AkerBP

QINETIQ

# Dual Channel Acoustic Communication Protocol

## Aker BP – QinetiQ  SWiG Review

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# Challenges (Why)

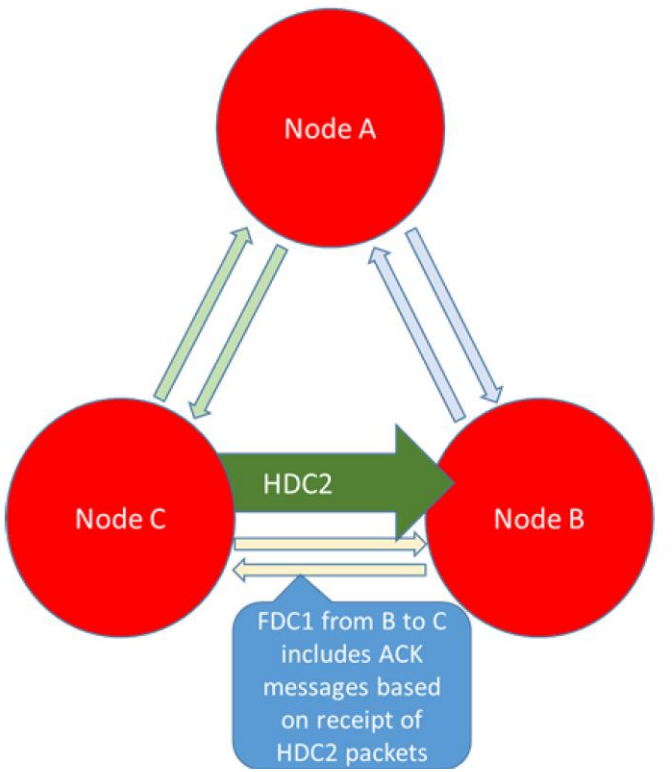
**Limitation Factors for multiple nodes to interoperate in an underwater acoustic network and share large amounts of data**

- Physics of Underwater Environment
- Efficiency of traditional Half Duplex methods
- Limited capacity for shared channels among users
- High data-rate, high spectral efficiency modulations are not compatible with SMAM (Simultaneous Multiple Access Modulation)
- Available standard (JANUS) has limited capabilities. SWiG level 1 is based on JANUS

# Motivation & Value Creation Drivers (Why)

- Increased interoperability  across devices for different applications  and backward compatibility with half duplex legacy devices. Including compatibility  with SWiG Accoustic Level 1 & JANUS.
- Enable efficient management of various types of data transmission in a network
- Enable improved data throughput in an underwater network and situational awareness among all nodes
- Increased flexibility to support a wide range of applications, in terms of frequency range and modulation
- Develop an attractive standard for suppliers to adopt freely inside and outside Oil & Gas domain
- Accelerate protocol development, documentation and standard delivery
- Contribute with value adding initiatives to SWiG

# Dual Channel Acoustic Communication Protocol (What)




FDC1 – a low bit-rate, simultaneous multiple access channel to cover cases of network nodes coordinating, negotiating & exchanging small bits of information. It can operate in full duplex or half duplex mode.

HDC2 – a high bit-rate, single access channel for high-speed communications. Coexists with FDC1 on an as-needed basis.

# Dual Channel, Full Duplex Acoustic Communication Network Protocol (What)

## High Level Scope

**1. Protocol Requirements definition**

1.1 Establish Network Requirements

1.2 Establish modem requirements, system performance requirements

1.3 Identify ideal modem functionality and capability to be simulated

1.4 Identify available modem functionality and capability to be implemented for verification of simulation (Next Phase)

Deliverable - Agreed on Requirements Documentation (pending agreement with SWiG)

**2. Protocol Development (ongoing)**

2.1 Develop protocol – handling strategies for re-queuing and dealing with legacy (half-duplex) modems

2.2 Review protocol with SWiG via teleconference meeting

2.3 Simulate protocol for evaluation and development for the ideal modem

2.4 Simulate protocol for available modem (Next Phase)

2.5 Determine minimum decoupling/cancellation requirements needed for protocol

2.6 Identify key parameters for protocol compliance and initial requirements for compliance testing.

2.7 Protocol Definition –Standard Documentation and Simulation Report

Deliver proposed protocol definition in IEEE standard format with simulation report.

# Protocol Requirements Definition (How)

- **Preliminary Work:**
  - Meeting with SWiG to present Dual Channel Protocol Concept
  - Sent a Survey to gather inputs on  proposed concept relevant and comments prior starting the work
  - Meeting with SWiG to present survey results and proposed way forward considering member inputs
  - Defined Stakeholder Requirements based on preliminary SWiG inputs. **(Strong focus on backward compatibility with existing half duplex devices without hardware changes to accelerate implementation as base case)**

- **System Requirements Identification:**

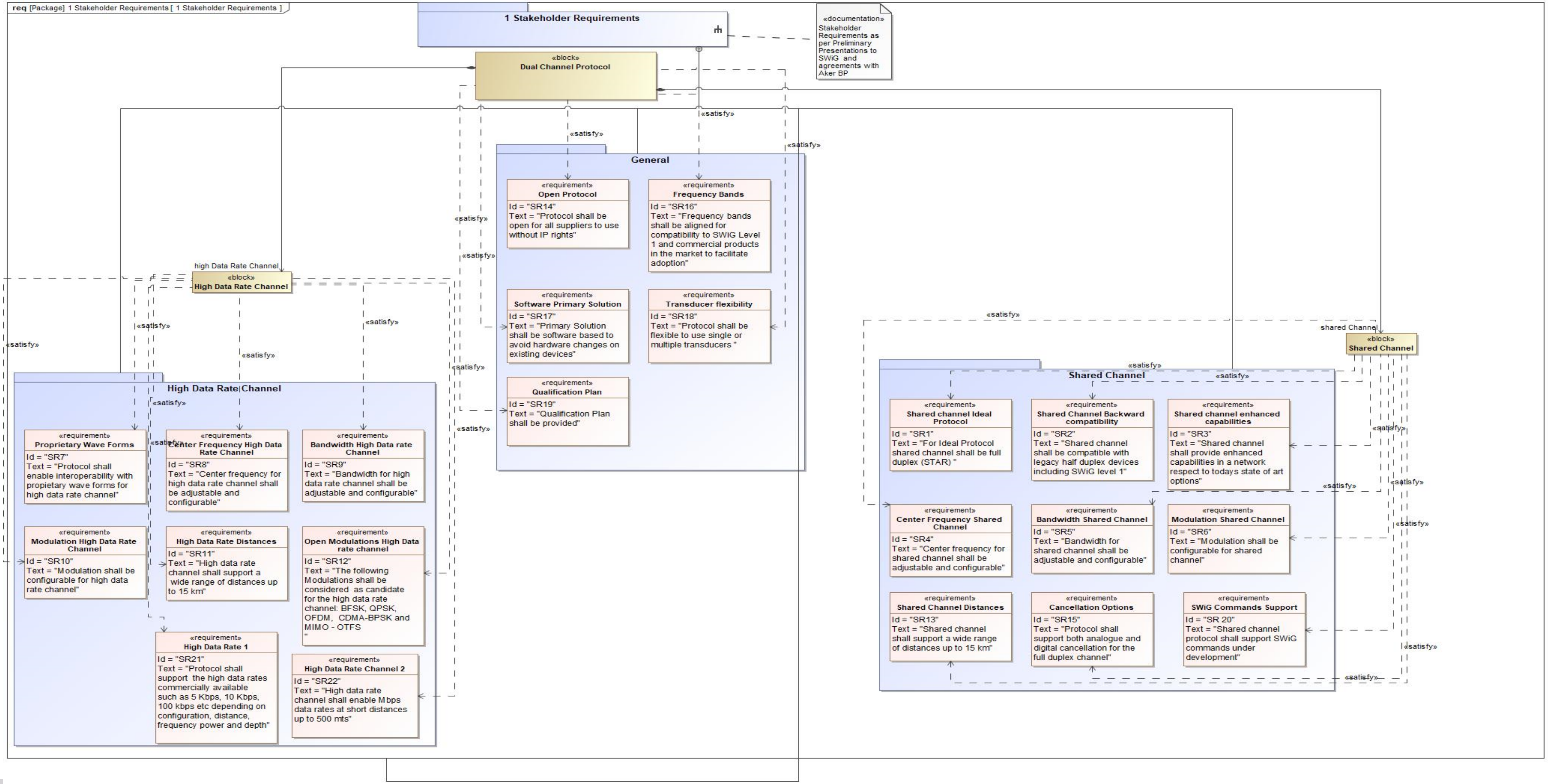
✓ A Survey was developed and sent to SWiG members to identify the needs on :
  - -Network Requirements
  - -Shared (Low data rate) Channel Requirements (FDC)
  - -High Data Rate Channel Requirements (HDC)

