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Annex 9 to the Working Party 5B Chairman's Report

WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT REVISION OF RECOMMENDATION ITU-R M.1798-1*

Characteristics of HF radio equipment for the exchange of digital data and electronic mail in the maritime mobile service

(2007-2010-20XX)

Summary of the revision

The working document towards a preliminary draft revision of Recommendation ITU-R M.1798-1 introduces an additional system that provides point-to-point communication for shore-to-ship, ship-to-shore, and ship-to-ship in the maritime HF band.

Annex 1, system interoperability, is modified. One annex 5, point to point communication system, is added.

Scope

This Recommendation describes a MF/HF radio systems and a HF data transfer protocols currently used in the maritime mobile service (MMS) for the exchange of data and electronic mail on frequencies of RR Appendix 17, and on non-RR Appendix 17 frequencies, providing a similar functional capability to narrow-band direct printing (NBDP) and many other features.

A method of providing completely transparent user interoperability is also described.

Keywords

HF, maritime mobile service, exchange data, electronic mail

Abbreviations/Glossary

Access provider: Company which proposes a connection to IPBC radio network to customer

ACK: Acknowledge receipt

ARQ: Automatic repeat request

AWGN: Additive white gaussian noise

CF: Crest factor

* This Recommendation should be brought to the attention of the International Maritime Organization (IMO).

CL: Constant length

Coast station: Set of shore equipment on a same site (reception and transmission site), designed to communicate into one or several radio cells

CM: Communication manager

CR: Code rate

CRC: Cyclic redundancy check

CRSs: Coastal radio stations

CS: Control signals

CW: Continuous wave

DBPSK: Differential binary phase shift keying

DPSK: Differential phase shift keying

DQPSK: Differential quadrature phase shift keying

DSP: Digital signal processing

FEC: Forward error correction

FFT: Fast Fourier transform

FSK: Frequency shift keying

GLN: Global link network

GMDSS: Global maritime distress and safety system

GPS: Global positioning system

IFFT: Inverse fast Fourier transform

IMO: International Maritime Organization

IP: Internet protocol

IPBC: Internet protocol for boat communication

IPBC radio network: Radio network achieved by whole of the radio cells dedicated for IPBC traffic

IRS: Information-receiving station

ISS: Information-sending station

LEN: Length

Maritime HF band: HF frequency range (4-30 MHz) which is divided in HF sub-band dedicated for maritime traffic

MMS: Martime mobile service

Mobile station: Set of ship equipment designed to communicate into a radio cell

NAK: Not acknowledged

NAVAREAS: Navigation areas

NAVTEX: Navigational Telex (the system name)

NCC: Network control centre

NBDP: Narrow-band dirct printing

OFDM: Orthogonal frequency division multiplexing

OSI: Open systems interconnection

PEP: Peak envelope power

PIB: Pactor IP-Bridge

PMC: Pseudo-Markov compression

PTP: Point to point

QAM: Quadrature amplitude modulation

QoS: Quality of service

Radio cell: Radio electric coverage area for a transmitter of a coast station, and for a radio transmission channel in an HF maritime sub-band

Radio transmission channel: Physical support which allows data transport; this support is characterized by a central frequency in a maritime HF sub-band and a bandwidth of 10-20 kHz.

RF: Radio frequency

RS: Reed-Solomon

RTT: Round-trip time

SES: Ship earth station

SLs: Speed levels

Related ITU-R Recommendations and Reports

Recommendations

ITU-R F.1487

ITU-R M.476

ITU-R M.625

The ITU Radiocommunication Assembly,

considering

a) that the use of software-defined radios will in future bring economical, technical and spectrum efficiency benefits, and that it should be possible to introduce the use of such radios without the need for further regulatory changes;

b) that a high-speed data service over HF radio may be useful for low-level graphics, and the updating of ~~E~~electronic ~~C~~chart ~~D~~display and ~~I~~information ~~S~~systems ~~(ECDIS)~~;

c) that HF data services will enhance operational efficiency and maritime safety;

d) that the introduction of new digital technology in the maritime mobile service (MMS) shall not disrupt the distress and safety communications in the MF and HF bands including those established by the International Convention for the Safety of Life at Sea, 1974, as amended;

e) that the limited use of narrow-band direct printing (NBDP) remains for distress communications in the polar regions (A4), since no coverage from geostationary-satellite networks provides service to maritime;

f) that HF data services may require bandwidths greater than 3 kHz;

g) that a maritime HF data system providing automatic connection with internet service providers would improve traffic-handling efficiency;

h) that HF has the potential to provide greater coverage in Arctic navigation areas (NAVAREAS) than either Inmarsat ~~EGC~~ enhanced group call or 518 kHz NAVTEX;

j) that there is a continuing need for ship-to-ship digital interoperability;

k) the continued expansion of HF maritime digital data services will generate increasing demands for maritime mobile Radio Regulations (RR) Appendix 17 spectrum;

l) that multiple standards for electronic mail could be used to encourage technological development, thus encouraging continued competition, so that users may benefit from continued advances in technology whilst noting the need for interoperability across networks, particularly for future distress and safety purposes, and the distribution of maritime safety information ~~(MSI)~~,

recognizing

a) that there is a need to specify the technical characteristics of HF radio systems and equipment for the exchange of HF data and electronic mail on mobile frequencies, including RR Appendix **17** frequencies;

b) that there are existing and developing global and regional HF electronic mail services operating on RR Appendix **17** frequencies and mobile frequencies outside of RR Appendix 17 (the use of mobile frequencies outside of RR Appendix **17** by the MMS is in conformity with ITU rules),

noting

a) that the characteristics for HF data services described in Annexes 2, 3, 4 and ~~4~~5 can be considered as meeting the requirements for exchange of digital data and electronic mail in the MMS[1],

recommends

1 that system interoperability should be achieved for the transmission of data messages in both the ship-to-shore and shore-to-ship direction should be achieved at the internet protocol (IP) level (see Annex 1);

2 that the examples of HF maritime data services, characteristics and modem protocols given in Annexes 2, 3 and 4 should be used in systems for the transmission and reception of data to and from ships using HF;

3 that in order to maintain ship-to-ship interoperability and compatibility with existing global maritime distress and safety system (GMDSS) equipment, the system should be capable of automatically accommodating radiocommunications in accordance with Recommendations ITU-R M.476 and ITU-R M.625 in both the forward error correction (FEC) and automatic repeat request (ARQ) modes;

4 that, if used in the GMDSS, this system should meet the applicable requirements of the IMO.

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[1] Recognizing the need to comply with Chapter VII of the RR.

Annex 1

System interoperability

1 Introduction

This annex describes the system interoperability (ship-to-shore and ship-to-ship) with details of the three HF electronic mail systems given in Annexes 2, 3 and 4 and a glossary is provided in Annex 5.

In Annex 5, a wideband HF data exchange system for point-to-point communication is proposed.

2 System interoperability

Ship-to-shore

In the ship-to-shore direction interoperability is maintained by the internet service provider (ISP) at the IP level. Typically, a ship will enter an e-mail, with or without attachments in the e-mail system and then click on the “send” button in the way that is familiar to all of us. This applies to any location, pole-to-pole, at any time.

Shore-to-ship

In the system as described in this Recommendation, there are no interoperability concerns on the part of the shore-side user. The shore-based sender of an e-mail to a ship can merely:

– click on the “reply” button; or

– address the message to shipname@xxx.com or callsign@xxx.com

The e-mail will be delivered via whatever system the ship is using. If there is a system failure, there will be an automatic re-route via an alternate system. These automated decisions are based on the contents of an extensive database. Consequently, the e-mail may be delivered via HF or an alternate satellite-based system. If there is an overall system failure, addressing problem or non-delivery for any reason, the system support operators will be alerted and take corrective action. This ensures that shore-based users need not be concerned about what system or network the ship is using. They need only address the e-mail and click on “send”.

Annex 2

HF data services modem protocol using orthogonal frequency division multiplexing ~~(OFDM)~~

Overview

This annex describes the architecture for an orthogonal frequency division multiplexing (OFDM) modem for an HF channel using digital signal processing (DSP). The algorithm definition and description of the implementation is provided. This includes the protocol, modulator and demodulator definition. The final section outlines how frequencies are selected and used in a spectrum-efficient manner.

There are two basic approaches for implementation of a wideband modem, single carrier and multicarrier. The OFDM modem described and in use is a multicarrier approach. The main advantage of using a multicarrier approach is that an equalizer is not required for estimating the fading channel, because the individual subcarrier bandwidth is small and can tolerate moderate fading. Thus, the multicarrier approach is a less complex implementation. Also, the multicarrier approach was selected to make the individual subcarriers similar to narrow-band DATAPLEX. The disadvantage of a multicarrier approach is that it is more sensitive to frequency offset and oscillator phase noise.

HF modem protocol

Introduction

The OFDM waveform uses 32 carriers to transmit 32 blocks every 1 520 ms. Like Recommendation ITU-R M.625 TOR transmissions, OFDM is a half-duplex communication protocol where, at any given time, one station is the information-sending station (ISS) and the other is the information-receiving station (IRS). The basic timing cycle is fixed, and the original calling or MASTER station establishes the cycle timing.

In the following sections, this paper describes the OFDM basic timing cycle, the block formats, and the basic link operations such as OVER, END and link establishment.

~~OFDM~~ Orthogonal frequency division multiplexing modulation

The OFDM waveform uses 32 carrier frequencies centred at 1 700 Hz. A full description of the waveform is in the following sections describing the modulator and demodulator.

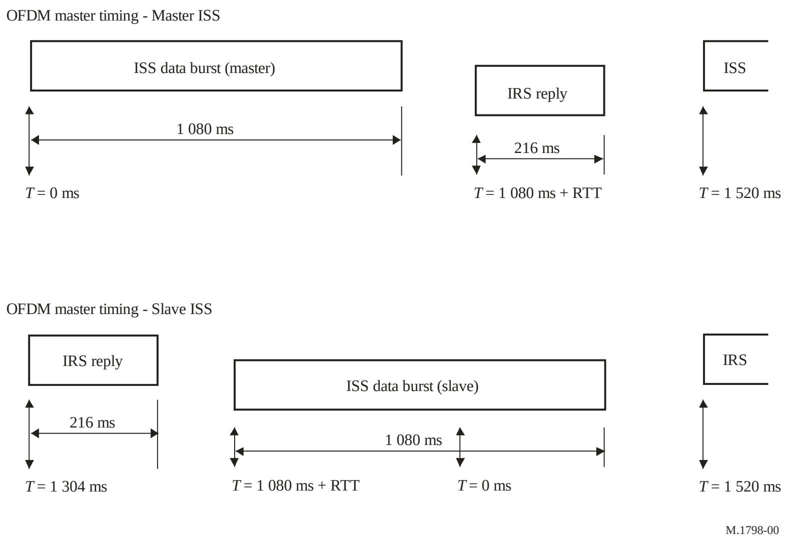
All OFDM transmissions use the 32 carrier (N = 32), 4 phase (M = 4) waveform where the ISS station sends one long data blocks per carrier for a total of 32 data blocks per burst. The IRS station responds with a 32 carrier (N = 32), 4 phase (M = 4) short burst containing 2 bytes per carrier for a total of 64 bytes.

Frame timing

Like Recommendation ITU-R M.625 TOR, OFDM is a half-duplex protocol where one station is the ISS and the other is the IRS. When linked, the OFDM cycle time is fixed at 1 520 ms; the ISS transmits a 1 080 ms long data burst, and the IRS replies with a 216 ms short response burst. The basic timing cycle at the MASTER station is summarized below for MASTER-ISS and SLAVE-ISS.
NOTE − RTT is the round-trip propagation and SLAVE station processing time.

The OFDM T = 0 cycle time reference is established by the MASTER station when the link starts. When ISS, the MASTER station always starts transmitting at T = 0, and the SLAVE station response must be completely received within the 440 ms receive interval immediately following the MASTER's 1 080 ms data burst. The SLAVE station always transmits the IRS reply as soon as it can after it receives the end of the MASTER ISS burst. When the MASTER is IRS, the 216 ms IRS reply starts

1 304 ms into the 1 520 ms cycle time so that the end of the reply occurs at the same time the MASTER ISS data burst would have ended. The SLAVE data burst starts at the same time in the cycle as the SLAVE IRS reply. The OFDM cycle timing philosophy follows the example set by Recommendation ITU-R M.625, except that the OFDM cycle time allows a greater path distance (224 ms versus 170 ms) between the two linked stations.



~~ISS~~ Information sending service block format

The OFDM protocol uses the ISS block illustrated below to transmit both data bytes and control messages to the IRS station. Every ISS transmission sends one data block on each of 32 carriers for a total of 32 blocks per long burst. Since the ISS sends a maximum of 32 blocks with 10 bytes per block every 1 520 ms, the resulting maximum data throughput for OFDM N = 32 M = 4 is about 210 bytes or 1 684 bit/s.

Information sending service ~~ISS~~ data block

SEQ_NR | LEN (11 bits) (5 bits)	**DATA** (10 bytes)	**CRC** (2 bytes)

SEQ_NR – 11-bit block sequence number 1 to 0x7FF
0x000 means discard this block

LEN – 0 to 10 is the number of valid data bytes in the block
31 signals a CONTROL block

DATA – 0 to 10 data bytes when LEN is 0 to 10
CONTROL block when LEN is 31

CRC – 16-bit cyclic redundancy check (CRC) sequence

Each data block starts with an 11-bit sequence number (SEQ_NR) that is used to correctly order the blocks at the IRS end of the link. The sequence number is incremented from 1 to 2 047 (0x7FF) with every new data or control block transmission so that the IRS station can reconstruct the entire data transmission by presenting the blocks in the correct order at the receive end. The sequence number rolls over from 2 047 to 1 after the 2 047th block has been encoded. The sequence number of a control block indicates when the control block should be decoded. The sequence number is set to 1 when the link starts, and it is not changed during OVERs.

During the link, the ISS station must ensure that no more than MAX_SEQ_NR_DIFF sequence number blocks are outstanding at any time, where MAX_SEQ_NR_DIFF is a programmable value less than (2 047 − 64) or 1 983. In other words, the difference between the oldest and newest block sequence number in any given ISS long burst must be less than or equal MAX_SEQ_NR_DIFF. This restriction is meant to limit the number of buffered blocks at the IRS end, and to allow the link to "catch up" if, for some reason, one or more blocks continue to fail to decode error-free at the IRS end.

The protocol allows the ISS station to repeat blocks in the same long burst. If the ISS station approaches the MAX_SEQ_NR_DIFF difference between the oldest and newest block sequence numbers in any given long burst, the oldest blocks should be repeated in the remaining open long burst slots to improve the probability that the block is received correctly. At any time, the ISS station may repeat current blocks if there are no new data blocks pending.

The 0000 sequence number is a special case. When a block is transmitted with a 0000 sequence number, this block can be discarded by the IRS station without any further decoding. At the end of an ISS transmission, for example, the 0000 blocks may be used as filler for all blocks after the last block containing valid data. The significance of the 0000 block will become apparent later when discussing the ARQ operation when the IRS station requests the retransmission of corrupted data blocks. If the ISS station transmits a 0000 block, it does not need to retransmit that block if the IRS station signals an error for that block. Note that the ISS station may also repeat current blocks rather than transmit 0000 blocks.

The 5-bit length (LEN) field serves a dual purpose. If LEN is a number between 0 and 10 it indicates the number of valid data bytes in the DATA portion of the block. The bytes after the first LEN bytes in the DATA portion of the block should be ignored. Note that 00 is a valid data block length that can be used to signal an idle or no data block. Unlike the 0000 sequence block, an idle block must be retransmitted if the IRS station signals an error for that block.

When LEN is set to 31, the block is identified as a CONTROL block, and the control message is contained in the data portion of the block. Like data blocks, if the IRS station signals an error receiving this block, it must be retransmitted. In addition, the ISS station may repeat CONTROL blocks in the same long burst just as it may repeat DATA blocks. Of course, the repeated block must have the same block sequence number.

The 16-bit CRC at the end of all blocks is a standard ITU-T polynomial remainder calculated over the entire block from the start of the sequence number field to the end of the data field. After the CRC is XOR'd with 0xFFFF, the two CRC bytes are transmitted, low byte first, at the end of the block. At the IRS location the CRC checker is initialized to 0xFFFF, and the calculated CRC remainder from the sequence number byte to the end of the block will equal 0xF0B8 if no errors have occurred.

Data blocks

In the OFDM ISS data blocks the LEN parameter is set to the number of valid data bytes in the block: 0 to 10 bytes.

~~OFDM~~ Orthogonal frequency division multiplexing data block

SEQ_NR | LEN (11 bits) (5 bits)	**DATA** (10 bytes)	**CRC** (2 bytes)

LEN – 00 to 10 valid data bytes

In any given ISS burst the data blocks may be assigned to carriers in any order. It is incumbent on the IRS station to reassemble the original data message in the correct order based on the sequence numbers in data blocks.

If the ISS station does not have enough blocks to fill all 64 slots, the ISS station may repeat current blocks in the remaining slots starting with the oldest block. The repeated blocks give the IRS station a second chance to decode all blocks error-free. Alternatively, the ISS station can fill the unneeded blocks is 0000 sequence number blocks, and those blocks will be discarded at the IRS end.

The ISS station must never have a range of more than MAX_SEQ_NR_DIFF block sequence numbers outstanding where MAX_SEQ_NR_DIFF is a programmable value. This means that in any given ISS long burst, the difference between the oldest sequence number and the newest number, taking the count wrap at 2 047 into account, must be less than or equal MAX_SEQ_NR_DIFF.

Control blocks

The OFDM protocol transmits control messages by setting the LEN field to 31 and loading the command in the first byte of the DATA field. The sequence number field is set to the next available number. All control frames are retransmitted if the IRS station fails to decode the block error-free.

ODFM has three control messages: MY_CALL, OVER and END.

~~OFDM~~ Orthogonal frequency division multiplexing control block

SEQ_NR | 11111 (11 bits) (5 bits)	CONTROL | IDLE FILL PATTERN (1 bytes) (9 bytes)	CRC (2 bytes)

SEQ_NR – 11-bit sequence number; it cannot be 0000

LEN – 31 for control block

CONTROL – OVER or END control code

IDLE FILL PATTERN – 10101010 (repeated 9 times)

Control blocks may be sent by the ISS at any time, and the IRS station must recognize the control command at the point it appears in the reconstructed serial data. For example, when the ISS OVER command is transmitted, no data blocks with a higher sequence number than the OVER command should be transmitted since the ISS station will shortly become IRS. The ISS station should generate the command block only once, but it can repeat this control block in unassigned carrier slots.

The CONTROL byte codes are shown below.

CONTROL – OVER (0x86)

1 0 0 0 0 1 1 0

CONTROL – END (0x98)

1 0 0 1 1 0 0 0

CONTROL – MYCALL (0xE0)

1 1 1 0 0 0 0 0

Typical OVER and END control blocks are shown below:

OVER CONTROL BLOCK

SEQ_NR | 11111	**10000110**	**IDLE FILL PATTERN**	**CRC**

END CONTROL BLOCK

SEQ_NR | 11111	**10011000**	**IDLE FILL PATTERN**	**CRC**

~~OFDM~~ Orthogonal frequency division multiplexing acquisition burst

The ISS station and the IRS station send a 1 700 Hz tone before the start of each burst. This tone is used to determine the frequency offset.

~~IRS~~ Information receiving station response format

When a station is the IRS, it receives 32 data blocks from the ISS station every 1 520 ms, and it responds with an ACK or not acknowledged (NAK) signal for each of the blocks. In addition, the IRS response sends link control commands to OVER the link and to END the link. The IRS response message is transmitted as a 216 ms short OFDM block sent in 32-carrier (N = 32) 4-phase (M = 4) format. There are 2 bytes sent per carrier; two bytes per carrier are assigned to each of the data blocks on that same carrier in the ISS long burst transmission.

On each carrier, only one IRS response code is transmitted for the data block received from the ISS station on the same carrier.

BLOCK 1 RESPONSE (16 bits)

The IRS station sends the following response codes:

ACK/NAK

FORCED_OVER

END_ACK

Any response other than one of these is treated as if a NAK was received. In this section, the coding for each of these response codes is listed along with a brief description.

~~ACK~~Acknowldege/~~NAK~~Not acknowledge

The IRS station decodes and calculates the CRC for each of the 32 incoming data blocks in the ISS long burst. If the CRC indicates that the block has been received without error, the IRS station responds with an ACK on the same carrier. In an error is detected, a NAK is transmitted. At the ISS end, an ACK signals the successful transmission of a block, and that block is dropped from the transmit queue. A NAK, on the other hand, forces the ISS station to retransmit the block on a different carrier. If the IRS station receives a block containing a sequence number that it has already acknowledged, it sends another ACK and discards the block. Any unknown response is treated by the ISS as if it was a NAK.

ACK Code (0x56A9)

0 1 0 1 0 1 1 0 1 0 1 0 1 0 0 1

NAK Code (0xA956)

1 0 1 0 1 0 0 1 0 1 0 1 0 1 1 0

The ACK/NAK responses are used by the ISS and IRS stations to gauge the quality of the link and determine when to abort the link. With OFDM we have 32 individual ACK/NAK responses every cycle and deciding when to drop the link is somewhat more complicated. For the OFDM initial implementation, we use the number of consecutive blocks where NO blocks decode correctly to increment the error counter. If the IRS and ISS stations see MAX_BLK_ERR transmit cycles without one single block ACK, the link will be aborted, where MAX_BLK_ERR is a programmable value. MAX_BLK_ERR equal to 20 is about 30 seconds. Any block ACK will reset the error count to 0.

FORCED_OVER

Typically, the OFDM ISS station controls the switch from ISS to IRS by transmitting the OVER control block to the IRS on one or more carriers. However, the IRS station can force an OVER by transmitting the FORCED_OVER code word. To avoid an outstanding data block problem, the FORCED_OVER code word will only be transmitted when the last block from the ISS on that carrier was received without error.

FORCED_OVER Code (0x6A95)

0 1 1 0 1 0 1 0 1 0 0 1 0 1 0 1

END_ACK

The IRS transmits the END_ACK code word in response to the ISS END control block to signal the end of the link. The END_ACK will be transmitted in response to each ISS END control block to ensure that the ISS station received the acknowledgment code word. When the ISS station receives one or more END_ACK response messages, it immediately goes to STANDBY even if there are outstanding unacknowledged data blocks. The IRS station uses the END_ACK response to force termination of the link immediately.

END_ACK Code (0x956A)

1 0 0 1 0 1 0 1 0 1 1 0 1 0 1 0

~~OFDM OPERATION~~Orthogonal frequency division multiplexing operation

In this section, the important protocol exchanges between ISS and IRS are discussed. Here, the data and control blocks and response code words that have been defined in the earlier section are combined to create the OFDM protocol. This section describes the ISS-IRS exchange during data block transfer, link OVER, link speed change, link END, and link CALLING operations.

Information sending station – information receiving station~~ISS-IRS~~ exchange

During an OFDM link, one station is the ISS and the other is the IRS. The ISS station transmits data blocks, and the IRS acknowledges those blocks when they are received error-free. The ACK and NAK code word responses from the IRS signal the ISS which blocks to send in the next burst.

Since OFDM transmits 32 blocks per burst, a procedure must be defined to assign data blocks to specific waveform carrier frequencies. The transmit data bytes fill 10-byte data blocks and the sequence number for each block indicates the order of these blocks. When an actual transmit frame is built, the individual data blocks are assigned, in order, starting with the first block on the first carrier, the second block on the second carrier and so on until the first 32 transmit blocks are assigned a carrier. The transmit block assignments are shown below for a typical first transmission.

The block sequence numbers start with block 0001 in the first data block after a link is established, and the numbers increment with each transmit block built until the end of the link. After the 2 047th block, the sequence number wraps to block 0001 again.

Information sending station orthogonal frequency division multiplexing transmit burst~~ISS OFDM TRANSMIT BURST~~

Carrier 1	Block 0001	CRC
Carrier 2	Block 0002	CRC
Carrier 3	Block 0003	CRC
Carrier 4	Block 0004	CRC
…	…	…
Carrier 30	Block 0030	CRC
Carrier 31	Block 0031	CRC
Carrier 32	Block 0032	CRC

If all of the blocks are decoded error-free, the IRS transmits a short response burst containing an ACK for each data block on each carrier. The ACKs are not sequence numbered.

Information receiving station orthogonal frequency division multiplexing response burst~~IRS OFDM RESPONSE BURST~~

Carrier 1	ACK (for block 1)
Carrier 2	ACK (for block 2)
Carrier 3	ACK (for block 3)
Carrier 4	ACK (for block 4)
…	…
Carrier 30	ACK (for block 30)
Carrier 31	ACK (for block 31)
Carrier 32	ACK (for block 32)

When a corrupted data block is detected, the IRS station sends a NAK response for that block on the same carrier. The ISS station retransmits every data block that the IRS has not ACK'd, including those blocks where no valid IRS response was decoded. To maximize the chance that the block will get through the next time, the ISS station will retransmit blocks on a carrier where the last block was properly ACK'd. For example, re-sent blocks are assigned first to carriers where both blocks were ACK'd the previous cycle, then to carriers where only one block was ACK'd the previous cycle. Moving the data blocks should keep data moving even if one or more of the carriers is blocked by interference. New blocks are added in the remaining open block slots, starting first with the carriers where both blocks were previously ACK'd then continuing with the carriers where one block was previously ACK'd. If there are no new blocks, then current blocks, starting with the oldest sequence number, may fill the open carrier slots.

For example, if we consider the case where we have only four carriers and two blocks are corrupted, the ISS station will retransmit the blocks as shown below:

~~ISS~~Information sending station

Carrier 1	DBlock 0001	CRC
Carrier 2	DBlock 0002	CRC

Carrier 3	DBlock 0003	CRC
Carrier 4	DBlock 0004	CRC

IRSInformation receiving station

Carrier 1	ACK (for block 1)
Carrier 2	**NAK** (for block 2)
Carrier 3	ACK (for block 3)
Carrier 4	**NAK** (for block 4)

ISSInformation sending station

Carrier 1	DBlock 0002	CRC
Carrier 2	DBlock 0005	CRC
Carrier 3	DBlock 0004	CRC
Carrier 4	DBlock 0006	CRC

IRSInformation receiving station

Carrier 1	ACK (for block 2)
Carrier 2	ACK (for block 5)
Carrier 3	ACK (for block 4)
Carrier 4	ACK (for block 6)

Note that the retransmitted blocks have been moved to block positions where the block was ACK'd in the last cycle. In the case above, DBlock 0007 is sent as the first block in Carrier 4 rather than Carrier 2 because there was an error in the Carrier 2 position in the last burst. It makes sense to fill the "good" positions first and leave the previously NAK'd positions to last to increase the probability that a block is transferred successfully. If a carrier is completely masked due to some channel interference or bandwidth limitation on one of the radios, new data blocks should first be assigned to those carriers that are getting through. The example below shows how this might apply in our simple case:

ISSInformation sending station

Carrier 1	DBlock 0001	CRC
Carrier 2	DBlock 0002	CRC
Carrier 3	DBlock 0003	CRC
Carrier 4	DBlock 0004	CRC

IRSInformation receiving station

Carrier 1	**NAK** (for block 1)
Carrier 2	ACK (for block 2)
Carrier 3	ACK (for block 3)
Carrier 4	**NAK** (for block 4)

~~ISS~~Information sending station

Carrier 1	DBlock 0005	CRC
Carrier 2	DBlock 0001	CRC
Carrier 3	DBlock 0004	CRC
Carrier 4	DBlock 0006	CRC

~~IRS~~Information receiving station

Carrier 1	ACK (for block 5)
Carrier 2	ACK (for block 1)
Carrier 3	ACK (for block 4)
Carrier 4	**NAK** (for block 6)

In this example, new blocks are assigned to Carriers 1 and 4 last since those carriers showed errors on the previous transmit cycle. If Carrier 4 is failing to pass blocks due to a bandwidth limitation, then we will resend Blocks 12 and 13 since all earlier blocks were transferred without error.

If there is no data to transmit, the ISS station can send blocks with the sequence number set to 0000. The IRS station ignores these blocks, and they do not need to be retransmitted if the IRS station returns a NAK for that block. As shown below, the ISS station may also repeat current blocks, starting with the oldest, in the remaining slots to increase the probability that the block will be received error-free.

If the ISS station has fewer than 32 blocks to transmit, the ISS station may repeat current blocks in the remaining open carrier blocks. Since the IRS station must use the sequence number to reconstruct the serial byte steam, a second block with the same block sequence number will be ignored. Repeating the blocks in the ISS long burst provides a second chance for the block to be received error-free.

~~ISS~~Information sending station

Carrier 1	DBlock 0001	CRC
Carrier 2	DBlock 0002	CRC
Carrier 3	DBlock 0003	CRC
Carrier 4	DBlock 0004	CRC

~~IRS~~Information receiving station

Carrier 1	**NAK** (for block 1)
Carrier 2	ACK (for block 2)
Carrier 3	ACK (for block 3)
Carrier 4	**NAK** (for block 4)

In this example, the ISS station has 5 blocks to send and it repeats Blocks 1 to 3 in the remaining blocks. At the IRS end, the first DBlock 0001 is NAK'd, but the second copy is received error-free. The ISS station does not need to resend DBlock 0001. The second copy of DBlock 0003 is NAK'd, but the first copy was received OK; the ISS station does not need to resend this block. Note that DBlock 0004 is NAK'd, and the ISS station will need to resend this block since it was sent only once in the long burst.

No attempt is made by the IRS to compare multiple copies of blocks with the same sequence number. It is assumed that the first block received with a correct CRC is a valid block, and that block is queued for output to the serial port. The IRS should also ACK all blocks received error-free even if it is a repeated block.

Flow control

The ODFM protocol does not include any specific link level flow control codes to allow the IRS station to halt ISS block transmission. Flow control is required; however, if the IRS station is unable to empty receive block buffers due to external serial port or USB port flow control activation. If the external flow control stops RX data output for an extended period of time, the IRS receive buffers may fill leaving no place to store new ISS data blocks.

When the IRS needs to slow the ISS block transfer rate, it can NAK some of all of the ISS long burst blocks even if the block CRCs are correct. If all of the blocks are NAK'd the ISS station will repeat all blocks in the next long burst. Note that halting the link data transfer with NAKs for a long period of time may cause the ISS station to abort the link.

OVER

The link OVER can be initiated from the ISS or the IRS end. The ISS requests the OVER by transmitting the OVER control command as one of the long burst data blocks. The ISS station can request the OVER at any time, but it should stop building new transmit data blocks after the OVER is issued. When the IRS station receives the OVER control command, it checks to confirm that all data block sequence numbers up to the OVER control block sequence number have been received. If there are no missing blocks, the IRS station sends the FORCED_OVER response message instead of ACK for all correctly decoded blocks and NAKs for the bad blocks. If there are missing blocks, the IRS station continues to send ACK/NAK response messages until all missing blocks have been received correctly, then it sends the FORCED_OVER response message instead of an ACK for all correctly decoded blocks. Note that there is no guarantee that those blocks with sequence numbers after the OVER block will be acknowledged before the link OVER occurs. The ISS end must keep track of the outstanding blocks.

