WINMOR Protocol Specification (Beta Release)

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1.0 Scope:
This document describes the preliminary WINMOR sound card protocol at the physical and data link levels. It is the complete specification of the WINMOR protocol. It does not address higher level protocol layers. The WINMOR protocol is not proprietary and is released to the public domain. This document describes the 500 Hz and 1600 Hz bandwidth modes using 93.75 Baud (PSK) and 46.875 baud FSK modulation.

2.0 Purpose:
The intent of this document is two fold:

a) To serve as a working document during protocol development and testing
b) To serve as a template to allow others familiar with the art to build compatible drivers that support the data link protocol layer.

3.0 Definitions and Syntax:
Several specific terms and syntax are used in this document:

Definitions: A term or item is defined using the := symbol. This symbol can be read as "is defined as"

Implementation directives: These are key words that indicate how an item is to be implemented or recommend a method of implementation. They are always indicated by capitalized italic words. These are:

MUST := this must be followed to implement the protocol
MUST NOT := this must not be done to implement the protocol
SHOULD := this is the recommended way to implement the protocol
MAY := this is alternative way to implement the protocol.

The syntax above is always used to distinguish between the common use of the same words.

& is used to indicate catenation. E.g. Frame := Pilot & Data

4.0 Overview of the Protocol:
The WINMOR protocol is intended to be used for sending messages and binary data error free over a HF radio link. It is a Selective Repeat Automatic Retry reQuest (SRARQ) protocol where the Information Receiving Station (IRS) acknowledges receipt of the data to the Information Sending Station (ISS). Normally during a connection session the IRS and ISS exchange roles multiple times. The protocol is designed to handle the type conditions normally encountered in amateur radio transmission.

Specifically:

Generally low S/N levels
Non "channelized" frequencies with interference
Poor to moderate propagation conditions including poor multipath environment.
Frequency offset (between send and receiver) and drift
Sound card sampling rate error and drift

The WINMOR protocol uses basic OFDM (Orthogonal Frequency Division Multiplexing) modulation and a number of modulation modes and error correction schemes to adapt to changing channel conditions. There is currently 2 operating bandwidths of 500 and 1600 Hz (@ 26 db below peak power output:

500 Hz BW 2 carriers 46.875 Baud 4FSK or 93.75 baud PSK using TCM 4PSK, 8PSK or 16PSK

1600 Hz BW 8 carriers 46.875 Baud 4FSK or 93.75 baud PSK using TCM 4PSK, 8PSK or 16PSK

WINMOR is not optimized for keyboarding or "chat" mode applications though this may be possible with the appropriate user client. An optional FEC broadcast (unproto) mode is also available.

4.1 Error Correcting Mechanisms

WINMOR employs a number of powerful error detecting and correcting mechanisms which are specifically adapted to the types of errors found in HF communications using popular FSK and PSK modulation schemes. This section outlines the error correction approach used.

Normally error correction is done in terms of "layers" for improved effectiveness and efficiency. The following briefly describes these layers and how they are used in WINMOR.

4.1.1. Outer Sumcheck Layer

This layer applies a standard CRC sumcheck calculation on the "corrected" data. It insures to a very high probability that the corrections are indeed correct and the data matches that which was transmitted. For Connect request frames, ID frames and all data frames a 16 bit CRC Polynomial of `x^16 + x^12 +x^5 + 1` is used. For short coded control and ACK frames an 8 bit CRC polynomial of `x^8 + x^7 +x^3 + x^2 + 1` is used.

4.1.2 Reed Solomon Layer

Reed-Solomon (R-S) FEC appends parity blocks (characters) to an uncoded message which are used to detect and correct errors. The total message size (with parity) must be equal to $2^n – 1$ where n is the character size in bits. WINMOR uses both 8 bit and 4 bit character sizes. Shortened R-S codes (where sender and receiver agree a priori to the message size and not transmit the "fill" part of the message) are used as is typical in many R-S applications.

For data frames the Reed Solomon layer is actually implemented in two formats. The first format is what is called weak R-S where a relatively few parity characters are appended to the message. This weak R-S format is usually sufficient to correct the frame under most conditions. If a data frame must be repeated (reciever did not ACK) then the second strong R-S format is used which transmits *just* the parity charactes of a more robust R-S code. These parity characters are then used along with the prior sent data (ignoring the weak R-S Parity bytes) to attempt to correct the original message part of the first weak R-S format. These two formats are alternated with each repeat of a data frame.

4.1.3 Viterbi Encoded TCM Layer

The next layer uses what is called Viterbi Encoded Pragmatic Trellis Coded Modulation. (See appendix B) This is used on all PSK modes but is not used on FSK. This scheme reaches to within about .2 db of the theoretical coding gain of the best similar length Trellis codes but uses a standard Viterbi encoder/decoder (NASA Voyager R=1/2, K=7). In TCM a single bit is added to each PSK symbol doubling the number of phases. The gain provided by the code exceeds that lost by the tighter spaced phase constellation by typically about 3 dB giving essentially a 3dB power improvement with no change in payload throughput or bandwidth. The layered use of the Viterbi inner encoding and R-S outer encoding is common in many advanced error correcting schemes.

4.1.4 Memory ARQ

The final layer used is what is commonly called memory ARQ (Automatic Retry reQuest). If decoding on the received data using the above layers is not sucessful Memory ARQ averages the received demodulated (soft) symbol values (frequency or phase/magnitude) on a symbol by symbol basis and attempts a decode (using the above layers) on the averaged values. This can be effective in very weak signal conditions. Memory ARQ is done only for data frames and is applied to both the weak R-S and strong R-S data formats.

5.0 Physical Layer Protocol Description:

The protocol requires the following hardware:

1) Radio connection. This *SHOULD* be a single sideband (SSB) transceiver capable of transmitting Upper sideband low distortion audio in the range of 600-2400Hz. When SSB transmission is used it *MUST* always done using Upper Sideband (USB). Other modulation schemes (e.g. NBFM) *MAY* be used in some applications.
2) Radio Frequency accuracy: If SSB modulation is used the radio *MUST* be able to be set to within +/- 100 Hz of a specific (published) frequency.
3) Frequency Drift: If SSB modulation is used the radio frequency *MUST* have a short term drift of < .5Hz/Second over any 5 second period.
4) The transceiver *MUST* have a Receive to transmit switching time of < 100 ms and a Transmit to Receive switching time of < 100 ms
5) The audio for the protocol *MAY* be generated using a standard PC sound card and appropriate software.

6) On Radios with built in sound card interfaces (e.g. Icom 7200) it is possible to use the radio's built in sound card to send and receive SSB audio.
7) The sound card capture device (receiving data) *MUST* be able to support a real or interpolated sampling frequency of 48000Hz +/- .1% (+/-1000 ppm)
8) The sound card playback Device (transmitting data) *MUST* be able to support a real or interpolated sampling frequency of 12000 Hz +/-.1% (+/- 1000 ppm)
9) The processor or PC used to implement the protocol *MUST* be able to complete the decoding of any frame and respond with the appropriate response in 500 ms or less. (this is currently estimated to equate to a Pentium/Celeron class processor of 500 MHz or above) It may be possible to reduce the PC requirement in the future at the expense of session throughput.

6.0 Data Link Layer Protocol Description:

6.1 Definitions:

Information Sending Station (ISS) := the station currently sending data to the other station. The ISS *MUST* only send data or control frames.

Information Receiving Station (IRS) := the station currently receiving data or commands from the other station. The IRS *MUST* only send Ack or control frames.