✓ Existing SWiG use cases and case studies were mapped, analysed and expanded with additional SWiG members inputs

✓ Information from Survey and Use cases was collated to define system requirements

✓ Ongoing work on commands definition for the SWiG main document have been also considered

# Stakeholders Requirements Definition (from Preliminary Work)



# Systems Requirements Definition Inputs

Survey Developed and Submitted to SWiG Members to capture Network Physical Characteristics and Data Requirements covering details on

1.1.1.1 Desired number of nodes
1.1.1.2 Desired geometry (i.e. range, distribution within range)
1.1.1.3 Messaging requirements for command/status:
- 1.1.1.3.1 Number of payload bits
- 1.1.1.3.2 Number of messages per node per minute/hour/day
- 1.1.1.3.3 Destinations of messages
- 1.1.1.3.4 Active acknowledgement required?

1.1.1.4 Messaging requirements for large data transfer (if needed)
- 1.1.1.4.1 Fraction of nodes with this requirement for TX
- 1.1.1.4.2 Fraction of nodes with this requirement for RX
- 1.1.1.4.3 Fraction of nodes with this requirement for TX/RX (i.e. high speed required in both directions)
- 1.1.1.4.4 Number of payload bits
- 1.1.1..4.5 Number of messages per node per minute/hour/day
- 1.1.1.4.6 Destinations of messages
- 1.1.1.4.7 Active acknowledgement required?

1.1.1.5 Special needs
- 1.1.1.5.1 Mesh network has been requested.
- 1.1.1.5.2 Store/forward requirements?
- 1.1.1.5.3 Broadcast requirements?
- 1.1.1.5.4 Large, blank area for special requirements
- 1.1.1.5.5 Special waveform or MIMO requirements for HD channel

Note: Numbering above as per Scope / Detailed tasking Document

# Summary of survey results

- Number of nodes ranged 2 to 200 (combination of fixed and moving nodes)
- Bits per second per node from 0 to 44 bps (for FD1 channel)
- Water column depth 1-5000 meters
- Point to point range 1 meter to 15 km
- Interference sources: Other acoustic equipment using same frequency, Vessel noise (dynamic positioning), production system noise: choke movements, leaks, AUVs, ocean life acoustic noise (shrimps, mammals,...), IMR/I&C nearby activity. Other interference in the form of acoustic reflections, at boundaries (sea floor, sea surface and equipment).
- User packet size 100 bits to 800 bits
- Message per hour: 50-200 messages
- Network Definition: Ad hoc networks ( with first-contact protocol ) and pre-programed formation
- Routing: Point to point, store & forward and mesh networks
- Mixed use ranging / communication
- TDMA needed for some SWiG members
- UUID not mandatory but may be required in the future
- Waveforms for HDC: SISO ASK or FSK, BFSK, QPSK,OFDM, CDMA-BPSK and MIMO-OTFS
- Special needs: Doppler tolerance to 5 mts/sec

  Adjustable center frequency and bandwidth

  Open -source platform independent desirable

# Systems Requirements Definition Inputs

Existing SWiG use cases and case studies were mapped, analysed and expanded with additional SWiG members inputs. Some summary results are listed as follows

- Application & Technology Area:  structures monitoring, drilling control, BOP wireless control, cathodic protection monitoring, dredging, environmental monitoring, tsunami monitoring, seismic survey, seabed subsidence monitoring, riser lifecycle monitoring, asset vibration monitoring, pipeline monitoring, outflow monitoring, Wireless WOCS, Resident & Non-resident UID data exchange with docking stations, surface vessels, rigs, subsea structures, other UID and ROV, Supervised autonomy, Swarm of AUVs, etc.
- Modulations: FHSS, MSK, DSSS, QPSK, CDMA, S2C
- Center Frequency (kHz): 10 kHz to 63 kHz
- Bandwidth (kHz): 3 kHz – 30 kHz
- Point to point range (m): 1-15000 m
- Area long dimension (m): 15000 -30000 m
- Area short dimension (m): 1-5000 m
- Burst bit rate (bps): 100-2400 bps
- Water depth (m): 20-6000 m
- Power Level (dB): 177-202 [dB re 1 microPa at 1m]
- Number of nodes: 2-4000 nodes ( However for definition of this protocol, a Max of 200 nodes has been used)
- MAC : Yes
- Routing: Point to point, one way & bi-directional enabled
- Usage: ranging and data
- Network throughput low & high estimates (bps) (100-10000).

