



Welcome To A New Dawn In Amateur Radio

High speed digital mesh networking

IP400 Project Overview

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Martin C. Alcock, M. Sc, MIEEE, VE6VH

Initial goals of the IP400 project



- A project to develop mesh networking for Amateurs
 - Initially in the 400MHz band
 - Expandable to other bands
 - 'IP' stands for "Intelligent Protocol"
 - Adapts based on signal to noise conditions
 - Self-configuring and self-healing
 - Loosely based on 802.15.4 protocol
- Raise the bar on data rates using off the shelf hardware
 - Remove limitations of 9600bps imposed by conventional techniques
 - Stay within regulatory limits
 - Move on as regulations are updated
- Develop a firmware base for mesh networking
 - Release it as open source

Where we have been



- Kicked off by an announcement of a new ST micro WL33 microcontroller
 - Operates in the 400 or 900 MHz Bands
 - 4FSK Data modem built in at 100-600 bps (802.15.4 physical layer)
- Experimentation started with off the shelf evaluation hardware (Nucleo)
 - No charge development tools available from manufacturer
 - Supports downloading and debugging
- A mini-node was developed
 - Basic mesh networking capability
 - Uses a module with the WL33 microcontroller, 100mW power output
 - Limited or no debug capability
- Developed early mesh networking firmware
 - Auto discovery with beaconing
 - Fixed or mobile support using a GPS receiver
 - Built-in chat and echo modes

Challenges encountered



- Availability of modules
 - 430 MHz band is not licensed as an ISM band in North America
 - Reliance on a single overseas source
 - 902 MHz ISM band variant sold in North America
- Silicon Bugs
 - Hardware difficulties encountered with back to back packets
 - Not originally designed for high volume data
 - No planned revisions
- Regulatory Challenges
 - Speed limited to 100Kb/s due to current rule structure
 - High bandwidth requirement of 50KHz
- Power limitations
 - Not suitable for existing power amplifiers, custom PA required

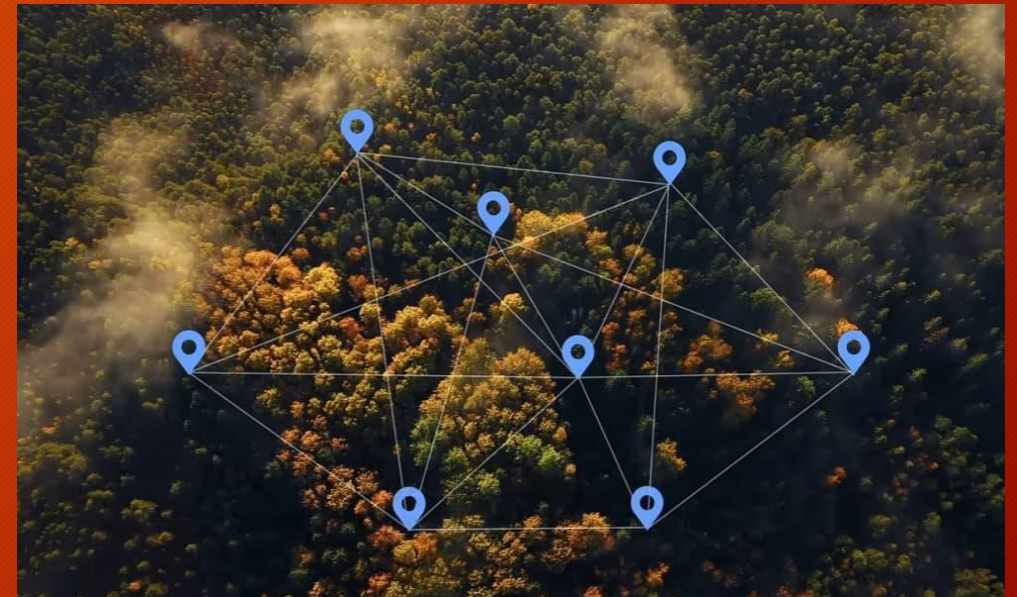
Where we are going



- Project was rebooted with a new set of goals:
 1. Create a firmware base for mesh networking
 2. Raise the bar on data rates.
 3. Breathe new life into ageing repeater systems.
 4. Extend terrestrial data networks to a mobile station.
- Create a new firmware architecture that is device independent
 - Backwards compatible support the legacy nodes
 - Support for new modems and modulation methods
- Develop new modems with higher data rates
- Develop a strategy to upgrade Allstar based repeater systems
- Development funded by a grant from ARDC

Goal 1: Why mesh networking?