Carrier := one of the modulation carriers. There are either 4 or 6 modulation modes supported depending on the desired session bandwidth:

1) 500Hz BW
   a. PSK Modes: 4PSK TCM, 8PSK TCM, 16PSK TCM
      2 Carriers at 1406.25 Hz and 1593.75 Hz
   b. Mode 4FSK
      2 groups of 1of 4 Carriers. (2 carriers active simultaneously)
      Group 1: 1312.5, 1358.375, 1406.25 and 1453.125 Hz
      Group 2: 1546.875, 1593.75, 1640.625 and 1687.5 Hz
2) 1600 Hz BW
   a. PSK Modes: 8 carrier 4PSK TCM, 8PSK TCM, 16PSK TCM
      8 Carriers at 843.75, 1031.25, 1218.75, 1406.25, 1593.75, 1781.25, 1968.75 and 2156.25 Hz
   b. Mode 8 carrier 4FSK
      8 groups of 1of 4 Carriers. (8 carriers active simultaneously)
      Group 1: 750.0, 796.875, 843.75 and 890.625 Hz
      Group 2: 937.5, 984.375, 1031.25 and 1078.125 Hz
      Group 3: 1125.0, 1171.875, 1218.75 and 1265.625 Hz
      Group 4: 1312.5, 1358.375, 1406.25 and 1453.125 Hz
      Group 5: 1546.875, 1593.75, 1640.625 and 1687.5 Hz
      Group 6: 1734.375, 1781.25, 1828.125 and 1875.0 Hz
      Group 7: 1921.875, 1968.75, 2015.625 and 2062.5 Hz
      Group 8: 2109.775, 2156.25, 2203.125 and 2250.0 Hz
   c. Modes: 2 carrier 4PSK TCM

2 Carriers at 1406.25 Hz and 1593.75 Hz

d. Mode 2 carrier 4FSK

2 groups of 1of 4 Carriers. (2 carriers active simultaneously)

Group 1: 1312.5, 1358.375, 1406.25 and 1453.125 Hz

Group 2: 1546.875, 1593.75, 1640.625 and 1687.5 Hz

Pilot := Leader of the Frame. The Pilot is used to enable rapid identification of a transmission, to DSP tune the receiving station accurately, to establish symbol and frame sync and to indicate the frame type. The single carrier of 1500.00 +/- .1% is sent at full modulation strength (Maximum PEP value) to maximize S/N during the Pilot interval

Pilot := P_{tun} & P_{fsync} & P_{fty}

P_{tun} is the tuning pilot. P_{fsync} is the frame sync identifier. P_{fty} is the frame type identifier. P_{tun} & P_{fsync} are always sent using single carrier DBPSK modulation with a root raised cosine envelope encoding for robustness.

P_{tun} := 20 adjacent symbols of the pilot carrier (1500.0 Hz) alternating phase on each symbol. The tuning signal *MAY* be extended up to 12 symbols (128 ms) for transceivers with slow R>T switching or slow VOX PTT response if using VOX.
P_{fsync} := Frame sync symbol consisting of one symbol of the same phase as the immediately preceding P_{tun} symbol. The P_{fsync} symbol serves as the frame sync symbol for the following P_{tfy} symbols.
P_{fty} := 4 sequential 4FSK symbols. These 4 symbols encode the 4 bit frame type with an extended 8,4 hamming code.

Frame := a unit of information. A frame is composed of a Pilot & Data. Frames are identified by the syntax F_{xyz} where xyz is the frame descriptor.

Symbol := A symbol is one modulation burst of data. The symbol rate is 93.75 symbols per second (baud) +/- .1% for PSK modes (93.75 = 12000/128) . For 4FSK modes the symbol rate is 46.875 symbols per second (baud) +/- .1% (12000/256) Pilot symbols consist of a single carrier with a root raised cosine envelope weighted at the maximum PEP value. Data and control symbols consist of:

1) 2 carrier PSK modulated with a root raised cosine envelope. Each carrier is weighted 53% of the pilot carrier

2) 2 Carrier 4FSK (one of 4 tones). Each carrier is weighted at 50% of the weight of the pilot carrier.

3) 8 simultaneous carriers PSK modulated with a root raised cosine envelope. Each carrier is weighted at 16.7% of the maximum PEP value.

4) 8 simultaneous carriers each 4FSK (one of 4 tones). Each carrier weighted at 14.3% of the maximum PEP value.

(Note: these carrier weightings are combined with limited soft and hard clipping to reduce the crest factor. The percentages above are subject to change.

For PSK modes the initial symbol following the Pilot is the reference symbol S_r. This establishes the reference for the next Differential symbol. The S_r symbol carries no information but establishes the reference phase for each carrier. The reference phase for each carrier need not be the same as a mechanism of reducing the crest factor. There is no reference symbol for 4FSK modes.

Byte := the number of contiguous symbols to make one byte. After the frame type data all frames send an integral number of bytes with a total length determined by the frame type.

Symbol Modulation: With the exception of the pilot described above all data symbols and all carriers *MUST* use the same modulation scheme. The supported schemes *MUST* include Viterbi encode Trellis Coded Modulation (Pragmatic TCM) PSK (differential phase shift keying) and 4FSK.

SessionID := a 2 byte integer B_{sid} defined as CRC16 (Calling sign & Target call sign) The session ID dramatically reduces the chances of a session contamination by a remote non connected but audible rogue signal. The Session ID is used in the computation of the sum check but is only sent specifically on data frames. Specific encoding example TBD.

6.2 Frame Types:

The following frame types *MUST* be supported. For Detailed frame parameters see the spread sheet in Appendix A.

6.2.1 Control frames:

F_{crq} Connect ReQuest frame: 2 Car 4FSK = type 0

Sent by the station initiating the connection (Client). Contains call signs of calling and target stations and 2 byte sumcheck. The session Bandwidth is set by the answering (Server) station.

F_{crq} Encoding:

F_{crq} := Pilot & S_r & B_{data} & B_{sch} & B_{scl} & B_{RS}

B_{data} := Calling call sign & Remote call sign. Callsigns are packed to 12 byte array of 6 bit characters and must be A-Z, 0-9 with an optional –ssid of 0 – 15. Function FormatCallsToByte is used to pack the 12 byte array.

B_{sch} is the high byte of the CRC16 sum check of B_{data}
B_{scl} is the low byte of the CRC16 sum check of B_{data}
B_{RS} is the 14 check parity bytes from a shortened RS (255,241) code correcting up to 7 bytes

F_{crq} Total payload (2 carriers) of 28 bytes including CRC16 and RS correction check bytes and is always sent using 2 carrier 4FSK modulation (2 user bits per symbol)

F_{ID} ID frame: 2 Car 4FSK = type 15

Sent by the station to ID. Contains call sign of sending station and optional Grid 6 character Grid square.The ID frame is sent automatically at 10 minute intervals by the ISS and upon a session end. At session end the ID frame may be optionally followed by a CW ID.

F_{ID} Encoding:

F_{ID} := Pilot & S_r & B_{data} & B_{sch} & B_{scl} & B_{RS}

B_{data} := Calling call sign & Grid Square. Callsign and grid square are packed to 12 byte array of 6 bit characters and must be A-Z, 0-9 with an optional, The call sign may have an optional –ssid of 0 – 15. Function FormatCallsToByte is used to pack the 12 byte array.

B_{sch} is the high byte of the CRC16 sum check of B_{data}
B_{scl} is the low byte of the CRC16 sum check of B_{data}
B_{RS} is the 14 check parity bytes from a shortened RS (241, 255) code correcting up to 7 bytes

F_{ID} Total payload (2 carriers) of 28 bytes including CRC16 and RS correction check bytes and is always sent using 2 carrier 4FSK modulation (2 user bits per symbol)

F_{ccf} Coded Control Frame (2 Car 4FSK = type 1)

Handles the following sub types by 1 byte code in the control frame:

F_{drq} Disconnect Request (code HFF)

F_{idl} Idle Code H00

F_{brk} Break (sent by the IRS to stop the ISS from sending data and go to the IRStoISSe state) Code(HAA)

F_{ovr} Over (sent by the ISS to force a link turnover. This causes the IRS to request a BREAK. Code(H55)

F_{rps} Request Packet Sequence number (sent by the ISS to get the last correctly sequenced packet from the IRS in preparation for a mode shift. Code(H11)

F_{ccf} := Pilot & B_{cod} & B_{sc8} & B_{RS}

B_{cod} is the 8 bit code value 00 - FF
B_{sc8} is the 8 bit sum check of B_{sid} & B_{cod}
B_{RS} is the 8 parity nibbles (4 bits) from a shortened RS (7,15) correcting up to four 4-bit characters.

