Ionospheric sounding Channel probing Occupancy/Congestion monitoring Performance assessment—Link
Transmission Adaptivity Level - (Fixed Frequency)	Data rate Adaptive transmission waveform Adaptive coding schemes Adaptive power control Adaptive null-steering Performance assessment—Transmission

Adaptive null-steering

An antenna system that is controllable is also an important adaptive technique. In antennas, a lobe is a direction of strength or good reception. A null is an absence of good signal transmission or reception. Adaptive antennas use null-steering techniques which might position a major lobe in the direction of the desired signal (beam-steered array) and/or deep nulls in the direction of the noise sources (null-steered array). One technique for reducing noise effects might be to steer the nulls within the pattern toward unwanted signals to reduce harmful effects. Other uses might arise in directing the pattern toward or away from certain areas such as in the auroral zone or a nuclear disturbance [Goodman, 1992].

Performance assessment - limited real-time channel evaluation (RTCE)

RTCE is the process of measuring appropriate parameters of a set of communication channels in real time and using the data thus obtained to describe quantitatively the states of those channels and hence the capabilities for passing a given class, or classes, of communication traffic [Maslin, 1987]. The transmission adaptivity level uses a *subset* of the full RTCE set of characteristic information for making determinations associated with level (see Section 2.1.5 for a discussion of RTCE).

2.1.2 Link adaptivity level

The link adaptivity level is relevant to point-to-point communications. The characteristics at this level include various frequency management and control functions, vertical and oblique sounding, channel probing, and spectrum monitoring.

Frequency management procedures

The concept of HF frequency management implementation has been discussed in CCIR Report 899-1 [CCIR, 1986]. This report suggests that the three stages for implementation of HF frequency management are: long-term forecasting, short-term forecasting, and immediate conditions. Adaptive frequency management deals with the issues that might be used to adjust frequency use, based on network conditions. At the link-adaptive level, the primary consideration is with immediate conditions and the choice of frequency to use for a particular message. The transceiver must keep track of propagating frequencies/channels based on the results of an analysis of real-time-channel-evaluation (RTCE) information to determine the best choice for message transmission. RTCE information gathering is an automatic technique that allows the receiver to adjust the frequency scanning according to information accumulated through passive or active techniques of traffic monitoring, sounding, polling, *etc.*. Once a list of propagating channels is determined, a channel ranking can be performed by taking into account the effects of the following characteristics:

- path loss,
- noise,
- interference
- multipath,
- fading,

- dispersion,
- Doppler shift, and
- user requirements. [Ripley *et al.*, 1996].

Also see Section 2.14 for system-level frequency management considerations.

Ionospheric sounding

Sounding is the process of testing the transmission medium for short-term propagation information. Soundings provide up-to-date indications of propagation characteristics over vertical (directly overhead) paths and oblique paths (along the actual communication route direction). It is not practical to sound all possible paths in a large communication network, but some benefits from sounding may still be achieved if selected paths are probed and the results are extrapolated to geographically nearby paths [Goodman, 1992].

Sounding can be divided into three subgroups for purposes of distinguishing the significance of each type. The sub-groups consist of:

- Ionospheric Pulse Sounding,
- Linear Sweep Sounding, and
- Channel Evaluation Sounding [Maslin, 1987].

Ionospheric pulse sounding

Ionospheric Pulse Sounding is used to test the propagation medium characteristics for such things as channel unit impulse response, signal propagation delay, and signal amplitude [Maslin, 1987]. Pulse sounding consists of emitting a pulse sweep over a portion or all of the HF band for a period of a few seconds to several minutes. The received signal is then analyzed. The sounding sweep over the link will indicate to the user or equipment the range of frequencies that will propagate. The transmitted energy can be focused either vertically or obliquely.

Vertical-incidence-sounder (VIS)

The Soundings would be emitted vertically and the reflected returns are received by the receiver as returns from the ionosphere.

Oblique-incidence-sounder (OIS)

The sounding would be emitted in the direction of the actual communications path, and the receiver is located at the remote location.

Oblique incidence backscatter sounding

The Soundings would be emitted in the direction of the actual communication, and the reflected returns are gathered by a co-located receiver very near the transmitter.