- Mesh networks are simple to deploy
- Little or no configuration
- Each station can be a repeater
- Multiple paths between stations
- High reliability
- Self-healing
- No distance limitations



Mesh network in the trees



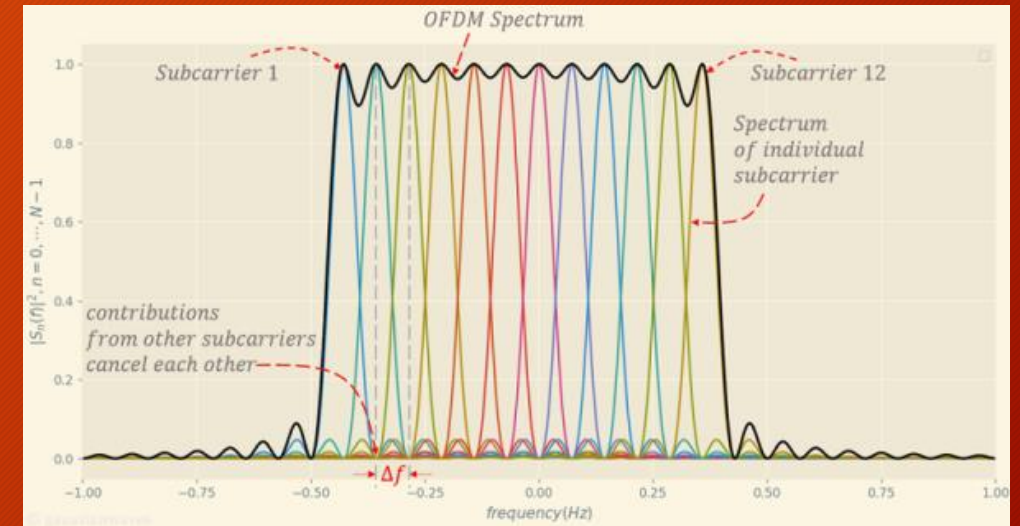
Advantages of a mesh network



Criterion	Centralized Network	Mesh Network
Architecture	Centralized	Decentralized
Reliability	Low	High, no single point of failure
Coverage	Limited	Extended by nodes
Deployment	Manual and Complex	Automatic and self-healing
Scalability	Can be overloaded	Stable as users increase

Goal 2: Raising the bar on data rates

- New modem based on OFDM
 - Orthogonal Frequency Division Multiplexing
 - Targeted for amateur use
- Commonplace in many devices
 - Cellular telephones (known as LTE since G4)
 - Digital Subscriber Lines (DSL)
 - Cable Modems
- Built-in FDMA
 - Carriers can be distributed between stations
 - Used commercially in MQTT



Goal 3: Breathe new life into repeaters



- Create a simple hardware upgrade for data
 - Implement the digitizing function of the audio path (currently CM-108)
 - Share audio between repeater and modem
 - Custom audio driver provides Allstar functionality
- PL tone based audio switching at the repeater
 - Audio transmissions are identified by PL tone
 - Modem data has no energy below 300Hz
 - Audio path muted on detection of a data packet
- Similar scheme at the radio user
 - A data message without a PL tone will not open squelch
 - Carrier detection provides indication that the radio is in use
 - Audio with PL tone will open squelch

Goal 4: Extending Data Networks



- Extend the LAN portion of an AREDN node
 - Connects the two networks together
 - IP400 nodes can access resources on the AREDN network
- New mobile data capabilities:
 - E-mail
 - SMS Messaging
 - Position reporting
- IP400 node requires ethernet connection to support AREDN
 - Can be supplied by a raspberry pi
 - Enables access to menus and remote upgrading

Achieving the goals



- Goal 1: Reuse previous mesh networking firmware
- Goal 2: Develop a higher speed modem based on OFDM
- Goal 3: Enable a data upgrade for existing repeaters
- Goal 4: Add ethernet based access to a node
- Requirements to fulfill the goals:
 - Next Generation Extensible software platform
 - New hardware for OFDM modem and repeater upgrades
 - Easy upgrade to an existing Alstar system
 - Raspberry Pi as ethernet server