F_{ccf} Total payload (2 carriers) of 6 bytes including CRC8 and RS correction check nibbles and is always sent using 2 carrier 4FSK modulation (2 user bits per symbol)

6.2.2 ACK Frames:

F_{ack} := Ack (2 Car 4FSK FEC = type 2)

Handles ACK for all carrier modes

F_{ack}:= Pilot & B_{ack} & B_{sc8} & B_{RS}

B_{ack} is a 8 bit field. The 8 bits correspond to the ACK for each carrier. The LSbit represents the highest carrier frequency.

B_{sc8} is the 8 bit sum check of B_{sid} & B_{ack}

B_{RS} is the 8 parity nibbles (4 bits) from a shortened RS (7,15) correcting up to four 4-bit characters.

(note the Coded control and ACK frames have the same length but different frame types)

F_{ack} Total payload (2 carriers) of 6 bytes including CRC8 and RS correction check nibbles and is always sent using 2 carrier 4FSK modulation (2 user bits per symbol)

6.2.3 Data frames:

Data frames consists of four modulation schemes each supporting two data types:

1: Data + weak Reed-Solomon FEC

2: Extended Reed-Solomon FEC
(the extended RS code is used to correct additional errors)

Data is first sent as a type 1 data frame (Data + Weak R-S encoding) if the data is not decoded correctly it is sent again as a type 2 (strong R-S Parity only). This strong R-S parity is appended to the *data* portion of the *previous* Data + Weak R-S Encoding (the Weak R-S parity bytes are discarded) and a new more robust R-S decode is attempted. Data frames alternate between Type 1 and Type 2 until there is a successful decode. Data type 2 is distinguished from type 1 by using the ones compliment of the Session ID. Some form of data summation (analog memory ARQ) *MAY* be used to average repeated Data + Weak R-S or Strong R-S Parity only to improve decoding performance.

F_{d16TCM} 16PSK Pragmatic TCM

Encoding for type 1 (Data + weak Reed-Solomon error correction):

F_{d16TCM} := Pilot & S_r & B_{sid} & B_{psn} & B_{bc} & B_{data} & B_{pad} & B_{sch} & B_{scl} & B_{RS} & B_{00}

Where:

B_{sid} is the 16 bit Session ID.

B_{psn} is the Packet Sequence Number (1 to 255 mod 256. PSN 0 is reserved)

B_{bc} is the byte count (the number of bytes in B_{data} only)

B_{data} is the data bytes (up to 108 bytes)

B_{pad} is remaining B_{00} if required to fill B_{data} frame if < 108 bytes are used

B_{sch} is the high byte of the CRC16 sum check per carrier

B_{scl} is the low byte of the CRC16 sum check per carrier

B_{RS} is the Reed Solomon 26 byte RS weak parity using a shortened RS code of 229,255 (13 error correcting)

B_{00} is a one byte fill necessary to complete the 141 bytes due to the 3 bits/symbol

Encoding for type 2 (Extended RS Parity):

F_{d16TCM} := Pilot & S_r & B_{sid} & B_{RSX} & B_{00}

Where:

B_{sid} is the ones compliment of the 16 bit Session ID.

B_{RSX} are the 138 extended Reed Solomon Parity bytes *only* of a strong RS code 117,255 (46 error correcting).

B_{00} is a one byte fill necessary to complete the 141 bytes due to the 3 bits/symbol

Data Frames using this modulation mode:

Two carrier 16PSK, 500 Hz BW

Eight carrier 16PSK, 1600 Hz BW

F_{d8TCM} 8PSK Pragmatic TCM

Encoding for type 1 (Data + weak Reed-Solomon error correction):

F_{d8TCM} := Pilot & S_r & B_{sid} & B_{psn} & B_{bc} & B_{data} & B_{pad} & B_{sch} & B_{scl} & B_{RS} Where:

B_{sid} is the 16 bit Session ID.

B_{psn} is the Packet Sequence Number (1 to 255 mod 256. PSN 0 is reserved)

B_{bc} is the byte count (the number of bytes in B_{data} only)

B_{data} is the data bytes (up to 72 bytes)

B_{pad} is remaining B_{00} if required to fill B_{data} frame if < 72 bytes are used

B_{sch} is the high byte of the CRC16 sum check per carrier

B_{scl} is the low byte of the CRC16 sum check per carrier

B_{RS} is the Reed Solomon 16 byte RS weak parity using a shortened RS code of 239,255 (8 error correcting)

Encoding for type 2 (Extended RS Parity): **F_{d8TCM}** := Pilot & S_r & B_{sid} & B_{RSX}

Where:

B_{sid} is the ones compliment of the 16 bit Session ID.

B_{RSX} are the 92 extended Reed Solomon Parity bytes *only* of a strong RS code 163,255 (46 error correcting).

Data Frames using this modulation mode:

Two carrier 8PSK, 500 Hz BW

Eight carrier 8PSK, 1600 Hz BW

F_{d4TCM} 4PSK Pragmatic TCM

Encoding for type 1 (Data + weak Reed-Solomon error correction):

F_{d4TCM} := Pilot & S_r & B_{sid} & B_{psn} & B_{bc} & B_{data} & B_{pad} & B_{sch} & B_{scl} & B_{RS} Where:

B_{sid} is the 16 bit Session ID.

B_{psn} is the Packet Sequence Number (1 to 255 mod 256. PSN 0 is reserved)

B_{bc} is the byte count (the number of bytes in B_{data} only)

B_{data} is the data bytes (up to 34 bytes)

B_{pad} is remaining B_{00} if required to fill B_{data} frame if < 34 bytes are used

B_{sch} is the high byte of the CRC16 sum check per carrier

B_{scl} is the low byte of the CRC16 sum check per carrier

B_{RS} is the Reed Solomon 8 byte RS weak parity using a shortened RS code of 247,255 (4 error correcting)

Encoding for type 2 (Extended RS Parity): **F_{d4TCM}** := Pilot & S_r & B_{sid} & B_{RSX} Where:

B_{sid} is the ones compliment of the 16 bit Session ID.

B_{RSX} are the 46 extended Reed Solomon Parity bytes *only* of a strong RS code 209,255 (23 error correcting).

Data Frames using this modulation mode:

Two carrier 4PSK, 500 Hz BW

Eight carrier 4PSK, 1600 Hz BW

F_{d4FSK} 4FSK modulation @ 46.875 baud

Encoding for type 1 (Data + weak Reed-Solomon error correction):

F_{d4FSK} := Pilot & B_{sid} & B_{psn} & B_{bc} & B_{data} & B_{pad} & B_{sch} & B_{scl} & B_{RS} Where:

B_{sid} is the 16 bit Session ID.

B_{psn} is the Packet Sequence Number (0 to 255 mod 256)

B_{bc} is the byte count (the number of bytes in B_{data} only)

B_{data} is the data bytes (up to 22 bytes/carrier)

B_{pad} is remaining B_{00} if required to fill B_{data} frame if < 22 bytes are used

B_{sch} is the high byte of the CRC16 sum check per carrier

B_{scl} is the low byte of the CRC16 sum check per carrier

B_{RS} is the weak Reed Solomon 20 byte check sum using a shortened RS code of 235,255 (10 error correcting)

F_{d4FSK} Encoding for type 2 (Extended RS Parity):

F_{d4FSK} := Pilot & B_{sid} & B_{RSX} Where:

B_{sid} is the ones compliment of the 16 bit Session ID.