Linear sweep sounding (chirpsounding)
Linear FM modulation or chirpsounding consists of sending a low power 2- to-30 MHz linear FM/cw test signal over the communication path [Maslin, 1987]. This method can be used over either a vertical or an oblique path. The data received from the chirpsounding equipment is similar to the pulse sounding equipment, but has the advantage of causing less interference to nearby equipment.

Channel evaluation sounding
Channel evaluation sounding consists of probing only frequencies that are allocated to this system, rather than a broadband approach of the other two methods. Channel evaluation provides information used in evaluation of signal-to-noise performance such as: data error rate, speech intelligibility, and noise levels [Maslin, 1987].

Channel probing

A wideband HF channel probe can be used to collect data over a single-hop polar path using the F layer [Goodman, 1992]. The collected data shows a scattering function when the doppler frequency is plotted against delay.

Occupancy/congestion monitoring

The channel is monitored for occupancy, congestion, and a "full" condition to determine if message traffic is possible. If the channel is busy, a backoff algorithm or continual monitoring can be used to determine when message traffic is possible.

Performance assessment - full RTCE complement

The link adaptivity level uses the full RTCE complete set of characteristic information for making determinations associated with level. (See section 2.1.5 for a discussion of RTCE.)

2.1.3 Network adaptivity level

At the network level of adaptivity, multinode networks are involved, so the characteristics of routing, adaptive routing, flow control, protocol handling, and data exchange become issues of importance.

Message routing schemes

Routing is defined as the process of determining the transmission path of the message through the network to enable the message to reach its destination node [Vijay, 1982]. The two major types of routing algorithms are deterministic and adaptive. Deterministic or fixed routing algorithms establish message routes based on network topology, average message delays, or both. Adaptive routing strategies use centralized or distributed schemes to forward messages based on some criterion that is usually not fixed over time. The message route is determined during message transmission to adapt to the current network traffic or conditions, such as node or link failures. The routing decision may come from the sender, may be dynamic with each node making routing decisions, or may be routed based on instructions issued by a centralized point such as a network control station.

Route selection is a Network-layer function that uses connectivity information, path information, and channel information to select the best route to get a message through the network. This information is constantly being updated through passive or active collection, by polling commands issued by the network controller, or by the use of one of the routing strategies. Using indirect routing techniques, the connectivity and path information will include possible links through transfer stations or relay stations. This will give the station increased connectivity, fewer delays, and, in general, better throughput. The possible routing-strategies support will be of both the fixed and adaptive type, using source, query, flood, hierarchical, or other routing techniques.

When a station cannot be directly linked with a desired destination, other stations may be used to assist in getting the message to its destination. When this assistance is done by station operators it is termed *indirect calling*. If it is done automatically by radio equipment, it is termed *relaying.*

Adaptive routing

Adaptive routing is the process of routing calls based on network conditions. The routing decision may come from the sender, may be dynamic with each node making routing decisions, or may be based on instructions issued by a centralized point such as a network control station (NCS). The sender may not have up-to-date information, so this node may not be able to direct traffic for maximum efficiency. In some cases, a centralized scheme may be desirable, but the central node may not have the latest information. The individual node in the process of relaying will probably have the best information for at least one hop. However, unless information is distributed or relayed throughout the system, this node may not be able to see beyond a single hop with any degree of efficiency.

Flow control

An unrestricted flow of messages into a network may lead to congestion. A network is considered to be *congested* when messages experience longer than expected delays. Network congestion can lead to a deadlock in which no message flow occurs. An unexpectedly high rate of message arrivals into the network can lead to congestion. If no remedy is applied, network congestion can eventually result in a buffer deadlock, thereby blocking all message movement [Vijay, 1982].

Flow control is a mechanism for preventing congestion in networks. Congestion arises when the nodes that are sending messages to a particular receiving node exceed the receiving node's capacity to process, or forward, messages. Thus, the problem reduces to one of providing each node with mechanisms to control the rate at which it receives the messages from other nodes. As such, flow control is the process of regulating the rate at which a sender generates messages so that the receiver can process them. From a network user's perspective, flow control is a mechanism that prevents entrance into the network those messages that cannot be delivered in a predefined time [Vijay, 1982].

Network flow control is a mechanism for distributing the traffic equally among network nodes. As such, flow control can reduce message delays during normal network operations and prevent any part of the network from becoming overloaded relative to the rest of the network as a whole [Vijay, 1982].