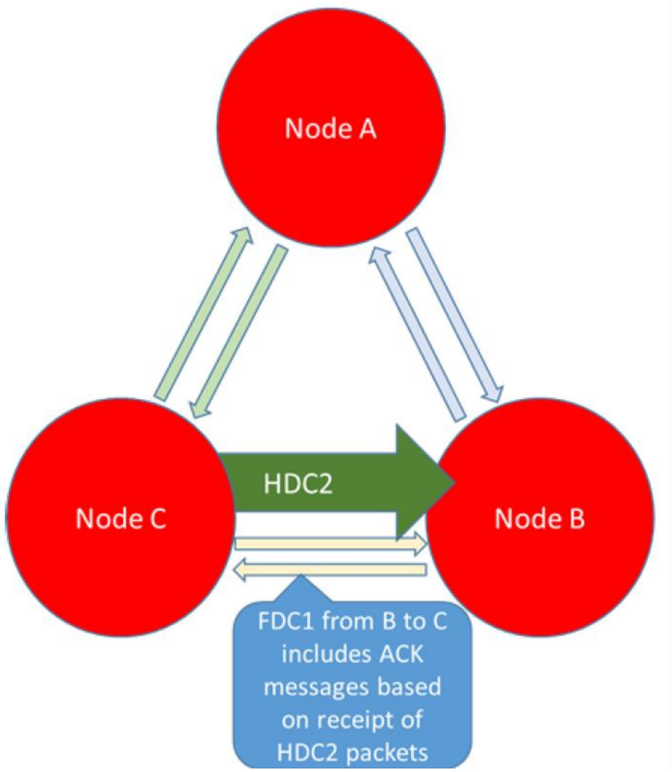
  Much higher data rates are desired for some applications, but the defined range is set as base, considering the majority of the use cases and can be expandable.
- Duration: From 5 days to 365 days and from 1 to more than 10 years

Seismic use case with 4000 nodes not considered at this stage as use case significantly exceeds SISO multiuser channel capacity. A separate development will need to be considered to address this case

# SWiG 2-Channel Acoustic Protocol

Neil Judell, Optimal Systems Laboratory, Inc.
On behalf of QinetiQ

# Network Architecture - 2 Channels




- FD1 – a low bit-rate, simultaneous multiple access channel. Channel capable of reconfiguring to lower bandwidth, lower bit-rate to permit operation of
- HD2 – a high bit-rate, single access channel for high-speed communications. Coexists with FD1 on an as-needed basis. Both channels can operate simultaneously by frequency division multiple access (FDMA)

# Points of note

- Software-based protocol
- Immensely flexible, supporting:
  - Single-transducer half-duplex, receiving only FD or HD at a time
  - Single-transducer half-duplex, receiving both FD and HD simultaneously
  - Multiple-transducer, supporting wide frequency range for HD
  - Multiple-transducer, supporting full-duplex
  - Both open-source and proprietary modulations for HD channel
  - Point-to-point, store-and-forward, mesh routing

# Relationship to OSI model

| Layer | | Protocol Data Unit | Function | Dual Channel Protocol |
|---|---|---|---|---|
| 7 | Application | Data | High level APIs | User level |
| 6 | Presentation | | Translation of data between network and application | User level |
| 5 | Session | | Managing communication sessions | User level |
| 4 | Transport | Segment, datagram | Reliable communication, including segmentation, acknowledgement (ACK) & multiplexing (MUX) | ACK and MUX defined in protocol, segmentation at user level |
| 3 | Network | Packet | Addressing, routing & traffic control | Defined in packet bits |
| 2 | Data link | Frame | Reliable transmission of data frames | Forward error correction, preamble |
| 1 | Physical | Bit, symbol | Transmission and reception of raw streams | Modulator definition |

# Delivered items

- Protocol Requirements Definition document
  - Network requirements, modulation requirements, operational requirements, configuration requirements

- Signaling, Routing, Physical Layer Access, Protocols document
  - Brief document summarizing multiple access modulations, media access control (MAC), routing, configuration, and the simulator

- Simulation document
  - In-depth detail document, describes the simulation software classes, describes the protocol elements that are defined by the software classes, as well as relevant simulation results

- Simulation software
  - Matlab objects that define the protocol and its behaviors, as well as simulation scripts using these objects to simulate relevant scenarios based on stakeholder requirements

# Network Requirements Summary (Requirements Document)

Distilled from down-selected use cases and survey

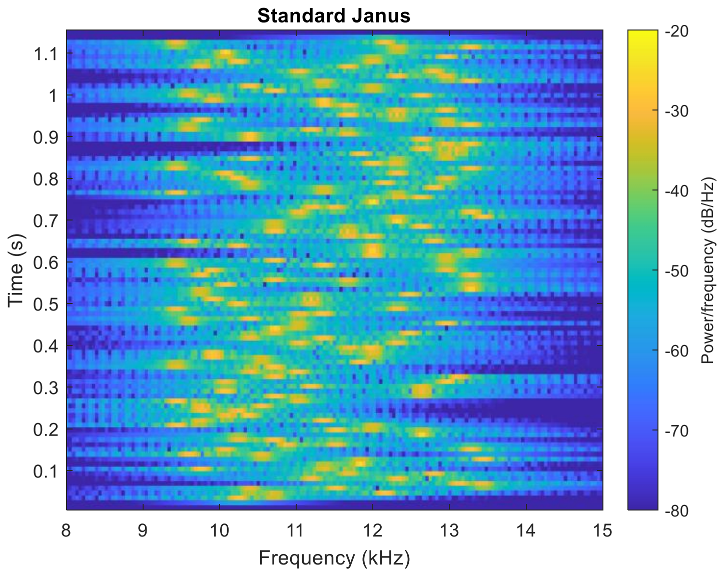
| Characteristic | Min | Max | Median | Detailed Tasking Paragraph number |
|---|---|---|---|---|
| Number of nodes | 2 | 200 | 40 | 1.1.1.1 |
| Point-to-point-range | 1 meters | 15,000 meters | 5,000 meters | 1.1.1.2 |
| Doppler | 0 | 5 meters/sec | N/A | 1.1.1.5.4 (From member) |
| Ranging pulses per node per hour | 0 | 30 | 30 | 1.1.1.5.4 (From use case) |
| TDMA | NO | YES | | 1.1.1.5.4 ( From Survey) |
| Ad hoc network | Yes | Yes | Yes | 1.1.1.5.4 |
| Acknowledgement required | NO | Critical messages only | | 1.1.1.4.7 |
| Packet size (small) (bits) | 80 | 800 | 100 | 1.1.1.3.1 |
| Small packets per node per second | 0 | 0.06 | 0.06 | 1.1.1.3.2 |
| Node throughput (BPS - FD) | 0 | 44 | 44 | 1.2.2.1 |
| Network throughput (BPS – FD) | 10 | 2400 | 480 | 1.2.2.2 |
| Network throughput (BPS - HD) (NOTE – this is the same as node-node for HD) | 100 | 10000 | 2400 | 1.2.2.2 |
| Message passing | Point-to-point | Store-forward/mesh | N/A | 1.1.1.5.2 |
| Power level (dB) | 177 | 202 | 190 | Based on use cases |
| Center Frequency | 10 kHz | 63 kHz | 16.5 kHz | Based on use cases |
| Bandwidth | 3 kHz | 30 kHz | 8 kHz | Based on use cases |