The ISS station should fill all data blocks after the OVER with blocks containing the sequence number 0000 so that those blocks will not need to be re-sent while waiting the IRS station to start the OVER sequence. The ISS station can also repeat current data blocks in the remaining open slots.

The IRS station can force an OVER at any time by sending at least one FORCED_OVER response message instead of an ACK when responding to the ISS long burst. When the ISS station detects the FORCED_OVER, it immediately turns the link around and it keeps track of those blocks that have not been acknowledged. All outstanding blocks will be transmitted after the next OVER.

~~ISS~~Information sending station

Carrier 1	DBlock 0005	CRC
Carrier 2	DBlock 0006	CRC
Carrier 3	CBlock 0007 OVER	CRC
Carrier 4	DBlock 0000	CRC

~~IRS~~Information receiving station

Carrier 1	ACK (for block 5)
Carrier 2	ACK (for block 6)
Carrier 3	ACK (for block 7)
Carrier 4	**NAK** (for block 8)

~~ISS~~Information sending station

Carrier 1	DBlock 0000	CRC
Carrier 2	DBlock 0001	CRC
Carrier 3	DBlock 0004	CRC
Carrier 4	DBlock 0000	CRC

~~IRS~~Information receiving station

Carrier 1	**NAK**
Carrier 2	FORCED_OVER
Carrier 3	FORCED_OVER
Carrier 4	**NAK**

Information receiving station~~IRS~~

Carrier 1	NAK
Carrier 2	NAK
Carrier 3	NAK
Carrier 4	NAK

Information sending station~~ISS~~

Carrier 1	DBlock 0010	CRC
Carrier 2	DBlock 0011	CRC
Carrier 3	DBlock 0012	CRC
Carrier 4	DBlock 0013	CRC

~~IRS~~Information receiving station

Carrier 1	ACK (for block 10)
Carrier 2	ACK (for block 11)
Carrier 3	ACK (for block 12)
Carrier 4	ACK (for block 13)

END

Either the ISS or IRS station can terminate the OFDM. Typically, the ISS ends the link by transmitting one END control block as the next block after the last data block. When the IRS station receives the END control block, it confirms that all data blocks with sequence numbers up to the END block have been received. If there are no outstanding blocks, the IRS station transmits a short burst with all slots set to END_ACK. If there are outstanding blocks, the IRS continues to send ACK/NAK response messages until all of the outstanding blocks are received correctly. Note that any data blocks that the ISS station transmits with sequence numbers after the number in the END block are discarded.

The ISS station should encode all blocks after the END control message using a sequence number of 0000 so that they will not be retransmitted.

When the ISS station receives four or more END_ACK response messages in the short block, it stops transmitting immediately and returns to STANDBY. The IRS station repeats an END_ACK frame two times after the last END control block is received to ensure that the ISS station receives the END_ACK message.

The IRS station issues the END_ACK response message when it wants to force link termination. When the ISS station receives the END_ACK response message, it immediately stops transmitting and returns to STANDBY even if there are outstanding data blocks.

ISS

Carrier 1	DBlock 0005	CRC
Carrier 2	DBlock 0006	CRC
Carrier 3	CBlock 0007 END	CRC
Carrier 4	DBlock 0000	CRC

Information receiving station~~IRS~~

Carrier 1	ACK (for block 5)
Carrier 2	ACK (for block 6)
Carrier 3	ACK (for block 7)
Carrier 4	**NAK** (for block 8)

ISS

Carrier 1	DBlock 0000	CRC
Carrier 2	DBlock 0000	CRC
Carrier 3	DBlock 0000	CRC
Carrier 4	DBlock 0000	CRC

Information receiving station~~IRS~~

Carrier 1	END_ACK
Carrier 2	END_ACK
Carrier 3	END_ACK
Carrier 4	END_ACK

Information receiving station~~IRS~~

Carrier 1	END_ACK
Carrier 2	END_ACK
Carrier 3	END_ACK
Carrier 4	END_ACK

~~OFDM~~ Orthogonal frequency division multiplexing link terminated

CALLING

The DATAPLEX link is established when the master station calls a remote station using a 9-byte CALLING block transmitted with a frequency shift keying (FSK)100 format. A unique 2-byte sync code at the beginning of the block identifies the CALLING block and establishes the link timing. This CALLING block is repeated every 1 020 ms, the DATAPLEX cycle time.

The remote station SELCAL is transmitted in 4.5 bytes by packing two SELCAL digits per byte; all SELCALs must have 9 digits with values of 0x0 to 0x9. The lower four bits of the last SELCAL byte selects the link format and a single byte calling frame TYPE byte completes the data portion of the CALLING block. A single byte checksum is included to confirm that the calling frame has been received error-free.

When an idle station receives a CALLING block with the local SELCAL and a correct checksum, a DATAPLEX link can start using the format specified by the calling station. After the link acknowledgment control code is received, the first data block transmitted by the master station contains the SELCALl of the calling station in a MYCALL control block. This block follows the previously described control block convention except that the MYCALL byte is followed by the master station SELCAL transmitted with two SELCAL digits per byte. After this first block is acknowledged in an FSK or differential phase shift keying (DPSK) DATAPLEX link, the link begins normal ISS-IRS data transfer exchanges.

Note that the sequence number is set to 0001 for the first block sent by the MASTER and the SLAVE after the link switches to OFDM.

CALLING control block

10101100	00110101	SC1 | SC2	SC3 | SC4	SC5 | SC6	SC7 | SC8	SC9 | RATE	TYPE	CKSUM

NOTE 1 − SC1-SC9 are the 9 SELCAL digits, 4 bits each, [0x0 − 0x9]
RATE = link format (2 = FSK200; 3 = FSK100;
4 = DPSK600; 5 = DPSK400; 6 = DPSK200;
8 = OFDM[N = 32, M = 4])
TYPE = 8-bit value passed to the application in the link request status message
CKSUM = 00 – (sum of bytes from SC1|SC2 to TYPE)

In the following example, the master station requests a link using OFDM format RATE 8 (N = 32, M = 4), and the remote station acknowledges the link request.

~~ISS~~ ~~IRS~~ Information sending station information receiving station

CALLING block (FSK100) --->

CALLING	**SELCAL**	**8**	**TYPE**	**CKSUM**

(My SELCAL received OK; link in FSK200)
<--- Start ODFM link

LINK_ACK

CALLING block (FSK100) --->

CALLING	**SELCAL**	**8**	**TYPE**	**CKSUM**

<--- Start ODFM link

LINK_ACK

~~ISS – OFDM~~Information sending station – orthogonal frequency division multiplexing (cycle change to 1 520 ms)

Carrier 1	MYCALL 0001	CRC
Carrier 2	MYCALL 0001	CRC
Carrier 3	MYCALL 0001	CRC
Carrier 4	MYCALL 0001	CRC

Information sending station – orthogonal frequency division multiplexing~~IRS – OFDM~~

Carrier 1	ACK (for block 1)
Carrier 2	ACK (for block 2)
Carrier 3	ACK (for block 3)
Carrier 4	ACK (for block 4)

The linking process starts in DATAPLEX FSK100 format and switches to OFDM after the ISS and IRS stations have correctly received the DPSK acquisition burst. The protocol cycle time switches from 1 020 ms to 1 520 ms after the ISS station receives the LINK_ACK response code from the IRS station.

The change in cycle time is a critical point in the linking protocol. Two possible error conditions can occur: first, the ISS station may not hear the IRS CS1 response code, and second, the IRS station may not hear the first ISS OFDM long burst.

There will be times that a channel supports FSK100 but not OFDM. When either the ISS or IRS station has repeated the OFDM long burst (ISS) or CS1 response (IRS) MAX_OFDM_LINK times without successfully establishing the OFDM link, both ISS and IRS must abort the link and return to STANDBY. MAX_OFDM_LINK is a programmable retry counter value.

Illustrated below is an example where the ISS station fails to decode the first CS1 response code from the IRS station. The ISS station repeats the DPSK_ACQ burst on a 1 020 ms cycle waiting for the CS1 while the IRS station is waiting for the first OFDM long burst.

~~ISS~~ ~~IRS~~Information sending station information receiving service

<--- OVER OK

CS0

DPSK Acquisition Burst (*T* = 0 ms) --->

DPSK_ACQ

<--- DPSK ACQ OK (*T* = 720 ms + RTT)

CS1

~~ISS~~Information sending station fails to decode CS1! Repeat DPSK_ACQ

DPSK Acquisition Burst (*T* = 1 020 ms) --->

DPSK_ACQ

DPSK Acquisition Burst (*T* = 2 040 ms) --->

DPSK_ACQ

DPSK Acquisition Burst (*T* = 4 080 ms) --->

DPSK_ACQ

<--- DPSK ACQ OK (*T* = 720 ms + RTT + 4 080 ms)

CS1

~~ISS~~Information sending station – orthogonal frequency division multiplexing~~OFDM~~wwwwwwwwwwwwwwwwwwwwwwwwww (cycle change to 2 672 ms)

Carrier 1	DBlock 0001	CRC
Carrier 2	DBlock 0002	CRC
Carrier 3	DBlock 0003	CRC
Carrier 4	DBlock 0004	CRC

~~IRS~~ Information receiving station ~~–~~ – orthogonal frequency division multiplexing~~OFDM~~

Carrier 1	ACK (for block 1)
Carrier 2	ACK (for block 2)
Carrier 3	ACK (for block 3)
Carrier 4	ACK (for block 4)

In the following example, the IRS station fails to decode the first OFDM long burst from the ISS station. The ISS station starts sending OFDM long bursts, but the IRS station does not receive a good burst until after it has repeated the CS1 response code. Note that the second IRS response code is transmitted during the time that the ISS is sending the second OFDM long burst.

~~ISS~~Information sending station ~~IRS~~Information receiving station

<--- OVER OK

CS0

DPSK Acquisition Burst (*T* = 0 ms) --->

DPSK_ACQ

<--- DPSK ACQ OK (*T* = 720 ms + RTT)

CS1

~~ISS~~Information sending station – orthogonal frequency division multiplexing~~OFDM~~ (cycle change to 2 672 ms)

Send OFDM long burst (*T* = 0 ms) --->

Carrier 1	DBlock 0001	CRC
Carrier 2	DBlock 0002	CRC
Carrier 3	DBlock 0003	CRC
Carrier 4	DBlock 0004	CRC

~~IRS~~Information receiving station fails to decode orthogonal frequency division multiplexing~~OFDM~~ block! Repeat CS1

Send OFDM long burst (T = 2 672 ms) --->

Carrier 1	DBlock 0001	CRC
Carrier 2	DBlock 0002	CRC
Carrier 3	DBlock 0003	CRC
Carrier 4	DBlock 0004	CRC

<--- DPSK ACQ OK (T = 720 ms + RTT + 4 080 ms)

CS1

Send OFDM long burst (T = 5 344 ms) --->

Carrier 1	DBlock 0001	CRC
Carrier 2	DBlock 0002	CRC
Carrier 3	DBlock 0003	CRC
Carrier 4	DBlock 0004	CRC

~~IRS~~ Information receivng station ~~=~~ – orthogonal frequency division multiplexing~~OFDM~~

<--- Send OFDM short burst (1 080 ms + RTT + 5 344 ms)

Carrier 1	ACK (for block 1)
Carrier 2	ACK (for block 2)
Carrier 3	ACK (for block 3)
Carrier 4	ACK (for block 4)

Functional description

Modulator

Shown in Fig. 1 is the modulator architecture. A number of parameters listed in Table 1 are used to define the modulator. The information bits, $x_1(n)$, of length log2(M)*L*N are first formatted into N frames, $x_2(m, n)$, as shown in Fig. 3 for M = 4. Each of the N parallel channels of length log2(M)*L are scrambled into $x_2(m, n)$. These scrambled frames are then mapped to L by N symbols, $x_4(m, n)$, and differentially encoded into symbols, $x_5(m, n)$. To aid in synchronization, a sequence of size S symbols is added resulting in ($L + S$) by N symbols, $x_6(m, n)$. The ($L + S$) by N symbols, $x_6(m, n)$, are applied to the input of the complex inverse fast Fourier transform (IFFT) resulting in the output, $x_7(m, n)$, of sample rate fs1. A cyclic extension of length P symbols is added resulting in ($L + S$) by ($N + P$) samples, $x_8(m, n)$. The samples are then converted from parallel to serial to get a complex signal, $x_9(n)$, of sample rate fs2 and length ($L + S$)*($N + P$). The modulated signal is interpolated by R resulting in ($L + S$)*(N + P)*R samples, $x_{10}(n)$, at a sample rate of fs3. The upconverter converts the complex baseband modulated signal to a real passband signal, $x_{11}(n)$ for input to a digital-to-analogue (D/A) converter. Details of the individual blocks are provided below.

TABLE 1

Modulator parameter descriptions

Parameter	Description
N	IFFT length
P	Extension length in samples
M	Order of PSK
L	Number of parallel symbols in burst
R	Interpolate rate
S	Number of synch symbols
Fs	Sample rate (Hz)

Design parameter selection

The modulator output has an audio spectrum with a 3 dB bandwidth of 300-3 000 Hz, and a centre frequency of 1 700 Hz. The modulator parameter values are shown in Table 2 for six possible parameter combinations. The number of PSK phases, *M*, is either 4 or 8. The number of subcarriers (*N*) are configurable as *N* = 16, 32, or 64 and were selected so that the resulting subchannel bandwidth, or symbol rate, is less than 200 Hz. The audio CODEC sample rate was selected to satisfy the Nyquist criterion, and is fixed at *Fs* = 8 kHz. The interpolator rate is fixed at *R* = 3, resulting in an overall symbol rate of 8 000/3 = 2 666.66 Hz, and a signal bandwidth of about the same. The values selected for the HF modem are *N* = 32 and *M* = 4.

TABLE 2

Modulator parameter values

N	***P***	***M***	***L* long**	***L* short**	***R***	***S***	***Fs***
16	2	4	288	32	3	8	8 000
32	4	4	144	16	3	4	8 000
64	8	4	72	8	3	2	8 000
16	2	8	288	32	3	8	8 000
32	4	8	144	16	3	4	8 000
64	8	8	72	8	3	2	8 000

A frame format is defined such that 64 frames are transmitted per long burst, independent of *N*. For the case of *N* = 32, two frames are sent on each of *N* = 32 sub-channels. A summary of the parameters and effective throughputs is shown in Table 3.

FIGURE 1

~~OFDM~~ Orthogonal frequency division multiplexing modulator

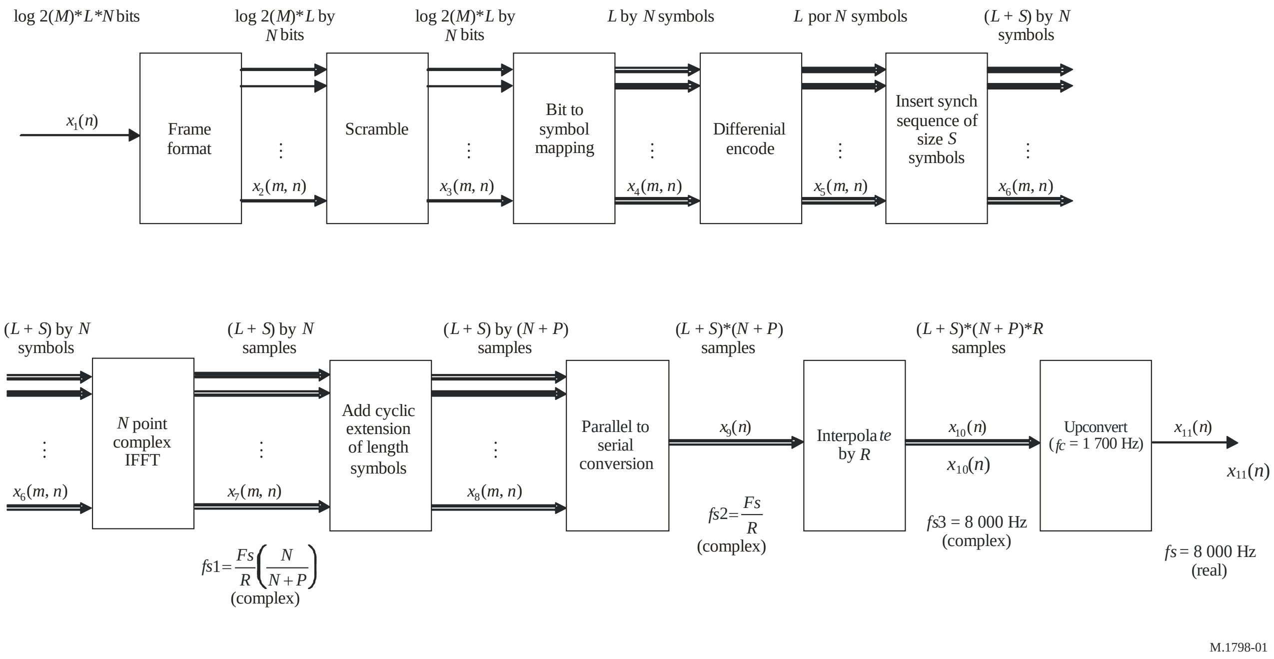


TABLE 3

~~OFDM~~ Orthogonal frequency division multiplexing modem parameters

	$M = 4$ **$N = 32$**
Sample rate out (*Fs*) (samples/s)	8 000
IFFT size (*N*)	32
Extension length (*P*) (s)	4
Interpolate rate (*R*)	3
Data symbols in burst (*L*)	144
Sync symbols in burst (*S*)	4
Phases to modulate (*M*)	4
Sample rate out of IFFT (samples/s)	2 370.3704
Bits input	9 216
Symbols input	4 608
Symbols into IFFT	4 736
Sample rate with extension (samples/s)	2 666.6667
Burst length (s)	1.998
Raw throughput (bit/s)	4 612.6126
Channel symbol rate (samples/s)	83.333333
Sync symbols in short burst (*S*)	4
Data symbols in short burst (*L*)	16
Short burst length (s)	0.27
Propagation delay (s)	0.224
Spacing of bursts (s)	2.492
Bytes per frame	36
Header bytes	4
CRC bytes	4
Effective throughput (bit/s)	2 876.4045
Utilization factor	0.6235955

The value of P was chosen so that the burst length (s) is greater than the maximum HF channel delay spread. Assuming a maximum spread of 2 ms (see Recommendation ITU-R F.1487), the number of required samples at Fs = 8 000 Hz is at least 16. For the case of N = 32, the extension is 1.5 ms (P = 4).

Using the modem parameter values selected, throughput analysis results are shown in Table 4. The signal generated by the OFDM modulator is passed through an HF channel using the model defined in Recommendation ITU-R F.1487. All of the simulations were run using 6 400 frames, or 100 bursts.

TABLE 4

Throughput simulation results for various extension lengths

FFT size (*N*)	**Extension (*P*)**	**Phases (*M*)**	**Throughput *good* channel (bit/s)**	**Throughput *moderate* channel (bit/s)**	**Throughput *poor* channel (bit/s)**
32	4	4	2 088.3	1 632.2	467.7
32	8	4	1 906.6	1 547.8	1 076.5
32	16	4	1 561.9	1 481.4	519.6

The remaining modem parameters to select have to do with burst lengths, or how much information and overhead bits to use in each burst. The protocol selected for the OFDM modem is ARQ, like that used in DATAPLEX, except the number of acknowledgements per burst is multiplied 64 times. Selection of the burst length parameters, *L* and *S*, in Table 3 is determined from analysis of the ARQ performance.

The performance of an ARQ protocol can be represented by a utilization factor (η), which is the proportion of time the transmission is not idle, assuming there is always a frame to be transmitted. For the case of error-free transmission and reception the factor is:

$$\eta = \frac{T_f}{T_f + 2\tau + T_p + T_a} \qquad (1)$$

where:

T_f : frame length

τ: one-way propagation delay

T_p: frame processing time

T_a: acknowledge burst length.

The maximum value of η is 1, which indicates maximum utilization. Selecting parameters that maximize η optimizes performance of an ARQ scheme.

For a channel with the probability of an unsuccessful transmission of a data or acknowledge frame given by P_f, the utilization factor is:

$$\eta = \frac{T_f}{\left(T + T_f\right)\frac{P_f}{1 - P_f} + \left(T_f + 2\tau + T_p + T_a\right)} \qquad (2)$$

where *T* is the retransmit time. Note that for $P_f = 0$, equation (2) becomes equation (1). One method of determining the ARQ parameters is to fix T, τ, T_p, and T_a; and select the optimum T_f for a given P_f.

Assume that for $N = 64$ the short burst requires $L = 8$ symbols to transmit the acknowledgement and $S = 2$ symbols for synchronization. For $N = 32$ and $N = 16$, the parameters are selected to give the same length (ms) as for $N = 64$. This results in a short burst of length $T_a = 270$ ms. Assume a maximum one-way propagation delay of $\tau = 110$ ms, as in DATAPLEX, which allows for a one-way distance of over 20 625 miles. The frame process time, T_p, is significantly less than the other parameters and is set at a value of 100 ms for this analysis.

The overall symbol rate of fs = 2 666.6 Hz with M = 4 and N = 64 results in an effective subchannel bit rate of R_b = log 2(M)*fs/N = 83.33 Hz. The number of bits in a frame is:

$$N_b = R_b T_f \tag{3}$$

and the probability of frame error is:

$$P_f = P_e N_b \tag{4}$$

where P_e is the probability of a bit error. The retransmit time is:

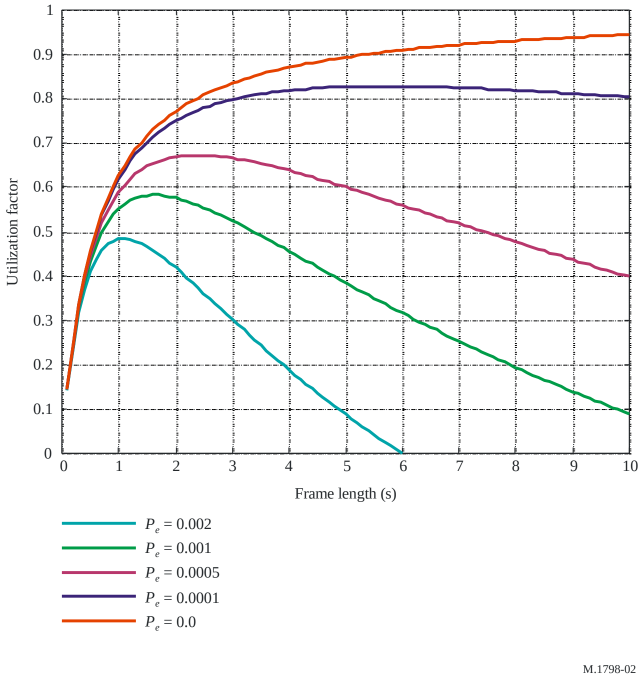
$$T = T_f + T_a + \tau \tag{5}$$

The optimization procedure involves using equation (2) and finding the maximum value of η as a function of T_f for a given P_e.

Figure 2 shows the optimization curves for bit-error probabilities of P_e = 0.002, 0.001, 0.0005, 0.0001, and 0.0. A first try at selection of burst size was to make the frame length nearly the same as for DATAPLEX. For the long burst, selecting L value of 144 for N = 32 results in a burst length of 1.998 as shown in Table 3. For this burst size of 1.998, the resulting utilization factor is nearly optimized for a P_e of about 0.001.

FIGURE 2

~~OFDM ARQ~~Orthogonal frequency division multiplexing automatic repeat request utilization



Long-frame format

Each burst consists of 64 frames with each frame having a 16-bit sequence number (SEQ_NUM), information bits (INFORMATION), and a 16-bit cyclic redundancy check code (CRC). For $M = 4$ there are 14 bytes of INFORMATION for a total frame size of 18 bytes. Figure 3 shows the frame structure for $M = 4$. Input to the frame formatter is log 2(M)*L*N bits and output are N parallel frames of log 2(M)*L bits.

Cyclic redundancy check ~~(CRC)~~

To verify whether the frame received has any errors, a ~~cyclic redundancy check (~~CRC~~)~~ is used. The CRC is the same as that used in DATAPLEX and is transmitted in each the 64 frames in the long burst. The CRC is a 16-bit standard ITU-T with generator polynomial.

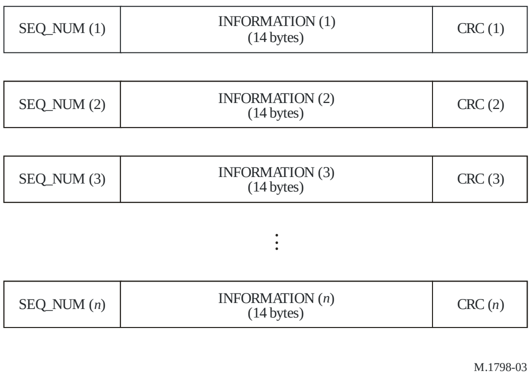
$$x^{16} + x^{12} + x^{5} + 1 \qquad (6)$$

Sequence numbers

A sequence number of length 16 bits is included at the start of each of the 64 frames in a burst. They are used for signifying to the receiver the frame order for parallel-to-serial conversion. The sequence numbers also allow for the possibility of not using all 64 of the frames in a burst for transmission. The generation of the sequence is the function of the protocol layer and is outside the scope of this Recommendation.

FIGURE 3

Frame structure for $M = 4$

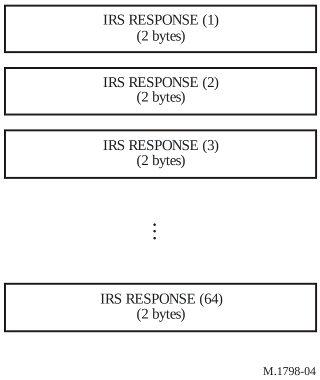


Short-frame format

The short frames are used as acknowledgments to the long frame and have the same function as ~~information receiving station (~~IRS~~)~~ response characters in DATAPLEX. A sequence number or CRC is not required. Shown in Fig. 4 are the frame formats for $M = 4$. In DATAPLEX the IRS RESPONSE is of length 8 bits. For the OFDM modem the IRS RESPONSE is longer and of length 16 or 24 bits, thus allowing for better cross-correlation properties of the IRS RESPONSE than DATAPLEX.

FIGURE 4

Frame structure for $M = 4$



Scrambler

Each of the 64 frames in each burst is scrambled for two beneficial effects. Scrambling produces bit patterns that have statistical properties, which make synchronization algorithms perform better. Another effect of scrambling in OFDM is the introduction of randomization of the subchannel phases. Since OFDM modulation is a sum of N individual band-limited signals, randomizing the phases reduces the peak-to-average power ratio of the modulated signal. Without scrambling, there is a greater potential for the generation of large amplitude spikes, although there is still the possibility of amplitude spikes with scrambling.

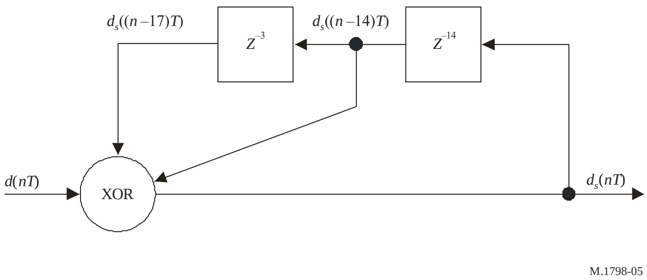
The scrambler is defined by the polynomial $1 + x^{14} + x^{17}$ or by the recursive equation:

$$d_s(nT) = d(nT) \text{ XOR } d_s((n-14)T) \text{ XOR } d_s((n-17)T) \qquad (7)$$

To implement the scrambler, a 17-state register is required along with an exclusive-or function as shown in Fig. 5.

FIGURE 5

Bit scrambler



To prevent the possibility of the same scramble pattern on different frames, the initial starting phase for each of the 64 frames differs by a single iteration. For the first frame, initializing the state register to 0, inputting an alternating 0/1 pattern, and iterating 18 times sets the starting phase.

Scrambling for subsequent frames is done the same except the number of iterations is increased one each time. To save on processing time, the initial state registers could be saved in a table and read when initializing the scrambler for each frame.

Bit to symbol mapping

For M = 4 there are four possible phase values with each phase corresponding to two bits or one symbol. The bits are first mapped to symbols represented by phase values as in Table 5. Another way of representing the symbols is shown as the I and Q amplitudes of a complex signal. Note that the phases are spread at an interval of π/2 for M = 4. Shown in Fig. 6 is a two-dimensional representation of the mapping.

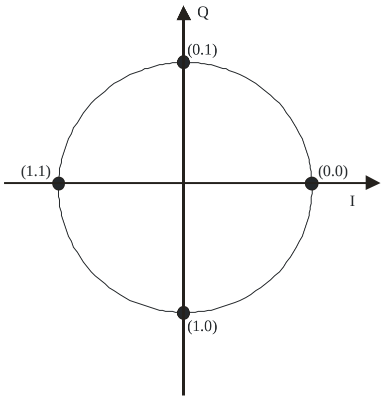
TABLE 5

Bit to symbol mapping for $M = 4$

Input bit pairs x_b		**I value**	**Q value**	**Output phase**
0	0	0	0	0
0	1	0	1	π/2
1	0	0	−1	−π/2
1	1	−1	0	π

FIGURE 6

Mapping for $M = 4$



Differential encode

The symbols out of the bit to symbol mapping are differentially encoded as the cumulative summation:

$$\psi(n) = [\psi(n-1) + \varphi(n)]_{mod\ 2\pi} \quad (8)$$

where ψ(*n*) is the encoded phase output and φ(*n*) is the phase of the mappings in Table 5. The possible encoded phase values are [0, π/2, π, 3π/2] for *M* = 4.

Synchronization sequence

To aid synchronization in the demodulator, *S* symbols are added to the start of each of the *N* parallel symbols prior to the IFFT. There exist methods that can synchronize to as few as two symbols, or no symbols. For larger number of synch symbols, the timing estimate is better at the expense of reduced throughput.

The methodology for synchronization is different for OFDM than of a single carrier modem. Timing information in OFDM is used to determine when to take the FFT, as opposed to when to sample the individual symbol. More about synchronization is found in the demodulator description.

The method of synchronization described in this Recommendation made use of the redundancy produced by the cyclic extension, thus removing the need for a synchronization sequence. The synchronization sequence is included for possible future use.

