Digital Radio Projects

IP400 Protocol Specification

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References

[1] gnu.org, "General Public Licence," [Online]. Available: https://www.gnu.org/licenses/gpl-3.0.en.html. [Accessed 25th February 2018].

[2] IEEE Standards Association, "IEEE Standard for Low-Rate Wireless Networks," IEEE, IEEE SA Standards Boad, 2020.

Revision Status

Revision	Date	Description
0.1	January 7th[h], 2025	Initial draft
0.2	January 10th, 2025	Added extended callsigns and modified alphabet
0.3	January 12th, 2025	Added 802 PHY fields and OFDM mode
0.4	January 22nd, 2025	Added mesh networking

Table 1 Revision status

Reference Documents

Author	Issue Date	Description
M. Alcock	Jan 2025	Next generation multi-mode repeater controller

Table 2 Reference Documents

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Introduction

The IP400 protocol is a new ad-hoc networking protocol for the amateur 400MHz band, which combines the best of its predecessors, including AX.25, AREDN, HamWan and Next Generation Packet radio. It runs at lower bit rates of 600 Kb/s 4FSK at the entry level, 2.4Mb/s can be realized using an OFDM transceiver, speed beyond that are limited only by implementation and available hardware.

The protocol is modelled on, but does not completely conform to, the IEEE 802.15.4g [2] standard for low rate smart utility wireless networks, to take advantage of built-in hardware available in several off the shelf components. The physical level is compliant, however beyond that the same is not necessarily true. Two standards can be considered, 4FSK at up to 600Kb/s, and OFDM to 2.4 Mb/s.

The network is designed to comply to different applications, including digital audio, video, telemetry, messaging and others. A standalone station can be realized inexpensively using off the shelf hardware and the software is open source to enable experimentation and encourage future development activity.

It is not only used as a replacement for existing systems but can form the backbone for linking between repeater systems, which can be analog, or employing a digital standard based on C4FM modulation such as D-Star, YSF, DMR, P25, NXDN, M17 and the like. Analog linking can be in a native PCM mode or can economize on bandwidth by utilizing compression techniques such as M17 codec2.

Video is also possible using H.264 compression, but limits are placed on frame sizes and rates, where the two are mutually exclusive. To conserve bandwidth, the high the frame rate the smaller the frame size, and vice versa.

This document discussed the protocol specification in terms of the lower layers, and also some applications at higher levels to advertise presence on the network.

Packet Format

There are three distinct layers in the packet, physical, link and network.

FSK Physical layer

The packet shall be sent at 600Kb/s, using 4FSK modulation at a baud rate of 300Ks/sec, with a max deviation of ±150KHz. Each packet will be prefixed and postfixed with a ramp up/down sequence, and contain the fields as shown in the smart utility network PHY description.

The minimum packet length is 3.8ms, the maximum 23.2ms, yielding a maximum of 263 packets per second down to 32 packets per second, depending on the frame length.

Field	802.15.4 layer 4FSK		Link Layer	Network Layer
Ramp Up	16[1]		Not part of Frame	
Preamble	32			
Sync	32			
PHY header	16			
Source	48		480 to 8456 bits	56-1053 bytes
Destination	48			
Flags	16			
Ext Callsign	0-128			
Payload	336-8184			
FEC	32			Not part of Frame
CRC	16		Not part of Frame	
Ramp Down	32			
Frame length	2316	14108		
Time to send	3.86ms	23.51ms		
Frames/Sec	963	69		

Table 3 Packet Format

The effective data rate at the network layer shall be from 431/kb/s to 581.5Kb/s, dependent on packet size.

At the link layer, the packet shall contain a source and destination address in excess 40 format, a packet type, payload and forward error correction field. The FEC will be ignored if the CRC matches, if not an attempt is made to correct the packet data.

The network layer removes the FEC to create a data frame from 60-1515 bytes in length. Table 3 illustrates the packet format.

[1] PA ramp time is speculative and represents a sample case of 20µsec.

The format of a frame in the physical layer shall conform to the IEEE specification for smart utility networks.

