RECOMMENDATION ITU-R F.764-1

MINIMUM REQUIREMENTS FOR HF RADIO SYSTEMS USING A PACKET TRANSMISSION PROTOCOL

(Question ITU-R 158/9)

(1992-1994)

The ITU Radiocommunication Assembly,

considering

a) that there is an increasing demand to provide a virtually error-free digital data service for HF radio systems;

b) that it is desirable to specify the requirements of HF packet radio systems,

recommends

1. that as a minimum requirement for HF packet radio system protocols:

1.1 the HF packet protocols should sustain the highest throughput for a wide range of channel conditions;

1.2 the packet protocols should employ error detection and correction schemes to ensure that the undetected error probability is better than 1×10^{-8} when the channel raw bit error ratio is 1×10^{-2};

1.3 the packet protocols when operated in ARQ mode should utilize selective repeat algorithms. The redundancy of FEC should be transmitted when a repeat of the packet in error is requested. If the repeated packet is received correctly, then the information is recovered and delivered to the message destination. If the repeated packet contains one or more errors, the two versions of the packet related to the same information are put through an FEC procedure and checked for errors. If the processed packet is deemed to be error free, then the information is delivered to the destination. The levels of FEC can be increased from 2 as described for higher performance. Also soft decision values of the received packet signal can be utilized for better FEC performance. Such a system is described in Annex 2;

1.4 the data transmission should be in synchronous mode;

1.5 the packet should contain sufficient preamble for receiver modem bit timing synchronization to take place;

1.6 the packet should have at least 16 bit frame synchronizations in order to reduce false frame detection;

1.7 the packets should contain identification of sending and receiving stations in order to prevent erroneous acceptance of traffic intended for other stations;

1.8 the packet transmitting station should employ some method of carrier detection, packet detection, or synchronization with other stations sharing the same radio channel in order to reduce packet collisions and interference with the packets already in transmission in the channel;

2. that this Recommendation should be updated as new techniques are developed and relevant information is reported. The study of the techniques for optimization of HF packet systems is also recommended;

3. that the following Notes should be considered as part of this Recommendation.

Note 1 – Annex 1 describes a system which employs an HF packet protocol.

Note 2 – Annex 2 describes a system which employs an HF packet radio protocol with selective ARQ and FEC.

Note 3 – Annex 3 lists features of a terminal node controller (TNC) which incorporates the AX.25 packet radio protocol.

Note 4 – Annex 4 describes a system which employs an HF packet protocol for data transmission, with error correction, detection of uncorrectable errors and repetition of frames not received or not corrected.

ANNEX 1

Transportable HF radiocommunication equipment for transmission of hard-copy messages

1. Introduction

A data terminal is described which can be interfaced with HF radios for the transmission of text messages when the propagation conditions do not permit intelligible voice communications. The system is suitable for use on ships and in remote areas where other means of communication are not available. The important characteristics of the system include:

– real-time channel evaluation and selection;

– interface with the telephone network for remote control;

– economical deployment in remote areas.

2. System configuration

The data terminal is designed to operate with transceivers in a network of up to 128 stations sharing a common set of frequencies.

3. System description

The data terminal is the size of a portable typewriter, consisting of an alphanumeric keyboard, a 20-character light emitting diode (LED) display and a 20-column printer. The package also includes a central processor, modems and a radio interface board (Fig. 1). A message of up to 1 280 characters can be entered into the terminal memory and may be checked on the LED display or printer and edited if required. When the operator is satisfied with the content of the memory, the message can be directed to a particular destination terminal by entering the destination terminal address via the keyboard.

Message transmission takes place under a packet radio protocol which not only identifies the sender and receiver but also allows the receiver to locate portions of the message corrupted by interference or fading. Optional ARQ is activated until the message is correctly received. The protocol is specifically designed to accommodate transceivers which cannot rapidly switch from receive to transmit: single frequency semi-duplex operation is used.