# Potential FD-Channel (low data-rate, shared) Modulations (Requirements Document)

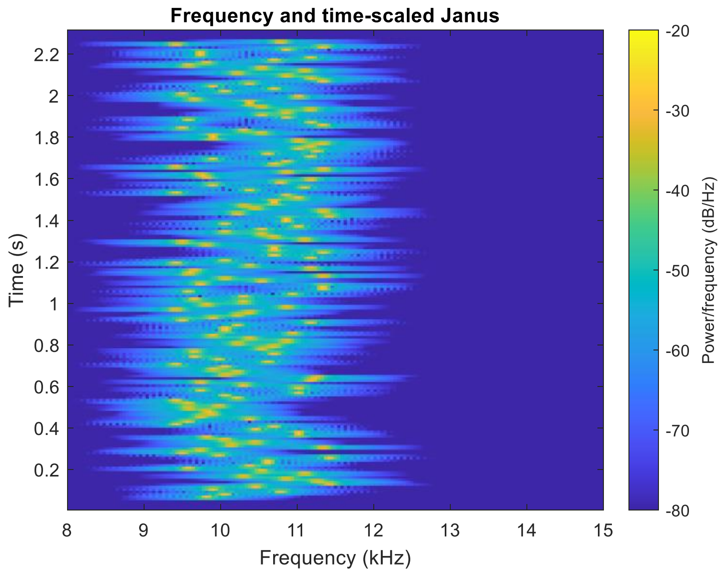
| Modulation method | Network throughput | Doppler behavior | Ranging behavior | Other |
|---|---|---|---|---|
| SWiG level 1 (slow FHSS - BFSK) | 110 bps | Poor | Poor | Poor collision behavior |
| SWiG Level 1 modified bandwidth/center frequency | Up to 250 bps | Poor | Poor | Poor collision behavior |
| Zadoff-Chu slow FHSS | Up to 250 bps | Excellent | Good | Good collision behavior |
| CDMA | Up to 4,000 bps | Fair (requires somewhat complex algorithm) | Excellent | Good collision behavior |
| SSC/S2C | Up to 4,000 bps | Good | Good | Good collision behavior |

# Frequency & Time Scaling Modulation

- Needed for configuring channel for reduced bandwidth, reduced bit rate for FD/HD sharing

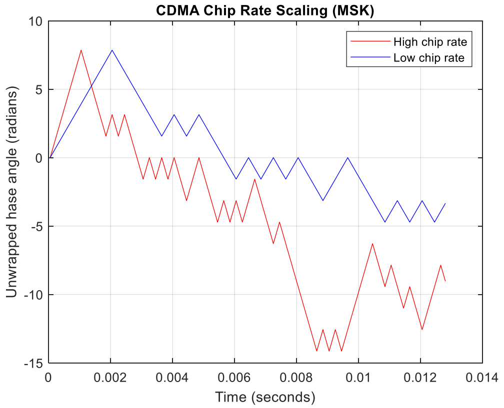


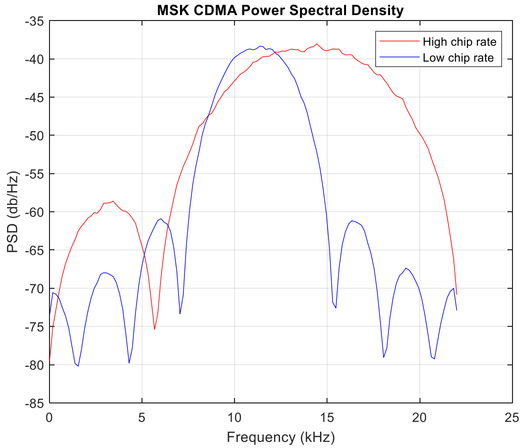

FHSS: scale tone intervals down, scale duration up.



# Frequency & Time Scaling Modulation

For CDMA: time scale the chip rate, but keep codes constant. Shift carrier frequency to match lower edge. Result is occupying a lower fraction of original spectrum, at reduced bit rate



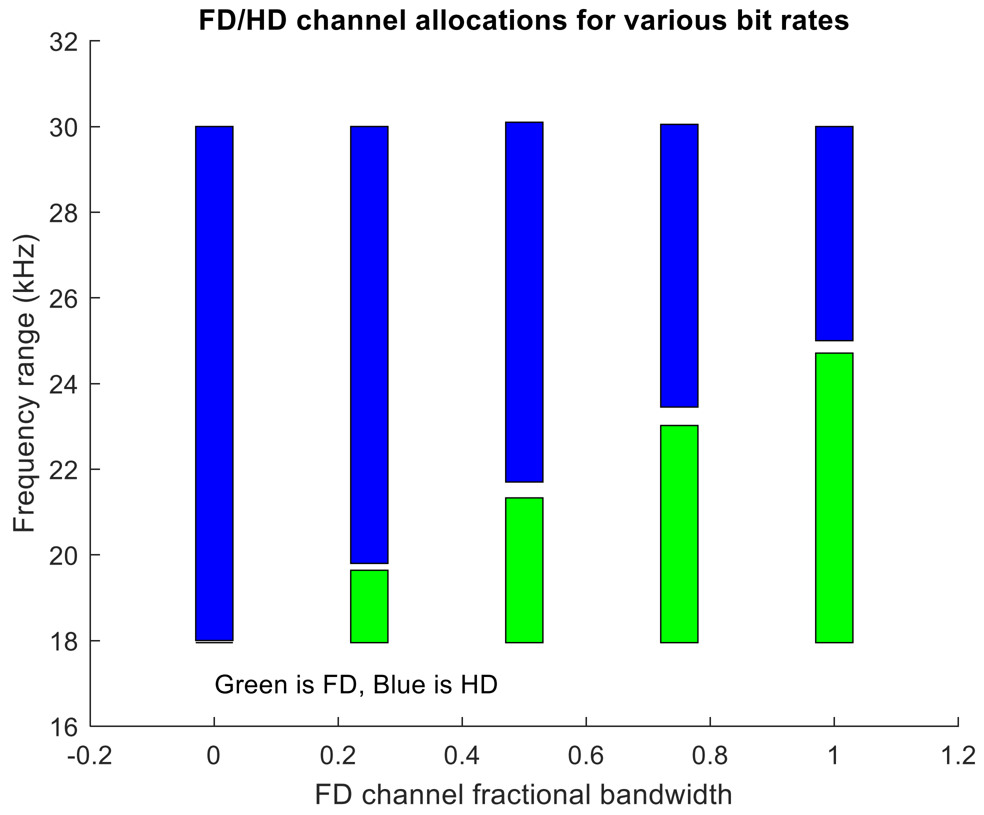
# Modulations and Configurations Specified (Requirements Document)

- FD1
  - Modulation methods (such as SWiG level 1, slow FHSS, Zadoff-Chu slow FHSS, CDMA, S2C)
  - Reduced symbol rate, with bandwidth of 0, ¼, ½ and ¾ full FD bandwidth
  - Access methods (such as CSMA, TDMA, SMAHD, SMAFD)
- HD2
  - QPSK streaming
    - DQPSK differential coding
    - 2:1 convolutional code
    - ISI filter
    - Rates: 10 Kbits/sec, 8.6 Kbits/sec, 7.3 Kbits/sec, 6Kbits/sec, 4.2 Kbits/sec
  - QPSK packets
    - BPSK with ISI header/training waveform
    - Short silence
    - DQPSK with ISI coded either BCH(511,250) hard without CRC or BCH(511,259) soft with CRC
- Additional open source Additional open-source definitions will be made for the following modulations (based on member inputs):
    - BFSK
    - BPSK-CDMA
    - OFDM
    - MIMO-OTFS ( if a suitable open-source arrangement can be made)