Protocol management

The primary purpose of a protocol is to establish orderly information exchange among processes, and to manage network resources efficiently. The general approach to describing the establishment of rules to manage the network is the concept of layering. Through a process of characterizing functions into a series of layers, the functionality of the network can be described. Each layer in a node supports its own protocols to communicate with the corresponding layer in another node. The protocols for layers that are relatively farther from the transmission link layer match the applications functions, while the protocols for layers closer to link layer contribute to the communication mechanism of the network [Vijay, 1982].

Network nodes exchange two types of messages: *control messages* and *data messages*. Data messages, or simply “messages,” are units of information exchanged between network users, such as operators or application programs. Control messages are used to exchange information among the layers at different nodes to facilitate transmission of data messages. Compared to data messages, control messages are not known to the network user and are transmitted within the network [Vijay, 1982].

Some of the numerous functions served by network protocol [Vijay, 1982]:

1. Orderly exchange of data messages.
2. Management of priorities at both the network entry and transmission levels within the network.
3. Process synchronization.
4. Session establishment between network users.
5. Session termination between network users.
6. Means for protocol validation.
7. Routing establishment and assignment of message routes.
8. Flow control and congestion prevention.
9. Sequenced transmission and delivery of messages.
10. Addressing of network components and users.
11. Efficient network resource utilization.
12. Resource management, monitoring, and protection.
13. Layered transparency between network users and nodes.
14. Reliable message transmission, including error control and recovery.
15. Testing of network resources, such as links and routes.

16. Security and privacy.
17. Optional packet switching through message segmenting and pipelining.

The protocols used in the system may be fixed or adaptive in nature. It seems only natural therefore to visualize the development of protocol schemes which are adaptive in nature or are selected adaptively, depending on the state of the channel. The system would observe channel conditions and might change the relative timings to exchange messages and control information with other nodes. Also line management, message handling, and buffer management might all be functions of channel conditions.

Data exchange

If the radio system is also a data exchange network this function might be a paramount mission for this network. It might be beneficial to adjust some exchange techniques in order to maximize transfer efficiency. Techniques that are candidates for possible adjustment based on network conditions might include: message size, error correction, handshaking techniques, and buffer control techniques.

Network reconfiguration

The architecture of the network might be fixed or adaptive in nature. It seems only natural therefore to visualize the development of architecture schemes which are adaptive in nature or are selected adaptively, depending on the state of the channel. The system would observe channel conditions and might change the relative timings to exchange messages and control information with other nodes. Also, line management, message handling, and buffer management might all be functions of channel conditions.

Performance assessment - network-wide RTCE

The network adaptivity level uses a network-associated subset of the full RTCE set of characteristic information. [See Section 2.1.5 for a discussion of real-time channel evaluation (RTCE).]

2.1.4 System adaptivity level

The system level is concerned with those capabilities that allow multimedia communication. Characteristics include: higher level system management, system-level frequency management and control, stress assessment of the environment, and system-level performance assessment.

Higher level system management

The higher level system management functions include: operator interface, determination of routes, queuing messages, determining message priority, reestablishment of packet order, ultimate flow control, message store-and-forward control. Many of these functions have adaptive characteristics. The operator interface is able to change many of the system characteristics in response to changing conditions. Route determination, message queuing, and flow control all allow the message to be rerouted to the best message path. Message store and forward allow messages to be retained until conditions are more favorable.

System level frequency management and control

The concept of HF frequency management implementation has been discussed in CCIR Report 899-1 [CCIR, 1986]. That report suggests that the three stages for implementation of HF frequency management are: long-term forecasting, short-term forecasting, and RTCE. An example of long-term forecasting is described later in this report under the subject of computer propagation modeling. Short-term forecasting might be adjustments made to compensate for an unpredicted needed change. Both long-term and short-term adjustment would require the operator to manually adjust the frequencies used, the way the receiver scans the list, or other possible means to assure that the receiver scans the desired frequencies under some kind of priority direction. Real-Time-Channel-Evaluation (RTCE) is an automatic technique that allows the receiver to adjust the frequency scanning based on information accumulated through passive or active techniques of traffic monitoring, sounding, polling, *etc.*

Stress environment assessment

In a stress environment, such as after a nuclear event, HF is considered to be more vulnerable to nuclear effects than any other component of the suite of communication systems. Although this may be so, it is also true that the HF channel tends to repair itself over time. So there is an ultimate survivability, if not continuity, associated with the use of HF in a nuclear-disturbed environment [Goodman, 1992].