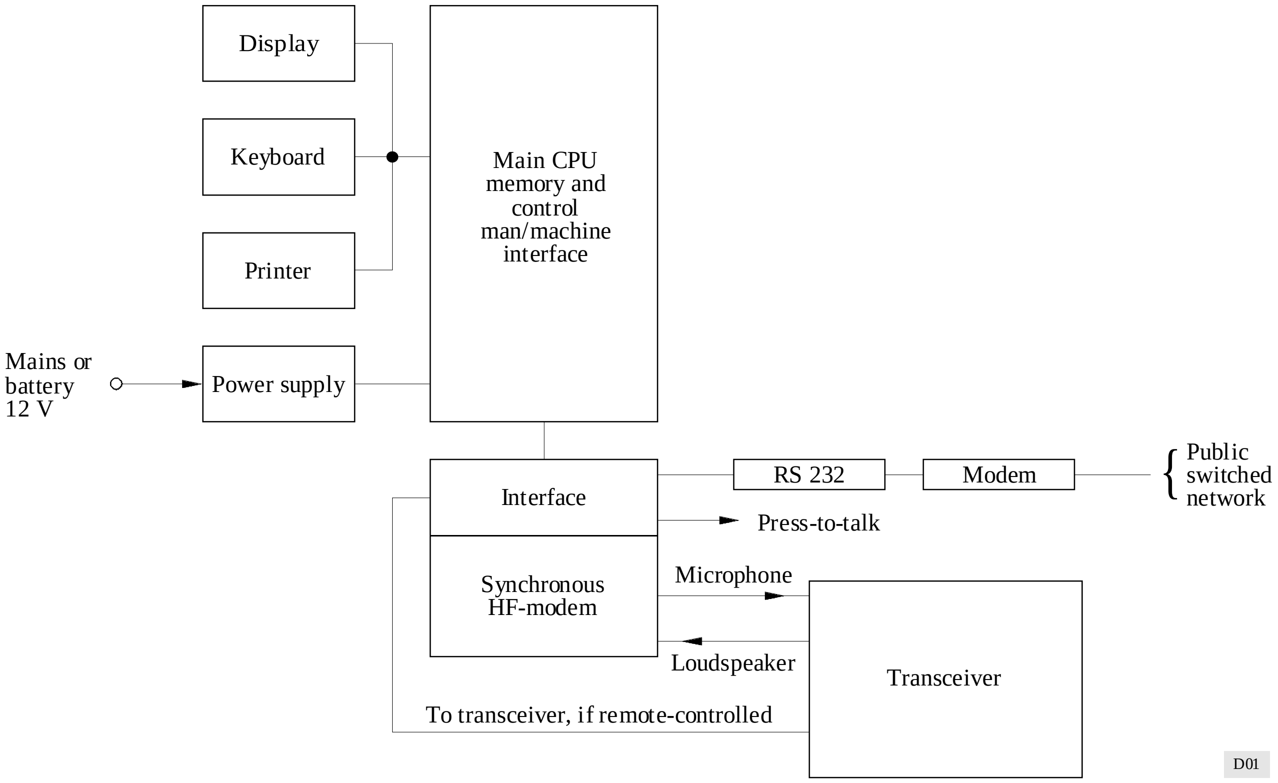
As each packet is received, the terminal stores it and automatically prints out the entire message at the conclusion of the transmission. A confirmation signal is returned to the originating terminal to indicate that the message has been successfully received. An operator is not required at the receiving end.

The system uses in-band frequency diversity to combat selective fading. Two FSK modems using 170 Hz shift operating at 100 bit/s are used to transmit identical data. The data are assembled into an 8-bit byte, including one parity bit. A one-byte cyclic redundancy code is added to form a robust code which allows a character error ratio of only one in 10^8 after ARQ is applied.

Frequency channel selection is under the control of the terminal. When message transmission is initiated, an automatic procedure is activated which causes the stations to search, among the frequencies assigned to the network, for a frequency capable of supporting data transfer. In this way, the reliability of the network is maintained even when experienced operators are not available. If no suitable frequency can be found, a message is printed informing the sender of this fact.

FIGURE 1

The hard-copy message terminal



Under good propagation conditions, a 630 character message may be transmitted in 90 s. When propagation conditions are poor, the data transfer rate is reduced because it is necessary to retransmit corrupted portions of the message. The system will automatically close down when conditions deteriorate to a point where the information throughput falls below an acceptable limit. This feature reduces interference in the radio spectrum. In such cases, printed messages inform the sender that the terminal is unable to carry out the exchange of communication.

4. Test results

Extensive tests have been carried out using both land based and shipboard stations over the period of one year. The path length varied from 50 km to 9 000 km using a variety of transmitters operating between 50 W and 300 W. A number of trans-auroral paths were included in the tests which covered all seasons and all hours of the day. Over one million characters have been successfully received and printed with no undetected errors. This demonstrates the robustness of the error control protocol.