B_{RSX} are the 46 extended Reed Solomon Parity bytes *only* of a strong RS code 209,255 (23 error correcting).

For 4FSK each carrier group of 4 tones is separated by 4 x 46.875 or 187.5 Hz.
Data Frames using this modulation mode:
Two carrier 4FSK, 500 Hz BW
Eight carrier 4FSK, 1600 Hz BW

6.3 Connected (ARQ) Protocol Details

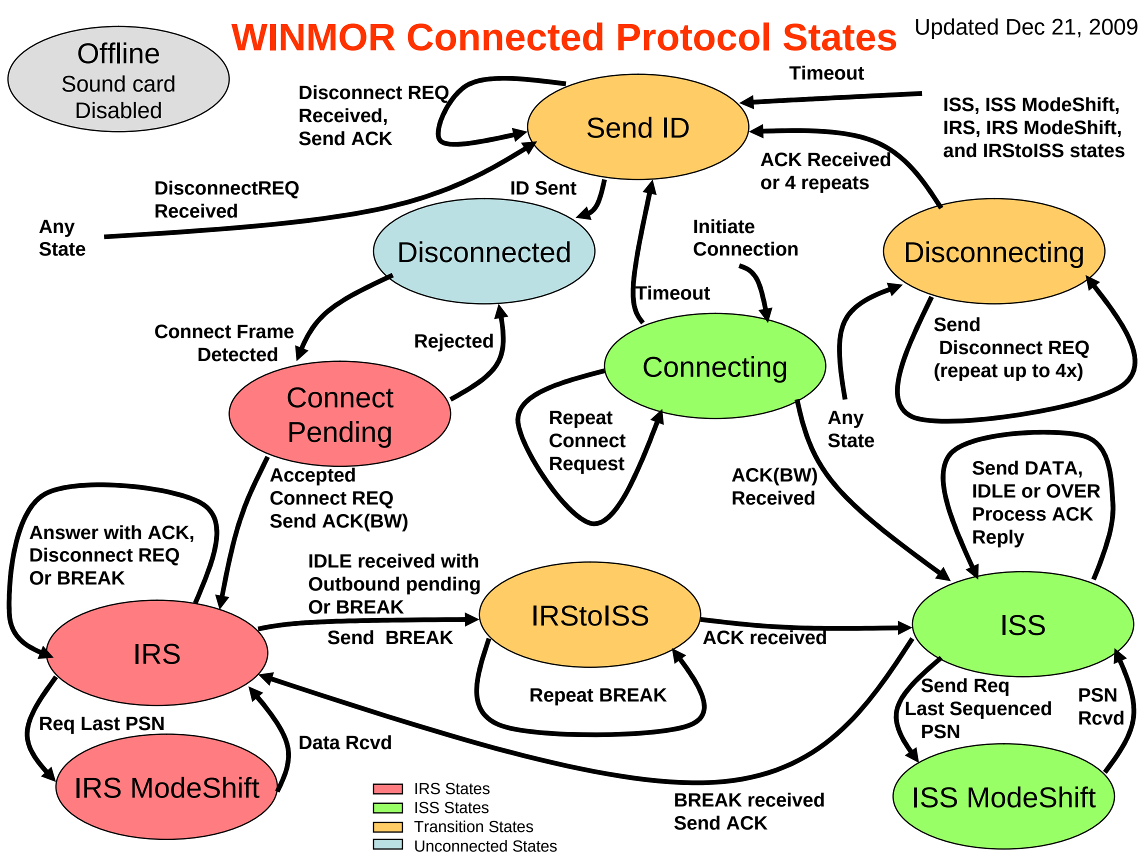


Fig 6 – 1 Simplified Connected Protocol State diagram:

6.3.1 Protocol Rules: (refer to state diagram Fig 6-1)

1) Offline.
   a. When WINMOR is in the Offline State it may send no data, receive no data and the sound card is deactivated and sound card resources released.
2) All other states, events, actions and state sequencing details are shown in the Protocol rules of Appendix C.

7.0 Unproto (FEC Broadcast) Mode:
Although WINMOR is primarily intended as an ARQ (server-client) forwarding protocol there is a provision to use the most robust data modes (4FSK 500 Hz and 4FSK 1600 Hz) in an FEC broadcast (Unproto) mode. This mode uses a staggered repeating of carrier data for additional robustness beyond the normal R-S FEC used in the 4FSK Modes. Figure 7-1 shows a simplified diagram of the Unproto states of WINMOR.

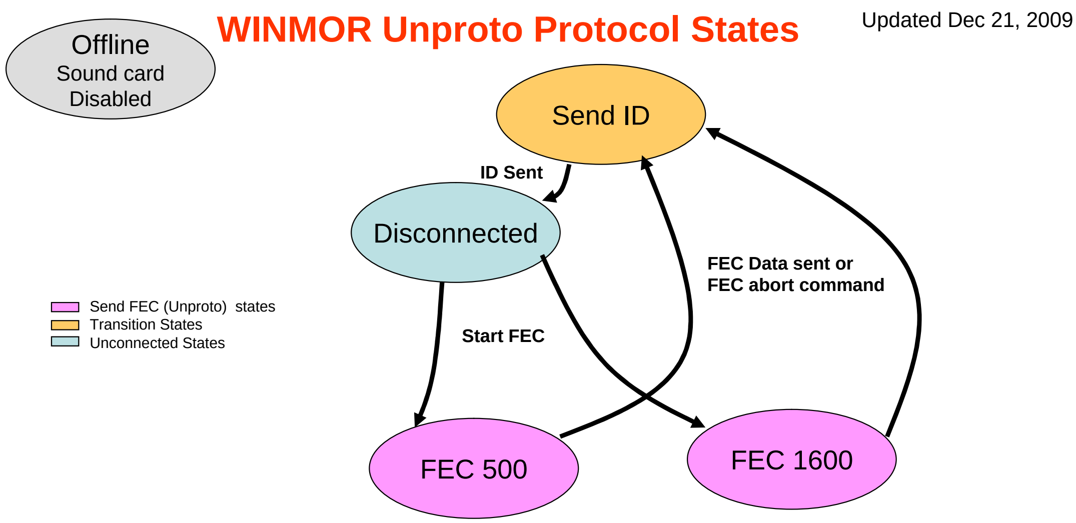


Figure 7-1 WINMOR Unproto States

7.1 FEC Unproto Frame Types
FEC Unproto is used only for ASCII data since 100% error correction is not assured. Any ASCII character except STX (Start of Text. Hex 02 and ETX (End of Text, Hex 03) may be sent. These two special characters are inserted upon receive to mark the received text if error correction was not possible for the specific PSN. Thus the uncorrected received text can be shown in a different color, or font if desired by the application.

$\mathbf{F_{FEC4FSK}}$ **4FSK modulation @ 46.875 baud**

Encoding for Data + weak Reed-Solomon error correction:

$\mathbf{F_{FEC4FSK}}$:= Pilot & B_{psn} & B_{psn} & B_{psn} & B_{bc} & B_{data} & B_{pad} & B_{sch} & B_{scl} & B_{RS} Where:

B_{psn} is the Packet Sequence Number (1 to 255 mod 256) (repeated 3 x)
B_{bc} is the byte count (the number of bytes in B_{data} only)
B_{data} is the data bytes (up to 22 bytes/carrier)
B_{pad} is remaining B_{00} if required to fill B_{data} frame if < 22 bytes are used

B_{sch} is the high byte of the CRC16 sum check per carrier
B_{scl} is the low byte of the CRC16 sum check per carrier
B_{RS} is the weak Reed Solomon 20 byte check sum using a shortened RS code of 235,255 (10 error correcting)

For 4FSK each carrier group of 4 tones is separated by 4 x 46.875 or 187.5 Hz.
Data Frames using this modulation mode:
Two carrier 4FSK, 500 Hz BW (Frame type 13)
Eight carrier 4FSK, 1600 Hz BW (Frame type 14)

FEC data is sent repeating frames in the following sequence:

FEC 500 Mode: (2 Carriers)
First Frame: PSN1, PSN1
Second Frame: PSN1, PSN2
Third Frame : PSN2, PSN3
Fourth Frame : PSN3, PSN4 etc
Last Frame: PSNn, PSNn
PSN number is modulo 256 skipping PSN 0
If there is insufficient data to fill each packet of a 2 carrier frame the data will be padded with ASCII NUL, Hex 00.