Performance assessment - system assessment

The System Adaptivity Level uses a higher level associated subset of the full RTCE set of characteristic information. This subset list includes the only real-time channel evaluation items that would be of concern to systems at the operator or higher level controlling system interface.

2.15 Real-time channel evaluation (RTCE)

The key to achieving significant benefits in the way that an operator or automated HF radio system controller uses the HF propagation medium for communication is to ensure that an adequate supply of real-time data is available for decision-making purposes. Off-line propagation analysis is the older time-proven method for getting this information. More recently automated and adaptive systems have turned to real-time collection of information to be used in propagation analysis. When a radio link is established with data or voice traffic passing across it, it is possible for a suitably equipped receiver to extract substantial RTCE information about the characteristics of the link. The data collected constitutes the HF communication channel parameters that are important for successful communication. Decisions on the message path, the channel to use, whether to use direct or indirect message handing, and how much noise and interference to expect are usually generated by some form of RTCE and frequency management routine. *RTCE is the process of measuring* *appropriate parameters from a set of communication channels in real time and using the data thus obtained to describe quantitatively the states of those channels and hence the capabilities for passing a given class, or classes, of communication traffic* [Darnell, 1975, 1982; Maslin, 1987].

The need for RTCE arises because of the variability in the total environment associated with the HF channel. In most cases, it is not necessary for the communicator to know what detailed fundamental physical principles create the distortions imposed by the ionospheric medium on a particular signal, only that it is possible to measure the characteristics of the available paths and, from this, to adapt the associated communications-link parameters for optimum information transfer [Galanos *et al.*, 1987]. The analysis, application, and ability to respond to RTCE information is integral to each adaptivity level, as shown in Sections 2.1.1 - 2.1.4. This implies automation (*i.e.*, microprocessor control) of the adaptive processes being used by the radio or controller system. Beyond automation, to be effective in reducing the data produced by the ionograms, the prediction programs, and the collected RTCE information, a comprehensive real-time frequency-management system should be used. The frequency-management system should have the following characteristics:

- take into account all the assigned operating frequencies,
- account for high and low power levels,
- account for the various antenna types,
- take into account the modem-specific and data-rate parameters,
- issue an automatic recommendation of the optimum operating frequency.

The system would be expected to operate continually, to measure the channel characteristics, and to make recommendations based on the system characteristics such as modem, antenna, *etc*.

2.2 User's requirements

HF radio is needed as a long-haul communication provider; it can be an alternative to satellite, microwave, or landline terrestrial communication systems. HF radio requires a frequency channel that is as clear as possible (*i.e.,* free of noise and interference). The attributes of the automated and adaptive HF radio communication link are that it will regularly monitor the operation of the varying HF medium to exploit the spectrum with the greatest efficiency possible [Ripley *et al.*, 1996]. Monitoring the HF environment was previously done by the operator in a very labor-intensive manner. Operators had to monitor noisy HF channels waiting for calls and making valuable judgement calls on procedures to make sure the communication was done with maximum efficiency. With the advent of automatic and adaptive HF systems, the radio can now remain muted until a valid call is received or transmitted.

Users' requirements include the basic function of using the radio to communicate on a specific channel with other users and with networks of users. The very basic requirement might be said to be the ability to key the mike to communicate with other users on some common frequencies and networks without knob tuning and adjusting. If automation and adaptive features are added to the basic radio, together with the advantage of long-range propagation offered by HF, this combination makes a communication mechanism that is ideally suited to quick, short messages by an operator who may have other pressing tasks and a heavy workload.

It is the work of the radio to maximize the abilities of the operator by automating the selection of the clearest and best path to the intended message receiver. The features of sounding, polling, connectivity path tracking, and indirect addressing all go to satisfy the needs of the operator to communicate over the greatest distance and to maximize the number of users possible on the channels provided. As the capabilities of the radio increase, so will the user's requirements, since as a feature is introduced to the operating users, it soon will become one of their necessities. New features and refinements such as those shown in the list below will rapidly become user requirements of next generation radios:

- frequency flexibility and agility,
- network topologies/configurations,
- alternate routing and message relaying,
- robust waveform,
- mobility,
- compatibility with other designs and other radios, and
- minimum operator intervention.