5. Network operation of terminals

Several data terminal-radio combinations can be operated as a network if the traffic volume is low and the traffic is uniformly distributed at the nodes. However, if the traffic at one of the nodes is concentrated in time, blocking can occur. A buffer storage unit should then be incorporated at the busy node to store the messages and perform network control functions to eliminate the blockage. The buffer storage unit has been implemented with a standard desk-top computer connected to the HF terminal through an RS 232 interface. The buffer storage unit is connected to the switched telephone network and permits several users access simultaneously. The messages entered by different users are formed into a queue and are transmitted when the radio channel becomes free. The buffer storage unit permits the terminal to receive a message while a user is entering a message to be transmitted.

ANNEX 2

HF radiocommunication equipment for digital facsimile and hard-copy messages

1. Introduction

An automatic HF digital facsimile and hard copy terminal is described in this Annex. The system has the following general characteristics:

– HF frequency evaluation and selection;

– access from the switched network for remote terminal operations;

– storage, editing and transmission of messages from disk media;

– high quality Group 3 facsimile image with 7.7×3.85 line/mm resolution;

– enhanced throughput through hybrid ARQ with forward error correction;

– hardware built to fit into one expansion slot of a 8088 based personal computer;

– interfaced to HF SSB transceivers via audio ports.

2. System description

The terminal is built around an 8088 microprocessor based personal computer that has a real-time multitasking disk operating system environment. The resources of the computer are utilized by the terminal software and the user has access to the file management utilities for entry or retrieval of information from the terminal. The information that is transmitted and received by the terminal is stored in the disk storage of the computer.

The HF modem is a 12 channel (see Recommendation ITU-R F.436) FSK modem with ± 42.5 Hz frequency-shift and with channel separation of 170 Hz. The modulator and demodulator are implemented in digital signal processing (DSP) devices and interfaced to the computer bus. The modem and interface hardware is contained on a plug-in card for the computer expansion bus. Data are fed to the modulators as 12 bit binary words at 10 ms intervals through a parallel data output port. The modem outputs are combined and applied to the audio input of an HF SSB communication transmitter.

The HF SSB receiver audio output is digitized and fed to the 12 modem inputs. The demodulator generates a 100 Hz clock synchronized to the received data signal. Each demodulator output “eye signal” is sampled in the middle of the bit timing interval and the sample is converted into a 5 bit digital word. At every 10 ms interval 12 demodulator samples are transferred to the computer memory for processing. Although the signalling rate is 100 Bd, the presence of 12 channels results in a raw data rate of 1 200 bit/s.

The terminal is designed to operate with a packet radio protocol which provides the system with a framework for exchange of control information such as station identification, message types and options. In particular, the protocol permits the implementation of a selective repeat ARQ algorithm, which ensures the message integrity. Every packet starts with a bit synchronization sequence followed by a packet framing word transmitted on all the channels. The computer combines all the sampled data from 12 channels and performs a matched filter detection for the packet framing word. The information following the framing word is called the packet header. The data bytes of the packet header are coded with block code of (12, 8) minimum distance 3, which is transmitted in parallel from the 12 modulators. The block code is decoded with a soft decision decoding algorithm by the receiver. The validity of the packet header is verified with a high rate error detection code which is transmitted as part of the header packet. In the packet header coding diversity is utilized instead of conventional in-band frequency diversity.

The information is assembled into 96 small packets and transmitted after the packet header. Each information packet contains data bytes plus a sequence number and error detection code. The information packets are then coded with a rate-half error correction code. The error correction code is chosen such that the information can be recovered for either half of the coded packet. The transmitter does not transmit the parity portion of the coded packets initially but saves them for future repetition requests. Each of the 12 modulators is fed with 3 information packets sequentially without any duplication. In addition to information packets, a packet is sent containing the sequence numbers of packets that are contained in that transmission. The receiving terminal checks the information packets for presence of errors. If the packet is error free, the information is stored in its proper location as indicated by the sequence number. If the information packet has one or more errors, the sampled analogue values of the packet from the demodulator output are saved for future processing. The message receiving terminal requests repeat of the outstanding information packets in the acknowledgement packet. Whenever the transmitter has to repeat an information packet, the parity part of the error detection code version of the packet is sent. The transmitter alternates the repetition of the same packet between the information and parity part of the coded packet. If the parity part of the error detection code of the packet is received error free, then the information is recovered by an inversion process. If the second transmission also contains errors, a soft decision error correction process is activated using the stored samples of the same packet from first and second receptions. The output of the error correction process is verified with error detection code of the packet before accepting the data. The receiver linearly combines the stored sampled analogue values of the same packet whenever the received packet fails the error detection process in order to build signal strength and utilize time diversity. When the transmitter has to repeat an information packet the repetition of that packet is made through a different channel to avoid persistent channel disturbance that could be present.