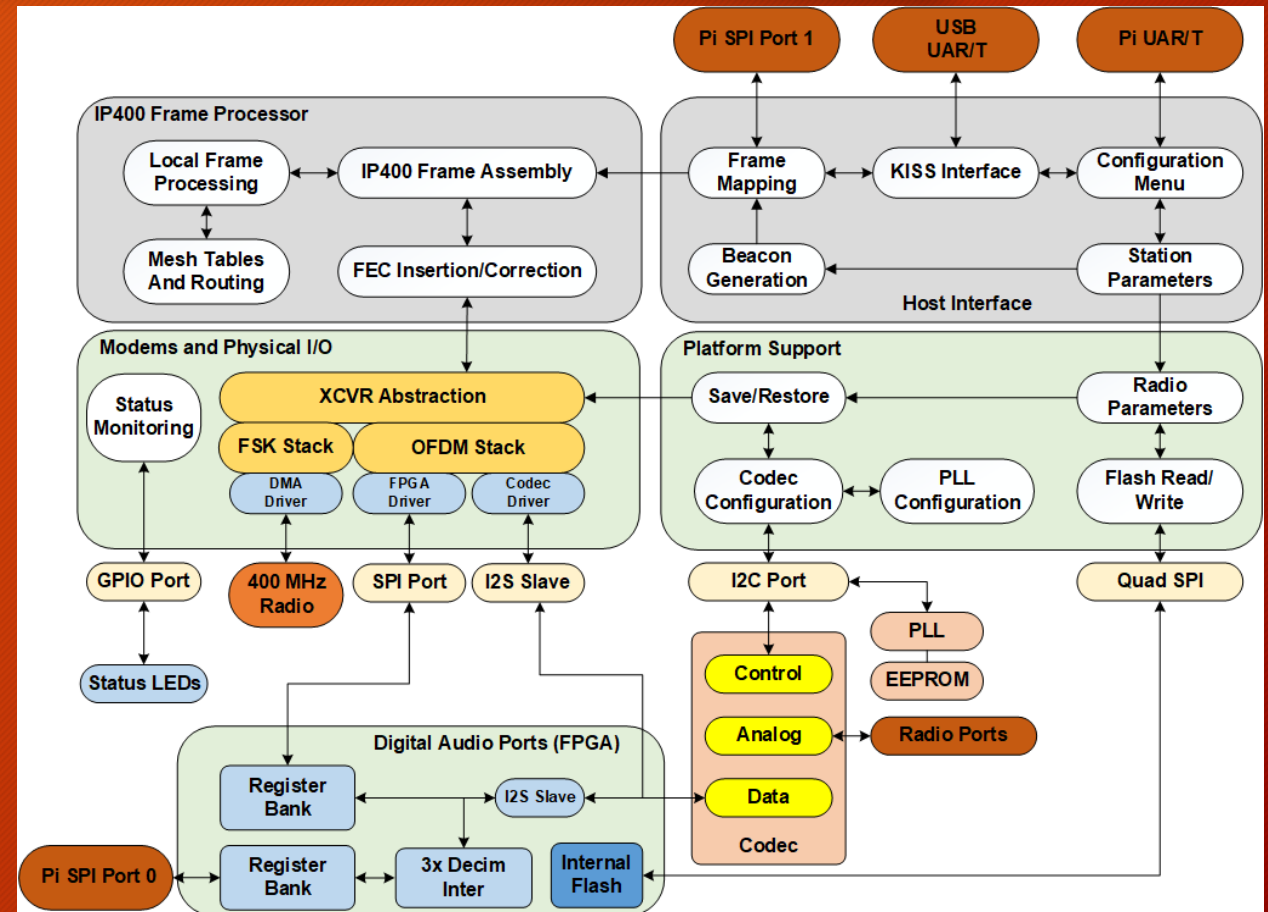
Goal 1: Mesh networking firmware



- Create a new extensible platform for mesh networking
 - Retain as much from previous development
 - Auto discovery and configuration using beacon frames
 - Position reporting using GPS receiver (lat, long, grid Sq, smart updates)
 - Retain VPN addressing scheme previously implemented
 - Broadcast address, Address specific, All Call and AX.25 Compatible
- Provide backwards compatible with AX.25
 - Add KISS and AXIP support
- Modem agnostic
 - Modem independent of mesh networking components
 - Allow for more than one modem type