FEC 1600 Mode: (8 Carriers)
First Frame: PSN1, PSN2,PSN3,PSN4,PSN1,PSN2,PSN3,PSN4
Second Frame: PSN1, PSN2,PSN3,PSN4,PSN5,PSN6,PSN7,PSN8
Third Frame : PSN5,PSN6,PSN7,PSN8,PSN9,PSN10,PSN11,PSN12
Fourth Frame : PSN9,PSN10,PSN11,PSN12,PSN13,PSN14,PSN15,PSN16 etc
Last Frame: PSNn-3, PSNn-2, PSNn-1, PSNn, PSNn-3, PSNn-2, PSNn-1, PSNn
PSN number is modulo 256 skipping PSN 0
If there is insufficient data to fill each packet of an 8 carrier frame the data will be padded with ASCII NUL, Hex 00.

8.0 Example Forwarding Scenarios:

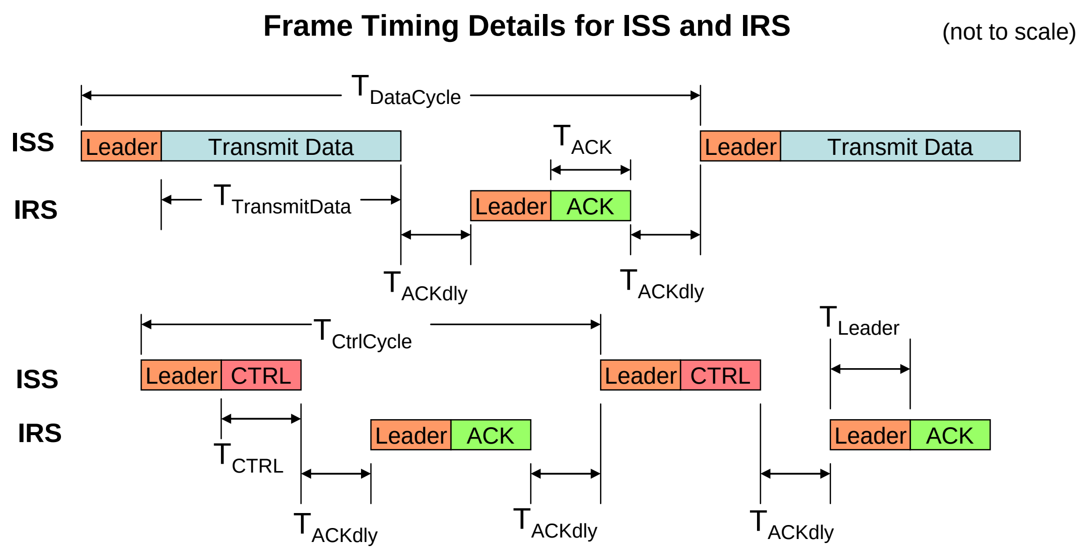
8.1 A typical Forwarding Session: (no errors or repeats)

CLIENT		SERVER	
State	**Frame Sent**	**State**	**Frame Sent**
CONNECTING	CONREQ		
		DISCONNECTED	ACK (BW)
ISS	IDLE		
		IRS	BREAK
ISS	ACK		
		IRStoISS	DATA

IRS	ACK		
		ISS	DATA
IRS	ACK		
		ISS	DATA
	…		
IRS	ACK		
		ISS	IDLE (end of data)
IRStoISS	BREAK		
		ISS	ACK
ISS	DATA		
		IRS	ACK
ISS	DATA		
	…..		
		IRS	ACK
ISS	IDLE (end of data)		
		IRS	ACK
DISCONNECTING	DIS REQ		
		SENDID	ACK
SENID (send ID Frame) DISCONNECTED			
		SENDID (Send ID Frame) DISCONNECTED	

9.0 Frame Timing

Fig 9 -1 below shows the simplified frame timing requirements for WINMOR. The $T_{TransmitData}$, T_{ACK}, and T_{CTRL} times can be calculated from the details in the WINMOR Rate worksheet shown in Appendix A.



T_{leader}	28 Symbols + optional 12 symbol VOX extenstion (298.6 – 426.6 ms)
T_{ACKdly}	100ms Min, 500 ms max
$T_{DataCycle}$	Repeat interval if NO ACK received >= $T_{Transmit\ Data} + T_{ACK} + 2(T_{Leader} + T_{ACKdly})_{max}$
$T_{CtrlCycle}$	Repeat interval if NO ACK received >= $T_{CTRL} + T_{ACK} + 2(T_{Leader} + T_{ACKdly})_{max}$