The terminal scans the assigned radio frequencies continually and when a message transmission is initiated, the message originating terminal calls the destination terminal sequentially on all the assigned radio channels. The message session is established on a frequency that is suitable for data transmission. In this way, the reliability of the network is maintained even when experienced operators are not available.

Interface to ITU-T Group 3 facsimile apparatus is provided through a special port built into the computer interface card of the terminal. The document is scanned in 7.7×3.85 line/mm resolution and the image data is compressed with an error free algorithm. This algorithm has been found to be 65% more efficient than the ITU-T Group 4 facsimile apparatus data compression technique. The image compression algorithm when applied to eight ITU-T test images results in an average image size of 12 kbytes. The compressed image is transmitted from the disk file and the receiving terminal places the image into disk storage. The image can be expanded with the inverse of the data compression algorithm and viewed by the video display unit of the computer or printed by the facsimile machine.

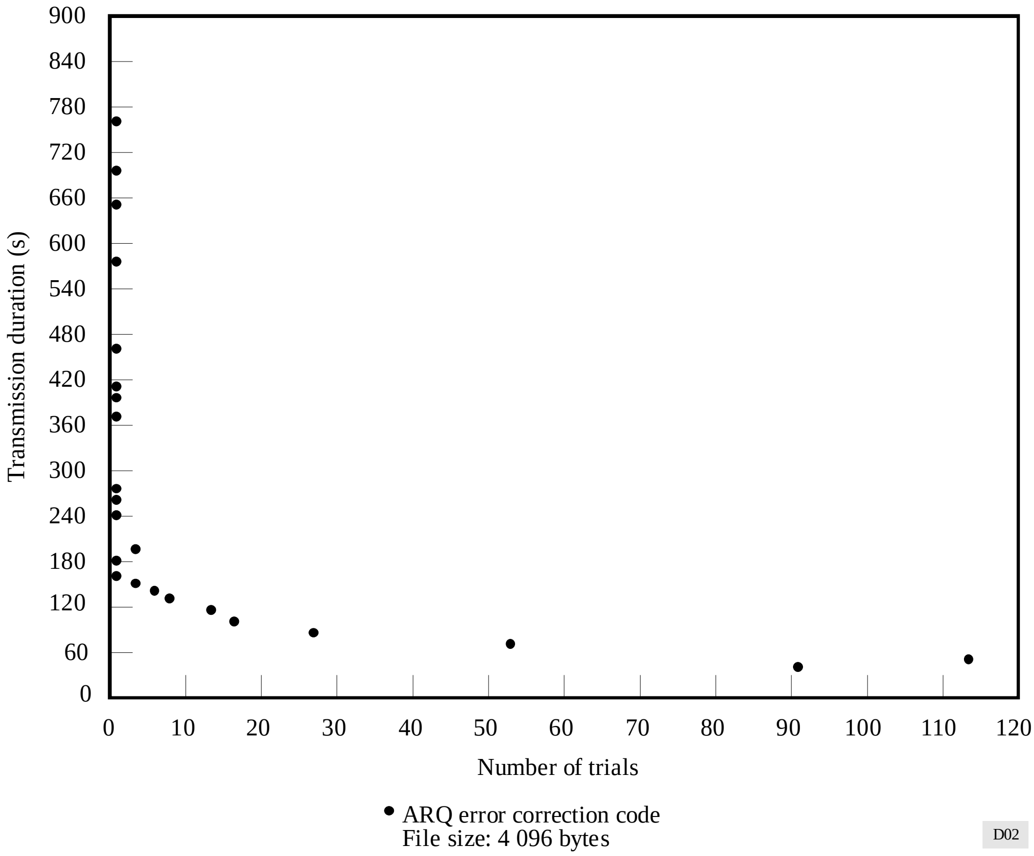
3. Experimental results

The system was tested on a link from Ottawa to a location near Vancouver, a distance of 3 500 km. A 4 096 byte test message was transmitted periodically over a 15-day trial period. The terminals were programmed to scan 3 assigned radio channels and no operator was utilized for channel selection. Figure 2 shows the distribution of transmission times for 344 experiments that were conducted during this trial. Tests were also made over a 100 km link near Ottawa; the results obtained were substantially the same as those obtained in the long range trial. The received files from the trials were checked for undetected errors and none was found in 6 Mbytes of data.