Extensible firmware platform

- Next generation mesh node firmware
- Supports several modems by using abstraction
 - Supports up to three different modem types
- UAR/T supported by USB or Pi Serial port
 - Configuration and KISS Data mode
- Pi SPI port for high speed data
- Built-in beacon generation and mesh table
- Runs on AMNC or Mini-node hardware
- Open Source



Goal 2: Raise the bar on data rates



- Develop an OFDM modem in the audio frequency band (similar to DSL)
 - Operate with any FM transceiver and frequency band
 - Regulatory compliance achieved using standard FM
 - Contain PAPR problem inherent in OFDM
- Support different audio bandwidths
 - Narrow band mode for older radios using mic and speaker
 - Wide band mode for new radios with data port
- Support different modulation schemes
 - Lowest common denominator for low SNRs and mobile operation
 - Higher order for static links and backbones
- Automatic adaptation and detection of bandwidth
 - No handshaking required
- Supports forward error correction
 - Reed-Solomon and Trellis coding

OFDM Audio Bandwidths



Mode	Bandwidth	Application	Radio Connection
Narrowband	2,625	Most FM radios using	Mic and speaker
Enhanced NB	3,656	Radios without sharp high end cut-off	
Wideband	5,766	Radios with direct modulator connections	Data Port
Enhanced WB	7,781	High end radios with extended passbands	

Tested with:FTM-3100, ICOM IC-2000H, Kenwood TK-760H, Kenwood TH-D74, Icom IC-2AT, Yaesu VR-120, TAIT TM-8100, Kenwood TK981, Kenwood TKR-901

OFDM Raw Data Rates vs Bandwidth



Constellation	Bits/Carrier	NB	ENB	WB	EWB
BPSK	1	2,426	3,353	5,294	7,147
QPSK	2	4,853	6,706	10,588	14,294
QPSK-8	3	7,260	10,059	15,882	21,441
QAM-16	4	9,680	13,412	13,412	28,588
QAM-32	5	12,132	16,765	16,765	35,735
QAM-64	6	14,520	20,118	31,765	42,882
QAM-128	7	16,940	23,471	37,059	50,029
QAM-256	8	19,360	26,824	42,353	57,176

Pitfalls of OFDM



- OFDM modulation is in the frequency domain, not time domain
 - Inverse and forward FFT used as a modulator/demodulator
- Peak to average ratio can be unmanageable
 - OFDM has high, unpredictable peaks in the time domain
 - Can be 6-12dB higher than the average
 - Led to the 802.11a in 5.6GHz band being abandoned
- Accurate sample timing required
 - OFDM symbols contain many samples in the time domain
 - Sampling clock offset leads to phase errors (Time shifting property of FFT)
 - Introduces errors in high data rate constellations
 - Determination of symbol start and end is more complex
 - Cannot tolerate frequency offsets between tx and rx
- FFT has a narrow dynamic range requirement
 - Saturation causes overflow leading to data errors
 - Too small a signal is lost in the transform (3db loss per transform pass)
 - AGC is the best solution for good performance and to ensure proper recovery