Inverse fast Fourier transform ~~(IFFT)~~

The IFFT is the main processing function in the OFDM modulator. It combines all the individual parallel signals and makes them orthogonal. The complex IFFT is given by the equation:

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k) e^{j2\pi nk/N}; \; n = 0, 1, 2, \ldots N-1 \qquad (9)$$

where *N* is the size of the IFFT, *X*(*k*) are the input symbols, and *x*(*n*) are the output samples. Note that the IFFT is computed in blocks of *N*, therefore requiring a multiple of *N* input length. Also, note that the output length is the same as the input and is (*L* + *S*) by *N* samples. The sample rate out the IFFT is given by:

$$fs1 = \frac{Fs}{R}\left(\frac{N}{N+P}\right) \qquad (10)$$

Cyclic extension

To combat HF channel multipath effects, the IFFT output is preceded with a cyclic extension of length *P* consisting of the last *P* outputs of each IFFT implementation. This has the effect of maintaining the subcarrier orthogonal condition in the presence of multipath, thus reducing the effect of inter-subcarrier interference. The size of *P* is selected based on the maximum amount of delay spread in the channel. The values, selected above, are *P* = 4, and 8 for *N* = 32.

Parallel to serial conversion

After adding the cyclic prefix, the (*L* + *S*) by (*N* + *P*) samples are converted from parallel to serial resulting in (*L* + *S*)*(*N* + *P*) samples at a rate of *Fs*/*R* = 8 000/3 = 2 666.67 Hz. The structure is shown in Fig. 7.

FIGURE 7

Parallel to serial conversion sample output structure

P(1)	*N*(1)	*P*(2)	*N*(2)	. . .	*P*(*L* + *S*)	*N*(*L* + *S*)

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Each $N + P$ block of samples can be considered a single, wideband symbol with each burst having $L + S$ samples.

Interpolator

An interpolator filter in the form of a linear-phase FIR is used to convert the sample rate from 2 666.67 Hz to 8 000 Hz. The output sample is at the desired D/A converter rate. The filter is designed using the least-squares error minimization technique with a Hamming window. The interpolation rate is $R = 3$ and the filter length is 33. The spectrum and impulse responses are shown in Fig. 8. Figure 9 shows the baseband modulator signal spectrum.

FIGURE 8

Response of the interpolator filter

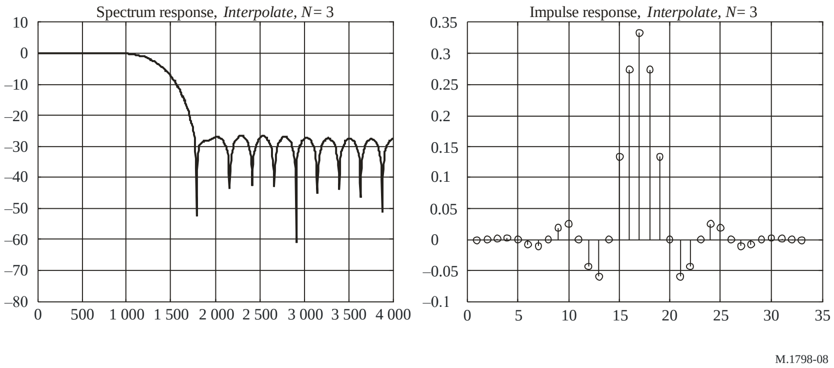
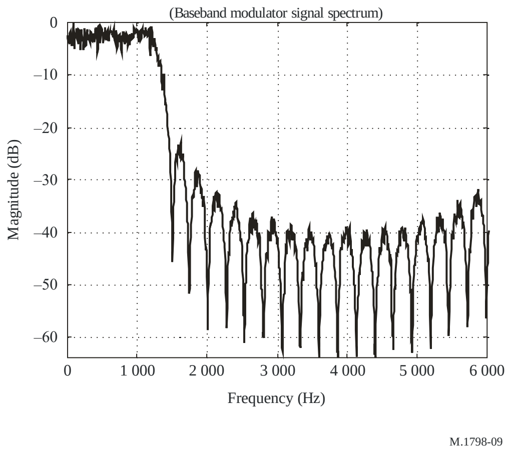


FIGURE 9

Spectrum of the baseband signal



Upconverter

The upconverter converts the baseband signal to a passband signal by mixing with sine and cosine signals at the carrier frequency f_c = 1 700 Hz and summing as shown in Fig. 10. This process also converts the signal from a complex to a real signal as is required for input to an HF radio. The final output sample rate is applied to a D/A converter prior to providing an analogue signal. Shown in Fig. 11 is the spectrum of the OFDM signal.

FIGURE 10

Upconverter

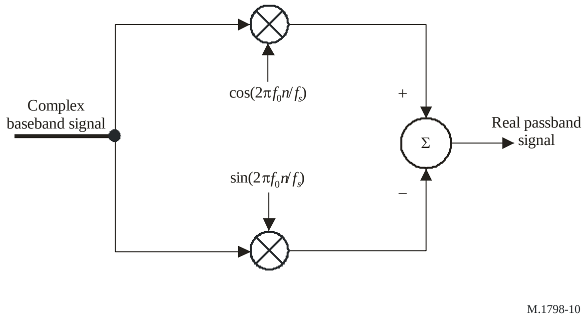
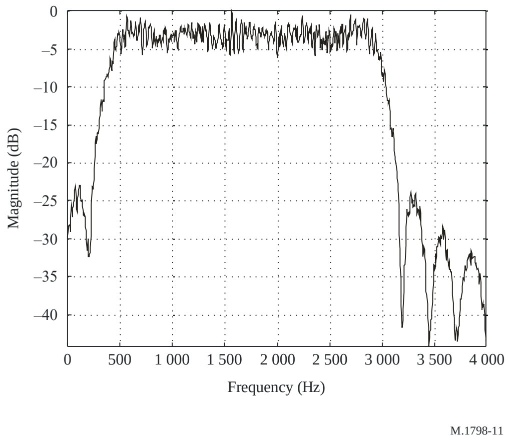


FIGURE 11

Passband modulator signal spectrum



Demodulator

Shown in Fig. 12 is the demodulator architecture. The signal from the A/D converter, $y_1(n)$, at a sample rate of 8 000 Hz and length $(L + S)*(N + P)*R$, is down-converted from a real passband signal into a complex baseband signal, $y_2(n)$. The complex signal, $y_2(n)$, is also used for timing and frequency recovery. The frequency offset, Δf, is used in the downconverter, and the timing recovery, τ_r, is used in selecting the first symbol in the cyclic prefix. The down converter output,

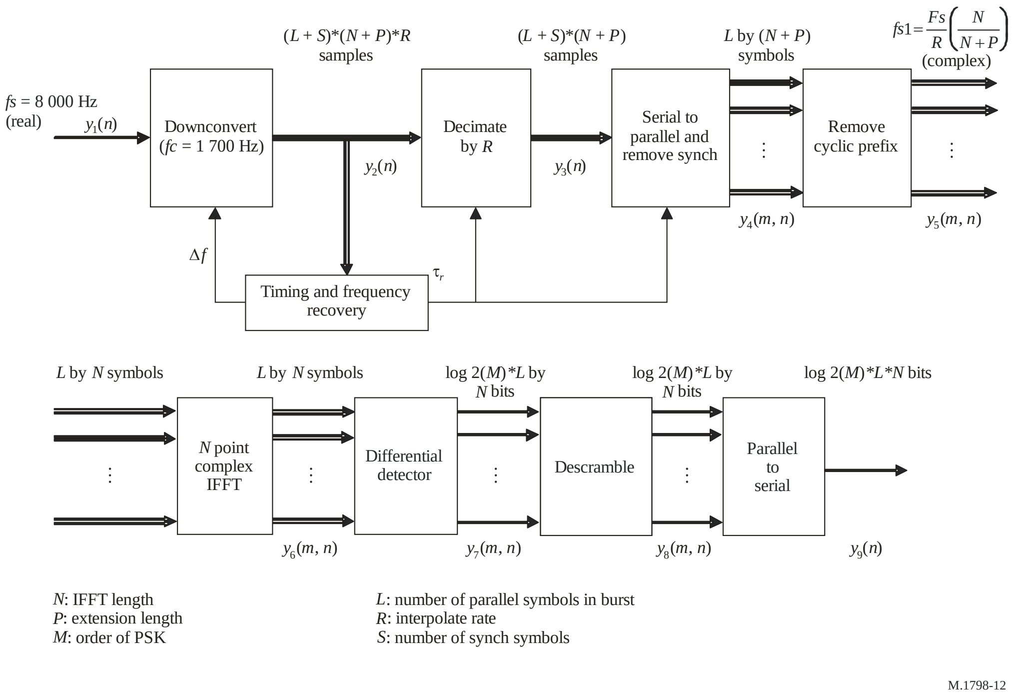
$y_2(n)$, is decimated by R into $(L + S)*(N + P)$ samples, $y_3(n)$. The synchronization symbols are then removed and converted from serial to parallel into L by $(N + P)$ symbols, $y_4(m, n)$. Note that at this stage in the demodulator there is one sample per symbol, so the terms "symbol" and "sample" can be interchanged. The cyclic prefix is removed resulting in L by N symbols, $y_5(m, n)$, at a sample rate of:

$$fs1 = \frac{Fs}{R}\left(\frac{N}{N+P}\right) \quad (11)$$

A complex FFT is then applied to $y_5(m, n)$ resulting in L by N symbols, $y_6(m, n)$. Then a detector recovers the symbols using a differential method, which eliminates the need for recovering the carrier phase, but still requiring recovery of the carrier frequency. Frequency is recovered for all of the subcarriers at the same time and is not required for the individual carriers. The detection is done individually on each of the N subcarriers. The symbols out of the detector are mapped into log $2(M)*L$ by N bits, $y_7(m, n)$, using the same mapping as the modulator. The bits are descrambler using the inverse process as that used in the modulator resulting in log $2(M)*L$ by N bits, $y_8(m, n)$. The bits are then finally converted from parallel to serial resulting in log $2(M)*L*N$ bits, $y_9(n)$. Details of the individual blocks are provided below.

FIGURE 12

~~DPSK~~ Differential phase shift keying demodulator



Downconverter

The downconverter, shown in Fig. 13, performs the reverse operation of the modulator upconverter except the carrier frequency is adaptively updated based on output of the carrier frequency recovery estimators. The input is mixed with quadrature sinusoids at the recovered carrier frequency of $f_0 + \Delta f$. The carrier frequency is f_0 = 1 700 Hz, the sample frequency is f_s = 8 000 Hz, and the frequency offset is Δf. Shown in Fig. 14 is the resulting spectrum output. Note that there is an undesired duplication of the spectrum centred at 2*f_0 = 3 400 Hz which is removed in the next stage of processing.

FIGURE 13

Downconverter

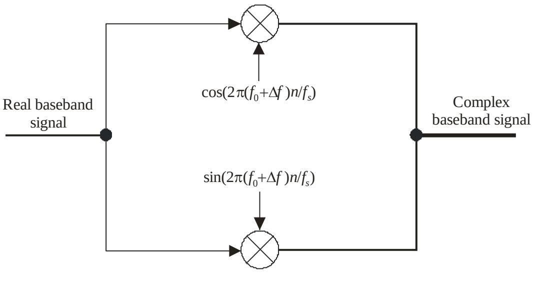


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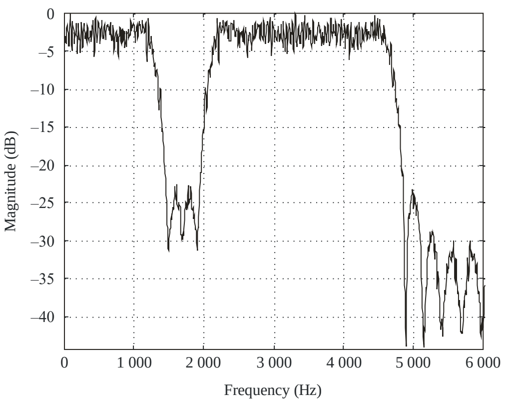
FIGURE 14

Downconverter signal spectrum



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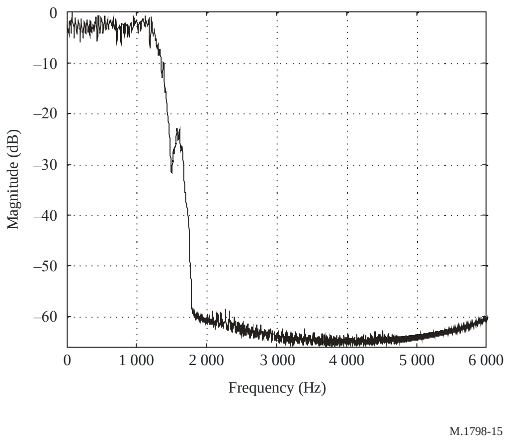
Decimation

The complex downconverter output is decimated by a factor of R = 3 from a sample rate of 8 000 Hz to a sample rate of 8 000/3 = 2 666.67 using the same filter as for interpolation in the modulator. Besides decimating, the band repetition centred at 3 400 Hz is filtered out, leaving the complex baseband signal. Shown in Fig. 15 is the resulting output spectrum.

FIGURE 15

Filtered downconverter signal spectrum



Timing and frequency recovery

Two uncertainties in the demodulator are the arrival time of the OFDM symbol and the carrier frequency. From Table 3 the baseband sample rate is 2 666.7 samples/s and the symbol rate is 83.33 symbols/s. This results in 16 samples/symbol. The timing recovery method uses the initial burst tone to capture the initial sample timing and samples in the middle of each symbol. The resolution is one sixteenth of a symbol and the ideal sample time in eight samples into the symbol.

OFDM is sensitive to frequency offset and the frequency recovery must be accurate to within 1 Hz. The frequency recovery algorithm is able to accurately recover frequencies with an offset up to ±50 Hz.

To accommodate off-frequency ship transmissions, the shore receivers in the network automatically track off-frequency ship transmissions, within legal limits, in order to optimize throughput. Such off-frequency operations are recorded and Customer Support is alerted in order to arrange shipboard equipment service.

Degradation due to frequency offset

The importance of frequency recovery in OFDM is illustrated by comparing the degradation due to carrier frequency offset and Weiner phase noise for multicarrier OFDM and single carrier ~~(SC)~~ signals. Analysis results follow for degradation in bit error rate ~~(BER)~~ due to carrier frequency offset and phase noise over an additive white Gaussian noise (AWGN) channel. Results for both single carrier and multicarrier signals are provided, and it is shown that the multicarrier signals are more sensitive to the each of the two degradation parameters.

$$D \approx \begin{cases} \dfrac{10}{\ln 10} \cdot \dfrac{1}{3}\left(\pi N \dfrac{\Delta F}{R}\right)^2 \dfrac{E_s}{N_0} & \text{OFDM} \\ \dfrac{10}{\ln 10} \cdot \dfrac{1}{3}\left(\pi \dfrac{\Delta F}{R}\right)^2 & \text{SC} \end{cases} \quad (12)$$

where N is the number of OFDM channels, ΔF is the frequency offset in Hz, and R is the symbol rate. Also, the S/N is given by E_s/N_0.

$$D \approx \begin{cases} \dfrac{10}{\ln 10} \cdot \dfrac{11}{60}\left(4\pi N \dfrac{\beta}{R}\right) \dfrac{E_s}{N_0} & \text{OFDM} \\ \dfrac{10}{\ln 10} \cdot \dfrac{1}{60}\left(4\pi \dfrac{\beta}{R}\right) \dfrac{E_s}{N_0} & \text{SC} \end{cases} \quad (13)$$

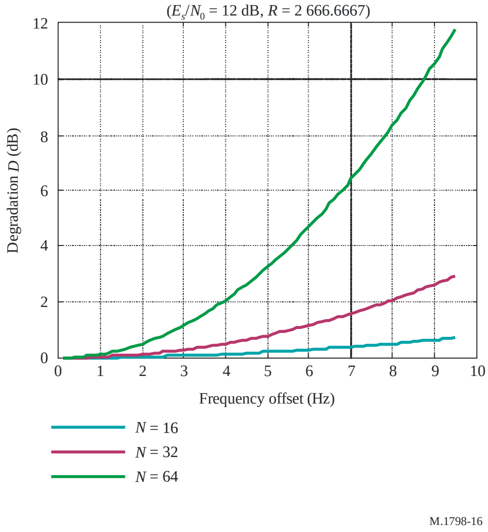
where β is related to the variance of the carrier phase θ by:

$$\sigma_\theta^2 = 4\pi\beta \quad (14)$$

The equations apply to M-PSK and M-QAM modulated signals. For this analysis the target ~~BER~~ bit error rate is 10^{-3}, which for 4-DPSK modulation corresponds to an E_s/N_0 of about 12 dB. The degradation for OFDM due to frequency offset is shown in Fig. 16. Note that there is more degradation for greater values of N.

FIGURE 16

Degradation for ~~OFDM~~ orthogonal frequency division multiplexing due to frequency offset



Serial to parallel conversion

Out of the decimator are $(L + S)*(N + P)$ complex samples. The synchronization symbols are removed and converted from serial to parallel resulting in L by $(N + P)$ symbols.

Cyclic prefix removal

The cyclic prefix is removed from the L by $(N + P)$ symbols resulting in L by N symbols.

Fast Fourier transform (FFT)

The fast Fourier transform (FFT) is the main processing function in the OFDM demodulator. The complex FFT is given by the equation:

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-j2\pi nk/N} \qquad k = 0, 1, 2, \ldots N-1 \tag{15}$$

where N is the size of the FFT, $x(n)$ are the input symbols, and $X(k)$ are the output samples. Note that the FFT is computed in blocks of N, therefore requiring a multiple of N input length. Also, note that the output length is the same as the input and is L by N samples. The sample rate out of the FFT is given by:

$$fs1 = \frac{Fs}{R}\left(\frac{N}{N+P}\right) \tag{16}$$

Differential detection

Output symbols are detected from the phase differences, instead of the absolute phase of the PSK signal, thus giving it the name DPSK. Single-symbol and multiple-symbol detection are shown below.

Single symbol differential detection

The differential encoding of the symbol phase is given as:

$$\varphi_k = \varphi_{k-1} + \Delta\varphi_k \tag{17}$$

The received symbols, given by r_k, are detected using the decision rule:

Choose $\Delta\hat{\varphi}_k$ if $\mathrm{Re}\left\{r_k r_{k-1}{}^{*} e^{-j\Delta\hat{\varphi}_k}\right\}$ is maximum.

For M = 4-PSK modulation the decision process consists of choosing the largest of four values.

Two symbol differential detection

Improvement in differential detection can be obtained my making a decision based on multiple symbols instead of a single one. For AWGN channels the BER approaches that of coherent detection as the number of symbols used in differential detection increases.

The decision rule for a two-symbol detector is:

choose $\Delta\hat{\varphi}_k$ and $\Delta\hat{\varphi}_{k-1}$, if $\mathrm{Re}\left\{r_k r_{k-1}{}^{*} e^{-j\Delta\hat{\varphi}_k} + r_{k-1} r_{k-2}{}^{*} e^{-j\Delta\hat{\varphi}_{k-1}} + r_k r_{k-2}{}^{*} e^{-j(\Delta\hat{\varphi}_k + \Delta\hat{\varphi}_k - 1)}\right\}$ is maximum.

For the case of M = 4-PSK the decision is picking the largest of M^2 = 16 values.

Descrambler

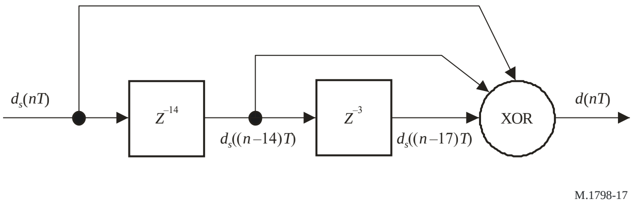
The descrambler is the inverse of the scrambler and is defined by the recursive equation:

$$d(nT) = d_s(nT) \text{ XOR } d_s((n-14)T) \text{ XOR } d_s((n-17)T) \quad (18)$$

To implement the descrambler, a 17-state register is required along with an exclusive or function as shown in Fig. 17.

FIGURE 17

Bit descrambler



The initial phases of the descrambler are set the same as in the scrambler, still using the scrambler implementation.

Parallel to serial conversion

The log2(M)*L by N parallel bits out of the descrambler are converted to log2(M)*L*N serial bits. It is possible to implement the CRC decoder before it is converted from parallel to serial, since the CRC decode is performed on each of the 64 parallel frames in the burst, but it is best performed as part of the protocol layer.

Cyclic redundancy check ~~(CRC)~~ decoder

The CRC decoder is the inverse of the CRC encoder with the generator polynomial:

$$x^{16} + x^{12} + x^5 + 1 \quad (19)$$

If the CRC check fails, the frame is rejected and a request for retransmission is generated.

Frequency selection

In a global communications network with several hundreds of channels, two dozen-plus stations and many thousands of ships moving a high volume of data, it is extremely important to have an efficient frequency selection system. The ALE Mil standard in common use would be totally inadequate and inappropriate in this situation and extremely spectrum-inefficient.

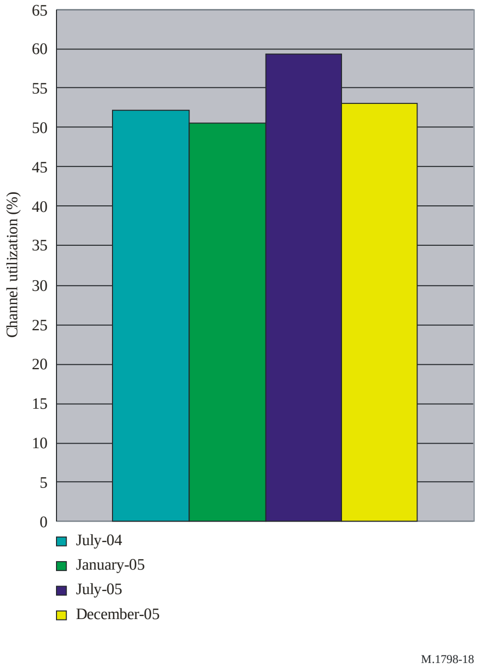
Consequently, one method uses a propagation analysis tool on board the ship that selects frequencies for scanning. Selection decisions are based on dynamically updated current conditions for that date, time and geographic position. This means that there is no waste of spectrum by sounding or attempting links on poor quality channels. The ship looks directly to propagating channels and scans for one that is available (not busy). Current propagation parameters are delivered to ships via the channel “free signals”.

Frequency usage

Ships will typically use a channel for anything from less than a minute up to 30 min. Communications vary from brief data bursts for tracking purposes to large files. The combination of large files and the large number of mobiles means that frequencies are occupied almost continuously. This results in the need for exclusive allocations with no possibility for sharing with other users or services. A recent usage record from one shore node is attached (see Fig. 18). If the available time in this chart was reduced by the daily time period when each frequency was not propagating, it can be seen that the occupancy would be close to 100%.

FIGURE 18

Per cent of channel utilization



Annex 3

Electronic mail system using Pactor-III protocol, including the system used by the Gglobal Llink Nnetwork (GLN)

Emission type

The system uses ITU emission type 2K20J2D.

Bandwidth

The bandwidth needed is two times 3 kHz (one duplex voice channel).

Communication system components

The system has the following components:

Transmission protocol

The system uses the efficient and well-proven PACTOR-III HF transmission protocol. Maximum net throughput with online data compression is approximately 5 200 bit/s. A description of the protocol is provided in § 4.1.

T-BUS communication protocol

The system uses the T-BUS communication protocol in order to control standard GMDSS HF/MF radio equipment. T-BUS is used by maritime radio manufacturers Skanti and Sailor (and others) in their GMDSS radio equipment. There are several versions of the T-BUS protocol, a description of the Skanti communication protocol is provided in § 4.2.

Modem

It is possible to use different types of modems as long as they can handle RS-232 communications with T-BUS protocol. The Norwegian system uses PTC-II modems.

Replacement for narrow-band direct printing (NBDP)

The HF Mail system is presently able to replace NBDP for general communications, probably also for safety and distress communications in the future.

1 The PACTOR-III protocol (Technical Description by Hans-Peter Helfert and Thomas Rink, SCS GmbH & Co. KG, Hanau, Germany)

1.1 Introduction

Similar to PACTOR-I and PACTOR-II, PACTOR-III is a half-duplex synchronous ARQ system. In the standard mode, the initial link setup is performed using the FSK (PACTOR-I) protocol, in order to achieve compatibility to the previous systems. If both stations are capable of PACTOR-III, automatic switching to this highest protocol level is performed.

While PACTOR-I and PACTOR-II were developed for operation within a bandwidth of 500 Hz, PACTOR-III is designed specifically for the commercial market to provide higher throughput and improved robustness utilizing a complete SSB channel. A maximum of 18 tones spaced at 120 Hz is used in optimum propagation conditions. The highest raw bit rate transferred on the physical protocol layer is 3 600 bit/s, corresponding to a net user data rate of 2 722.1 bit/s without data compression. As different kinds of online data compression are provided, the effective maximum throughput depends on the transferred information, but typically exceeds 5 000 bit/s, which is more than 4 times faster than PACTOR-II. At low SNR, PACTOR-III achieves a higher robustness compared to PACTOR-II.

The ITU emission designator for PACTOR-III is 2K20J2D.

1.2 Speed levels ~~(SLs)~~ and bandwidth

Depending on the propagation conditions, PACTOR-III utilizes 6 different speed levele (SLs), which can be considered as independent sub-protocols with distinct modulation and channel coding. The symbol rate is 100 bauds on all SLs. Up to 18 tones are used, spaced at 120 Hz. The maximum occupied bandwidth is 2.2 kHz (from 400 to 2 600 Hz). The centre frequency of the entire signal is 1 500 Hz. The tone representing the “lowest” channel is sent at a frequency of 480 Hz, the highest tone is 2 520 Hz. As tones are skipped on the two lowest SLs, the gaps between them increase to *N* times 120 Hz in these cases. Figure 19 illustrates the number and position of the used channels at the different SLs.

Similar to the PACTOR-II protocol, the digital data stream that constitutes a specific virtual carrier is swapped to a different tone with every ARQ cycle in order to increase the diversity gain by adding additional frequency diversity. Considering that in the normal state the numbers of the virtual data carriers correspond with the numbers of the respective tones, the swapped mode assigns carrier 0 with tone 17, 1 with 16, 2 with 9, 3 with 10, 4 with 11, 5 with 12, 6 with 13, 7 with 14 and 8 with 15. Tones 5 and 12 can be considered as equivalent to the two carriers of PACTOR-II, as they transfer the variable packet headers and the control signals (see below).

FIGURE 19

Number and position of the used channels at the different ~~SLs~~speed levels

	CN	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SL																			
1							x							x					
2					x		x		x			x		x		x			
3				x	x	x	x	x	x	x	x	x	x	x	x	x	x		
4				x	x	x	x	x	x	x	x	x	x	x	x	x	x		
5			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
6		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	TF	480	600	720	840	960	1 080	1 200	1 320	1 440	1 560	1 680	1 800	1 920	2 040	2 160	2 280	2 400	2 520

CN: channel number
TF: tone frequency (Hz)
x: indicates that the tone is used in the perspective SL

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1.3 Modulation, coding, and data rates

As modulation, either differential binary PSK (DBPSK) or differential quadrature PSK (DQPSK) is applied. After full-frame bit-interleaving of the entire data packet, an optimum rate 1/2 convolutional code with a constraint length (CL) of 7 or 9 is used. Similar to the PACTOR-II protocol, the codes with higher rates, i.e. rate 3/4 and rate 8/9, are derived from that code by so-called puncturing: Prior to the transmission, certain bits of the rate 1/2 encoded bit stream are “punctured”, i.e. deleted and thus not transmitted. At the receiving side, the punctured bits are replaced with “null” bits prior to decoding with the rate 1/2 decoder. The decoder treats these null bits neither as a "1" nor as "0", but as an exactly intermediate value. Thus, these bits have no influence on the decoding process. The coding gain of a "punctured" code nearly matches the coding gain of the best known specific rate 3/4 or 8/9 codes with a comparable constraint length, provided that the puncture pattern is chosen carefully. The major advantage of this approach is that a single code rate decoder (in our case a rate 1/2 decoder) can implement a wide range of codes. Therefore, punctured codes are used in many modern communication systems. In the SCS modems, a Viterbi decoder with soft decision is used for all speed levels, yielding a maximum of coding gain.

Figure 20 shows the modulation, the CL and the code rate (CR) of the applied convolutional code, the physical data rate (PDR), i.e. the raw bit rate transferred on the physical protocol layer, the net data rate (NDR), i.e. the uncompressed user data rate, as well as the crest factor (CF) of the signal for the different SLs.

The following two figures show the BERs for the different speed levels. In Fig. 21, the rates are referenced to the normalized energy per bit (E_b/N_0). Due to the different number of tones (2-18) and the different modulations (DBPSK/DQPSK), this figure does not reveal the performance with respect to the channel *S*/*N*. Thus, in Fig. 22, the rates are referenced to the channel *S*/*N* at a channel bandwidth (BW) of 3 kHz. The different speed levels cover a wide *S*/*N* range. For maximum throughput with SL6, a channel *S*/*N* of 14 dB is required.

FIGURE 20

Parameters of the different ~~SLs~~speed levels

SL	Modulation	CL	CR	PDR	NDR	CF (dB)
1	DBPSK	9	1/2	200	76.8	1.9
2	DBPSK	7	1/2	600	247.5	2.6
3	DBPSK	7	1/2	1 400	588.8	3.1
4	DQPSK	7	1/2	2 800	1 186.1	3.8
5	DQPSK	7	3/4	3 200	2 039.5	5.2
6	DQPSK	7	8/9	3 600	2 722.1	5.7

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It should be noted, that the performance in terms of throughput (bit/s) depends on the implementation of the ARQ protocol and cannot be deduced from the physical data rates and the BERs. Performance measurements will be presented below.