- Other modulation manufacturer can define that does not interfere with FD1 by use of FDMA (note that this requires Class A or true Class D power amplifier – Class S will distort into FD1, for these cases shutting down FD1 channel during HD2 operation is recommended)

# Spectrum Use for FD1/HD2 examples

Frequency/time-scaling SWiG for FD1, Frequency/time-scaling QPSK for HD2



# Signaling, Routing, Physical Layer Access, Protocols document

- Primarily addresses reasoning for design selection
  - Addresses FD1 modulations, HD2 modulations
  - Addresses MAC variants
  - Addresses routing choices
  - Discusses protocol very briefly
  - Bibliography of references reviewed in making design decisions

# Network Simulator: Fundamental Types of Interest

- Modulators:  derived from base class modulatorClass, includes SWiG Level 1, advanced SWiG, generic DSSS, QPSK. Includes modulation type, access method (CSMA, full-duplex, half-duplex, etc.), interference susceptibility value, packet loss function, center frequency, bandwidth

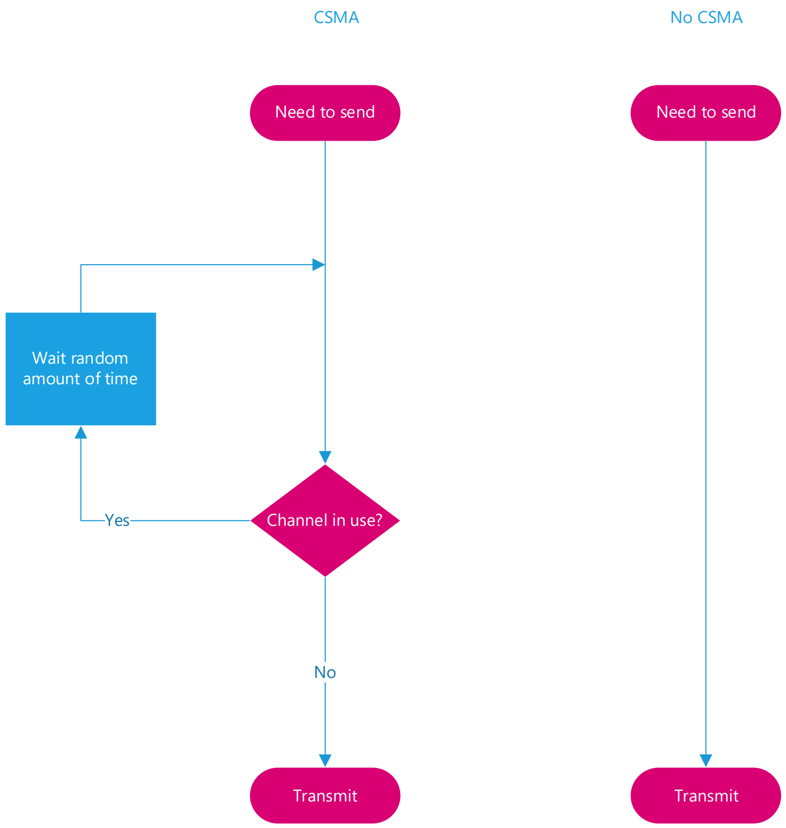
- Packets: derived from packetClass, consists of data, source, destination, type of modulation used for transmission, whether or not this packet requires acknowledgment, whether this packet IS an acknowledgment

- Nodes: derived from nodeClass, consists of modulators supported by the node, store and forward routing table, mesh routing table, logic for configuring and running the network

# Network Simulator: Physical Layer Protocol

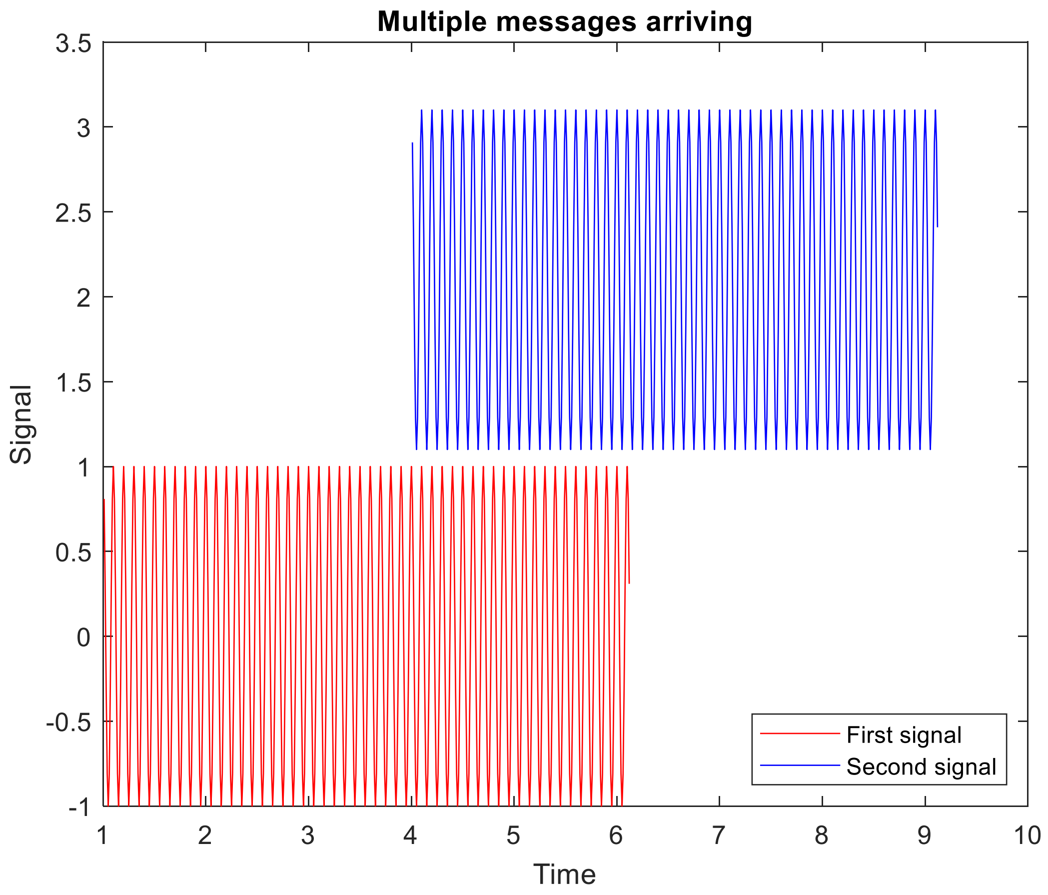
- Modulation waveforms specified by selection of modulator(s)
- Center frequency and bandwidth configurable based on messaging
- Time to revert to original center frequency and bandwidth based on time from configuration messaging
- Noise, interference and packet loss naively modeled
- Susceptibility to preamble overlap specified (SWiG Level 1 is particularly sensitive)
- MAC (configured at the modem level to emulate hardware/software)
  - CSMA half-duplex
  - Half-duplex no waiting
  - Full-duplex (with realistic self-interference)
- Decoding capability
  - Single signal (first received)
  - Simultaneous multiple decoding