Overcoming the difficulties

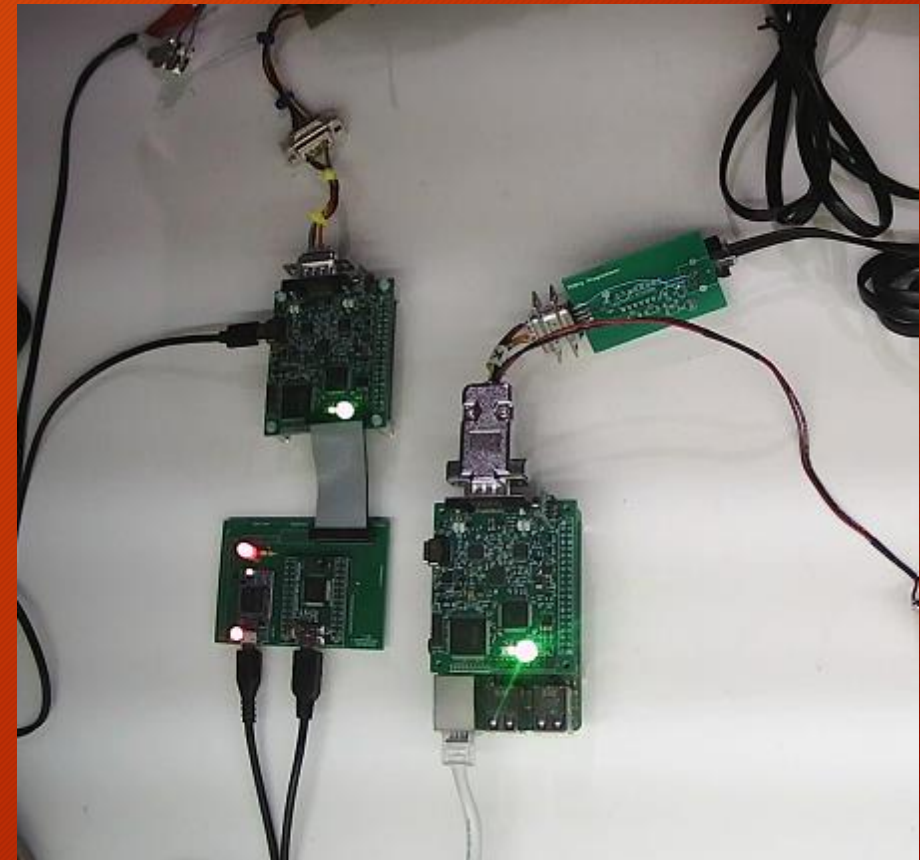


- Modulate an FM transceiver with OFDM at baseband
 - Contain peak to average ratio issue
 - Solve multipath and collisions (FM capture effect)
 - Meet regulatory requirements already in place
- TCXO based sampling clock source
 - 1 ppm maximum frequency drift
 - Remove the possibility of sampling offset and phase shifting
- Automatic Gain Control
 - Keep FFT input levels in proper range
 - Ensure high SNR for large constellations
 - Removes requirement for large FEC bandwidth and retries
- Use equalizer
 - Overcome non-linearities of tx and rx radio and channel

Advanced Mesh Network Controller



- High end microcontroller and FPGA technology
- Standalone or Pi HAT operation as repeater upgrade
- Powered by 12V or USB
- Dual purpose UART connections
 - USB-C interface standalone mode
 - Pi UART connection for HAT mode
- Two radio ports
 - Separate repeater/modem ports
 - Audio switching using PL tones
- High speed data connection over SPI
- Menu operation for configuration and diagnostics
- Debug capabilities using external programmer
- Flash parts are all field upgradeable



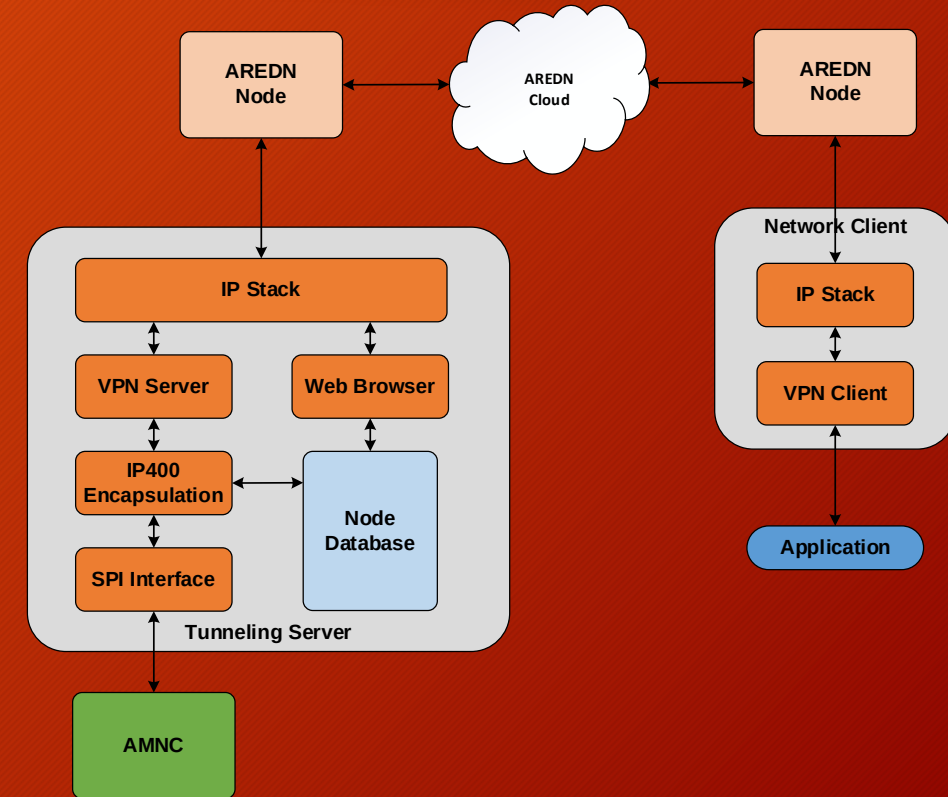
Goal 3: Upgrading existing repeater systems