FIGURE 21

~~BER~~ Bit error rate for the different ~~SLs~~ speed levels with respect to the energy per bit

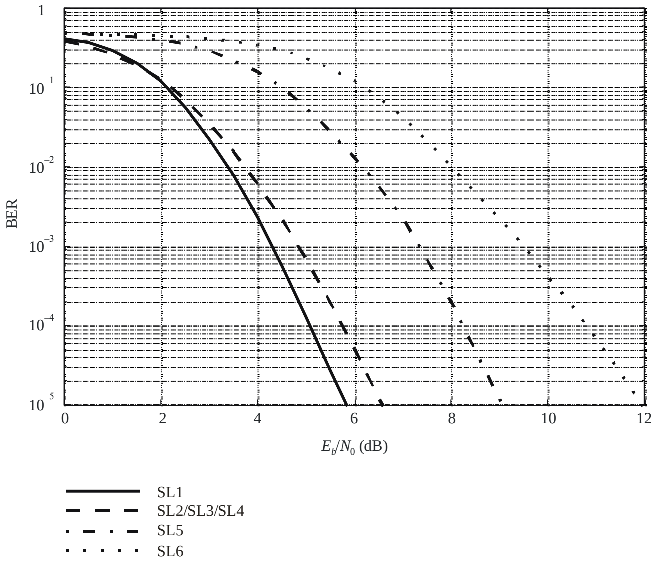

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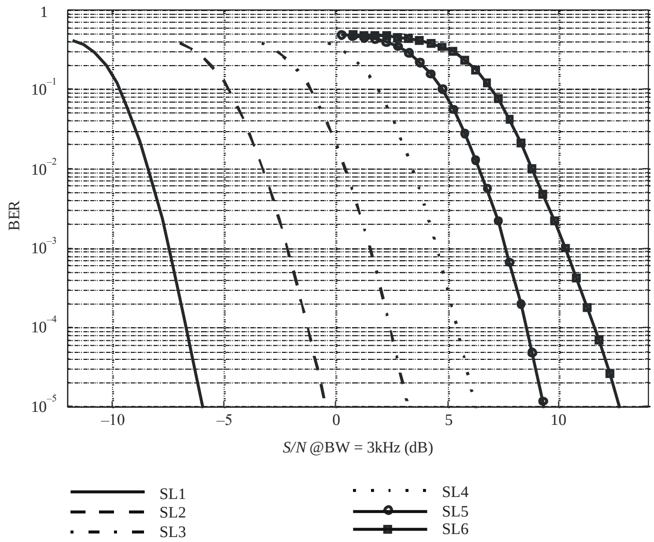
FIGURE 22

~~BER~~ Bit error rate for the different ~~SLs~~ speed levels with respect to the channel *S*/*N*



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1.4 Crest factor ~~(CF)~~ and transmitter output power

One of the most important characteristics of the PACTOR-III signal is the low crest factor (CF), especially with the lower SLs. As most HF power amplifiers are peak-power limited and use a peak-power automatic level control ~~(ALC)~~, PACTOR-III provides considerably more transmitter output power than comparable multicarrier modes like, for example, OFDM modes when using the same power amplifier, thereby increasing the *S*/*N* at the receiver. Up to SL4, the CF fairly compares to the CF of single-carrier modes. Even with SL5 and SL6, the CF is about 3 dB lower than the CF of typical OFDM modes, thereby doubling the transmitted RMS power. In the context of Digital Radio Mondiale ~~(DRM)~~, it has been found that single-carrier modes perform much better than OFDM modes if the coding is weak (rate > 2/3); OFDM modes without coding are well known to be a disaster when used over highly frequency selective channels. With strong coding (rate <= 1/2), OFDM modes perform slightly better than single-carrier modes. These results are based on two assumptions:

a) the transmitted RMS power is the same for both modes, meaning that the peak power of the OFDM mode is several dBs higher than that of the single-carrier mode;

b) an optimum ~~DFE~~ decision feedback equalizer is used with the single-carrier mode (an optimum MLSE equalizer cannot be used because the channel impulse response is too long).

If the peak power is held constant, the single-carrier mode performs better for all reasonable coding rates, but the required optimum ~~DFE~~decision feedback equalizer presents an inevitable obstacle. PACTOR-III is designed to provide the benefits of both modes by minimizing the CF and avoiding the use of an equalizer.

SCS modems operate with constant peak power at all speed levels to optimally exploit the available output power of peak-power limited HF power amplifiers. Thus, the RMS output power changes when switching through the speed levels, due to the different CFs. The channel *S*/*N* at the receiver changes accordingly. This has to be kept in mind when interpreting the BERs in Fig. 22.

1.5 Cycle duration

In the standard mode, the ARQ cycle durations are 1.25 s (short cycles) and 3.75 s (data mode), which is one of the requirements to obtain easy compatibility to the previous PACTOR standards. In this mode, due to signal propagation and equipment switching delays, PACTOR-III is capable to establish ARQ links over a maximum distance of around 20 000 km. To further extend the maximum distance, a Long Path Mode is available, enabling ARQ links up to a maximum distance of 40 000 km, with cycle times of 1.4 s (short cycles) and 4.2 s (data mode), respectively. The calling station initiates a link in Long Path Mode by inverting the first byte of the call sign in the FSK connection frame (for details, see the PACTOR-I protocol description).

1.6 Structure of packets and control signals

Except from different data field lengths, the basic PACTOR-III packet structure is similar to the previous PACTOR modes. It consists of a packet header, a variable data field, a status byte and a CRC. Two types of headers are used: Sixteen variable packet headers consisting of 8 symbols each are sent alternately on tones 5 and 12 to code 4 bits of information: bit 0 defines the request-status indicating a repeated packet. Bits 2 and 3 specify the speed levels 1 to 4 according to a modulo-4 logic, whereas the detection of levels 5 and 6 is performed by additionally analyzing the constant packet headers. Bit 4 gives the current cycle duration: “0” specifies short and “1” data cycles. Figure 23 shows the hexadecimal codes of the variable packet headers.

FIGURE 23

Definitions of the variable packet headers (initiating tones 5 and 12)

VH0	0x1873174f	VH1	0xfc0f6047	VH2	0x0a4c7ea7	VH3	0x09bce11f
VH4	0x8e67c43c	VH5	0x7268a47b	VH6	0x842bba9b	VH7	0x87db2523
VH8	0x4d55aa6a	VH9	0xb15aca2d	VH10	0x4719d4cd	VH11	0x44e94b75
VH12	0x3ccd91a9	VH13	0xc0c2f1ee	VH14	0x3681ef0e	VH15	0x357170b6

M.1798-23

The remaining tones 1-4, 6-11 and 13-18 are preceded by constant headers that characterize the respective tones without transferring any additional information. They support frequency tracking, memory-ARQ, the listen-mode and the detection of the speed levels 5 and 6. Figure 24 presents the hexadecimal codes of the constant packet headers.

FIGURE 24

Definitions of the constant packet headers (initiating tones 1-4, 6-11, 13-18)

CH0	0xc324	CH1	0xf987	CH2	0xblc8	CH3	0xf370
CH4	0x801d	CH5	0x7c3d	CH6	0xd8f1	CH7	0x5a3c
CH8	0x792d	CH9	0x8397	CH10	0x33aa	CH11	0x5a3c
CH12	0x823c	CH13	0x073f	CH14	0xf798	CH15	0xd801

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The headers are followed by the data fields that transfer the user information. On the 6 different speed levels, 5, 23, 59, 122, 212, and 284 payload bytes are transferred in the short cycle and 36, 116, 276, 556, 956, and 1 276 payload bytes in the long cycle, respectively. After de-interleaving and decoding of the entire data transferred on all tones within a certain cycle, the actual information packet is obtained, which consists of the user data, a status byte and 2 CRC bytes. The status byte characterizes the packet by a two-bit packet counter to detect repetitions (bit 0 and 1), provides information on the applied data compression (bits 2, 3 and 4), suggests to switch to the data mode when the amount of characters in the transmit buffer exceeds a certain number (bit 5), indicates a changeover request (bit 6) and initiates the link termination protocol (bit 7). For details, see the graphic below. The final part of the packet is a 16-bit CRC calculated according to the CCITT-CRC16 standard.

PACTOR-III uses the same set of six 20-bit control signals (CS) as PACTOR-II. They are transmitted simultaneously on the tones 5 and 12 and all have the maximum possible mutual hamming distance to each other. Hence they reach exactly the Plotkin boundary and represent a perfect code. This allows the use of the cross correlation method for CS detection, a kind of soft decision that leads to the correct detection of even inaudible CS, due to the high correlation gain. CS1 and CS2 are used to acknowledge/request packets and CS3 forces a break-in. CS4 and CS5 handle the speed changes: CS4 demands an increase of the speed to the next higher level. CS5 acts as a NAK asking for a repetition of the previously sent packet and at the same time for a reduction of the speed to the next lower level. CS6 is a toggle for the packet length and inquires a change to long cycles in case that the actual state is short cycles and vice versa. All CS are always sent in DBPSK in order to obtain maximum robustness.

Figure 25 illustrates the PACTOR-III ARQ operation.

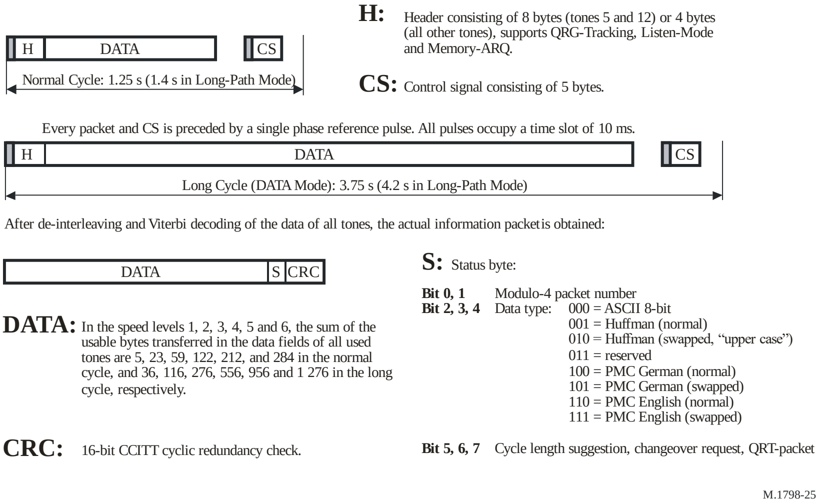
1.7 Online data compression

Like in the previous PACTOR modes, automatic online data compression is also applied in the PACTOR-III protocol, comprising Huffman and run-length encoding as well as Pseudo-Markov Compression (PMC), (see below). The information sending system (ISS) automatically checks, whether one of these compression modes or the original ASCII code leads to the shortest data package, which depends on the probability of occurrence of the characters. Hence, there is no risk of losing throughput capacity. Of course, PACTOR-III is still capable to transfer any given binary information, e.g. programs or picture and voice files. In case of a binary data transfer, the online data compression normally switches off automatically due to the character distribution. An external data compression in the terminal program is usually performed instead.

Huffman compression exploits the “one-dimensional” probability distribution of the characters in plain texts. The more frequently a character occurs, the shorter its Huffman symbol has to be. More details including the code table used in the PACTOR protocols can be found in the description of the PACTOR-I standard.

FIGURE 25

PACTOR-III ~~ARQ~~ automatic repeat request operation



Markov compression can be considered as a double Huffman compression, since it not only makes use of the simple probability distribution, but of the two-dimensional probability. For each preceding character, a probability distribution of the very next character can be calculated. For example, if the actual character is “e”, it is very likely that “i” or “s” occurs next, but extremely unlikely that an “X” follows. The resulting probability distributions are much more concentrated than the simple one-dimensional distribution and thus lead to a considerably better compression. Unfortunately, there are two drawbacks: Since for each ASCII character a separate coding table is required, the entire Markov coding table becomes impractically large. Additionally, the two-dimensional distribution and thus the achievable compression factor depends much more on the kind of text than the simple character distribution. We have therefore chosen a slightly modified approach which we called Pseudo-Markov Compression (PMC), because it can be considered as a hybrid between Markov and Huffman encoding. In PMC, the Markov encoding is limited to the 16 most frequent "preceding" characters. All other characters trigger normal Huffman compression of the very next character. This reduces the Markov coding table to a reasonable size and also makes the character probabilities less critical, since especially the less frequent characters tend to have unstable probability distributions. Nevertheless, for optimum compression, two different tables for English and German texts are defined in the PACTOR-II and PACTOR-III protocols and automatically chosen. When transferring plain text, PMC yields a compression factor of around 1.9 compared to 8-bit ASCII.

Run-length encoding allows the effective compression of longer sequences of identical bytes. The special prefix byte "0x1D" is defined, which initiates a 3-byte run length code. The second byte is called the "code byte" and contains the original code of the transferred byte within the range of the entire ASCII character set. The third byte provides the number of code bytes to be displayed on the receiving side within the range between "0x01" to "0x60". Values between "0x00" and "0x1f" are transferred as "0x60" to "0x7f", values between "0x20" and "0x60" are transferred without any change. For example, the sequence "AAAAAAAA" is transferred using the 3-byte run-length code "0x1D 0x41 0x68".

1.8 Signal characteristics and practical considerations

As the FSK PACTOR standard is used for the initial link establishment, frequency deviations of the connecting stations of up to ±80 Hz are still tolerated. Similar to the PACTOR-II mode, a powerful tracking algorithm is provided in the SCS modems to compensate any divergence and exactly match the signals when switching to the DPSK mode, which requires a high frequency accuracy and stability.

The PACTOR-III signal provides a very high spectral steepness in order to avoid any spillover in adjacent channels. Therefore, low quality audio filters may cause distortion of the side tones of the higher speed levels, both on the transmitting and on the receiving side. To partly compensate for that, SCS modems allow the amplitude of the signal edges to be enhanced individually in two steps using the "Equalize" command, which defines the function of the PACTOR-III transmit equalizer. A value of "0" switches this function off, "1" means a moderate, and "2" a strong enhancement of the side tones of the signal.

Further, it has to be taken into consideration, that, due to the different possible "tones" settings related to the FSK mode used for the initial link setup, a shift of the center frequency of the signal may occur with the automatic switching to PACTOR-III. Therefore, the "tones" settings should be checked carefully and adapted to the other stations in the network in order to make sure that no offset occurs between the linked stations and the PACTOR-III signal is placed symmetrically within the filter bandwidth. Usually, identical "tones" settings on both sides of a PACTOR-III link are required for proper operation. SCS recommends to set "tones" to "4", defining the FSK connection tones as 1 400 and 1 600 Hz, which are balanced around the PACTOR-III center frequency of 1 500 Hz, to avoid incompatibilities between PACTOR-III users.

Figure 26 shows the spectrum of a PACTOR-III signal at speed level 6 with all 18 tones active.

1.9 Performance measurements

The performance of ARQ modes with different speed levels critically depends on the implementation of the ARQ protocol and the automatic selection of an appropriate speed level for the given channel conditions. PACTOR-III comprises memory-ARQ to smooth the transitions between speed levels and to improve the throughput at low *S*/*N* ratios. In memory-ARQ, the combination of re-transmitted data packets allows for safe data transmission over extremely bad channels even if each received packet is corrupted. Figure 27 presents the results of throughput measurements over an ~~additive white Gaussian noise channel (~~AWGN~~)~~ channel and poor channel. The *S*/*N* is evaluated with respect to the RMS output power at SL1 to correct for the different CFs. Due to the bit error rates presented in Fig. 22, the maximum throughput of 2 720 bit/s should be achieved with SL6 at a channel *S*/*N* of more than 14 dB with respect to the RMS output power at SL6. According to Fig. 20, the CFs of SL1 and SL6 differ by 3.8 dB. Therefore, the maximum throughput should be achieved at a channel *S*/*N* of more than 18 dB with respect to the output power at SL1 which fairly agrees with the measured AWGN throughput in Fig. 27.

FIGURE 26

Spectrum of a PACTOR-III signal at ~~SL6~~ speed level 6 with all 18 tones active

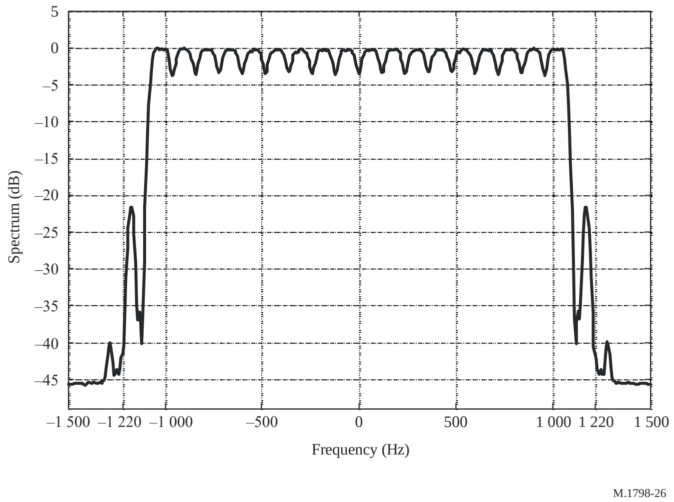


FIGURE 27

Throughput of PACTOR-III

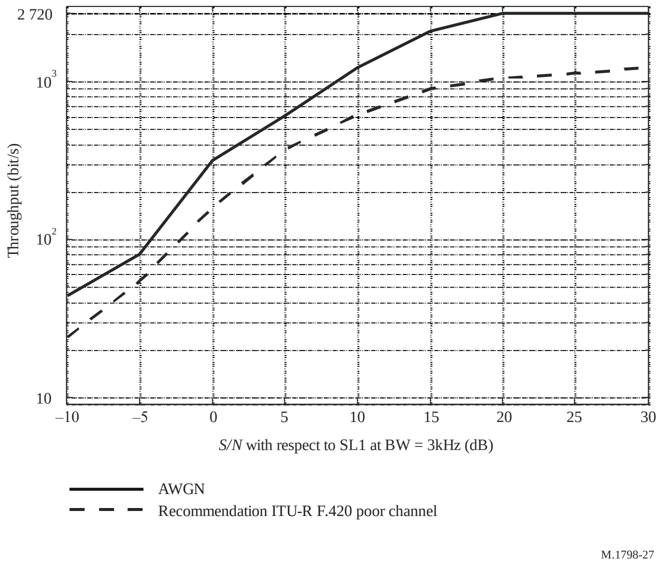


FIGURE 28

~~BER~~ Bit error rate for the different ~~SLs~~ speed levels with respect to the energy per bit

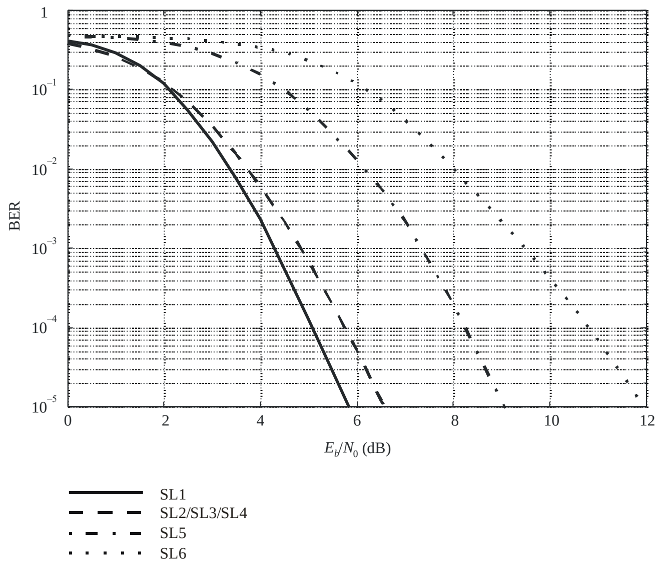
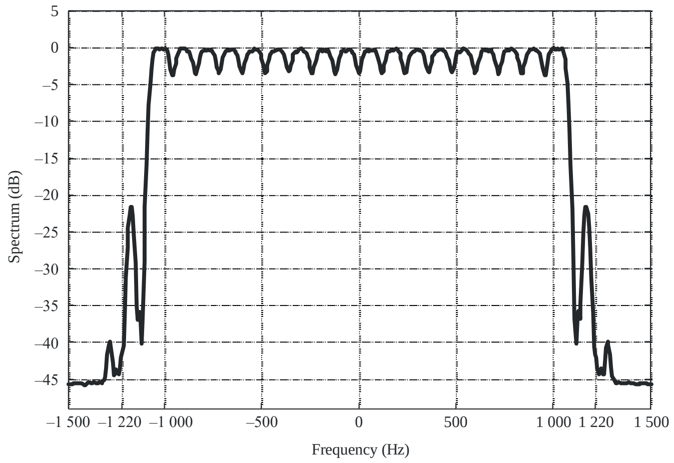


FIGURE 29

Spectrum of a PACTOR-III signal at ~~SL~~ speed level 6 with all 18 tones active



2 Typical communication protocol ~~(T-BUS)~~

Interface Protocol

Physical characteristics:

8 data bits,
1 start bit,
1 stop bit,
1 parity bit,
odd parity,
2400 bit/second.

Word formats:

Address word

Sync	T/R	Remote Terminal Addr.

Reserved addresses:

C2h : Receiver
C3h : Transmitter
FFh : Broadcast

Command word

Subadr./mode	Wdcnt/modecod

Reserved commands:

00h : Reset
14h : Telex mode & frequency input
*) 24h : USB mode & frequency input
*) 34h : AM mode & frequency input
*) 44h : CW mode & frequency input
*) 85h : Set scan table entry & radiomode/entry nr. & frequency input
*) 90h : Step to next entry
*) A0h : Empty table
*) B1h : Go to table entry & entry nr.

*) Commands concerning DSC.

Data words

Frequency input:

10 MHz	1 MHz
100 kHz	10 kHz
1 kHz	100 Hz
10 Hz	1 Hz

Radio mode + entry nr. :

Radio mode	Entry nr.

1h : Telex mode Entry nr. = { 0h .. Fh }
2h : USB mode
3h : AM mode
4h : CW mode

Entry nr. :

Not used	Entry nr.

Entry nr. = { 0h .. Fh }

Status word

Err			Remote Term Addr.

Err : Error return status.

Message Format:
A message consists of an Address word followed by a Command word and possible corresponding Data words.

Example: TX 19.1201 MHz in Telex mode.

C3h
14h
19h
12h
01h
00h

3 Global ~~L~~link ~~N~~network ~~(GLN)~~

General overview

The global link network (GLN) is a network of cooperating coastal radio stations (CRSs) offering data access for the maritime mobile service. Due to the increasing demand for e-mail transfer and internet access on sea going vessels and the decreasing use of ~~narrow-band direct-printing (~~NBDP~~)~~ and radio telex, these radio stations now offer data services on shortwave.

Organizational structure

All CRSs are operated by independent companies. These companies have joined together to form the GLN. They use common technology and common modulation. The CRS are free to offer their own additional services depending on local requirements. If the connection to the network control centre (NCC) fails for political, military or other reasons, every station is able to operate independently. In such cases the CRSs may also offer long-distance communications outside the main communication networks.

Technical structure

The GLN is based on the so called Pactor IP-Bridge (PIB). PIB enables transparent data connections based on the TCP/IP protocol over 2k4 radio channels in all the maritime MF/HF bands. PIB may be used for any type of data service with a maximum transfer speed up to 5 600 bit/s compressed. All network servers operate with a Linux OS and additional software packages which ensure a high fail-safe performance.

NCC

The NCC is operated under an agreement with the CRSs. It is responsible for data bases, accounting, backup, data security and development. The NCC also operates a mail server for small stations without their own data infrastructure. The NCC offers basic data services like weather information, e-mail online compression, web mail, tracking and crew e-mail to all customers of the GLN network.

CRS

The CRSs hold one or more radio channels on standby for automated data links between vessels and the internet. They may offer additional services like data transfer (FTP), credit card services, web hosting and wireless server administration to specific customers. All CRSs continue to function if the connection to the NCC fails. The CRSs are responsible for their site installations, frequency assignments through their national authorities, power fail systems and solid IT infrastructures at their own locations. They are also responsible for all regulations, endorsements and licenses required by the local authorities. All CRSs may be operated remotely.

The CRSs use fixed frequencies in semi-duplex or simplex mode. They transmit a 100-baud FSK beacon signal on those channels which are not occupied. The beacon signal contains channel quality information, an appropriate call sign and information about channel availability. A Morse identifier may be inserted into the beacon signal if required.

Traffic lists are transmitted at regular intervals by all CRSs.

Ship earth station ~~(SES)~~

The application required to join the GLN should be forwarded to a CRS. This application allows the ship earth station (SES) to access any CRS inside the GLN without any additional registrations. To obtain an automated link, the SES may use existing MF/HF radios or a dedicated radio. The radio is connected to a specific communication server or the control software of the communication server may be integrated into new GMDSS terminals. The communication server may be connected to a ships data network and is a standard e-mail and web server. The server automatically selects the best free channel if data transfer is requested by the user. It also offers fallback capabilities if no radio channel are available.

Internet

All interconnections between the CRSs are via the internet. The CRSs may be connected to the internet by any available service like SDSL, ADSL, ISDN, or Dialup modems as well as Wi-Fi and satellite link. The total bandwidth per radio channel should not be less than 10 kbit/s. A fixed IP is not required for the radio sites. The GLN offers direct access to any web server world wide.

Interfacing

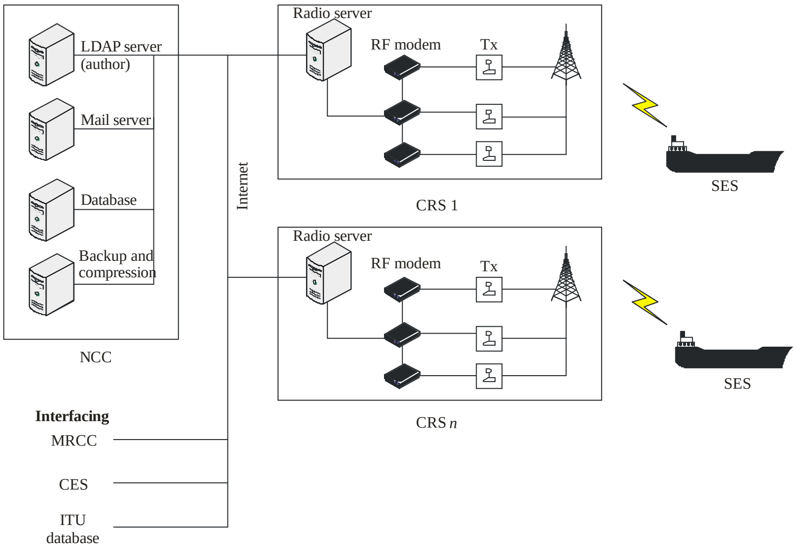
Due to the employment of standard internet technology at any part of the network, the GLN network is open for any additional services such as transfer of telemetric data, chat communications with other networks, position transfers and also for ship/ship and ship/shore communications.

Data security

Data is encrypted on all segments of intercommunication between the CRSs, SES and the NCC. Moreover, the data transferred on the radio link can not be read by other radio listeners. Firewalls, spam filters, virus scan and other security facilities are self-evident.

FIGURE 30

~~GLN~~ Global link network general overview



MRCC: maritime rescue coordination centre.

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Services

The GLN offers commercial communications as well as all types of communications which are currently covered by the radio telex system as part of the GMDSS. Because the PIB is able to transfer data below a *S*/*N* of 0, links are established under difficult conditions.

E-mail service

The GLN enables access to any e-mail server on the world wide web. Attachments and documents can be forwarded via GLN to and from shore. All data will be compressed online and interrupted connections will resume automatically with no double data transfer.

Weather information service

The GLN offers free weather download to all SESs. This includes weather faxes and forecasts as well as ice cards and grip data.

Vessel tracking

Position information is transmitted with every connection from SES to NCC and may be forwarded to any tracking service or e-mail address. An NMEA 0183 port is implemented to the system.

Crew mail

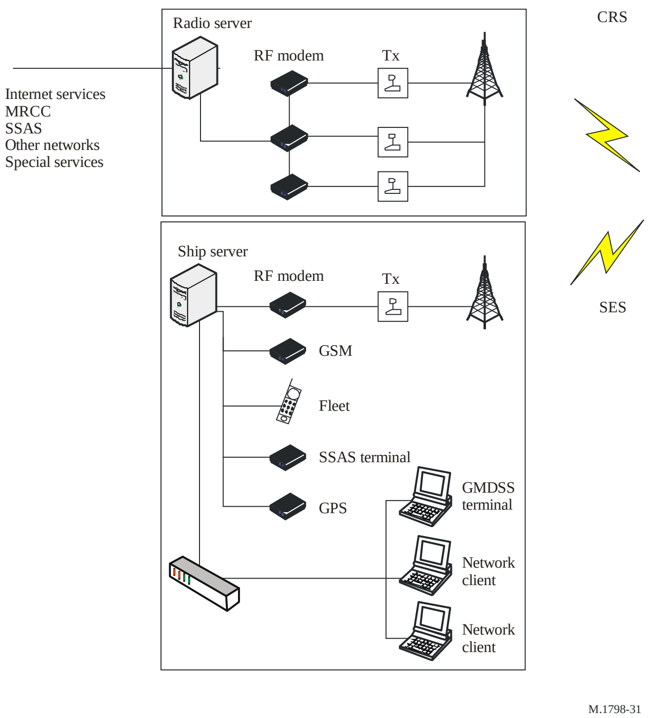
Up to 255 e-mail accounts may be implemented per vessel. They may be charged to the shipping company or the crew may pay by credit card directly to the CRS.

Ship security alert system (SSAS)

SSAS capability is implemented in the system.

FIGURE 31

Coastal radio and ship station overview



Coverage

The GLN offers world wide coverage. It is not a closed network and is open for new sites at any time. New stations inside the network benefit from worldwide coverage for vessels from the beginning. This is made possible by roaming technologies.

Range

Depending on their location and quality of radio equipment, environmental noise, antennas and transmission power used, the average range of each station is between 1.750 and 2.500 nautical miles.

FIGURE 32

~~GLN~~ **Global link network radio stations worldwide**
(August 2006)

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Locations (August 2006 – subject to change)

Norway, 3 sites, up to 12 channels, 6 MHz, 8 MHz, 12 MHz

Germany, 1 site, 9 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz

Switzerland, 1 site, 10 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz

Kenya, 1 site, 15 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz

Republic of South Africa, 1 site, 15 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz

Angola, 1 site, 15 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz

China, 1 site, 5 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz

Philippines, 1 site, 5 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz

Australia, 1 site, 5 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz

Argentina, 1 site

Chile, 1 site
USA, RI, 1 site, 5 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz
USA, WA, 1 site, 5 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz
USA, AL, 1 site, 5 channels, 4 MHz, 6 MHz, 8 MHz, 12 MHz, 17 MHz.

Annex 4

Wideband HF data transmission

1 Introduction

The internet protocol for boat communication (IPBC) system is planned to allow data transmission on HF maritime bands 4-26 MHz in a radio transmission channel 10-20 kHz bandwidth.

The system can be used for all ships, although first studied for fishing ships.

This document describes the architecture system and its aim.

2 System requirements

– HF maritime band use;
– IPBC dedicated equipment on board;
– increasing of data rate according to actual systems;
– dynamic management of radio links;
– multi-users;
– system approach promoting the development of low-cost mobile stations;
– optimization of the HF spectrum.

3 System overview

3.1 General information

The radio data transmission system is divided into four vectors:

– the users of the network;
– the access provider;
– the HF coast station transmission and reception;
– the mobile ship HF station.

The aim of this system is to allow ships to access the Internet network for digital mail by a radio link operating in a HF maritime band (4-26 MHz) with a 10-20 kHz bandwidth channel in order to obtain a useful radio data rate up to 22 kbit/s.

For coverage from 40 to 250 NM, low frequencies (4 to 8 MHz) will be used, promoting the ground-wave propagation.