# MAC – CSMA (Carrier Sense Multiple Access) vs no CSMA



# Simultaneous multiple access, multiple decode

- No simultaneous multiple access: Second signal interferes with first – neither decodes
- Single decode – First signal decodes, second signal ignored (contributes to interference, but signal design permits rejection)
- Multiple decode – Both signals decoded at receiver

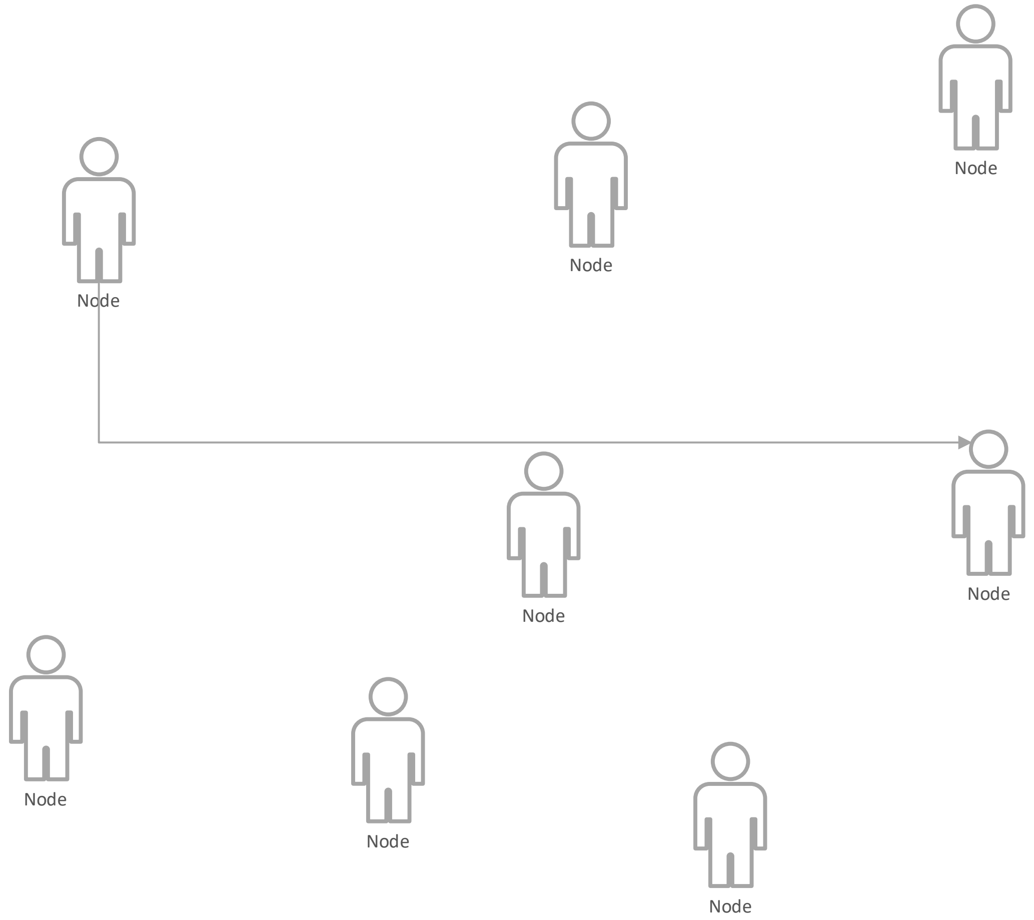


# Simulator: Routing

- Point-to-point (configured by setting no routing tables for a node)
- Store-and-forward (configured by setting a store-and-forward routing table for a node)
- Mesh (configured by setting a mesh routing table for a node)