Fig 9 – 1 Frame Timing Details

Appendix A: WINMOR Mode Rate Worksheet

(details of frame construction for all modes, all bandwidths)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	'WINMOR 94 Baud Mode Rate Worksheet 500, 1600 Hz BW											Revised: 12/21/2009			Rick Muething, KN6KB				
2																			
3		Info	Samp	Baud	# of	~BW	Raw	Ldr	Ovrhd	Payld	RS-FEC	Frame	Frame		Rx+	Cycle	-----------	Net max	---------------
4	Mode Description	bits	/sym		car	(Hz)	bps/Hz	(sym)	/Car	/Car	/Car	Length	Length	ACK	Tx+O	Length		Throughput	
5		/sym							(sym)	(sym)	(sym)	(sym)	(sec)	(sec)	(sec)	(sec)	(bits/sec)	(byt/min)	(wrds/min)6
6	Connected Modes (ARQ)																		
7	8 Car 16PSK Prag TCM + RS	3	128	93.75	8	1600	1.41	29	24	288	72	413	4.405	0.555	0.3	5.260	1314	9856	3285
8	8 Car 8PSK Prag TCM + RS	2	128	93.75	8	1600	0.94	29	32	288	64	413	4.405	0.555	0.3	5.260	876	6570	2190
9	8 Car 4PSK Prag TCM + RS	1	128	93.75	8	1600	0.47	29	56	272	64	421	4.491	0.555	0.3	5.345	407	3053	1018
10	8 Car 4FSK +RS	2	256	46.88	8	1600	0.47	14	24	88	30	206	4.395	0.555	0.3	5.249	268	2012	671
11	2 Car 16PSK Prag TCM + RS	3	128	93.75	2	450	1.25	29	24	288	72	413	4.405	0.555	0.3	5.260	329	2464	821
12	2 Car 8PSK Prag TCM + RS	2	128	93.75	2	450	0.83	29	32	288	64	413	4.405	0.555	0.3	5.260	219	1643	548
13	2 Car 4PSK Prag TCM + RS	1	128	93.75	2	450	0.42	29	56	272	64	421	4.491	0.555	0.3	5.345	102	763	254
14	2 Car 4FSK +RS	2	256	46.88	2	450	0.42	14	24	88	30	206	4.395	0.555	0.3	5.249	67	503	168
15	Short 2 Car 4FSK +RS	2	256	46.88	2	450	0.42	14	24	24	16	78	1.664	0.555	0.3	2.519	38	286	95
16	2 Car Connect Request (4FSK) +RS	2	256	46.88	2	450	0.42	14	0	28	28	70	1.493						
17	2 Car Coded Control 4FSK + RS	2	256	46.88	2	450	0.42	14	2	2	8	26	0.555						
18	2 Car ACK 4FSK +RS	2	256	46.88	2	450	0.42	14	2	2	8	26	0.555						
19	FEC Modes (Unproto)																		
20	8 Car 4FSK +RS FEC Unproto	2	256	46.88	8	1600	0.47	14	24	88	30	206	4.395	0.000	0	4.395	160	601	100
21	2 Car 4FSK +RS FEC Unproto	2	256	46.88	2	450	0.42	14	24	88	30	206	4.395	0.000	0	4.395	40	150	25
22																			
23	Leader Preamble (93.75B symbols)	20																	
24	Leader extension (93.75D symbols 0-16)	0		See Note 1															
25	Calculated Leader extension (ms)	0																	
26																			
27	Notes:	1) Leader extension up to 16 symbols (171 ms) may be used for slow switchover Trancievers or VOX operated PTT.																	
28		Nominal VOX extenstion is 12 symbols or 128 ms																	
29		2) The above modes yield the following speed ranges depending on session bandwidth:																	
30		1600 Hz BW Sessions: 8x16PSK, 8x8PSK, 8x4PSK, 8x4FSK, 2x4PSK, 2x4FSK ~ 19.6:1 speed range																	
31		500 Hz BW Sessions: 2x16PSK, 2x8PSK, 2x4PSK, 2x4FSK ~ 4.9:1 speed range																	
32		3) Session BW is set by Server (answering) station using one of 2 coded ACK frames (500, or 1600 Hz)																	
33		4) All FSK modes use pragmatic Trellis Code Modulation (one redundancy bit/symbol) and use the standard R=1/2, K=7																	
34		(NASA Voyager) Viterbi Encoder/Decoder based on Phil Karns Code.																	
35		5) Rx + Tx + O refers to the receive to transmit, transmit to receive plus software overhead delays and is typical for modern hardware.																	
36		The protocol acutally measures the latency due to RX>TX switchover, sound card and CPU processing latency.																	
37		6) Word per minute calculation based on average word of 5 char + space and a 50% compression ratio (typical using B2 compression on																	
38		mid to large messages). Short messages will be less. FEC unproto based on 2x repeat, 5 char+space/word, no compression.																	
39		7) Ovrhd per carrier includes: Session ID, PSN, ByteCount, SumCheck and 6 symbols for Viterbi Decoder flushing on FSK modes																	

Appendix B: Pragmatic Trellis Code Modulation (PTCM)

Trellis code modulation is a combination of FEC encoding with PSK modulation used to improve the Bit error rate of uncoded PSK modulation. Pragmatic means using standard available encoders/decoders (e.g. Viterbi) in place of the slightly more optimized Ungerbroeck Trellis coded modulation encoder/decoders. Pragmatic TCM is within about .2 dB of the optimized Ungerbroeck code of the same constraint length over the typical bit error rates encountered.

Figure B-1 shows the block diagram of the PTCM encoder as employed in the WINMOR midrange speed mode (Trellis 8PSK). Similar schemes are used for the 4PSK and 16PSK modulation modes. In all cases the TCM adds one bit to the user symbol doubling the number of PSK phases per symbol.

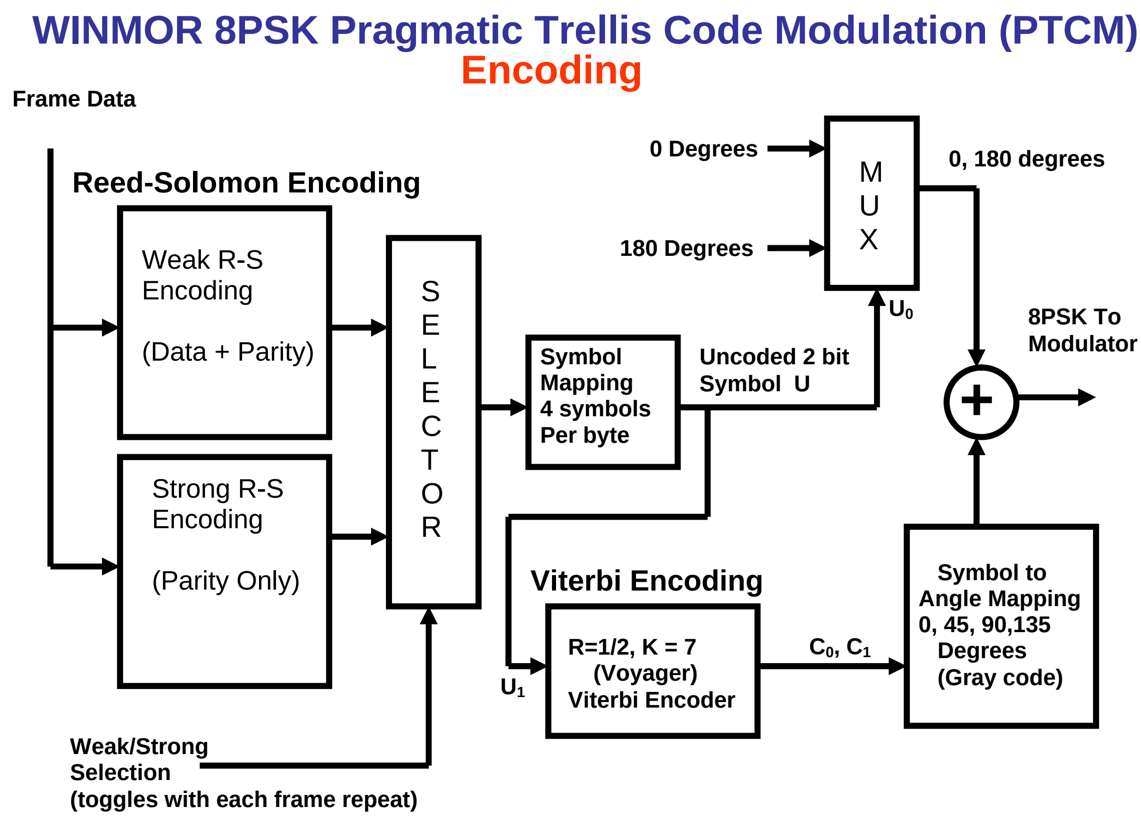


Figure B-1 WINMOR 8PSK PTCM Encoding

The encoding is summarized as follows:
A frame consists of 64 Payload (user data) bytes + 6 bytes of overhead. This frame is encoded using a weak R-S (Reed-Solomon) code (243,255) shortened to 82 bytes. This code will correct up to 6 byte errors in the 82 transmitted bytes. The resulting 82

bytes are mapped into 328 symbols of 2 bits each. The most significant symbol Bit U_0 is not FEC coded and selects an angle of 0 degrees (U_0 = 0) or 180 degrees (U_0 = 1) The least significant bit U_1 is fed into a standard (NASA Voyager) R= ½ , K=7 Viterbi Encoder which produces 2 FEC coded output bits C_0 and C_1 for each input bit U_1.
C_0 and C_1 are mapped to one of 4 phase values 0, 45, 90 or 135 using a gray code mapping. This phase value is added to the output of the multiplexer (0 or 180 degrees) to obtain the final 8PSK modulation angle (0 to 315 degrees in 45 degree steps)

Figure B-2 is a diagram of the PTCM decoder used by WINMOR's Trellis 8PSK mode.