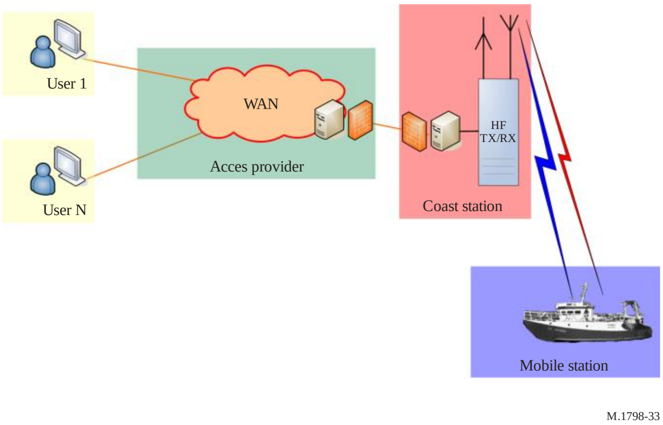
For long-distance connections over 200 NM, 8 to 26 MHz frequencies will be used. In this case, the ionospheric wave propagation is unavoidable. The modulation encoding will be appropriated.

The system does not work in real time; communications are “file transfer” type.

No direct ship-to-ship connections are planned.

FIGURE 33

General synoptic



3.2 HF radio link

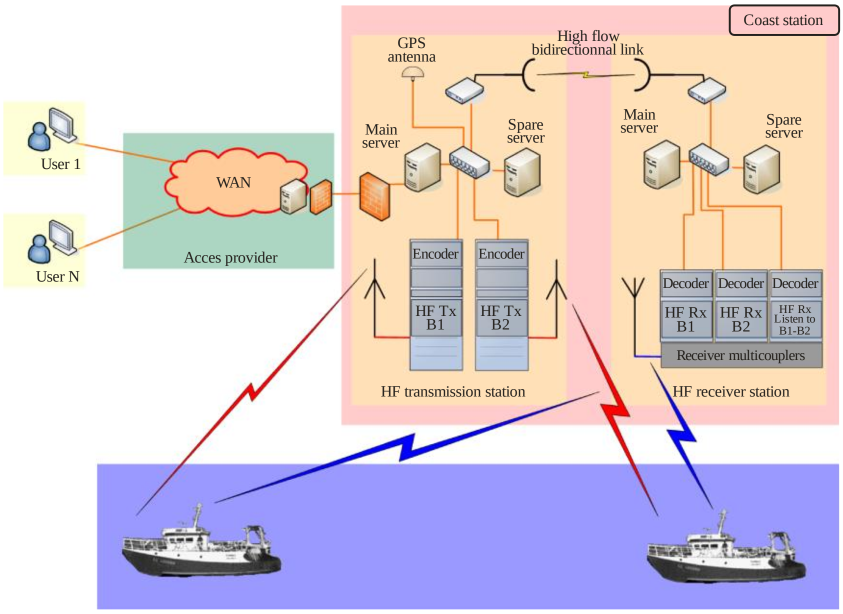
This link is based on two components:

– coast station;

– mobile maritime station.

FIGURE 34

General synoptic – HF radio link



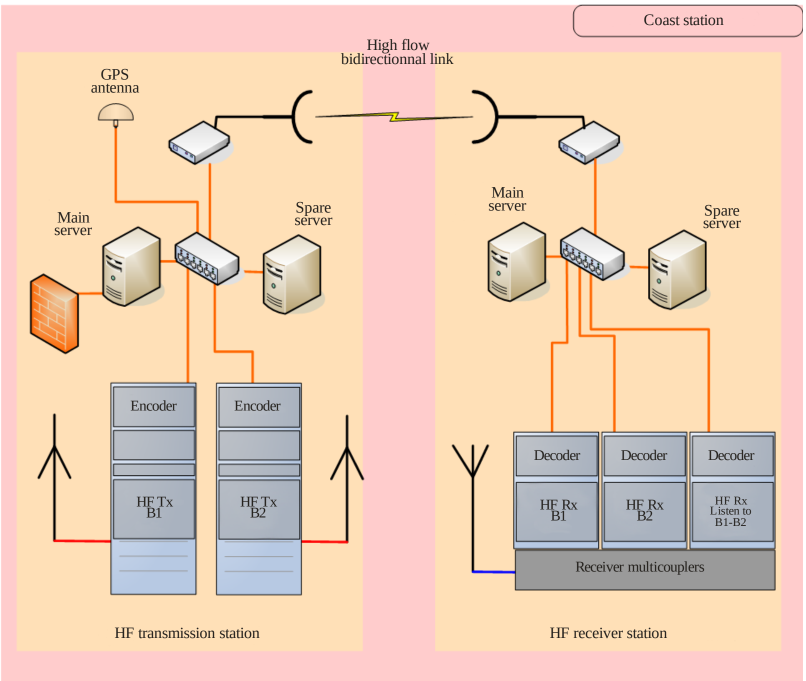
3.2.1 Coast station

The coast station can be equipped with channels in several HF bands in order to expand the coverage area. A dynamic management of transmitters is planned to adapt to the traffic.

The transmission part is physically separated from the reception part to allow the simultaneous working of transmitters and receivers.

FIGURE 35

Coast station synoptic



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3.2.1.1 Receiver station

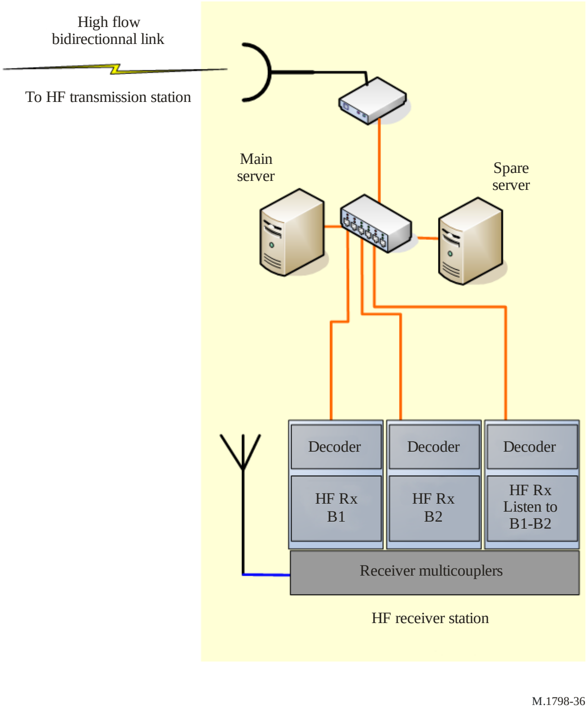
It is planned to have many fixed receiver frequencies according to used channels.

The demodulated signal from each receiver is sent to the server located on the reception site.

This server is linked to the transmission site via a high-flow bidirectional link.

FIGURE 36

Reception coast station synoptic



3.2.1.2 Transmission station

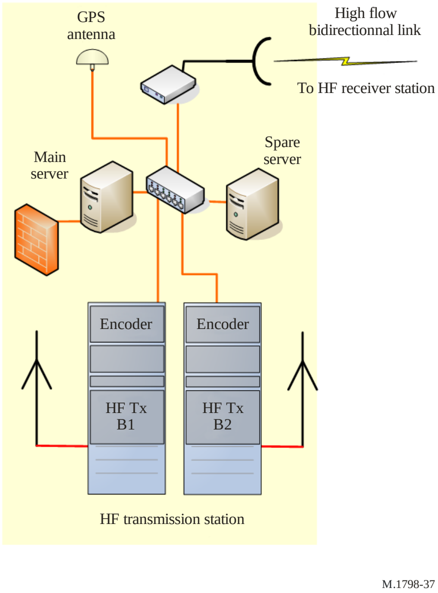
It is planned to have at least one transmitter for each exploitable HF maritime band and one spare transmitter. The spare transmitter can be used for another radio transmission channel in case of high data traffic.

A GPS receiver allows synchronizing transmissions.

This coast station owns an Internet connectivity from its access provider.

FIGURE 37

Transmission coast station synoptic



3.2.1.3 HF maritime mobile station

The system has been initially studied to equip medium length ships (12/30 m long), but it can fit all kinds of ships.

The half-duplex mode is used on the ships.

The mobile station consists of a transceiver and a human machine interface.

The transmitter and the receiver work on separate frequencies.

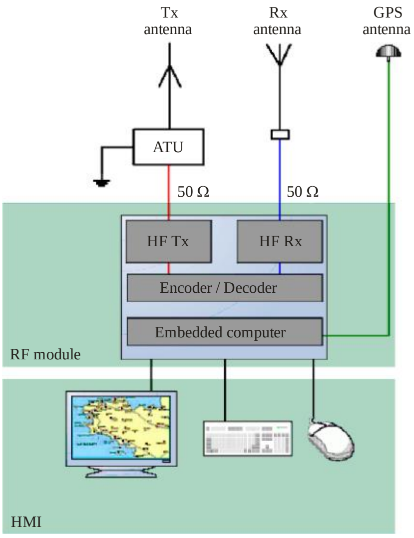
The power of the HF amplifier would be approximately 150 W CW (300 W PEP) with good linearity to accept the modulation in a 10-20 kHz bandwidth channel.

A GPS receiver is used to know the ship position and as a synchronization reference.

The system is totally transparent for the user.

FIGURE 38

Mobile station synoptic



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3.3 Working modes

The mobile maritime station is permanently listening to one of the transmission frequencies of the coast station in its navigation area.

If the station is multiband/multichannel, the best frequency will be automatically selected in the navigation area based on the information below:

– ship position given by the GPS receiver;

– memorized database of the maritime station, including the global frequency plan of the IPBC coastal radio network;

– received signal strength indicator;

– best signal/noise ratio.

In the case where the ship is located in two coast stations cross-checking, the choice will be made from the above parameters by adding course and speed information to locate the next ship position and then the concerned coverage area.

The coast station transmitter is permanently transmitting:

– information addressed to all ships (broadcast mode);

– information for only a group of ships (selective broadcast mode);

– information and messages addressed to a single ship;

– information for traffic management;

– acknowledge receipts for ship-to-shore data.

We can distinguish between two working modes:

– shore-to-ship link request;

– ship-to-shore link request.

3.3.1 Mode 1: Shore-to-ship link request

The service provider receives a message addressed to a ship.

After an automatic database research to know the last ship position, the message is sent to the coast station proxy that is associated with the radio cell of the ship.

The coast station transmits the message to the selected ship; its ID is included in every frame sent.

The ship receiver keeps every frame received in a buffer.

The ship transmitter regularly acknowledges the frames received.

During all the transfer duration, the same frequency is kept by the ship until the entire ACK reception.

The coast station has to give up the message transmission if the radio link becomes too bad due to propagation conditions.

The ship receiver then looks for a better-quality radio transmission channel.

3.3.2 Mode 2: Ship-to-shore link request

When the user of the mobile station has his message prepared with the recipient, the process becomes automatic and transparent. The file transfer is not realized in real time.

The mobile station uses the same synchronization reference from the GPS reception to allow connection to the coast station.

The mobile station is permanently informed of the free “slots” to be used for a new contact.

The ship selects a free “slot”, and sends the connection request including the ID, position, number of slots needed for its transmission and a part of the file.

If the ship transmission is perfectly received by the coast station, it transmits an ACK and allocates slots to carry on the transmission.

The coast station regularly acknowledges frames received.

The message buffered in the proxy server of the coast station is then sent to the access provider.

3.3.3 Ship tracking

When switching on the mobile radio equipment, the signalling process becomes automatic. The mobile station logs on to the most appropriate radio cell (according to the position and availability of the radio network) using mode 2 (ship-to-shore link request).

The station will regularly attempt a new identification if no cell radio is available.

Each mobile station is contacted, at close intervals, by the coast station in its radio cell in order to know its position (automatic tracking). The given information expands the confidential database that is necessary for traffic management.

The mobile station is declared out of the initial cell radio if the coast station fails several times to contact it.

Before stopping the on-board equipment, an automatic signalization is sent to the coast station to inform it that the mobile station is leaving the IPBC radio network.

3.4 Frequency reuse

For coast stations using low-band frequencies (4-8 MHz, 40-200 NM coverage), ground-wave propagation will be promoted. This will make the reuse of frequencies by several coast stations easier.

On the contrary, the high-band frequencies must be shared between the coast stations in use.

3.5 ~~IPBC~~ Internet protocol for boat communication system and ~~GMDSS~~global maritime distress and safety service

The IPBC system was not initially planned to be a GMDSS equipment. It is not dedicated for the management of distress at sea.

IPBC equipment transmission is inhibited if the GMDSS mobile station is used.

It could also efficiently replace radio telex in the future.

This system can also largely improve safety navigation. It gives permanent and quick information that can be linked to a specific area with an affordable cost.

However, an alarm access "Ship security alert system" will be possible.

3.6 Other ~~IPBC~~ internet protocol for boat communication applications

It should provide an economical possibility for all developing countries to manage their national sea area in terms of resources, protection and ecology management.

4 System architecture

4.1 General principle

The radio link must be reliable and secure.

The use of the radio transmission channel is optimized by the communication protocols. For this, applications do not work in real time and all communications are of a "file transfer" type.

The radio transmission channel is shared between every mobile station in a radio cell.

FIGURE 39

Radio cell low frequencies

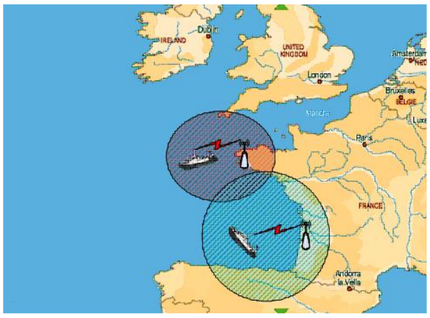

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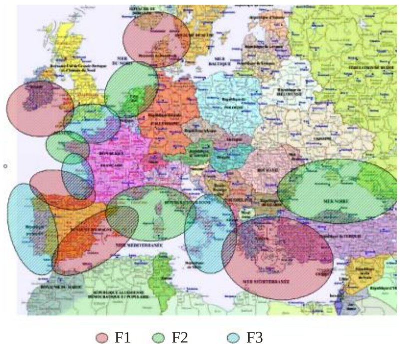
FIGURE 40

Example of frequency management



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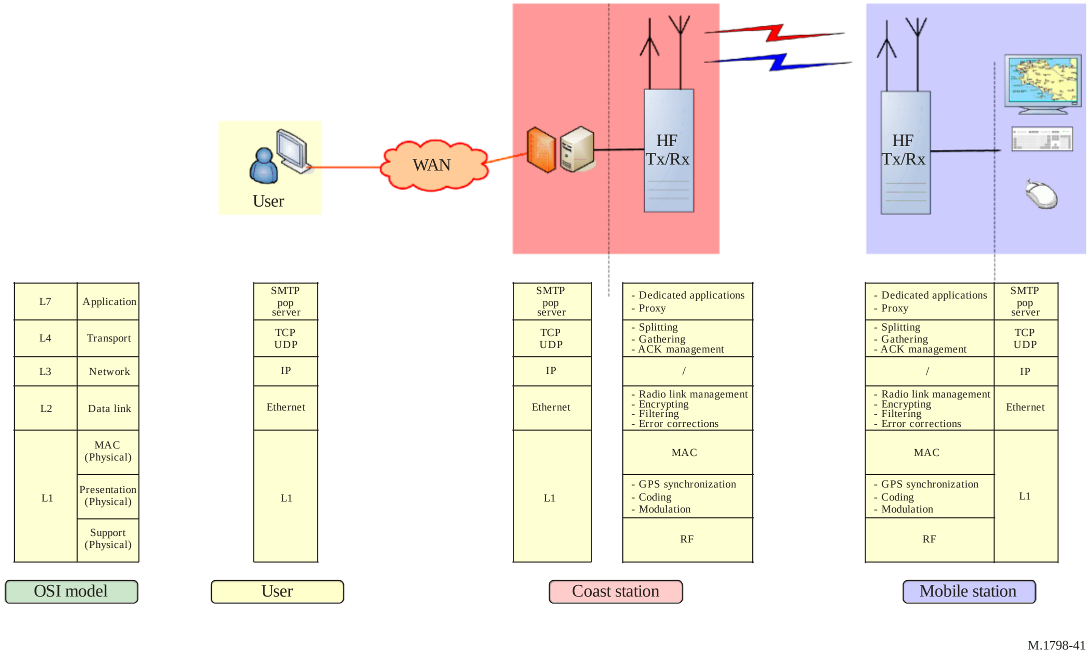
4.2 ~~OSI~~ Open systems interconnection model

The system can be described with the open systems interconnection (OSI) layer model.

FIGURE 41

Open systems interconnection~~OSI~~ model



On each extremity of the radio link, the interfaces offer a standard connection to the local network. On the shore side, this local network owns an Internet connection.

4.3 Physical layer (L1)

This layer is an interface between the software world and the radio channel transmission.

This layer includes:

– a physical support sublayer;

– a physical presentation sublayer:

  – modulation;

  – coding;

  – synchronization;

– a MAC sublayer.

FIGURE 42

Open systems interconnection~~OSI~~ model – physical layer L1

L7	Dedicated applications Proxy
L4	Splitting Gathering ACK management
L3	/
L2	Radio link management Encrypting Filtering Error corrections
L1	MAC
	GPS synchronization Coding Modulation
	RF

M.1798-42

4.3.1 Physical support

The physical support is a radio transmission channel whose main characteristics are frequency-dependent.

The radio transmission channel can be submitted to:

– multipath;

– Doppler effect;

– propagation delay.

The mobile station works in half-duplex mode.

4.3.2 Physical presentation

This layer realizes the modulation and demodulation of the signal, and synchronization on the GPS signal.

4.3.2.1 ~~OFDM~~ Orthogonal frequency division multiplexing modulation

The radio transmission channel uses OFDM coded data.

This process allows the obtainment of a good compromise between data rate and signal robustness according to the constraints of the radio transmission channel.

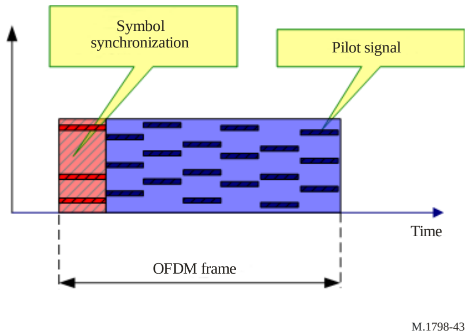
The OFDM uses subcarriers which are modulated one-to-one in QAM.

With the OFDM process, fixed-length frames must be used. The beginning of each frame is reserved for a synchronization preamble.

Some pilot subcarriers allow the characterization of the radio transmission channel.

FIGURE 43

Orthogonal frequency division multiplexing~~OFDM~~ process



For a detailed description (see Chapter 5).

4.3.2.2 Modulation encoding

A coding is applied to the data to transmit in order to optimize the spectrum of the radio transmission channel.

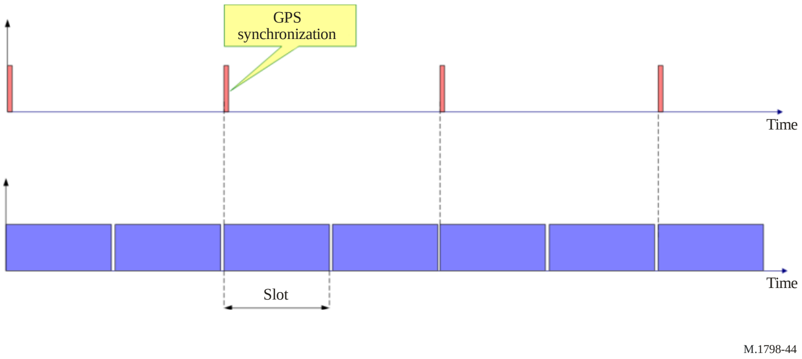
4.3.2.3 Synchronization on the GPS signal

This sublayer makes the frame synchronization from the GPS signal; it is the time reference for all mobile and coast stations. For this purpose, this time, common for all stations, is split into frame-length OFDM "slots".

Each "slot" can be occupied or not by an OFDM frame.

FIGURE 44

Synchronization on the GPS signal



M.1798-44

4.3.3 Media access control ~~(MAC)~~

This sublayer identifies each coast and mobile station. The ID could be the MMSI number of the ship or coast station.

4.4 Link layer (L2)

The link layer is composed of:

– an “error corrections” sublayer;

– a “filtering” sublayer;

– an “encrypting” sublayer;

– a “radio link management” sublayer.

FIGURE 45

Open systems interconnection~~OSI~~ model – link layer L2

L7	Dedicated applications Proxy
L4	Splitting Gathering ACK management
L3	/
L2	Radio link management Encrypting Filtering Error corrections
L1	MAC
	GPS synchronization Coding Modulation
	RF

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4.4.1 Error correction

The error correction depends on the desired robustness of the coding.

For a detailed description (see Chapter 6.1).

4.4.2 Filtering

This sublayer is different for the coast station and for the mobile station.

For the coast station:

– When transmitting, an ID is added to the sent messages addressed to a specific ship.

– When receiving, the messages are checked that they come from the right ships.

For the mobile station:

– When transmitting, the ID is added to the message.

– When receiving, only the messages that are addressed to it are kept.

4.4.3 Encrypting

An encryption can be applied to the data to assure confidentiality.

4.4.4 Radio link management

This sublayer makes the radio link management protocol. It is based on a master/slave communication.

The master is the coast station and the slaves are the mobile stations.

4.4.4.1 Radio link management on the shore station side

The coast station is the master:

– it manages the transmission commands to mobile stations;

– it addresses messages to mobile stations;

– it addresses ACK.

The list of mobile stations in the radio cell is permanently known by the coast station.

For a detailed description (see Chapter 6.2).

4.4.4.2 Radio link management on the ship station side

The coast station regularly allocates free slots to allow contact by the mobile station.

The space between the free slots can be dynamically changed according to the traffic on the radio transmission channel.

The mobile station is a slave; the messages can only be transmitted to the coast station in two ways:

– If its message can be held in a single frame, it sends it all in a free slot.

– If not, it requests a slot allocation in a free slot with the beginning of the message; the coast station acknowledges receipt and allocates slots in which the mobile station will transmit the rest of the message.

The link layer keeps in memory the slot map sent by the coast station in order to know the free slots.

4.5 Transport layer (L4)

The transport layer is in charge of the following functions:

– splitting the large files in several packets;

– gathering of packets in a single file;

– sending and receiving the ACK.

FIGURE 46

Open systems interconnection~~OSI~~ model – transport layer L4

L7	Dedicated applications Proxy
L4	Splitting Gathering ACK management
L3	/
L2	Radio link management Encrypting Filtering Error corrections
L1	MAC
	GPS synchronization Coding Modulation
	RF

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This layer is in charge of the splitting of files into appropriately sized packets with the lower layers (size of an OFDM frame), and of gathering packets back in files for upper layers.

Two transport protocols concerning the HF link are implemented on this layer:

– The first one provides a "reliable" connection, managing reception checking. It is mainly used for mail.

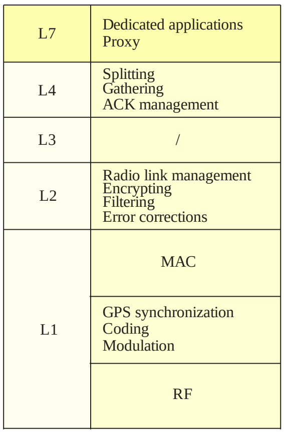
– The second one does not manage reception checking; it is used for broadcasting and tracking.

For each protocol, only one file transfer is possible in the same time.

4.5.1 Application layer (L7)

FIGURE 47

Open systems interconnection~~OSI~~ model – Application layer L7



M.1798-47

This application layer gives an access interface to the radio network.

The communicating interfaces of the applications can be:

– IPBC dedicated (ship tracking, weather forecast, etc.);

– standard using a dedicated proxy (e.g. mail, FTP, etc.).

5 Layer L1 principle – ~~OFDM~~orthogonal frequency division multiplexing

5.1 Introduction

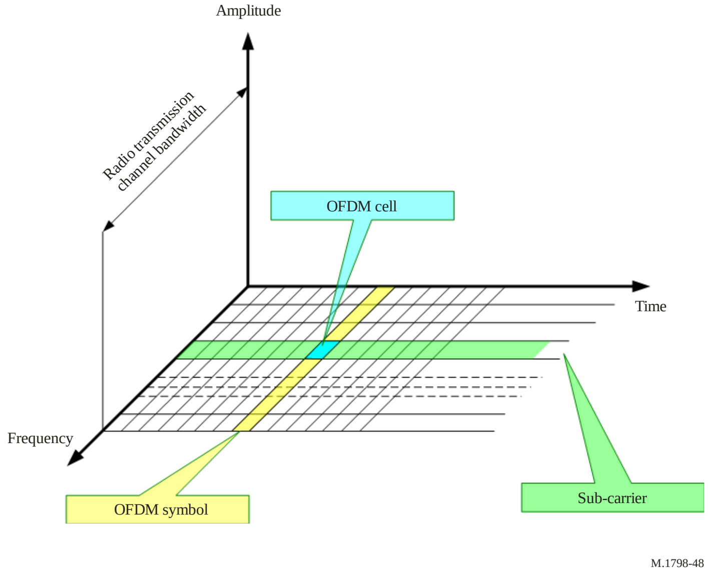
The bandwidth of the radio transmission channel is divided in the frequency domain to form subcarriers.

The radio transmission channel occupation is organized in the time to form OFDM symbols.

An OFDM cell is equivalent to a subcarrier in an OFDM symbol.

FIGURE 48

Orthogonal frequency division multiplexing~~OFDM~~ introduction



5.2 Principle

The OFDM uses a large number of closely-spaced orthogonal subcarriers to obtain high spectral efficiency to transmit data. These subcarriers are frequency-spaced ($F_u = 1/T_u$), where T_u is the OFDM symbol duration.

The phases of subcarriers are orthogonal to each other to enhance signal diversity caused by the multipath, especially in long distance.

A guard interval (T_d) is inserted in the OFDM symbol to reduce multipath effect, thus reducing the inter-symbol interference.

The OFDM symbol duration is $T_s = T_u + T_d$.

The OFDM symbols are then concatenated to make an OFDM frame.

The OFDM frame duration is T_f.

FIGURE 49

Spectral representation of an orthogonal frequency division multiplexingOFDM frame

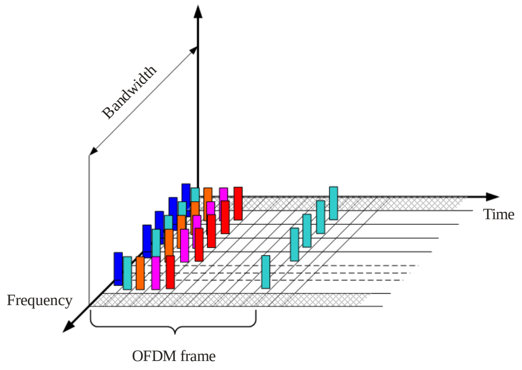
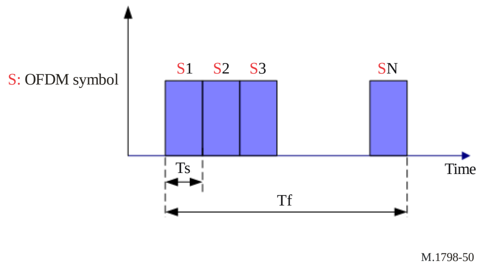


FIGURE 50

Temporal representation of an orthogonal frequency division multiplexingOFDM frame



5.3 Modulation

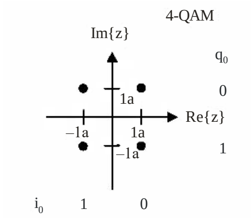
Every subcarrier is modulated in amplitude and phase (QAM: quadrature amplitude modulation).

Modulation patterns can be either 64 states (6 bits, 64-QAM), 16 states (4 bits, 16-QAM), or 4 states (2 bits, 4-QAM).

The modulation pattern depends on the desired robustness of the signal.

FIGURE 51

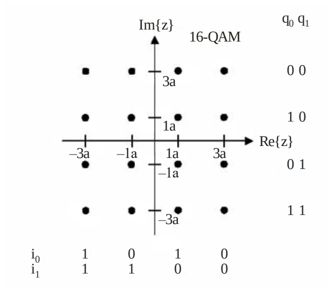
4-~~QAM~~ Quadrature amplitude modulation constellation



M.1798-51

FIGURE 52

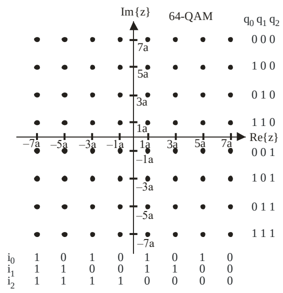
16-~~QAM~~ Quadrature amplitude modulation constellation



M.1798-52

FIGURE 53

64- Quadrature amplitude modulation~~QAM~~ constellation



M.1798-53

5.4 Synchronization

In order to allow a good demodulation of each subcarrier, radio transmission channel response must be determined for each subcarrier and equalization should be applied. For this, some of the subcarriers of the OFDM symbols may carry pilot signals.

The pilot signals allow the receiver to:

– detect if a signal is received;

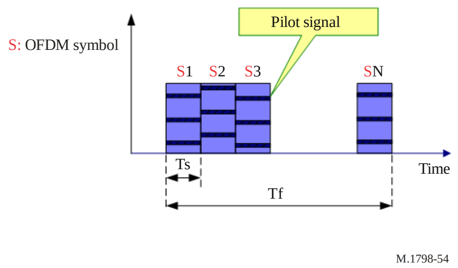
– estimate the frequency offset;

– estimate the radio transmission channel.

The number of pilot signals depends on the desired robustness of the signal.

FIGURE 54

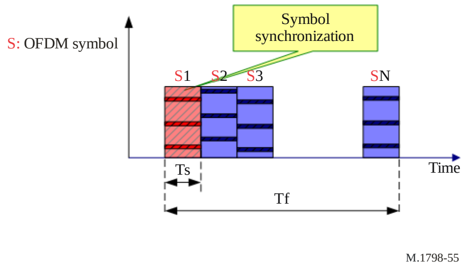
Pilot orthogonal frequency division multiplexing~~OFDM~~ signal



The first symbol sent is a known synchronization symbol, in order to synchronize in the time each OFDM frame.

FIGURE 55

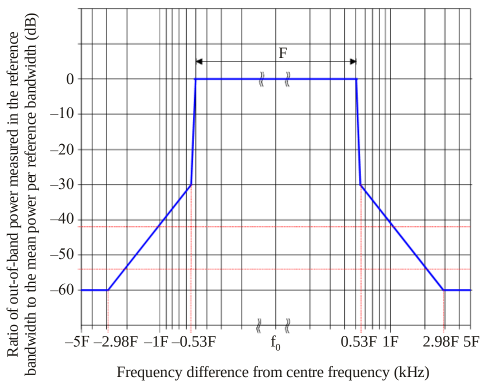
Synchronization symbol



5.5 Spectral occupation of HF signal

FIGURE 56

Spectral occupation of HF signal with bandwidth *F* = 10-20 kHz



6 Link layer principle (L2)

The link layer is composed of:

– an "error corrections" sublayer;

– a "filtering" sublayer;

– an "encrypting" sublayer;

– a "radio link management" sublayer.