2.3 Impact of requirements for automatic/adaptive HF on systems design

HF radio system designers must be aware of the drawbacks as well as the benefits of automatic and adaptive HF radios. As the radios become more capable they also become more expensive, more bulky, draw more input current, and may even require larger antennas. It is the responsibility of the radio designer to make the necessary tradeoffs between adding a feature and keeping the size and cost minimized. It is responsibility of the system designer to require manufacturers to include the functions and features needed for network-capable operation at the same time that they offer a low-cost, small size, automatic, and adaptive radio for the individual user.

2.4 Principles and components of automatic/adaptive HF radio systems

Specific items attributed to automation and adaptivity might include:

- selective calling,
- multi-channel frequency scanning
- real-time channel evaluation,
- real-time path sounding
- link quality analysis

- automatic link establishment (ALE)
- automatic relaying
- power control, and
- frequency hopping.

Selective calling
This feature allows for the linking and selective conversation between two individual stations on a single specified HF channel. The radio performs its functions of scanning and handshaking until it has linked with the second party. After linkup is achieved, the speakers are unmuted for two-way communication.

Multi-channel frequency scanning
This feature allows for automatic operation of frequency selection. One of the most important elements in HF radio operation is the operating frequency. As stated above, HF radio propagation is dependent on the chosen operating frequency, and this choice will vary during different parts of the day. If there were a way to have a group of frequencies, have them spread across the frequency range from 3 to 30 MHz, and then to have automatic hardware to scan the range automatically, then this would constitute an automated system. *Scanning* is the procedure where, under computer control, the receiver goes from frequency to frequency, pausing momentarily on each channel to check for traffic, specifically traffic for this station. Channel frequency scanning is a very important part of automating a radio system.

Real-time channel evaluation
This feature allows the radio to measure the appropriate parameters of a set of communications channels in real time and using the data thus obtained to describe quantitatively the states of those channels, and hence their relative capabilities for passing a class (or classes), of communication traffic [CCIR, 1986].

Real-time path sounding
This technique is the process where, either automatically (as a timed event) or manually, a short beacon-like identifying broadcast, on a selected channel, is issued to provide information on the connectivity, propagation, and availability of available channels; and to select known working channels for possible later use for communication. The broadcast benefits both the sender and the receiver as the information may be utilized by both the sender and all of the receiving parties.

Link quality analysis
This feature concerns the automatic measurement of the quality of the signal on links between stations. As communication messages are passed between stations, error, noise, and multipath-spread information about the path is stored to support a later decision about which channel might be adequate or "best" for use at a later time. The information is stored at each

receiver but may also be transferred to other stations such as a net control station.

Automatic Link Establishment (ALE)
This feature allows for the simplification of HF radio operation. It is a combination of selective calling, and/or link quality analysis to provide automatic connectivity. ALE improves the performance of connectivity and allows for quiet or muted operation.

Automatic Relaying
This feature allows for the automatic retransmission of a message to a different receiver. This feature drastically improves connectivity, since messages can be rerouted around areas with no connectivity.

Frequency hopping
This technique is the transmission of the same information or packet on different frequencies at different times. This feature provides a degree of anti-jam protection and it lowers power densities while offering a degree of covertness.

Power control
This feature allows for the control of the transmitted power to achieve acceptable range without over-burdening the HF environment.

2.5 Conclusion

As the family of HF ALE radios evolves, their design is constantly being updated with new features and functions that continually make them more helpful and desirable to individual and network users. These features can be broadly grouped into features added to increase the level of automation and those that will serve to increase the radio's ability to adapt to changing HF propagation conditions. A fully adaptive HF system typically operates under microprocessor control, incorporates automation for most operator-intensive functions, and is capable—through a marriage of a variety of diversity schemes with a set of channel intelligence functions—of automatically establishing and maintaining links in an adaptive manner in response to time-varying channel propagation, external noise, and electromagnetic-compatibility (EMC) conditions.

Some of the described features will be added to the present second generation radios and some will be features that will have to wait to be incorporated into third generation radios, which are coming soon.