The preamble field shall contain multiples of the 16 bit sequence 0x7777, to the length of the field specified.

The sync field shall contain the value 0x7DFF74FD in hexadecimal.

The PHY header field shall contain the bits as shown in Table 4.

Type	0	1-2	3	4	5-10	11-14	15
Mode Switch	0	Reserved	FCS Type	Whitening	Frame Length		
	1	Parameter	New FCS	New Mode		Checksum	Parity

Table 4 802.15.4. PHY Header Field

The fields in the header are described in

Field	Value	Interpretation
FCS Type	0	32 bit frame check sequence
	1	16 bit frame check sequence
Whitening	1	Data whitening has been applied to payload field
Frame Length	42-1023	Length of the link layer payload in octets
New FCS	0/1	Same coding as FCS field
New Mode Bits 1-2	0	FSK (default)
	1	OFDM
	2	Reserved
	3	Reserved
Bits 3-6	-	Reserved
Checksum	BCH(15,11) using the generator Polynomial $1 + x + x^4$	
Parity	Sum of all bits from 0-10, up to the New Mode field	

Table 5 PHY header field for 4FSK

OFDM Physical Layer

In the OFDM mode the symbol time shall be 120µsec, using a nominal bandwidth of 1.094MHz and channel spacing of 1.2MHz. The DFT size shall be 128, with 104 active carriers, 8 pilot and 96 data tones. Each carrier shall be modulated using 16QAM, convolutionally coded at rate ¾. The raw data rate is 3.6Mb/s, the convolutional coding results in a user rate of

Field	Bits		OFDM Symbols	
Ramp Up	32[2]		.16	
Short Training	384		1	
Long Training	384		1	
PHY header	16			
Source	48			
Destination	48		1	
Flags	16			
Ext Callsign	256			
Payload	1	8448	1	22
Ramp Down	32		.16	
Symbols/Frame			4.32	25.32
Time to send			0.51ms	3.03ms

Table 6 OFDM Physical Layer

The effective data rate at the network layer shall be from 740Kb/s to 1.53Mb/s depending on frame length.

[2] PA ramp time is speculative and represents a sample case of 20µsec.

Source and Destination Field Coding

The source and destination fields shall be coded using an excess-40 scheme, which can compress callsigns of up to 6 characters into four bytes, the remaining two are reserved for ports. In cases where an extension is needed, a further characters can be accommodated with additional compressed fields before the payload portion of the packet. The end is signified by an FF_{16} in the first (and only) byte of the last field.

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6
Callsign in Excess 40 format				Port Number	

Table 7 Source and Destination Coding

Byte 1	Byte 2	Byte 3	Byte 4
Callsign extension characters 6-12 in Excess 40 format			
Callsign extension characters 13-18 in Excess 40 format			
FF_{16}	-		

Table 8 Callsign extension

The callsign field shall conform to the code set as illustrated in Table 9.

Character	Coding	Character	Coding	Character	Coding	Character	Coding
0	0	Space	10	J	20	T	30
1	1	A	11	K	21	U	31
2	2	B	12	L	22	V	32
3	3	C	13	M	23	W	33
4	4	D	14	N	24	X	34
5	5	E	15	O	25	Y	35
6	6	F	16	P	26	Z	36
7	7	G	17	Q	27	_	37
8	8	H	18	R	28	-	38
9	9	I	19	S	29	@	39

Table 9 Callsign character coding

The field shall be encoded using the following formula. Unused characters shall be replaced with a space (00).

$$F(3,0) = \sum_{n=1}^{n-6} C(n) + C(n-1) \times 40$$

Where F is the field value in bytes, C is the character and n the index into the callsign field. Each callsign can be up to 6 characters. The maximum value of a legally encoded callsign field is F423FFFF. A value of all 1's (FFFFFFFF) is a broadcast address to all stations, addresses outside these limits are not used.

The port number shall be in the range of 1 to 65,535. Allocated port numbers are listed in Table 10.