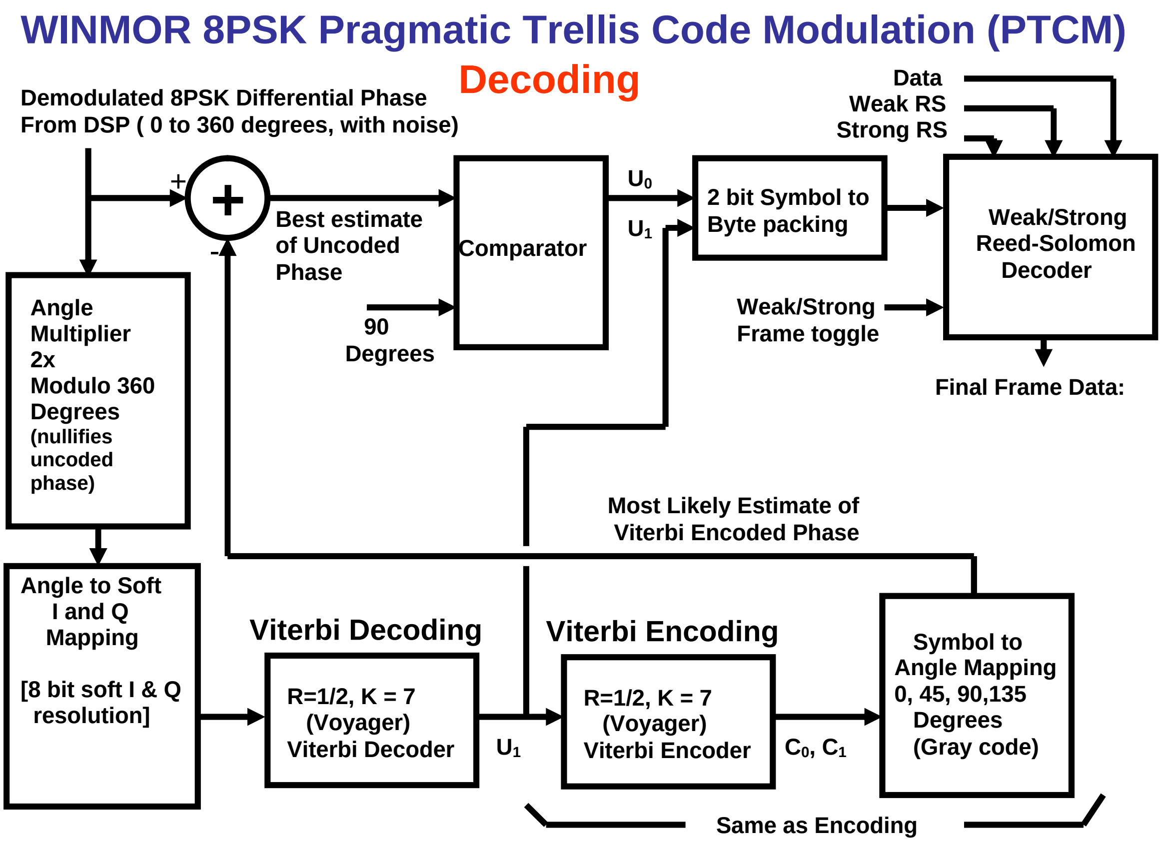


Figure B-2 WINMOR 8PSK PTCM Decoding

The decoding operation is somewhat more complicated and summarized as follows: The demodulated differential phase angle from the DSP (0 to +360 degrees, with noise) is the input to the decoder (one angle per symbol time). The angle is doubled, modulo 360 to nullify the 0 or 180 degree component of the uncoded bit. The resulting phase value 0 to 360 degrees in nominal (now 90) degree steps) is recoded to soft I and Q values which will be the soft I and Q inputs for two binary values input to the Viterbi encoder. Figure B-3 shows the mechanism for the angle to soft I

& Q mapping. The Viterbi decoder generates the best estimate for the original binary bit for each pair of soft I and Q inputs. This bit becomes the decoded symbol least significant bit U_1. U_1 is also fed into a Viterbi Encoder and Symbol to Angle mapper (exactly the same as is used in the encoder in Fig B-1) to yield the most likely estimate of the original Viterbi encoded phase angle value. This most likely estimate (0 to 135 degrees in 45 degree steps) is then subtracted from the original differential phase angle from the DSP to yield a best estimate of the uncoded bit phase (nominally 0 or 180 degrees). The resultant best estimate is compared to 90 degrees to generate U_0 the most significant bit of the symbol. The symbols composed of U_0 and U_1 are then packed 4 symbols/byte for Reed-Solomon decoding. If this is the initial transmission of the frame the weak R-S code of 243,255 (6) shortened to 82 bytes is used. This weak R-S code will correct up to 6 byte errors in the total 82 bytes transmitted. If the frame is a repeat (requested after a decode failure of initial attempt) then the 82 bytes of data are interpreted as the ID + parity only component of a strong R-S code of 175,255 code which can correct up to 40 errors of the shortened 150 code consisting of the 70 original payload + overhead bytes concatenated with the 80 strong R-S parity bytes. Thus the strong R-S code can correct up to 40 errors of the 150 bytes of data plus strong parity (transmitted over two frames).

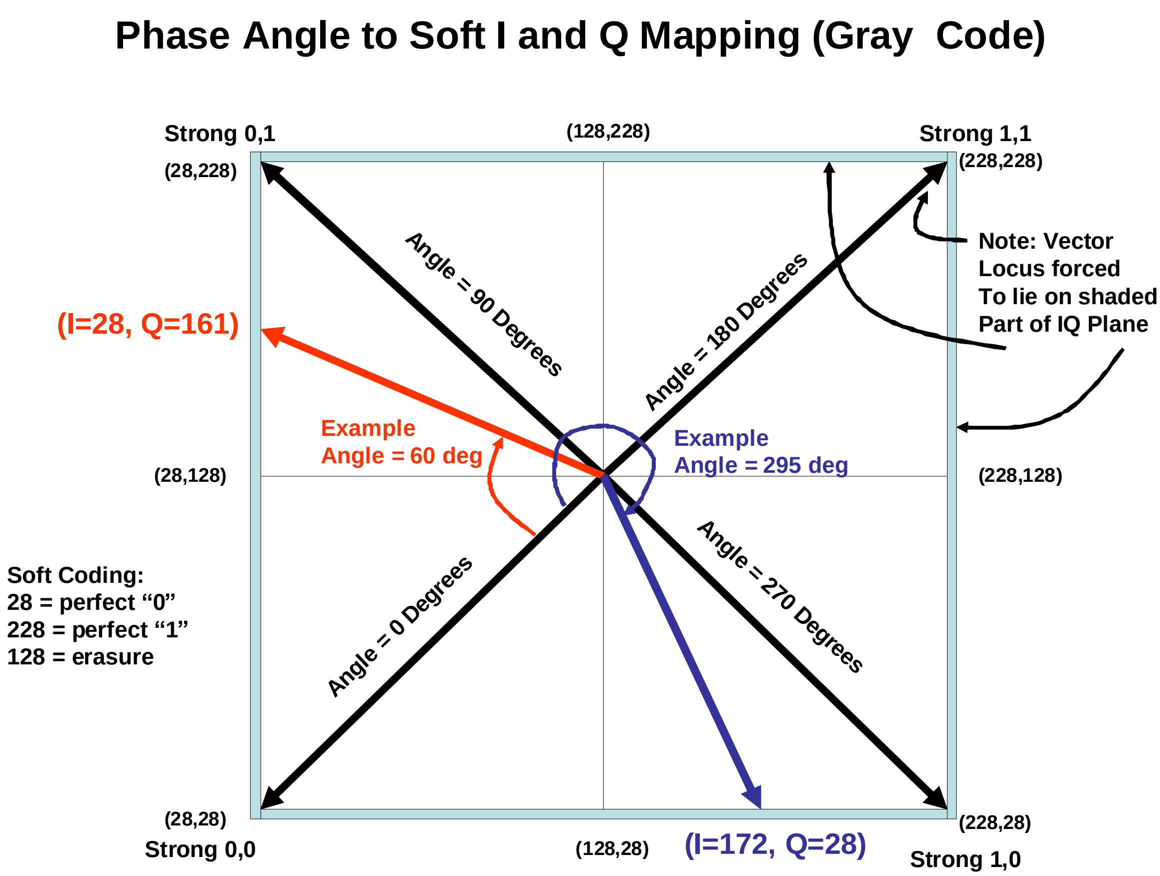


Figure B-3 Phase Angle to Soft I and Q Mapping with examples.