The HF system design achieved reliable data and message transmission over HF radio channels. The memory ARQ performs as a diversity on demand technique adapting the system to changing channel conditions, thus achieving higher throughput when compared to systems utilizing in-band frequency diversity and simple ARQ protocols where the received data is discarded in the presence of errors. The parallel modems are used in a flexible mode where the data can be coded and spread over all the channels, and the error correcting capability of soft decision decoding enhances the performance when extra protection is required for packet headers. The built-in facility for monitoring different radio frequencies improves the success for establishing a link under changing propagation conditions. The data compression algorithm incorporated into the terminal software performs efficient data compression thereby reducing the size of the file and time to transmit. The images are reproduced by the receiving terminal with the same fidelity as the scanned image in the transmitting terminal due to error protection provided by the data transmission protocol.

FIGURE 2

Distribution of transmission time



The system has been tested through HF skywave paths for a period of three months and the performance met all the design goals. The HF facsimile and data terminal provides reliable data service with a modest combination of equipment.

ANNEX 3

Features of a terminal node controller (TNC)

1. The TNC includes a modem allowing it to be connected to most types of radio equipment via audio interfaces. The TNC is connected to a computer via an RS 232-C interface.

It allows computers to communicate with each other via the radio.

2. The TNC rearranges the message from the computer into addressed packets which are then transmitted via the radio. The receiving TNC decodes the packets and transfers the message to the associated computer.

3. The received messages are essentially error-free since the TNC utilizes error-checking codes (CRC codes) and ARQ.

4. The TNC can function with the radio as a store-and-forward station of packet messages; this is known as a “digipeater”.

Thus it is possible to increase the transmission distance or to form a network that can, in turn, be connected to other networks.

5. The TNC protocol is AX.25 which is based on ITU-T Recommendation X.25. AX.25 was developed for use primarily on VHF and UHF radio links and has not been optimized for use on HF radio links.

ANNEX 4

Automatic HF data transmission system

1. Introduction

This Annex describes a system developed for automatic HF transmission of digital data, facsimiles, files and messages.

The terminal is built around an IBM-PC type personal computer which stores the data to be transmitted and data received.

It offers all the functions required to select the best available frequencies at any given time in order to communicate with a specified correspondent.

When the best frequency (for simplex operation) or best frequencies (for half-duplex operation) have been selected, a message, facsimile or any other data file is transmitted by a procedure combining FEC coding, error detection and selective repetition of errored packets.

2. Description of the data transmission procedure

2.1 Principles

The data transmission procedure is a level 2 protocol (LLP – link level protocol) designed in conformity with OSI architecture.

It is compatible with the waveform of an adaptive serial modem (for example, complying with STANAG 4285).

The basic unit transmitted is a 106.6 ms frame containing 128 wanted symbols.

The system provides for simplex/half-duplex data transmission by selectively acknowledged frames. Each frame which is not received or not corrected is selectively repeated until it is acknowledged by the receiver, thereby confirming error-free reception of the data frame.

The protocol is equipped with mechanisms for:

– setting up the link from a master station (transmitting the data file) to a slave station (receiving the data file);

– data transfer with power, bit rate and frequency adaptivity according to the quality of the HF channel;

– flow control: the slave station may request the master station to cease sending data blocks;

– reversal of the direction of transmission in the course of a connection (i.e. the master/slave roles are inverted);

– disconnection of the link.

The level 2 ARQ mode relies on the following level 1 functionalities:

– automatic frequency selection to search for a suitable frequency for setting up the connection and providing frequency adaptivity;

– three possible modem bit rates:

  3 600 bit/s (8-PSK modulation)

  2 400 bit/s (4-PSK modulation)

  1 200 bit/s (2-PSK modulation).

Each modem frame is coded using a Reed-Solomon code with symbols of 8 bits and performing the functions of error correction and detection of incorrectable errors.