6.1 Error correction

The error correction scheme depends on the desired robustness of the coding.

The efficiency can vary between 0.5 and 0.75 (turbo code) depending on the error correction schemes and modulation patterns.

TABLE 6

General efficiency versus error correction (LEST study)

Configuration	External code efficiency (if used)	Internal code efficiency (if used)	Efficiency due to puncturing	Global coding efficiency
No. 1	RS(204,188) $\frac{188}{204}=\frac{47}{51}\approx 0.92$	Not used		$\frac{188}{204}=\frac{47}{51}\approx 0.92$
No. 2 and No. 3	RS(204,188) $\frac{188}{204}=\frac{47}{51}\approx 0.92$	Convolutional Code NRSC (K=7) $\frac{1}{2}$	$\frac{1}{2}$	$\frac{47}{102}\approx 0.46$
			$\frac{2}{3}$	$\frac{94}{153}\approx 0.61$
			$\frac{3}{4}$	$\frac{141}{204}\approx 0.69$
			$\frac{5}{6}$	$\frac{235}{306}\approx 0.77$
			$\frac{7}{8}$	$\frac{329}{408}\approx 0.81$
No. 4		Turbo-Code (dual Binary) $\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}=0.5$
			$\frac{3}{4}$	$\frac{3}{4}=0.75$

6.2 Radio link management on the shore station side

This sublayer carries out the radio link management protocol. It is based on a master/slave communication. There is a master: the coast station; and one or several slaves: the mobile stations.

The radio link management protocol includes the half-duplex working and the time antenna commutation for the mobile station.

A coast station can be equipped with several transceivers in order to manage many radio transmission channels.

The coast station is the master:

– it manages the transmission commands to mobile stations;

– it addresses messages to mobile stations;

– it addresses ACK.

The coast station permanently owns the list of mobile stations existing in the radio cell, and they can be enquired individually at any time.

The coast station checks the link by including a header tag in every sent frame.

The header tag is composed of:

– the map of the *N* next “slots” for the mobile stations transmission;

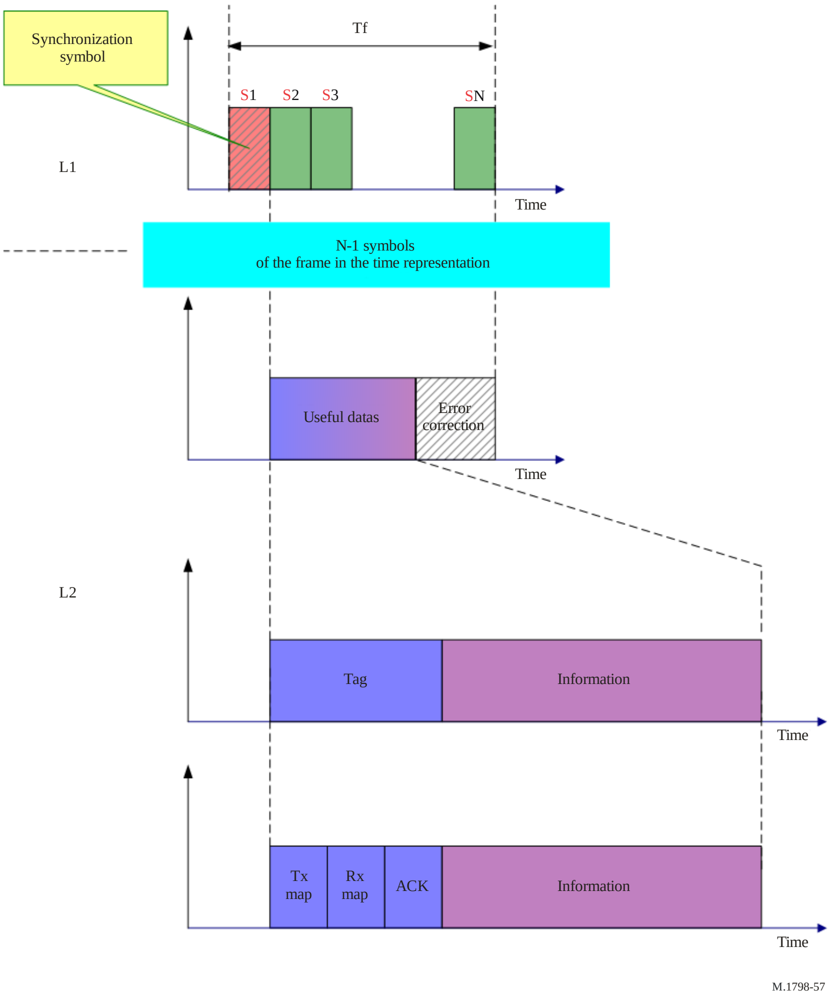
– the map of the *N* next “slots” addressed to the mobile stations reception;

– the *M* last ACK.

The parameters *N* and *M* can be dynamically modified according to the mobile station quantity using a radio transmission channel.

FIGURE 57

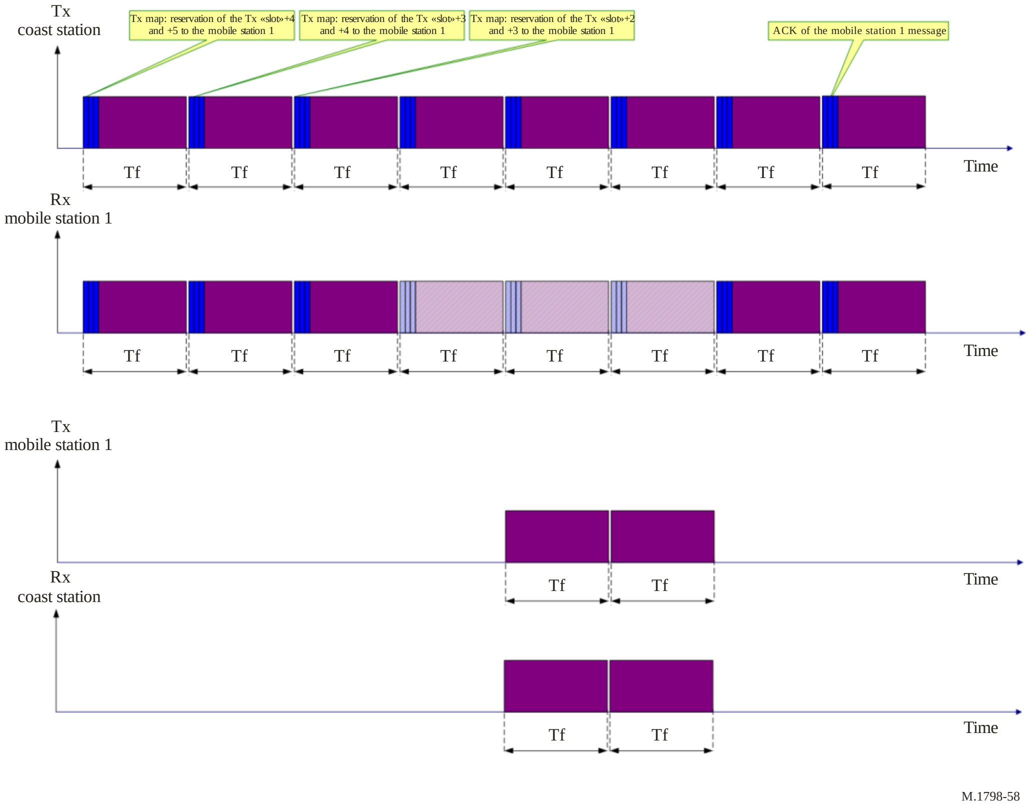
Orthogonal frequency division multiplexingOFDM frame synoptic at L1 and L2 layers level



6.3 Radio link management chronogram

FIGURE 58

Radio link management chronogram



7 Basis for experimentation

The real-time test field is planned for 2008-2009.

The OFDM symbol is a multiple of an 83 µs elementary time *T*.

The IPBC can offer several protection modes according to the desired signal robustness and the propagation conditions. Please find below the chosen mode for the ground-wave propagation experimentation.

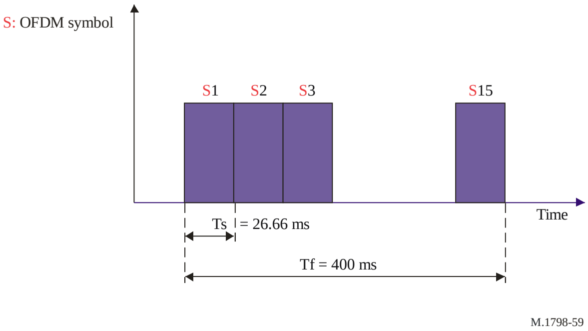
TABLE 7

Orthogonal frequency division multiplexing ~~OFDM~~ characteristic parameters summary

Elementary time T (µs)	83
Useful symbol duration T_u (ms)	$288 \times T = 24$
Guard interval duration T_g (ms)	$32 \times T = 2.66$
Total symbol duration T_s (ms)	26.66
Frame duration T_f (ms)	400
Symbol number/frame	15

FIGURE 59

Orthogonal frequency division multiplexing~~OFDM~~ timing



The space between the subcarriers is $1/T_u$ = 41.66 Hz.

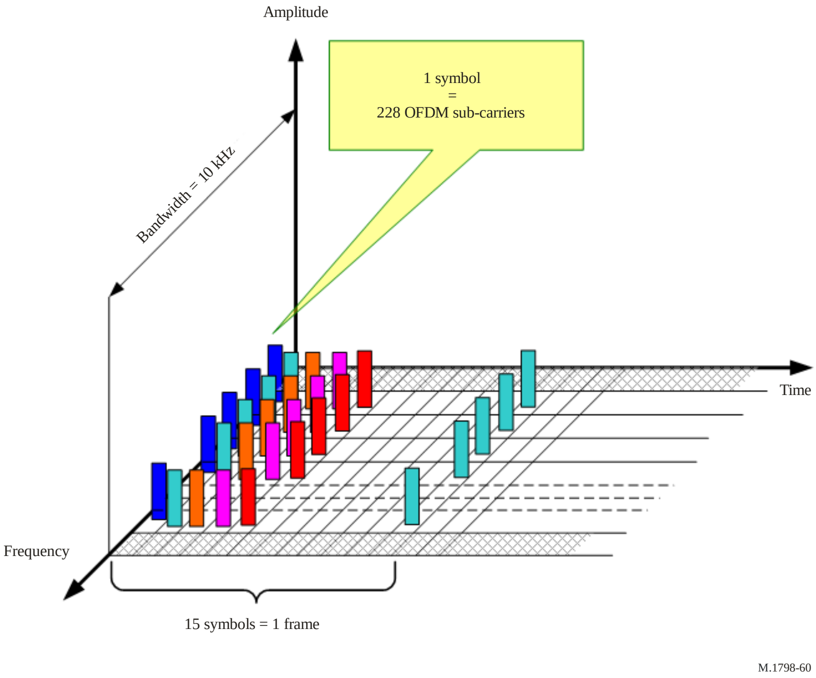
TABLE 8

Number of subcarrier versus bandwidth

Bandwidth (kHz)	**Number of subcarrier**
10	228
20	460

FIGURE 60

Diagram for 10 kHz bandwidth



The OFDM symbol is equivalent to some bit according to the modulation. A symbol is composed of 228 subcarriers for a 10 kHz bandwidth.

Every subcarrier is modulated in QAM and can be matched to 6, 4, or 2 bits for the 64-QAM, 16-QAM and 4-QAM.

We obtain the channel radio data rate in Table 9:

TABLE 9

Channel data rate versus ~~QAM~~ quadrature amplitude modulation

QAM type	Bits/symbol	Bits/frame (400 ms)	Bits/s
64	1 368	20 520	51 300
16	912	13 680	34 200
4	456	6 840	17 100

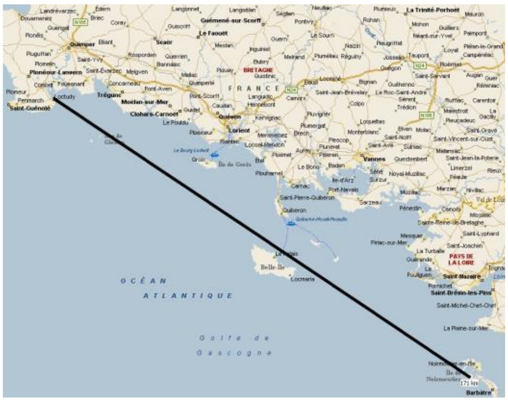
8 First test results

8.1 Propagation measure campaign, sea travel of ground wave

In 2007, Telecom Bretagne led a real propagation measure campaign on a 170 km Earth/sea/Earth path in order to verify the channel attenuation, the admissible coherence bandwidth and the absence of multipath.

FIGURE 61

Visualization of the measure on the chart



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Simultaneously, a SCIPION ionospheric radar system recorded the results in real time.

The used frequencies were the following:

– 4 177 kHz;
– 6 270 kHz;
– 8 385 kHz;
– 12 495 kHz.

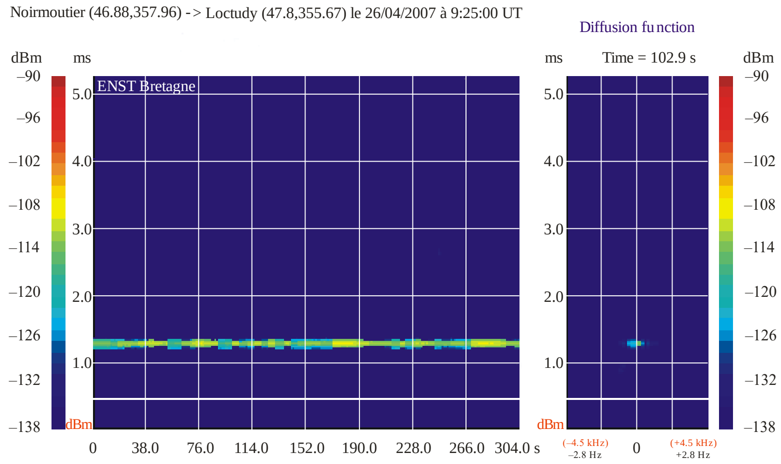
Conclusion:

– the attenuation for sea surface wave corresponds to the theoretical result (ITU publication);
– coherence bandwidth: > 9 kHz;
– skywaves are present through E and F layers.

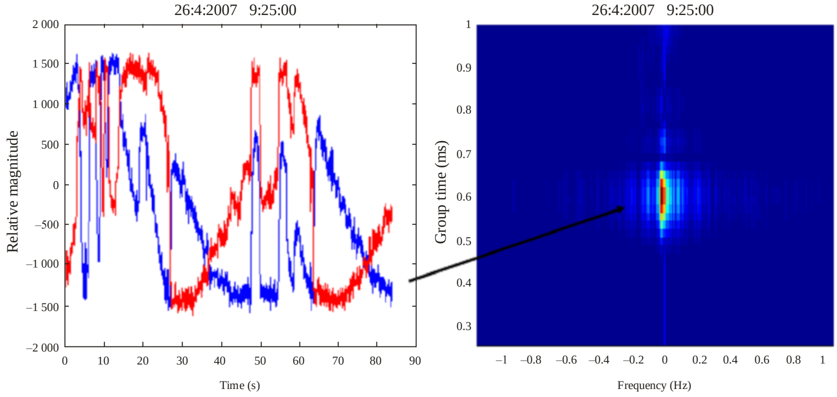
The following figures illustrate the results of the measures.

FIGURE 62

Response of the radio transmission channel at $F = 4.177$ MHz



Channel probe on fixed frequency, measure from SCIPION radar



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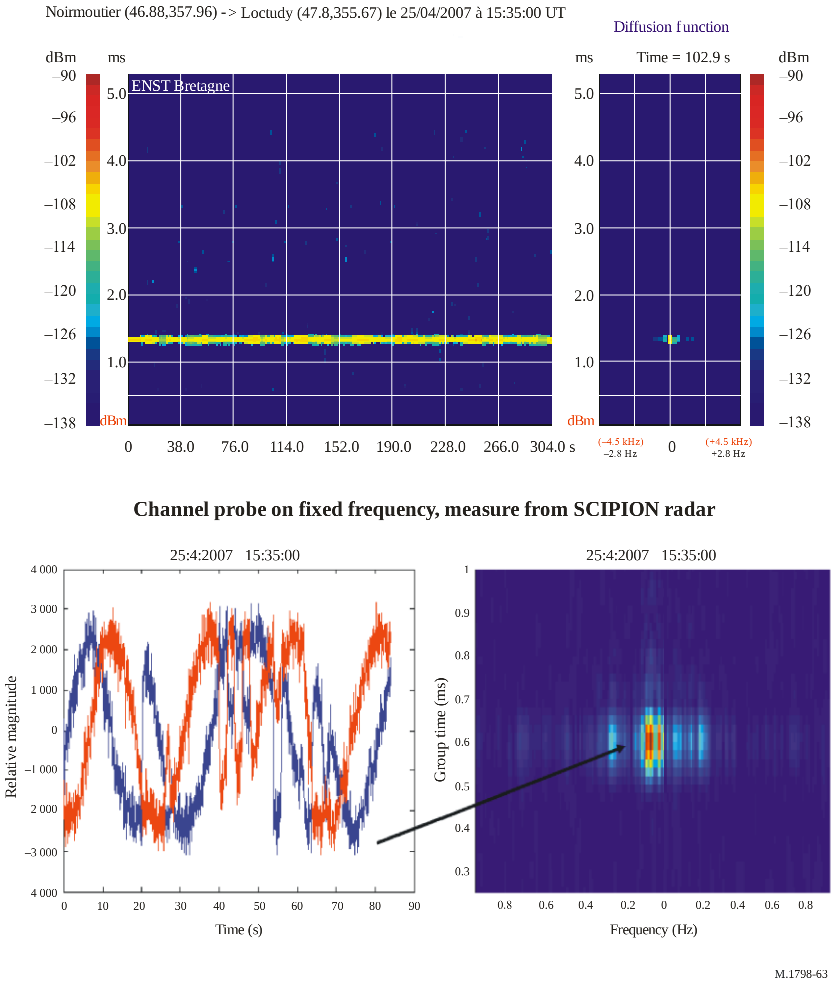
Ground-wave monitoring (I and Q channels) on 84 s 2 048 sample spectrum

Resolution: 40.96 ms Resolution: 0.012 Hz

FIGURE 63

Response of the radio transmission channel at *F* = 6.27 MHz

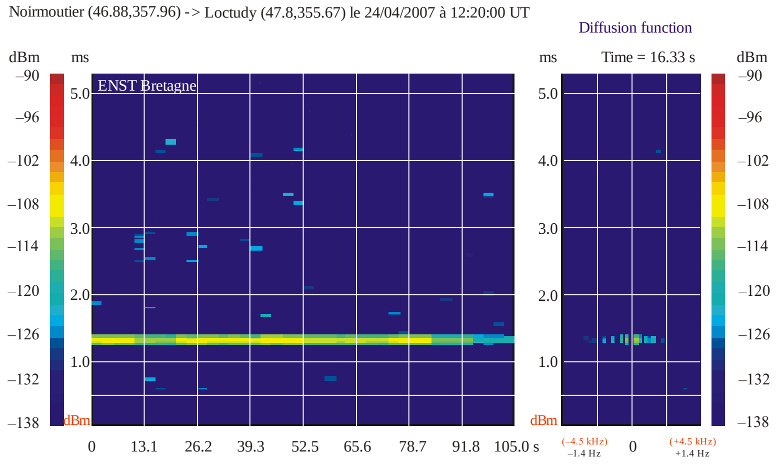


Ground-wave monitoring (I and Q channels) on 84 s 2 048 sample spectrum

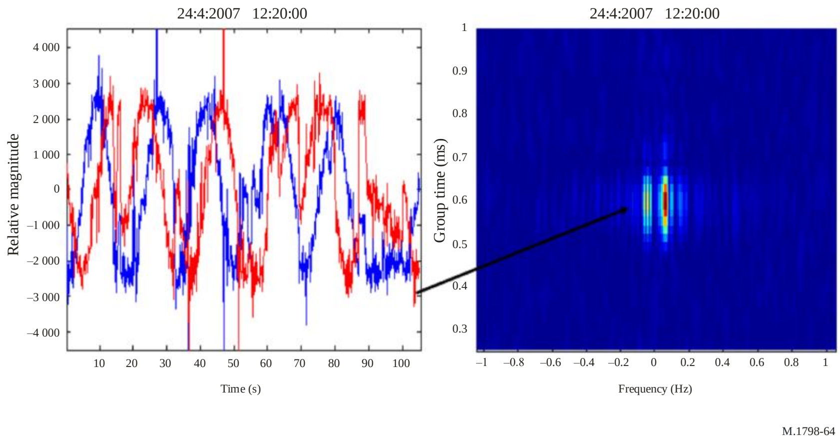
Resolution: 40.96 ms Resolution: 0.012 Hz

FIGURE 64

Response of the radio transmission channel at *F* = 8.385 MHz



Channel probe on fixed frequency, measure from SCIPION radar

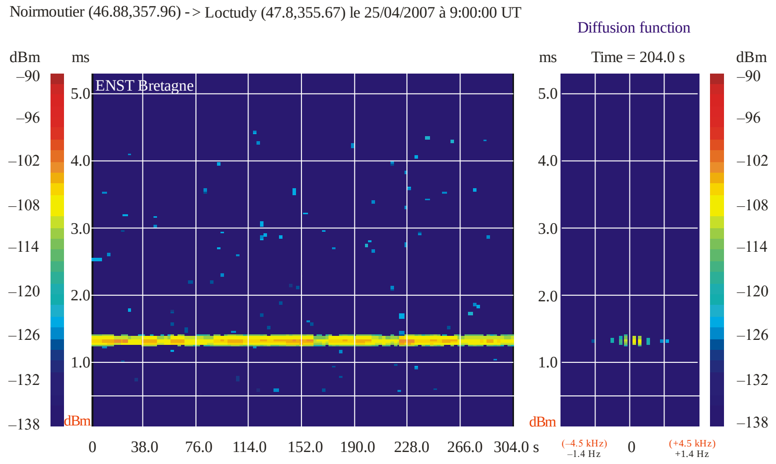


Ground-wave monitoring (I and Q channels) on 105 s 1 280 sample spectrum

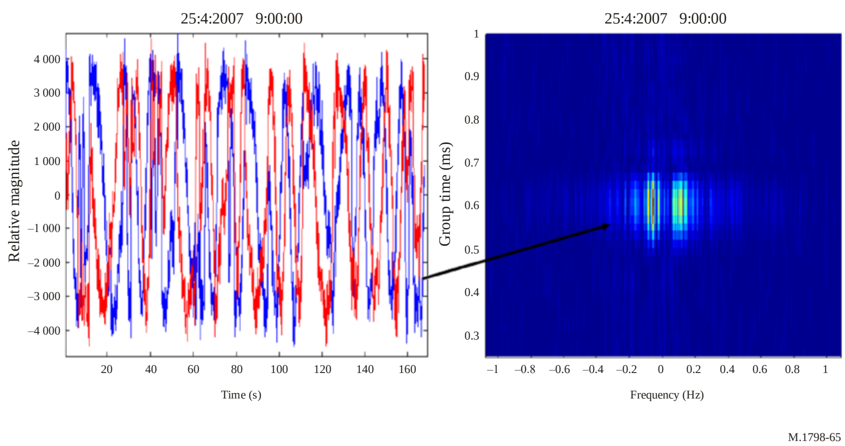
Resolution: 81.92 ms Resolution: 0.009 Hz

FIGURE 65

Response of the radio transmission channel at F = 12.495 MHz



Channel probe on fixed frequency, measure from SCIPION radar



Ground-wave monitoring (I and Q channels) on 167 s

Resolution: 81.92 ms

2 048 sample spectrum

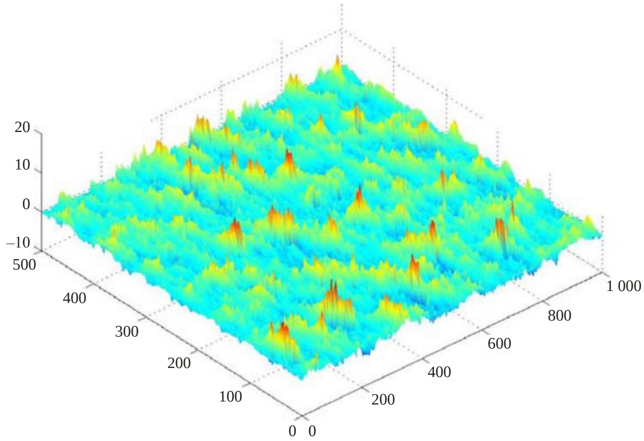
Resolution: 0.006 Hz

8.2 Channel modelling

A study created a model of an HF radio transmission channel for ground waves propagating on Earth/sea transition.

FIGURE 66

Heave model

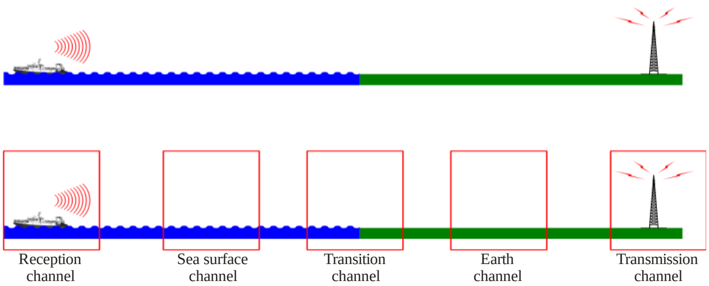


M.1798-66

This study included the vectors of Earth/sea/Earth transition, and took into account the heave effect.

FIGURE 67

Representation of the radio transmission channel into theoretical subchannels



M.1798-67

FIGURE 68

Conductivity of the sea versus its salinity at some temperatures

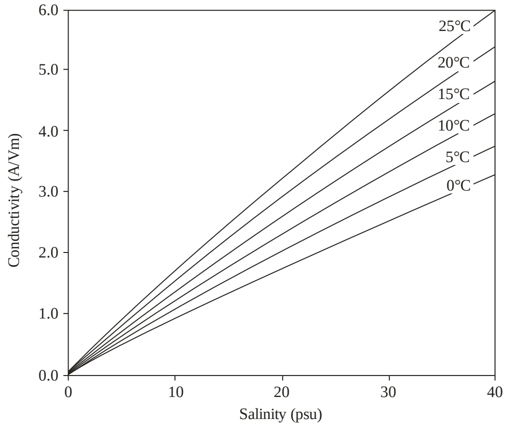


FIGURE 69

Pulse response of the earth subchannel

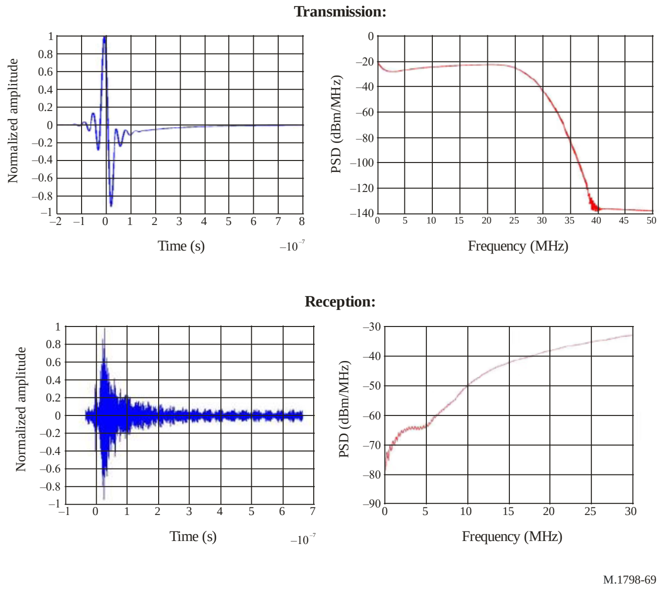


FIGURE 70

Pulse response of the transition subchannel

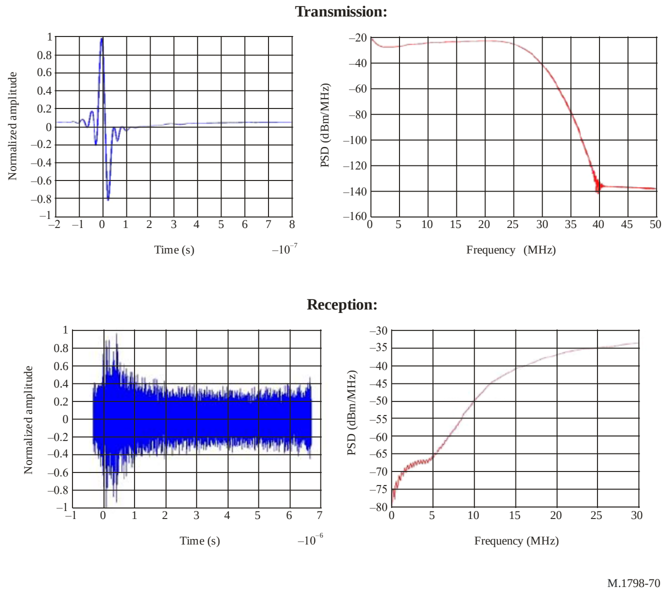


FIGURE 71

Pulse response of the sea subchannel

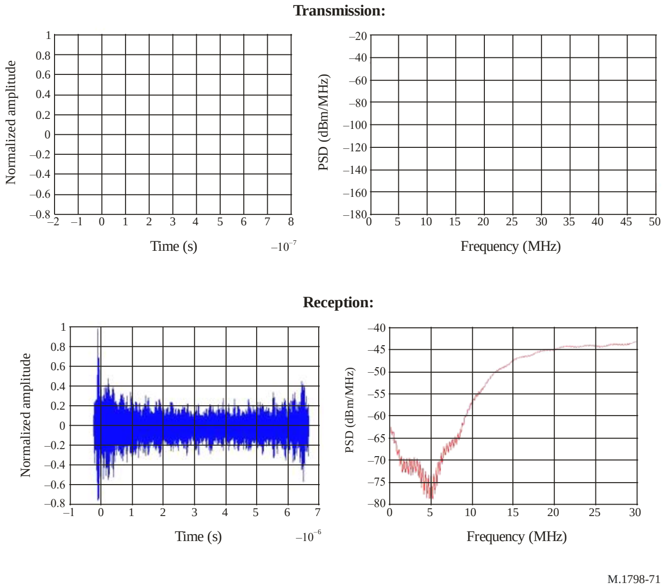
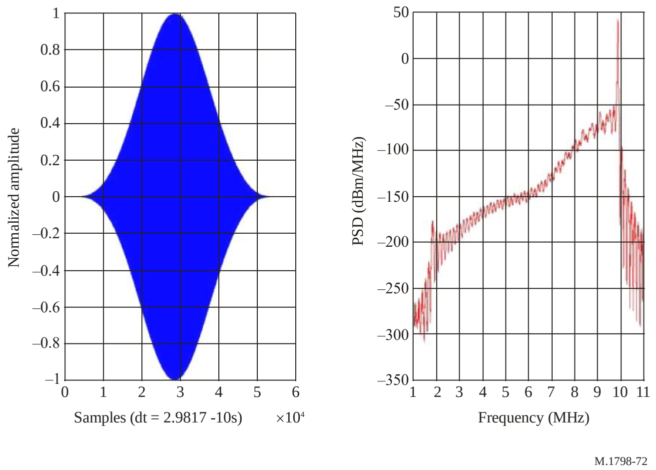


FIGURE 72

Pulse response of the main channel from 2 to 10 MHz



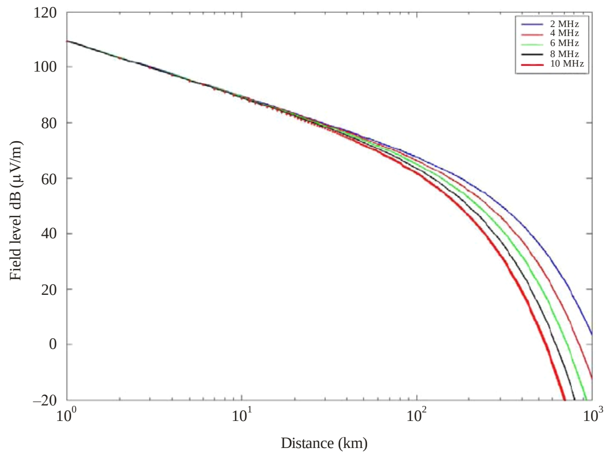
Field level calculation, Millington method.