Port Number	Usage
1	Network control messages
4	Encapsulated IP packets
11	Audio packets
17	Text (chat) packets
75	Video packets
93	Encapsulated AX.25 packets

Table 10 Allocated port numbers

Flags Field

Bits	Field	Purpose
15-12	Hop Count	Repeat Hop Count
11-8	Coding	Packet Coding
7-6	Compression	Compression method used
5	Unused	
4	Source callsign extended	Source call sign has an extension
3	Destination callsign extended	Destination call sign has an extension
2	Command	Local command packet
1	Connectionless	Packet has no connection
0	Repeat	Packet can be repeated

Table 11 Packet Flag Field

The HOP count reflects the number of times a packet has been repeated, to a maximum of 15 times. This is set to zero at the packet origination, if the repeat flag is set, the packet is repeated if the hop count is less than maximum.

The packet coding is described in Table 12.

Coding	Packet content
0000	UTF-8 Text Packet
0001	Compressed Audio packet
0010	H.264 Compressed Video packet
0011	Data Packet
0100	Ping Packet
0101	IP encapsulated packet
0110	AX.25 packet
0111	Encoded DTMF Frame
1000	DMR Frame
1001	D-Star Frame
1010	TIA Project 25
1011	NXDN
1100	M17
1101	TBD
1110	
1111	Local command frame

Table 12 Packet Coding

The data compression type for an audio packet is shown in Table 13

Type	Coding	Bit Rate	Bits/20ms
00	µLaw	64Kb/Sec	1280
01	Raw PCM-16	128 Kb/s	2560
10	M17 coded	3.6Kb/s	64
11	AMBE	9.6Kb/s	1536

Table 13 Audio compression field

The data compression type for H.264 video packets is shown in Table 14.

Type	Image Size	Frames/Sec	Bit Rate
00	240x180	24	145152
01	320x240	24	258048
10	480x360	12	290304
11	640x480	6	258048

Table 14 H.264 Video Compression

Mesh Networking

The heart of the network is its ability to auto-configure and generate routing information dynamically. This is accomplished by each station transmitting a beacon frame periodically, the time between frames is programmable in the setup data.

Beacon Frame

A beacon frame is a ping packet sent using the network control port number. The source field contains the callsign of the originating station, the destination is always a broadcast address. The packet is repeated by each station that hears it, up to the maximum in the hop count (15).

The payload of the beacon frame is shown in Table 15.

Field	Contents
Capabilities	A copy of the setup flags showing station capabilities
Location	A null terminated string with location information
Version	Two ascii numbers representing the firmware major and minor version numbers

Table 15 Beacon frame payload contents

The capabilities field has the following fields:

Bit	Contents
0	Station has the capability of using FSK
1	Station has the capability of using OFDM
2	Station is an AREDN node
3	Set repeat mode on all frames by default
4	Use the extended callsign field (for calls longer than 6 characters)
5-7	Data rate

Table 16 flag fields

The data rates for the FSK and OFDM modes are listed below:

Bits 5-7	Data Rate and Modulation (FSK)		Data Rate and Modulation method (OFDM)	
000	1200 bps	2 FSK	400 Kb/s	QPSK rate ¼
001	9600 bps		800 Kb/s	QPSK rate ½
010	56 Kb/s		1200 Kb/s	QPSK rate ¾
011	100 Kb/s		1600 Kb/s	QAM-16 rate ½
100	200 kb/s	4 FSK	2400 Kb/s	QAM-16 rate ¾
101	300Kb/s			
110	400 Kb/s		TBD	
111	600 Kb/s			

The location data is a null-terminated string which takes the following format:

```
<SRC>,LAT,LONG,<Time>,<GRDSQ>
```

The fields are defined in Table 17

Tag	Value
SRC	Identifies the data source. GPS from a gps receiver, FIX from fixed setup data
LAT	Latitude in the form DDMM.MMMMM N/S
LONG	Longitude in the form DDMM.MMMMM E/W
Time	GPS time of fix, or elapsed time since startup if using setup
GRDSQ	Grid square only if not using GPS location

Table 17 Beacon Location field