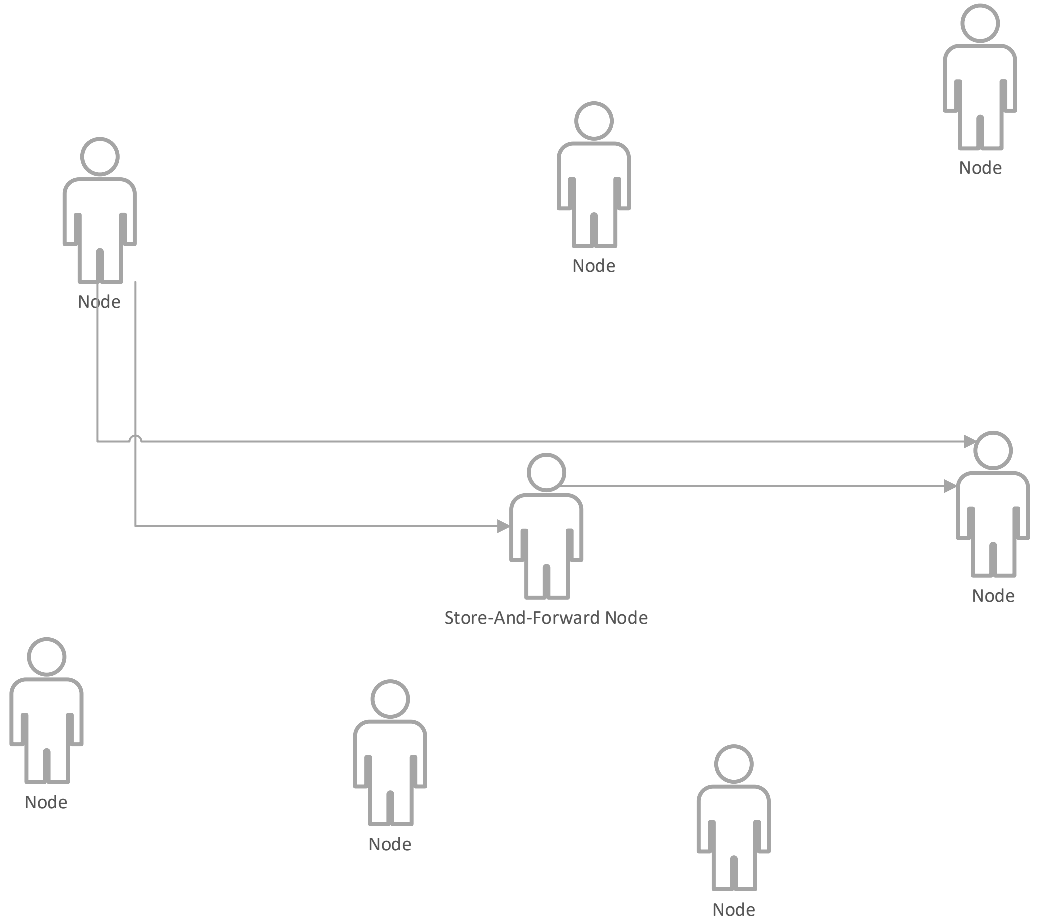
# Routing – point-to-point

Each node transmits message, hoping it will reach destination



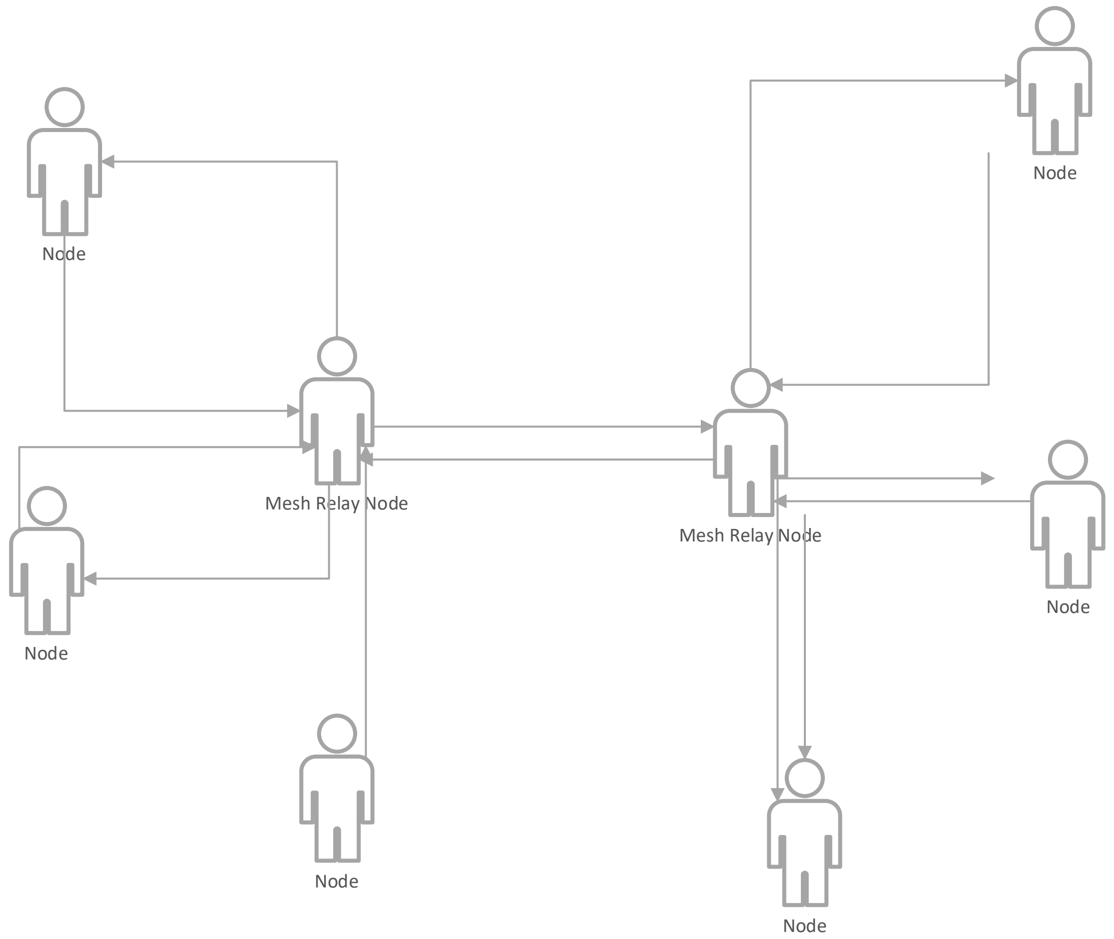
# Routing – store-and-forward

- With store-and-forward, node transmits message, hoping to reach destination
- Store-and-forward relays message, increasing probability of receipt by destination



# Routing - Mesh

- Normal nodes communicate only with own mesh relay nodes
- Mesh relay nodes communicate with own normal nodes and own other mesh relay nodes
- Greatest flexibility of message passing