- Simple hardware addition of a HAT to existing Pi
- AMNC provides digital audio path, replaces CM-108 USB module
- Custom Allstar driver replaces USB radio module
- FPGA provides Allstar-compatible audio from either radio port
- Data and voice modes can co-exist or operate separately
- Two modem data paths:
 - Pi UART can be used for AX.25 KISS operation
 - Pi SPI provides a higher speed path for UDP frames up to 1500 bytes
- Dual operation enables repeater and data modes
 - Separate audio/data paths or combined
 - Switching using PL tone detection

Goal4: Extending LAN based networks

- Every IP400 node has a VPN address 172.16.x.x
 - Generated from callsign and a manufacturer unique ID
- Raspberry Pi connects AMNC node to AREDN LAN
 - Implements a P-P Tunneling Protocol Server
 - Routes traffic to/from IP400 nodes using VPN addressing
 - Encapsulates IP traffic as IP400 frames
 - Uses SPI interface for higher speeds
- Transparent routing using beacon database
 - Created from beacon frames and hop tables
 - Converts a VPN address into a callsign + routing data
- Web browser based user interface
 - User view into current beacon database
 - Dynamically updated



What's Next?

- Beta trial ready to start
 - Beta units are in production now
 - Volunteers to conduct trials are requested
 - Deep discounts on hardware
 - Exposure to different radio types
 - Integration with existing applications
- Production units scheduled for Q1, 2027
 - Dependent on successful beta trial
- Repeater upgrades
 - Next development phase
 - Based on resource availability



Planned UFP Releases



Release Date	Version	Features
Q3, 2026	2.0	UFP for Mini-node with KISS, SPI, 4FSK mode
Q4, 2026	2.1	Add AMNC with KISS, SPI, OFDM-AB up to QAM-64, all BW, CRC only
Q1, 2027	2.1a	FPGA upgrade and addition of custom driver for Allstar and FPGA
Q2, 2027	2.2	Add QAM-128, QAM-256 and FEC using Trellis coding

Digital Hamstore Inc



- Manages manufacturing and distribution of amateur projects
- Contractor for manufacturing and distribution of AMNC
- Run by amateurs, for amateurs
- Design expertise
 - Digital, Analog or RF
- PCB Layout
 - Surface mount layout up to 16 layer PCB
- Manufacturing
 - Small quantities up to 1000's
- Distribution
 - Factory direct
 - Via distributor
- Website at digitalhamstore.com

Summary



- Primary goals of IP400 project have been achieved:
 - New hardware module for standalone or Pi HAT operation
 - Higher data rates with data mode called OFDM-AB
 - Simple hardware and software upgrade for existing repeaters
 - Extends the AREDN LAN
- Primary development completed
 - Beta Trial ready to start
- Hardware in production after beta trial
 - Available factory direct or through a distributor
- Repeater upgrade to follow

More Information/Contact



For more information please
visit www.adrcs.org

Questions can be directed to:

email: ve6vh@adrcs.org

Landline: (403) 670-9100

Meshphone: 403-55512

We want your ideas!!