Held out parameters:

– average sea salinity: σ = 5 s/m, *E* = 70;
– vertical polarization;
– average power: 1 kW.

FIGURE 73

Field level versus distance



M.1798-73

9 Experimentation results

During the year 2009 several experiments on the components of IPBC system have been performed:

– surface wave propagation;
– transmitter;
– receiver.

For data transmissions tests:

The transmission site was in the city of Brest (France).

The receiving/monitoring site was in the city of Quimper (France).

For radio surface wave characterizations:

Two fishing vessels were equipped with testing equipments with an aim of confirming the first series of measurements to characterize the propagation channel by surface wave in terms of:

– loss path of channel;
– the band of coherence;
– the presence or not of multiple ways (presence of skywave);
– the variability of the channel.

A fishing vessel of 25 m was equipped with a System Scipion (an ionosphere radio wave sounder that has been developed by Telecom Bretagne in France) connected on a vertical whip antenna of 7.5 m.

The frequencies hereafter were used:

– 8 240 kHz;

– 4 080 kHz.

Modulation ~~BPSK~~binary phase shift keying, radio frequency (RF) power 20 W.

The emissions were automatic with a sequence of 1 mn all the quarter hour or half hour.

A reception GPS was used for time synchronization and tracking positioning.

FIGURE 74

Interior and external images of the embarked equipment

M.1798-74

Three systems of reception were installed:

– The first at the headland of Corsen (Bretagne/France) in the immediate vicinity of the sea. The antenna used is of the whip type.

– The second system was installed in the building of Telecom Bretagne near Brest. The antenna used is a loop.

– The third site near Quimper (the same that was used for data transmissions tests) was used in monitoring with a vertical antenna and magnetic loop antenna.

FIGURE 75

Images of the site and the reception antenna of Corsen

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The transmitting system was activated when the ship left the harbour and could be, constantly, stopped by the captain of the ship in the event of failure or any trouble.

9.1 Results and interpretations

Effects of distance TX/RX on the field received level for a sea path:

The following figure represents the evolution of the level of reception of the signal recorded on the site of the Corsen, the ship being at a distance from 192-240 km.

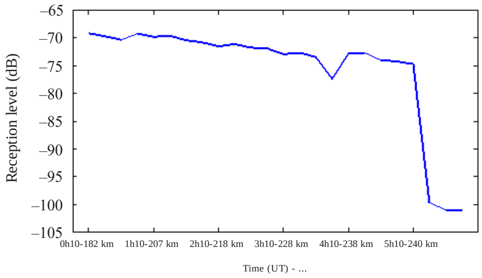
The quasi-linear variation allows an estimate of the variation of power received according to the distance.

The fall of power observed to 236 km can be explained by operations of the ship.

The transmitter was stopped to 240 km.

FIGURE 76

Evolution of the level of reception in Corsen on 13 May 2009 from 00h10 with 5h50 of 192 km with 240 km



M.1798-76

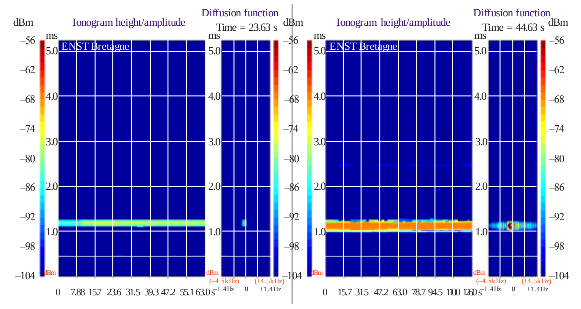
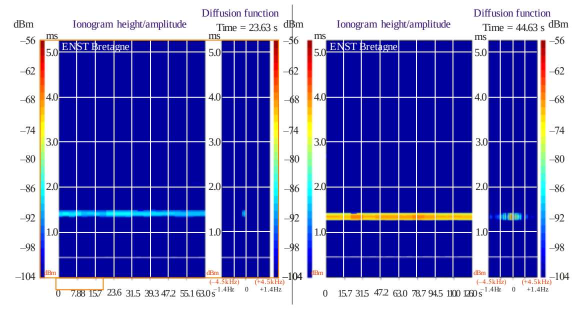
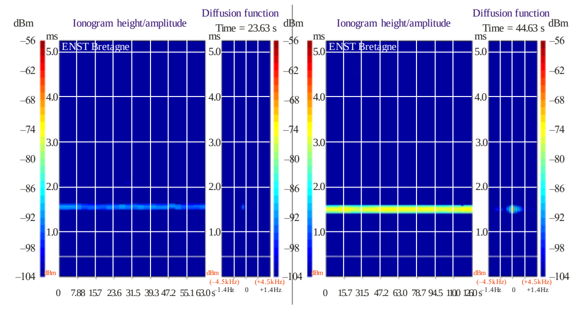
Figure 77 shows the evolution of the power of the signals recorded on the sites of Brest on the left (loop antenna) and Corsen on the right (whip antenna close to the sea).

A variation of level clearly appears in connection with the distance.

These variations are different because of the type of antenna used and the ground path for the site from Brest.

FIGURE 77

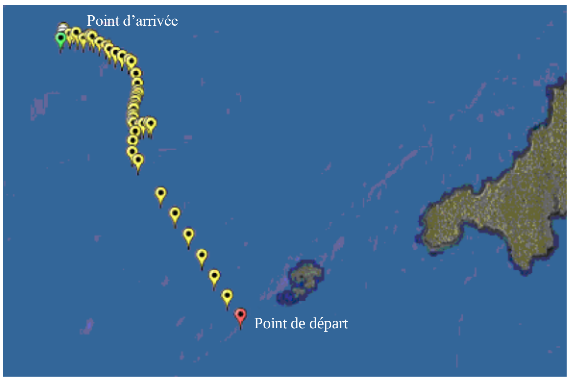
Sequence of recordings of the signal received in Brest and Corsen

Brest *f* = 8.240 MHz Corsen	
	12 May with 20h10 Distance: 126 km
	May 13 with 0h10 Outdistance: 192 km
	May 13 with 5h10 Distance: 238 km

M.1798-77

FIGURE 78

Road followed by the trawler on 11 July 2009
Distance varying from 205 km to 327 km

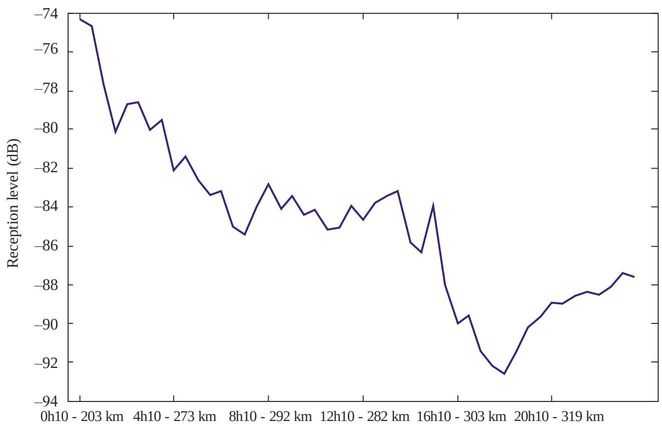


M.1798-78

The linear variation of the level of reception according to the distance is also highlighted on Fig. 79 correspondent at the way reproduces on Fig. 78.

FIGURE 79

Evolution of the level of reception in Corsen on 11 July 2009



M.1798-79

9.2 Influence of land on a mixed path land/sea

On Figs 80 and 81, the first four points correspond to approximately equal distances between TX/RX (±2 km). The variation of the level received between these points is, however, about 25 dB.

This is explained by the transition between ground wave-sea wave and a possible effect of partial mask effect due to the proximity of the coast.

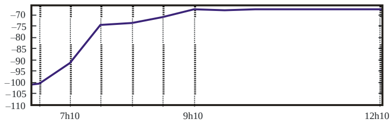
FIGURE 80

**Road followed by the trawler on 10 July 2009
Between 6h40 and 12h10**

M.1798-80

FIGURE 81

**Evolution of the level of reception in Corsen
on 10 July 2009**



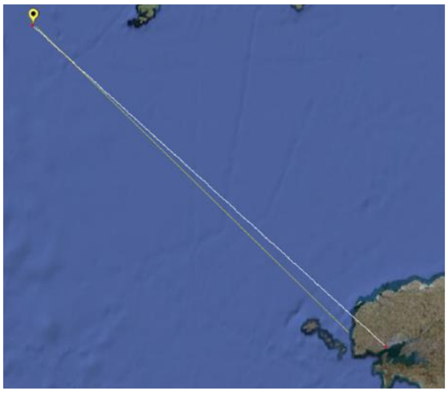
M.1798-81

Figures 82 and 83 present an example for which the difference in level of reception between the two sites is about 25 dB.

This difference is justified mainly by a portion of land path of 25 km for the site of Brest.

FIGURE 82

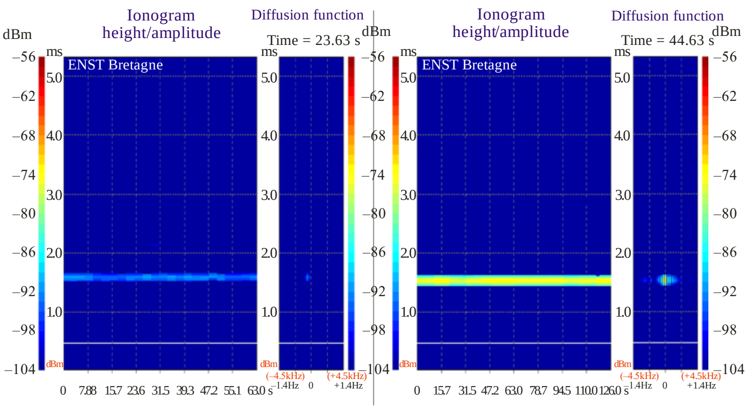
Position of the trawler on 13 May 2009 at 05h10



M.1798-82

FIGURE 83

Recording of the signal received in Brest on the left and Corsen on the right
13 May 2009 at 05h10



M.1798-83

Other analyses proved the influence of the antenna on the selectivity of the received path.

The skywave is much more significant in Brest than in Corsen.

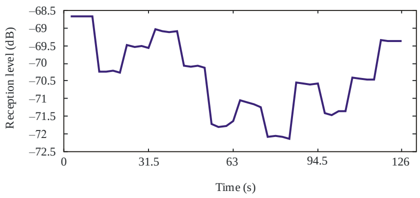
At Corsen, the time of group makes it possible to distinguish the sea wave (1, 8 ms) from the skywave >2 ms.

The superposition and the spreading-out of the various paths due to the sea wave and the skywave will thus be taking into account the specification of the receivers and received antennas.

The figures hereafter give indications on the variations of levels of signal received for evolutions of the ship over short periods with orientations of ships and the state of the sea.

FIGURE 84

Evolution of the level of reception in Corsen on 13 May 2009 from 00h40 to 00h42



M.1798-84

Figures 85 and 86 present a situation of fishing during which the distance remains stable (±7 km) and where one attends many changes of course causing significant fluctuations of the received level.

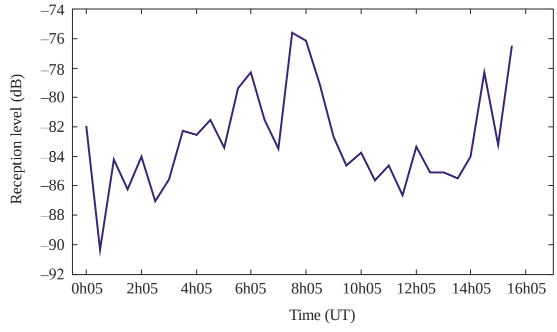
FIGURE 85

Road followed by the trawler on 9 June 2009 Between 00h05 and 15h15

M.1798-85

FIGURE 86

**Evolution of the level of reception in Corsen on 9 June 2009
Between 00h05 and 15h15**



9.3 Data transmission

Use for testing OFDM protocol.

9.3.1 Coastal

An RF power of 1 kW CW was used.

The amplifier was in class AB with the use of diplexer filter to decrease intermodulation and to increase the global linearity compatible with OFDM modulation.

The antenna matching was carried out to guarantee a wave band higher than 12 kHz.

Various antennas were used with, in particular, a vertical whip of 16 m supplemented by a plan of ground screen with 36 radians of 20 m.

The choice of the vertical antenna is justified by the fact of keep the same polarization as the ship antenna in favour of sea wave propagation.

9.3.2 Ship

The RF power used was 250 W CW.

The antenna was of vertical whip of 7.50 m with a matching “pi” presenting a bandwidth higher than 12 kHz (OFDM channel with 10 kHz).

9.4 Reception

9.4.1 Coastal

The receiver, connected on a vertical antenna standard whip of 8 m and 50 Ω matching, presenting a bandwidth of 12 kHz in baseband thus allowing a treatment by the decoding software.

Several receivers were used making it possible to watch several frequencies simultaneously and to compare several types of reception antennas.

9.4.2 SHIP

The ship used the same antenna for receive and transmit.

The broad band receiver (>12 kHz) was preceded by a selective pre-amplifier for the rf bands 4 and 8 MHz allocated for the tests by the French Administration.

9.5 Conclusions

– The experimentation results show the importance to install the coastal stations close to the sea to minimize the land / sea path.

– The use of vertical polarization has been demonstrated as very important.

– The type of antenna used to favour the sea wave with a vertical directivity pattern weakest possible to attenuate the sky wave is an important element.

– Measurements on the sea surface wave confirm:
  – the received level decrease when the frequency increases;
  – the received level is an opposite function of the distance;
  – the level received is very strongly attenuates at the time of the crossing of portions of terrestrial path;
  – the assessments radio link is on conformity with a few dB close with the results published by ITU;
  – the band of coherence seems most of the time higher than 9 kHz;
  – maximum dispersion is weak;
  – the sky wave (by the E layer 90-100 km of altitude) and/or by the F layer (on average to 200 km) can generate signals fields levels upper than surface wave.

This pointed out the importance to work on antenna emission and reception for the coastal stations with very low vertical patterns.

FIGURE 87

Transmitting antenna in Brest

M.1798-87

Annex 5

Wideband HF data exchange system for point-to-point communication

1 Introduction

This annex describes point-to-point (PTP) communication for shore-to-ship, ship-to-shore, and ship-to-ship for exchanging digital data.

The system is applicable for many services such as PTP data exchange, electronic mail services, and ship position reporting services.

The system operates on the HF maritime bands of 4-26 MHz in a radio communication channel with a 10 kHz bandwidth, providing data rate up to 51 kbit/s .

The system establishes a communication link using FSK and then exchanges data using OFDM.

The system operates in half-duplex mode using OFDM modulation.

The system uses adaptive modulation and coding to optimize the spectral efficiency and throughput in the maritime HF band.

2 System overview

The system consists of:

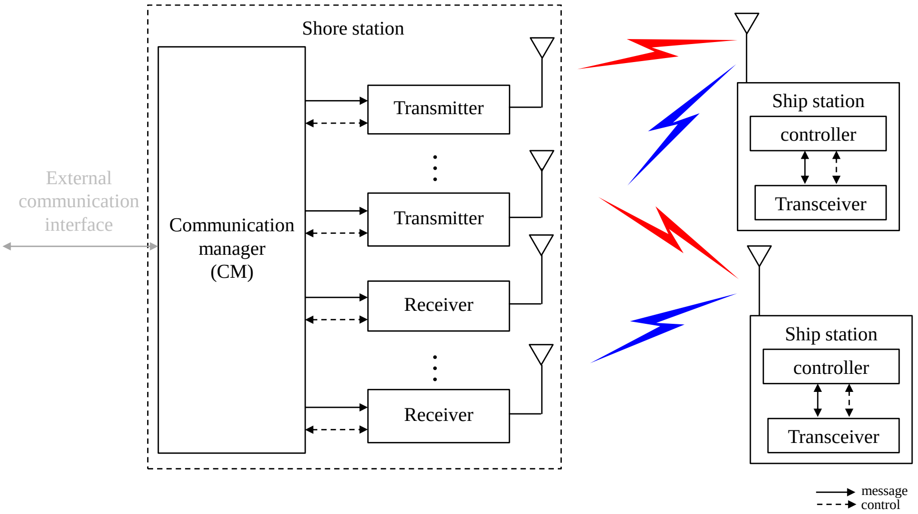
– the shore HF station;

– the ship HF station;

– the CM.

FIGURE 88

Wideband-HF data exchange system for point-to-point communication system



2.1 Shore station

The shore station consists of separated transmitters and receivers.

The shore station can simultaneously transmit via several frequencies.

The shore station uses the GNSS signal as reference clock information.

2.2 Ship station

The ship station includes the RF transmitter and receiver.

The ship station uses the GNSS signal to determine a ship's position.

2.3 Communication manager

The CM transmits or receives messages or control signals with shore transmitters and shore receivers.

The CM controls wideband HF communication.

The CM can communicate with external users through a network interface.

3 System architecture

3.1 Shore transmitter

The shore transmitter:

– receives messages from the CM;

– translates messages to the FSK signal;

– translates messages to the OFDM signal;

– transmits RF signals to ships via antennas;

– reports operating status to the CM.

A shore transmitter consists of:

– FSK modulator;

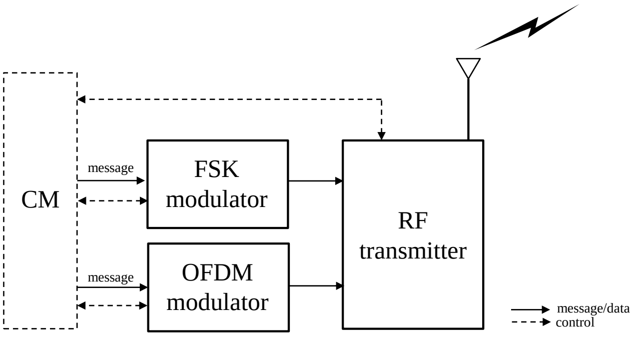
– OFDM modulator;

– RF transmitter;

– Transmit antenna.

FIGURE 89

Shore transmitter



3.1.1 Frequency shift keying modulator

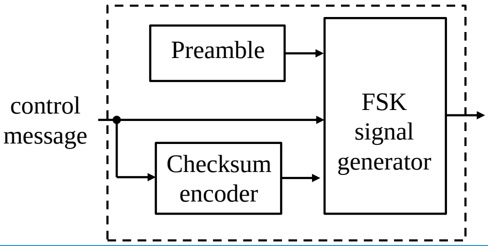
The FSK modulator is used to establish PTP connections.

The FSK modulator generates the preamble, control message, and checksum.

The control message contains information for establishing PTP connection.

FIGURE 90

Frequency shift keying modulator



3.1.1.1 Preamble

The preamble is a two-bytes length code.

The preamble is described in 5.2.2.

3.1.1.2 Checksum encoder

The checksum encoder generates a one-byte length word.

3.1.1.3 Frequency shift keying signal generator

The FSK signal generator is described in 4.1.

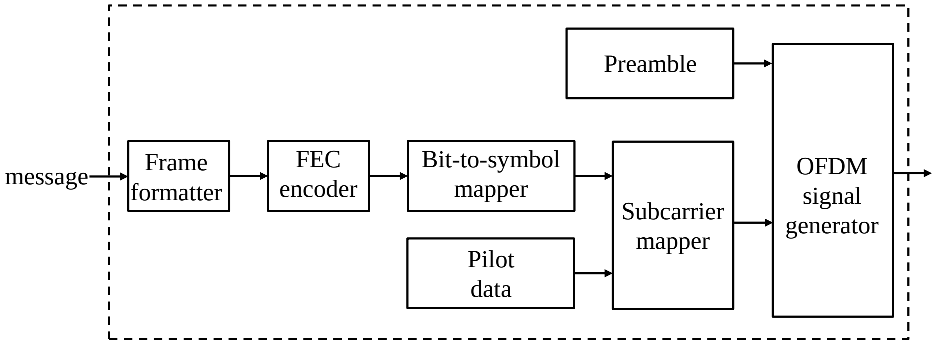
3.1.2 Orthogonal frequency division multiplexing modulator

The OFDM modulator generates the preamble, messages, FEC parity and pilot data.

The OFDM modulator consists of the preamble, frame formatter, FEC encoder, bit-to-symbol mapper, pilot data, subcarrier mapper, and OFDM signal generator.

FIGURE 91

Orthogonal frequency division multiplexing modulator



3.1.2.1 Preamble

The preamble is used as the first OFDM symbol.

The preamble is described in 4.2.5.

3.1.2.2 Frame formatter

The frame formatter generates a frame according to the specifications described in 5.3.2 and 5.3.3.

3.1.2.3 Forward error correction encoder

The error correction scheme determines the robustness of the coding.

The system uses Reed-Solomon (RS) code, convolutional code, and turbo code.

FEC is described in 4.2.4.

3.1.2.4 Bit-to-symbol mapper

Bit-to-symbol mapping is described in 4.2.3.

3.1.2.5 Pilot data

Pilot data is described in 4.2.5.

3.1.2.6 Subcarrier mapper

A subcarrier mapper organizes the OFDM subcarriers according to the formatted streams and pilot data.

3.1.2.7 Orthogonal frequency division multiplexing signal generator

An OFDM signal generator creates the OFDM baseband signal according to the output of the subcarrier mapper.

An OFDM signal generator is described in detail in 4.2.

3.1.3 Radio frequency transmitter

The RF transmitter upconverts the baseband signals to a 4 – 26 MHz RF signals and amplifies them to the desired transmission power.

[Editor's note: the output RF power should be reviewed in next meeting.]

The output RF power of the shore transmitter can be adjusted up to 1 kW peak envelope power (PEP).

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Specifications of the RF transmitter are given in 4.4.

3.2 Shore receiver

The shore receiver:

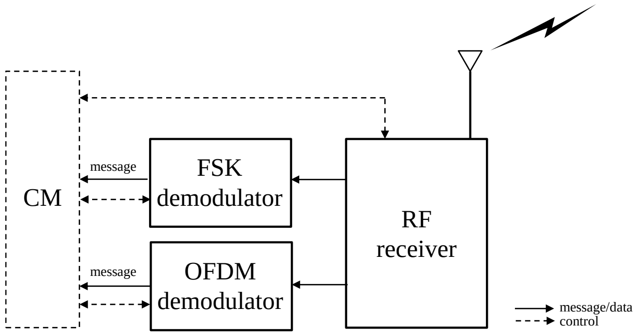
– receives RF signals from ships via antennas;
– translates FSK signals to messages;
– translates OFDM signals to messages;
– transmits messages to the CM;
– monitors operating status and reports to the CM.

A shore receiver consists of:

– FSK demodulator;
– OFDM demodulator;
– RF receiver;
– Receive antenna.

FIGURE 92

Shore receiver

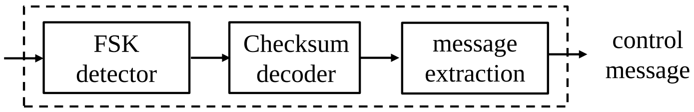


3.2.1 Frequency shift keying demodulator

The FSK demodulator detects FSK signals in the received RF signals, and extracts messages. The checksum decoder checks the data integrity.

FIGURE 93

Functional block diagram of frequency shift keying demodulator

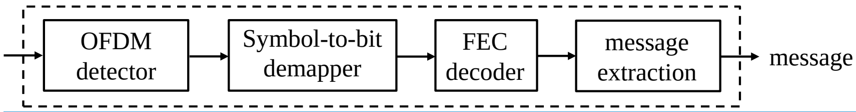


3.2.2 Orthogonal frequency division multiplexing demodulator

The OFDM demodulator detects OFDM signals in the received RF signals, and extracts messages. The FEC decoder recovers the original data.

FIGURE 94

Functional block diagram of orthogonal frequency division multiplexing demodulator



3.2.3 Radio frequency receiver

The RF receiver downconverts the received RF signals to baseband signals and amplifies them to the desired level for the analog-to-digital converter.

Specifications of the RF receiver are given in 4.5.

3.3 Ship station

The ship station:

– receives messages from the input device via the controller;

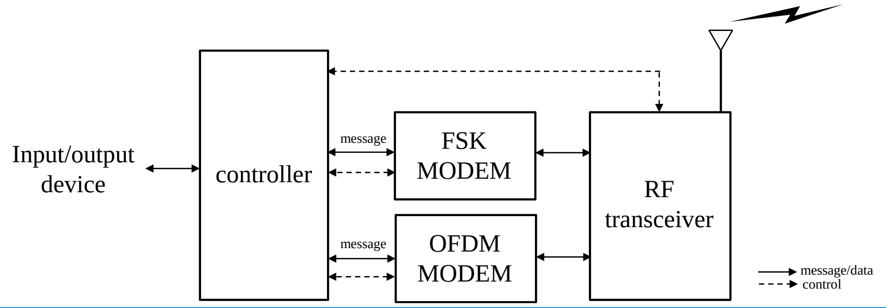
– translates messages to FSK or OFDM signals;
– transmits RF signals to shore stations or other ship stations via antenna;
– receives RF signals from shore stations or other ship stations via antenna;
– translates FSK or OFDM signals to messages;
– transmits messages to the controller;
– monitors operating status and reports to the controller.

A ship station consists of:

– controller;
– FSK MODEM;
– OFDM MODEM;
– RF transceiver and antenna.

FIGURE 95

Ship station



3.3.1 Controller

This unit receives the following information:

– messages from external devices;
– messages from the FSK demodulator;
– messages from the OFDM demodulator;
– monitoring signals from the MODEM;
– monitoring signals from the RF transceiver.

This unit sends the following information:

– messages to external display devices;
– messages to external storage devices;
– messages to the FSK modulator;
– messages to the OFDM modulator;
– control signals to the MODEM;
– control signals to the RF transceiver.

The control function of the controller is:

– to check Quality of Service (QoS);
– to manage the time schedule;
– to manage the packet schedule;
– to control the FSK, OFDM, and RF transceiver parameters.

This unit provides external data interfaces with other devices.

3.3.2 Frequency shift keying MODEM

The FSK MODEM is the same as specified in 3.1.1 and 3.2.1.

3.3.3 Orthogonal frequency division multiplexing MODEM

The OFDM MODEM is the same as specified in 3.1.2 and 3.2.2.

3.3.4 Radio frequency transceiver

The RF transmitter upconverts the baseband signals to RF signals and amplifies them to the desired transmission power. The RF receiver downconverts the received RF signals to the baseband and amplifies them to the desired level for the analog-to-digital converter.

3.4 Communication manager

The CM provides the following functions:

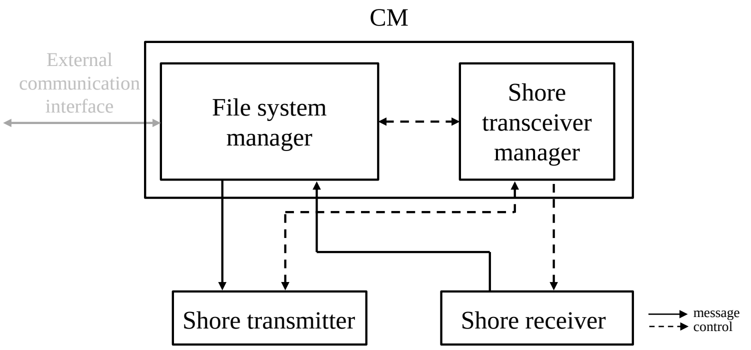
– controls the operating parameters of the shore transmitter and shore receiver;
– manages the communication time schedule;
– manages the communication packet schedule;
– monitors the operating status and communication quality of the shore transmitter and shore receiver;
– exchanges information with external users.

The CM includes:

– the file system manager;
– the shore transceiver manager.

FIGURE 96

Communication manager



3.4.1 File system manager

The file system manager:

– divides metadata into sub-data blocks for transmission;

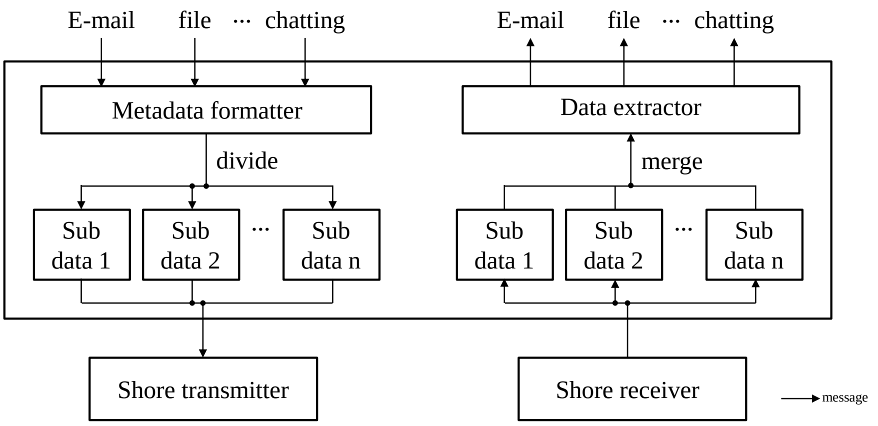
– merges received sub-data blocks into metadata;

– sends messages to the shore transmitter;

– receives messages from the shore receiver.