2.2 Basic transmission units of the protocol

The protocol uses the following main units, which are similar to those of an HDLC type protocol:

2.2.1 Link protocol data units (LPDU) corresponding to a 106.6 ms modem frame.

A data or acknowledgement LPDU contains, apart from error correction coding and level 2 material:

– 29 wanted octets corresponding to a mean wanted bit rate of 2 400 bit/s;

– 21 wanted octets corresponding to a mean wanted bit rate of 1 800 bit/s;

– 13 wanted octets corresponding to a mean wanted bit rate of 1 200 bit/s;

– 5 wanted octets corresponding to a mean wanted bit rate of 600 bit/s;

Surveillance LPDUs are assigned to flow control and link marking when there are no data to be transmitted and to link connection and disconnection requests.

2.2.2 Link service data units (LSDU) are the data units to be transmitted. An LSDU has a maximum size of 10 koctets and is segmented into several LPDUs for transmission purposes.

2.3 Description of the protocol

2.3.1 Connection

This phase is carried out in two stages:

– automatic frequency selection,

– once the frequency has been chosen:

  – the calling station sends an LPDU CR: connection request;

  – the called station acknowledges with an LPDU CC: connection confirmation.

The connection is then set up.

2.3.2 Data transfer

2.3.2.1 Selective acknowledgement mechanism

The acknowledgement mechanism is based on the division of LSDUs into blocks of 256 LPDUs. Each block is divided into super-frames containing a maximum of 64 information frames (LPDU).

The blocks of each super-frame are selectively acknowledged by the receiver. Acknowledgement is constituted by an LPDU indicating unreceived frames. Unreceived or incorrected frames are repeated at the beginning of another super-frame. The super-frame is filled up with new frames still to be transmitted. The numbers of the first unreceived octet and the first octet to be transmitted are managed by variables similar to those of an HDLC protocol (N_NOT_RECEIVE and N_TO_SEND). Two frames of a given super-frame cannot be more than 256 frames apart (outstanding frame window).

Example:

– Superframe transmitted:

0	1	2	3	...	...	58	59	60	61	62	63

– Acknowledgement of receipt:

0, 7, 45 not received

– Superframe transmitted:

0	7	45	64	65	...	119	120	121	122	123	124

– etc.

2.3.2.2 Adaptivity

Three adaptivity mechanisms are used: power adaptivity, bit rate adaptivity and frequency adaptivity.

The criteria triggering the adaptivity mechanisms are based on the number of unreceived or incorrected frames and the reception or non-reception of acknowledgements of receipt.

The first transmission is carried out at the power set after the automatic frequency selection phase. The system moves up to maximum transmission power in the event of an indication of non-reception of frames. If the super-frame is received properly, the calling station lowers the power level by one increment. The process is asymmetrical: power is increased more rapidly than it is decreased.

If the degree of impairment of transmission quality proves to be too great, bit rate adaptivity is used with a choice of three possible rates. After a certain number of unreceived frames or acknowledgements of receipt, the system switches over to a coding corresponding to a lower transmission rate. If the link quality improves, it switches over to a higher bit rate.

When the transmission quality is inadequate even at the lowest bit rate, the link is momentarily disconnected, a new frequency is selected and transmission restarts on a new frequency without any data loss.

The adaptivity criteria can be set as parameters and the bit rate adaptivity phase may be deactivated as required.

2.3.2.3 Flow control and marking

When reception of an LSDU is completed, if the receiver is not ready to receive another LSDU, RNR (receive not ready) frames are transmitted to the calling station indicating saturation of the receiver. Transmission restarts at the initiative of the receiver, which transmits RR (receive ready) frames when it becomes available.

When there are no data to be transmitted, the connection is maintained by the level 2 by sending a mark comprising RR frames.

2.3.3 Disconnection

Normal disconnection takes place at the initiative of the link master station, which sends an LPDU DISC (DISConnection) and awaits confirmation of the disconnection (LPDU UA – Un-numbered ACK).

The slave may refuse disconnection (LPDU FRMR: FRaMe Reject). The master then transmits a frame indicating transfer of token to the slave, which must send an acknowledgement. The connection is then inverted and the master/slave roles reversed.

3. Results

Figure 3 indicates the mean wanted bit rate obtained by simulation as a function of the signal-to-noise ratio for FEC coding corresponding to a wanted bit rate of 1 800 bit/s on different standardized channels.

FIGURE 3

Mean wanted bit rate