A similar approach to PTCM encoding and decoding is done on both the 4PSK mode (no uncoded bits, 2 Viterbi bits) and the 16PSK mode (2 uncoded bits, 2 Viterbi bits).

References:

1) A Pragmatic Approach to Trellis-Coded Modulation. A. Viterbi, J. Wolf, E. Zejavo, R. Padovani IEEE Communications Magazine July 1989, pp11-19
http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=31452

2) Data Recovery in Differentially Encoded Quadrature Phase Shift Keying. J. Bard, M. Nezami, and M. Diaz Mnemonics, Inc Melbourne, FL.
http://whitepapers.silicon.com/0,39024759,60446221p,00.htm

3) Error Control Coding, Second Edition. Shu Lin and Daniel Costello
Pearson Prentice Hall 2004 ISBN 0-13-042672-5

4) Trellis Coded Modulation Tutorial, Charan Langton, 2004.
http://www.complextoreal.com/chapters/tcm.pdf

Appendix C: Detailed State Change Rules

These rules provide the detail that implements the WINMOR Protocol State Diagram shown in Fig 6-1.

1 Rules for IRStoISS State

1.1 Event = ACK 00 Received
Action: Send Data (data pending or IDLE)
Next State: ISS

1.2 Event = No ACK received by BREAK timeout
Action: Repeat BREAK
Next State = IRStoISS

1.3 Event: Inactivity Timeout
Conditions: none
Actions: Send ID Frame (no ID delay)
Next State: SENDID

1.4 Event: Disconnect Request Received
Conditions: none
Actions: Send ID Frame (8 sec ID delay)
Next State: SENDID

2 Rules for DISCONNECTED State

2.1 Event = Connect request Frame detect (before Decode)
Conditions: Decode Frame type Connect Request
Action: none
Next State: CONNECT PENDING

3 Rules for CONNECTING State

3.1 Event = Bandwidth specific ACK received
Conditions: Matches current session ID
Action: Send IDLE, set Repeat ON if no Data pending
Next State: ISS

3.2 Event: Bandwidth specific ACK received
Conditions: Matches current session ID
Actions: Send DATA, set Repeat ON if Data is pending
Next State: ISS

3.3 Event: Connect request Timeout
Conditions: none
Action: Send ID Frame (no ID delay)
Next State: SENDID

4 Rules for CONNECT PENDING State

4.1 Event = Successful Decode to Target Call sign
Conditions: Target Call sign matches local call sign
Action: Send bandwidth specific ACK, set Repeat OFF
Next State: IRS

4.2 Event: Decode Failure
Conditions: Sumcheck fail or Target <> Local call sign
Actions: none
Next State: DISCONNECTED

5 Rules for DISCONNECTING State

5.1 Event = Control Frame Timeout
Conditions: Disconnect Repeat count < 5
Action: Send Disconnect Request, set Repeat ON
Next State: DISCONNECTING

5.2 Event: Control Frame Timeout
Conditions: Disconnect Repeat count > = 5
Actions: Send ID Frame (no ID delay)
Next State: SENDID

6 Rules for IRS State

6.1 Event = Data Received, Good match to ID bits
Conditions: Session ID match on at least one carrier
Action: Send ACK for each carrier correct, no repeats
Next State: IRS

6.2 Event: Data Received, Poor match to ID
Conditions: Session ID mismatch on all carriers
Actions: none
Next State: IRS

6.3 Event: Control Received, Request Last PSN
Conditions: Session ID match, Sumcheck OK
Actions: Send ACK containing Last PSN
Next State: IRS MODESHIFT

6.4 Event: Inactivity Timeout
Conditions: none
Actions: Send ID Frame (no ID delay)
Next State: SENDID

6.5 Event: Connect Request Frame Received
Conditions: Session ID Match, Sumcheck OK
Action: Send Bandwidth specific ACK
Next State: IRS

6.6 Event: Disconnect Request Received
Conditions: none
Actions: Send ID Frame (8 sec ID delay)
Next State: SENDID

6.7 Event: ID Frame Received
Conditions: none
Actions: Send ACK 00
Next State: IRS

7 Rules for IRS MODE SHIFT State

7.1 Event = Data Received
Conditions: Session ID Match
Action: Send ACK for each carrier no repeats
Next State: IRS

7.2 Event: Control Frame Idle received
Conditions: none
Actions: ACK(0), No repeat
Next State: IRS

7.3 Event: Inactivity Timeout
Conditions: none
Actions: Send ID Frame (no delay)
Next State: SENDID

7.4 Event: Disconnect Request Received
Conditions: none
Actions: Send ID Frame (8 sec ID delay)
Next State: SENDID

8 Rules for ISS State

8.1 Event = ACK received
Conditions: OB bytes pending after ACK processed, no speed shift required
Action: Send next OB Packet with Repeat
Next State: ISS

8.2 Event: ACK received
Conditions: OB bytes pending after ACK processed, speed shift
Actions: Send Control request last PSN with repeat
Next State: ISS MODESHIFT

8.3 Event: ACK received
Conditions: no OB bytes pending after ACK processed
Actions: Send Control Idle with repeat
Next State: ISS

8.4 Event: Inactivity Timeout
Conditions: none
Actions: Send ID Frame (no ID delay)
Next State: SENDID

8.5 Event: Disconnect Request Received
Conditions: none
Actions: Send ID Frame (8 sec ID delay)
Next State: SENDID

8.6 Event: ID Timeout (10 minutes) expired

Conditions: none
Actions: Send ID Frame (no delay or CWID) repeat until ACK 00
Next State: ISS

9 Rules for ISS MODE SHIFT State

9.1 Event = PSN Received
Conditions: Session ID Match, Sumcheck OK, OB Packets Remaining
Action: Send next Data packet
Next State: ISS

9.2 Event = PSN Received
Conditions: Session ID Match, Sumcheck OK, no OB Packets Remaining
Action: Send Idle, set repeat

9.3 Event: Inactivity Timeout
Conditions: none
Actions: Send ID Frame (no ID delay)
Next State: SENDID

9.4 Event: Disconnect Request Received
Conditions: none
Actions: Send ID Frame (8 sec ID delay)
Next State: SENDID

10 Rules for SENDID State

10.1 Event = ID Timeout Reached (nominally 0 or 8 seconds)
Conditions: none
Action Send ID Frame followed by CWID if CWID is enabled
Next state: DISCONNECTED

10.2 Event: Disconnect Request received (while waiting for ID timeout)
Conditions: Session ID matches current session
Action: Send ACK(FF) with session ID
Extend ID Timeout by 8 seconds
Next State: SENDID

11. Rules for FEC500 and FEC1600 States

11.1 Event = FEC500 or FEC1600 start command
Conditions: Must be in the disconnected state
Action: Enter FEC500 or FEC 1600 State, Send staggered FEC data
Next state: FEC500 or FEC1600 as appropriate

11.2 Event All pending outbound data sent
Conditions: none
Action: Enter SENDID state
Next State: SENDID

11.3 Event Abort FEC command (FEC OFF)
Conditions: none
Action: Clear outbound buffer. Enter SENDID State
Next State: SENDID

11.4 Event FEC 500 or FEC 1600 Data received (frames 13 , 14)

Conditions: Must have FEC reception enabled;
Must be in DISCONNECTED state
Action: Decode FEC, remove redundant PSN’s
Flag incorrectable PSN’s
Next State: DISCONNECTED