FIGURE 97

File system manager



3.4.2 Shore transceiver manager

The shore transceiver manager supervises the communications as follows:

– manages the FSK communication protocol;

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– manages the FSK communication time schedule;
– manages the FSK packet schedule;
– manages the OFDM communication protocol;
– manages the OFDM communication time schedule;
– manages the OFDM packet schedule;
– transmits acknowledgment;
– monitors the QoS.

and controls the following transceiver parameters:

– FSK parameters (rate, type, etc.);
– OFDM parameters (modulation, FEC, etc.);
– carrier frequency;
– transmit power;
– receive gain;
– transceiver switching.

4 Technical characteristics

4.1 Frequency shift keying modulation

4.1.1 Modulation

Data (control message) are transmitted using binary FSK modulation.

The data transmission rate is 100 bit/s.

The frequency shift between the mark and space is 170 Hz (+85 Hz for mark and -85 Hz for space).

4.2 Orthogonal frequency division multiplexing modulation

4.2.1 Introduction

The OFDM uses a large number of closely-spaced ($41^{2/3}$ Hz) orthogonal subcarriers to obtain high spectral efficiency for data transmission. These subcarriers are frequency-spaced ($F_u = 1/T_u$), where T_u is the OFDM symbol duration.

The OFDM symbol duration is $T_s = T_u + T_g$.

A guard interval (T_g) is inserted in the OFDM symbol to reduce the multipath effect, thus reducing the inter-symbol interference.

The OFDM symbols are then concatenated to make an OFDM frame.

FIGURE 98

Spectral representation of an orthogonal frequency division multiplexing frame

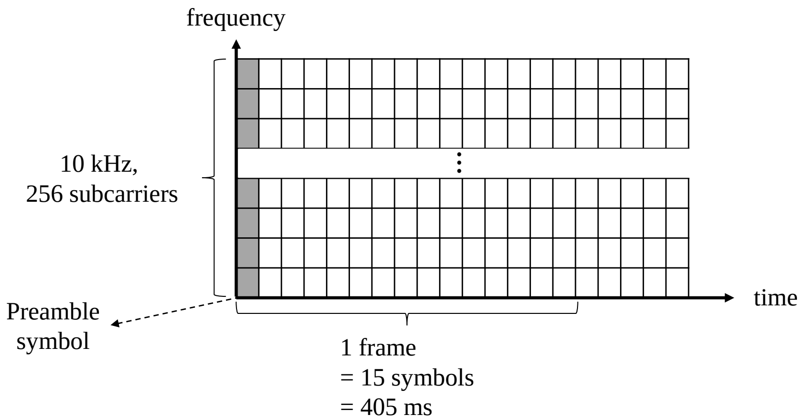
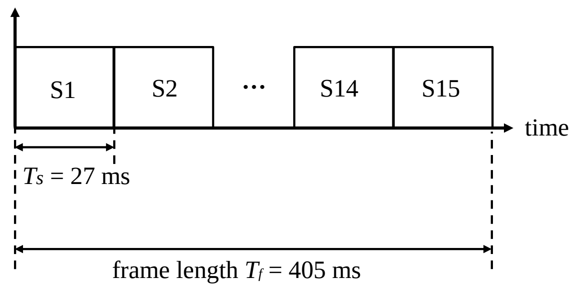


FIGURE 99

Orthogonal frequency division multiplexing frame



4.2.2 Orthogonal frequency division multiplexing parameters

TABLE 10

Orthogonal frequency division multiplexing parameters

Parameter	Specification
Bandwidth	10 kHz
Number of subcarriers	256
Number of data subcarriers	228
Reference sampling rate (×3 oversampling ratio)	32 ksamples/s
FFT period (T_u)	24 ms
Subcarrier spacing	$41^{2/3}$ Hz
Guard interval (T_g)	3 ms

Symbol duration (T_s=T_u+T_g)	27 ms
Number of symbols per frame (N_s)	15
Frame length (T_f)	405 ms
Number of symbols per short frame	2
Short frame length	54 ms
Modulation	4-QAM, 16-QAM, 64-QAM
FEC	Convolutional code, RS code, Turbo code

4.2.3 Modulation

Each subcarrier is modulated by 4-quadrature amplitude modulation (QAM), 16-QAM, or 64-QAM.

FIGURE 100

4-quadrature amplitude modulation constellation

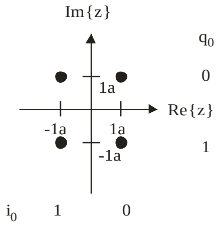


FIGURE 101

16-quadrature amplitude modulation constellation

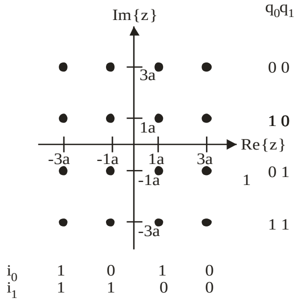
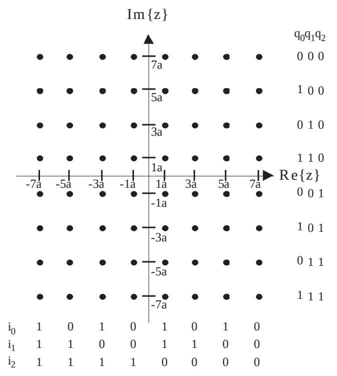


FIGURE 102

64-quadrature amplitude modulation constellation



4.2.4 Forward error correction

The error correction scheme depends on the desired robustness of the coding.

The system employs RS code and/or convolutional code, or Turbo-code.

TABLE 11

Forward error correction schemes

Mode	Outer code	Inner code	
1	RS (204,188)	-	
2	RS (204,188)	Convolutional code (K=7, r=1/2)	Puncturing 1/2
3	RS (204,188)	Convolutional code (K=7, r=1/2)	Puncturing 2/3
4	RS (204,188)	Convolutional code (K=7, r=1/2)	Puncturing 3/4
5	RS (204,188)	Convolutional code (K=7, r=1/2)	Puncturing 5/6
6	RS (204,188)	Convolutional code (K=7, r=1/2)	Puncturing 7/8
7	-	Turbo-code (duo binary, r=1/2)	Puncturing 1/2
8	-	Turbo-code (duo binary, r=1/2)	Puncturing 3/4

4.2.5 Synchronization

To allow a good demodulation of each subcarrier, the radio transmission channel response must be determined for each subcarrier and equalization should be applied. For this, some of the subcarriers of the OFDM symbols carry pilot data.

The pilot data allows the receiver to:

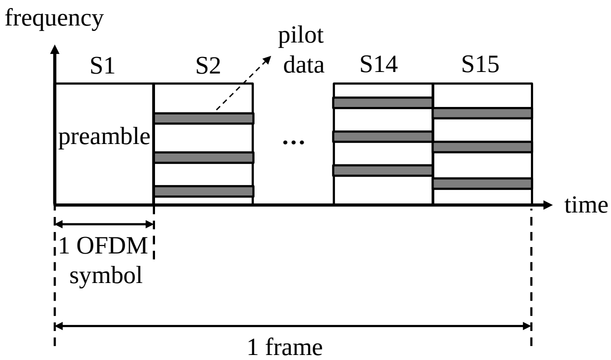
– estimate the frequency offset;

– estimate the radio transmission channel.

The amount of pilot data depends on the desired robustness of the signal.

FIGURE 103

Pilot data in orthogonal frequency division multiplexing signals



Pilot data is shown in Table 3.

TABLE 12

Pilot data

-1+1j , 1-1j , -1-1j , 1+1j , 1-1j , -1+1j , -1+1j , -1-1j , 1-1j , 1+1j , 1-1j , 1+1j , -1+1j , 1-1j , -1+1j , -1-1j , -1+1j , -1+1j , 1+1j , 1-1j , 1+1j , 1+1j , 1+1j , 1-1j , 1-1j , 1-1j , 1-1j , 1-1j , -1-1j , -1+1j , -1-1j , 1+1j , 1+1j , 1+1j , -1+1j , 1+1j , 1-1j , 1+1j

First symbol of each OFDM frame transmits the preamble symbol. The preamble symbol is used to detect the OFDM signal, estimate channel characteristics, and estimate carrier frequency offset. The preamble symbol is shown in Table 4.

TABLE 13

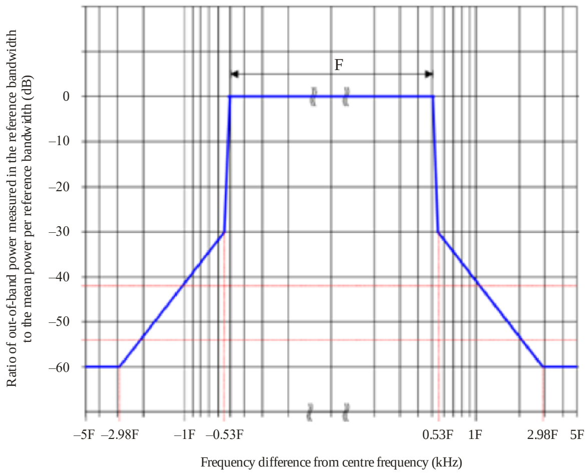
Preamble symbol

-1+1j , -1-1j , 1+1j , 1-1j , -1+1j , 1+1j , 1-1j , -1-1j , -1+1j , -1-1j , -1-1j , -1+1j , -1-1j , 1+1j , -1+1j , 1-1j , 1-1j , 1-1j , 1+1j , 1+1j , 1-1j , -1+1j , 1-1j , -1+1j , 1-1j , 1-1j , -1-1j , -1-1j , 1+1j , -1-1j , -1+1j , 1-1j , -1+1j , 1+1j , 1+1j , -1+1j , -1+1j , -1-1j , 1-1j , 1+1j , -1+1j , 1+1j , -1-1j , 1-1j , -1+1j , -1+1j , -1-1j , -1-1j , 1-1j , -1+1j , 1+1j , -1-1j , 1+1j , 1+1j , 1+1j , 1+1j , 1-1j , -1+1j , -1-1j , 1+1j , 1-1j , 1-1j , -1-1j , -1-1j , -1+1j , -1-1j , 1+1j , 1-1j , 1-1j , -1-1j , -1+1j , 1+1j , -1+1j , -1-1j , -1-1j , -1+1j , 1+1j , -1-1j , 1-1j , -1+1j , 1-1j , 1-1j , 1+1j , 1+1j , -1+1j , 1-1j , -1+1j , 1-1j , 1-1j , 1-1j , -1-1j , -1-1j , -1-1j , 1+1j , 1-1j , -1+1j , -1+1j , 1+1j , 1+1j , -1+1j , 1-1j , 1+1j , -1+1j , -1-1j , -1+1j , 1+1j , -1-1j , 1-1j , 1+1j , 1+1j , 1-1j , 1-1j , 1+1j , -1-1j , 1-1j , -1+1j , -1+1j , -1+1j , -1+1j , -1+1j , 1+1j , -1-1j , -1+1j , 1-1j , -1+1j , -1+1j , 1+1j , 1+1j , 1+1j , 1-1j , -1+1j , -1-1j , 1+1j , -1+1j , -1-1j , 1-1j , 1+1j , 1-1j , 1-1j , 1+1j , 1-1j , -1+1j , 1+1j , -1-1j , 1-1j , 1-1j , 1+1j , 1+1j , 1-1j , -1+1j , 1-1j , -1+1j , 1-1j , 1-1j , -1-1j , -1-1j , 1-1j , -1+1j , -1-1j , 1+1j , -1-1j , 1-1j , 1-1j , -1-1j , -1-1j , -1+1j , 1+1j , 1-1j , -1-1j , 1-1j , -1+1j , 1+1j , -1-1j , -1-1j , -1+1j , -1+1j , -1+1j , 1-1j , -1-1j , 1+1j , -1-1j , -1-1j , -1-1j , -1-1j , -1+1j , 1-1j , 1+1j , -1-1j , -1-1j , -1-1j , 1-1j , 1-1j , 1+1j , 1-1j , -1+1j , -1-1j , -1-1j , 1-1j , 1+1j , -1+1j , 1+1j , 1-1j , 1-1j , 1+1j , -1+1j , 1-1j , -1-1j , 1+1j , 1-1j , 1-1j , 1+1j , 1+1j , -1+1j , 1-1j , -1+1j , 1-1j , 1-1j , 1-1j , -1-1j , -1-1j , -1+1j , 1-1j , 1+1j , -1-1j , -1-1j , 1-1j , 1-1j , -1-1j

4.2.6 Spectrum occupancy of the radio frequency signal

FIGURE 104

Spectrum occupation of the radio frequency signal with bandwidth F = 10 kHz



4.3 Data rate

In the 10 kHz channel bandwidth, the maximum raw data rate is about 51 kbit/s.

4.4 Transmitter specifications

TABLE 14

Transmitter specifications

Parameter	**Specification**
Frequency band	4 MHz to 26 MHz
Carrier frequency tolerance	Within ±0.3 ppm
Spectrum occupancy	Comply with the requirement of Figure 17
Carrier suppression	≥ 40 dBc
Spurious emission	≥ 50 dBc, without exceeding the absolute mean power of 50mW (+17 dBm)

4.5 Receiver specifications

TABLE 15

Receiver specifications

Parameter	Specification
Frequency band	4 MHz to 26 MHz
Adjacent channel protection	20 dB (at ±10 kHz) 25 dB (at ±20 kHz) 35 dB (at ±30 kHz)
Sensitivity	-91.4 dBm (BER = 0.05 after error correction with a block length of 1,000 bits)
Spurious response rejection	≥ 60 dB
Intermodulation	≥ 50 dB
Blocking	≥ 40 dB (|f-f_c| > 30 kHz)

5 Communication protocol

5.1 Characteristics

The system consists of a link establishment stage and a data exchange stage for PTP communication.

The system is a half-duplex system.

In the PTP communication, an information-sending station (ISS) sends information and an information-receiving station (IRS) receives information and acknowledges the ISS.

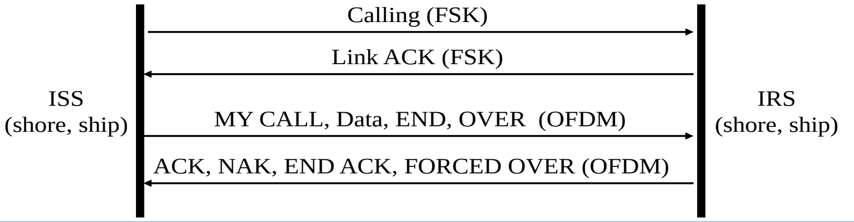
ISS and IRS do not distinguish between shore stations and ship stations.

The link establishment stage uses FSK modulation.

The data communication stage uses OFDM modulation.

FIGURE 105

Communication protocol



5.2 Link establishment using frequency shift keying

5.2.1 Frame timing

The link establishment frame timing is 1020 ms.

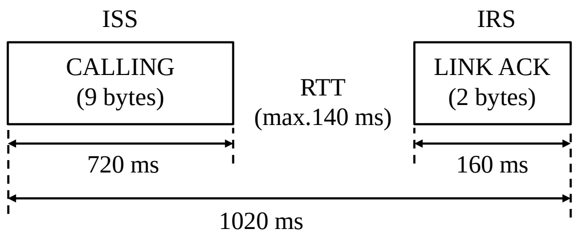
An ISS resends the CALLING block every 1020 ms when the IRS is not responsive.

The CALLING block is 720 ms in length and the LINK ACK block is 160 ms in length.

And, a maximum allowable round-trip time (RTT) is 140 ms.

FIGURE 106

Frame timing of link establishment



5.2.2 Block format

5.2.2.1 CALLING block

The data length of CALLING block is 9 bytes.

A two-byte preamble symbol is used to detect the CALLING block in the IRS.

SC1 - SC9 denote the MMSI of IRS (MMSI is defined in the most recent version of Recommendation ITU-R M.585).

The MMSI of IRS is transmitted in 4.5 bytes by packing two MMSI digits per byte.

A nibble RATE specifies the link format.

A single-byte TYPE is used to specify the transmission data format.

A single-byte checksum is included to confirm that the calling frame has been received error-free.

FIGURE 107

CALLING block format

1010 1100	0011 0101	SC1| SC2	SC3| SC4	SC5| SC6	SC7| SC8	SC9| RATE	TYPE	check sum

Preamble symbol

TABLE 14

RATE and TYPE in CALLING block

RATE		TYPE	
Value	Communication mode	Value	Data type
14	Annex 5	0	File
		1	Image
		…	…

5.2.2.2 LINK acknowledge receipt block

When MMSI in a received CALLING block is matched, the IRS responds with a LINK ACK.

FIGURE 108

LINK acknowledge receipt block format

0x56A9 (2 bytes)

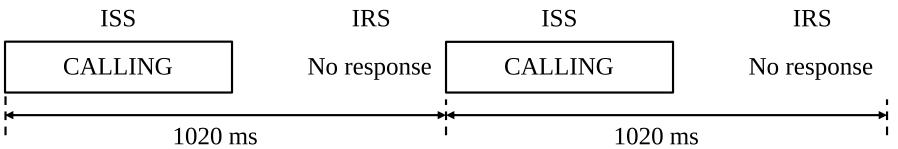
5.2.3 Protocol scenarios

5.2.3.1 Scenario 1

If the ISS does not receive a LINK ACK, the ISS resends a CALLING block every 1020 ms.

FIGURE 109

Protocol scenario 1

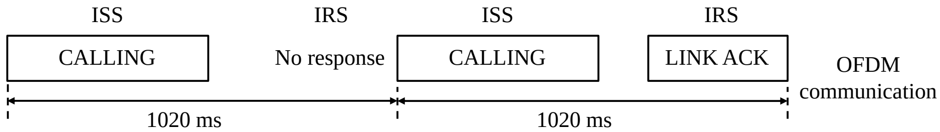


5.2.3.2 Scenario 2

If the ISS receives a LINK ACK, the ISS switches to OFDM communication after link establishment with a frame timing of 1020 ms.

FIGURE 110

Protocol scenario 2



5.3 Data communication using orthogonal frequency division multiplexing

5.3.1 Frame timing

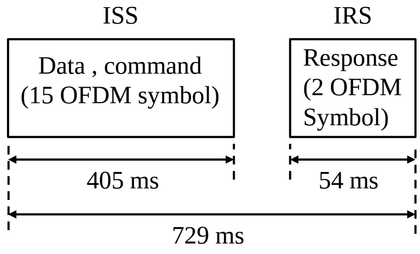
The data communication frame timing is 729 ms.

The ISS sends data or a command every 729 ms.

The ISS frame timing is 405 ms and the IRS frame timing is 54 ms.

FIGURE 111

Frame timing of data communication



5.3.2 Information sending station control block format

The ISS has three control messages: MYCALL, END, and OVER.

5.3.2.1 MYCALL control block

The control message of the MYCALL block is 0xE0.

The MMSI of the IRS is transmitted in 4.5 bytes by packing two MMSI digits per byte.

The remainder of the packet is filled with fill patterns.

FIGURE 112

MYCALL control block format

Preamble (1 OFDM symbol)	Control (0xE0) (1 byte)	MMSI (9 digits) (4.5 bytes)	Fill pattern (‘1010’)
	+ FEC		

5.3.2.2 END control block

The control message of the END block is 0x86.

The remainder of the packet is filled with fill patterns.

The END control block is used to signal the end of the link.

FIGURE 113

END control block format

Preamble (1 OFDM symbol)	Control (0x86) (1 byte)	Fill pattern (‘1010’)
	+ FEC	

5.3.2.3 OVER control block

The control message of the OVER block is 0x98.

The remainder of the packet is filled with fill patterns.

The OVER control block is used to signal an exchange role between the ISS and IRS.

FIGURE 114

OVER control block format

Preamble (1 OFDM symbol)	Control (0x98) (1 byte)	Fill pattern (‘1010’)
	+ FEC	

5.3.3 Information receiving station response block format

The IRS has four response messages: ACK, NAK, END_ACK, and FORCED_OVER.

The IRS response block consists of one OFDM symbol for the preamble and one OFDM symbol for the control message.

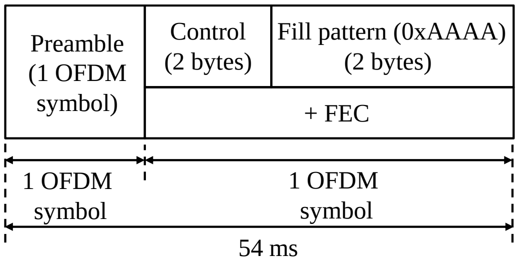
5.3.3.1 Acknowledge receipt, END_ACK, and FORCED_OVER response block

The control messages of the ACK, END_ACK, and FORCED_OVER block are 0x56A9, 0x956A, and 0x6A95, respectively.

The remainder of the packet is filled with fill patterns.

FIGURE 115

Acknowledge receipt, END_ACK, and FORCED_OVER block format



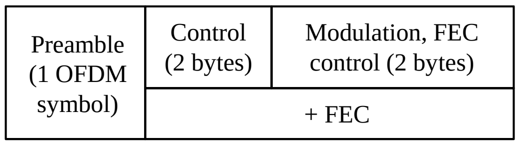
5.3.3.2 Not acknowledged response block

The control message of the NAK block is 0xA956.

A two-byte modulation and FEC control message is sent to the ISS to change the modulation and/or FEC scheme.

FIGURE 116

Not acknowledge block format



5.3.4 Protocol scenarios

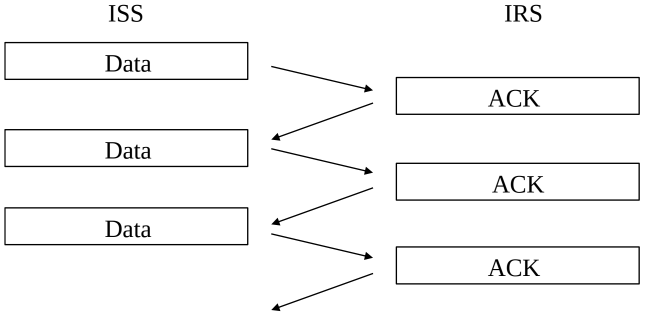
5.3.4.1 Data communication scenario 1

If the IRS receives data without any errors, the IRS responds with an ACK.

The ISS sends next data after receiving an ACK.

FIGURE 117

Data communication protocol scenario 1



5.3.4.2 Data communication scenario 2

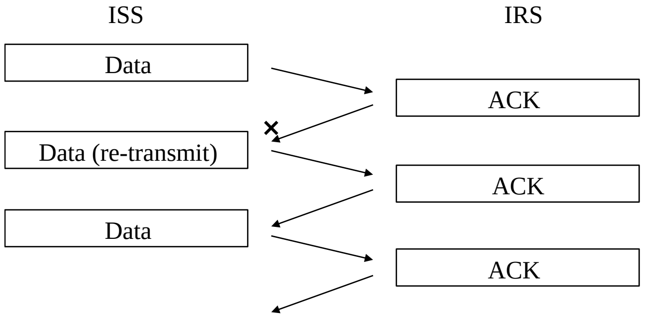
If the IRS receives data without error, the IRS responds with an ACK.

The ISS resends data if the ISS fails to receive an ACK.

The IRS identifies data using a sequence number.

FIGURE 118

Data communication protocol scenario 2



5.3.4.3 Data communication scenario 3

If the IRS fails to receive data, the IRS responds with a NAK and sends modulation and FEC control message at the same time.

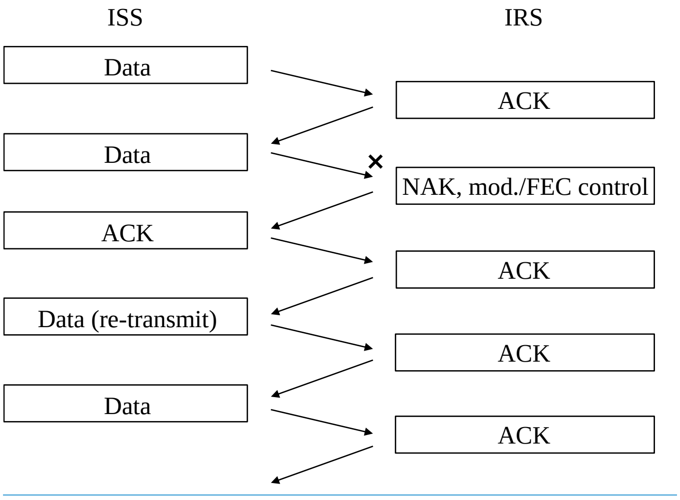
The ISS responds with an ACK after receiving a NAK.

The IRS responds with an ACK after receiving an ACK.

If the ISS receives an ACK, the ISS resends data after changing the modulation and FEC scheme.

FIGURE 119

Data communication protocol scenario 3



5.3.4.4 Data communication scenario 4

If the IRS fails to receive data, the IRS responds with a NAK and sends modulation and FEC control message at the same time.

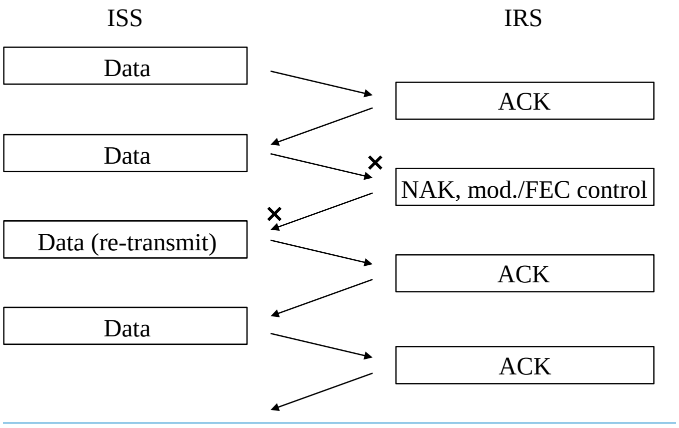
The ISS resends data if the ISS fails to receive a NAK.

If the IRS receives data without the error, the IRS responds with an ACK.

If the ISS receives an ACK, the ISS sends next data without changing the modulation and FEC scheme.

FIGURE 120

Data communication protocol scenario 4



5.3.4.5 Data communication scenario 5

If the IRS fails to receive data, the IRS responds with a NAK and sends modulation and FEC control message at the same time.

The ISS resends data if the ISS fails to receive a NAK.

If the IRS fails to receive data, the IRS responds with a NAK and sends modulation and FEC control messages at the same time.

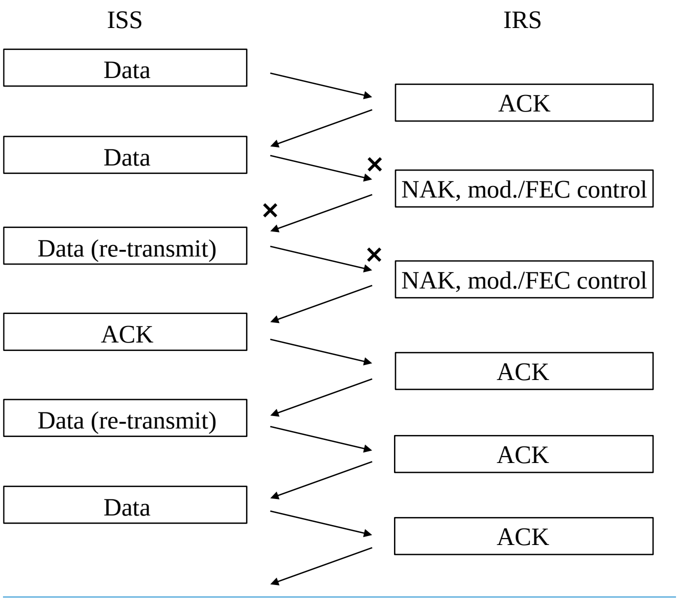
The ISS responds with an ACK after receiving a NAK.

The IRS responds with an ACK after receiving an ACK.

If the ISS receives an ACK, the ISS resends data after changing the modulation and FEC scheme.

FIGURE 121

Data communication protocol scenario 5

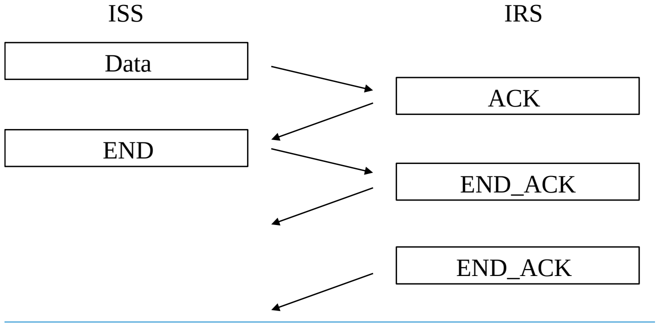


5.3.4.6 END scenario

If the IRS receives an END control message without error, the IRS responds twice with an END_ACK.

FIGURE 122

END protocol scenario



5.3.4.7 OVER scenario

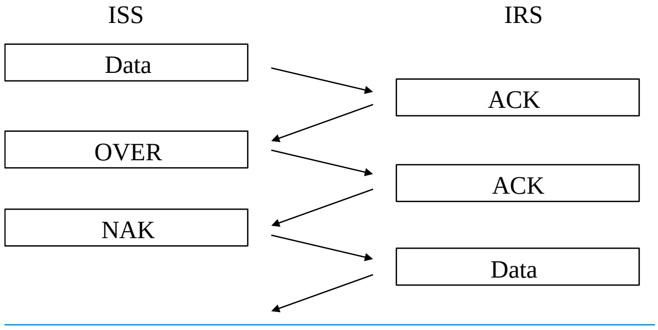
If the IRS receives an OVER control message without error, the IRS responds with an ACK.

The ISS responds with a NAK after receiving an ACK.

If the IRS receives a NAK, the IRS becomes an ISS and sends data.

FIGURE 123

OVER protocol scenario



~~Glossary~~

~~Access provider~~ ~~Company which proposes a connection to IPBC radio network to customer~~

~~ACK~~ ~~Acknowledge receipt~~

~~Coast station~~ ~~Set of shore equipment on a same site (reception and transmission site), designed to communicate into one or several radio cells~~

~~CW~~ ~~Continuous wave~~

~~GMDSS~~ ~~Global Maritime Distress and Safety System~~

GPS	Global Positioning System
IPBC	Internet protocol for boat communications
IPBC radio network	Radio network achieved by whole of the radio cells dedicated for IPBC traffic
Maritime HF band	HF frequency range (4-30 MHz) which is divided in HF sub-band dedicated for maritime traffic
Mobile station	Set of ship equipment designed to communicate into a radio cell
OFDM	Orthogonal frequency division multiplexing
PEP	Peak envelope power
QAM	Quadrature amplitude modulation
Radio cell	Radio electric coverage area for a transmitter of a coast station, and for a radio transmission channel in an HF maritime sub-band
Radio transmission channel	Physical support which allows data transport; this support is characterized by a central frequency in a maritime HF sub-band and a bandwidth of 10-20 kHz.