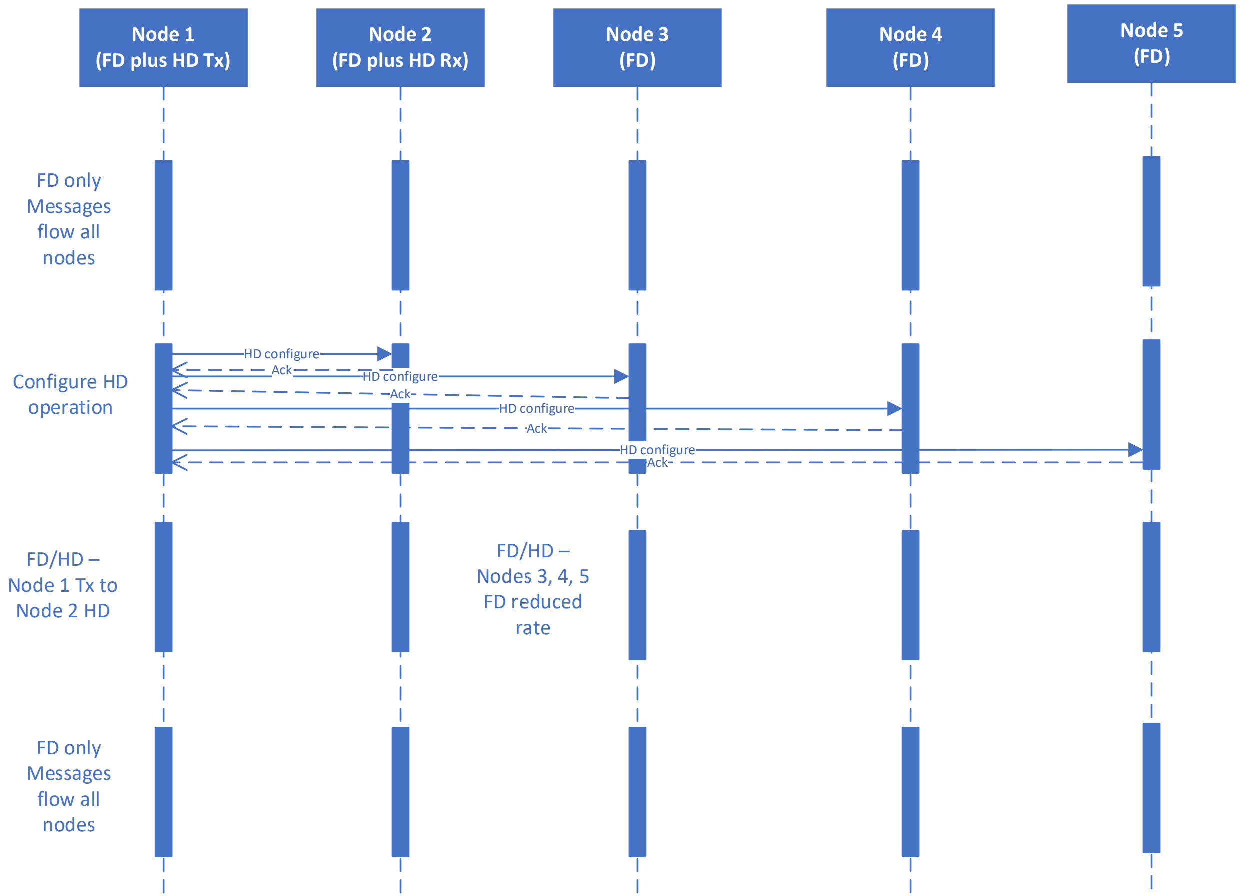


# Network Simulator:  Network and message operations

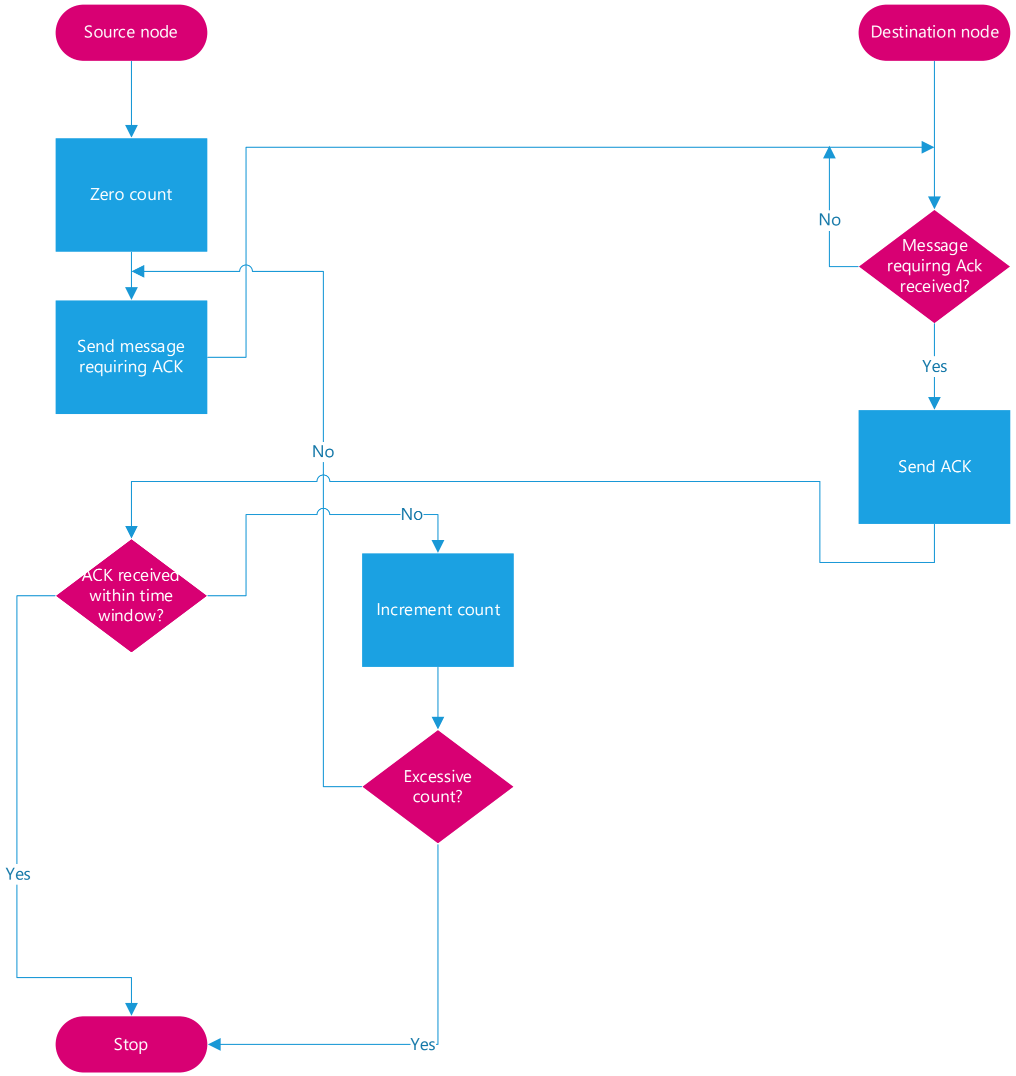
- Send message:  message may or may not require ACK. If message requires ACK and none received in a timely fashion, message resent. Receiving nodes automatically ACK messages sent to them, if required. This function works whether modulator is set to FD1 or HD2

- Schedule HD channel event. A node pushes configuration messages to all other nodes, requiring ACK from all. A time to begin HD2 operations is in the message, as well as duration of the HD2 operation. Configuration data includes new FD1 center frequency and bandwidth. Originating node will wait for the latter of : all ACKS, or time to start. HD operation will then begin with originating node as primary sender.

# HD channel configuration and use – sequence diagram



# ACK messaging sequence



# Simulator: Definition of protocol

- Best understanding of protocol definition is to see examples in provided simulator scripts
- Protocol is defined as methods within objects, so protocol is effectively specified as both basic elements and an application programming interface (API)
- SWiG can define the API that manufacturers can supply, providing uniform application capability for end-users

# Simulation Results: Self-cancelling vs. not self-cancelling: no CSMA vs. CSMA

15 nodes in a 6km x 6km x 600m uniform distribution

| DSSS, SC, no CSMA | 0 repeaters | 1 repeater | 2 store & forward | 4 store & forward | 2 Mesh | 4 Mesh |
|---|---|---|---|---|---|---|
| Fraction messages lost | 0.3/0.2 | 0.03/0 | 0.02/0 | 0.006/0 | 0.06/0.02 | 0.3/0.2 |
| Mean latency | 2.6/5.0 | 3.5/4.6 | 3.6/4.3 | 3.7/4.2 | 3.5/4.1 | 2.8/4.2 |
| Sigma latency | 0.9/9.6 | 1.7/6.2 | 1.8/4.6 | 1.8/4.6 | 1.8/5.7 | 1.2/7.8 |
| Median latency | 2.7/2.8 | 3.2/3.2 | 3.2/3.4 | 3.3/3.3 | 3.1/3.1 | 2,7/2.7 |
| Max latency | 4.5/92 | 11.3/38 | 13/37 | 11/37 | 14/39.9 | 10/64 |
| FD throughput (bps) | 328 | 448 | 442 | 453 | 413 | 337 |

| DSSS, NSC, no CSMA | 0 repeaters | 1 repeater | 2 store & forward | 4 store & forward | 2 Mesh | 4 Mesh |
|---|---|---|---|---|---|---|
| Fraction messages lost | 0.4/0.3 | 0.3/0 | 0.3/0 | 0.2/0 | 0.3/0.03 | 0.4/0.2 |
| Mean latency | 2.7/47.5 | 3.1/29.2 | 3.2/33 | 3.5/22 | 3.1/37.9 | 2.7/56.8 |
| Sigma latency | 0.9/200 | 1.3/74 | 1.5/89 | 1.9/57 | 1.3/99.1 | 1.1/191 |
| Median latency | 2.8/2.9 | 2.9/3.6 | 2.9/3.6 | 3.1/3.8 | 2.9/3.8 | 2.7/3.1 |
| Max latency | 5/2197 | 6.8/577 | 10.1/757 | 12/607 | 9.6/997 | 8.5/1566 |
| FD throughput (bps) | 271 | 345 | 342 | 348 | 325 | 277 |

| DSSS, NSC, CSMA | 0 repeaters | 1 repeater | 2 store & forward | 4 store & forward | 2 Mesh | 4 Mesh |
|---|---|---|---|---|---|---|
| Fraction messages lost | 0.4/0.3 | 0.4/0.3 | 0.4/0.4 | 0.4/0.4 | 0.4/0.4 | 0.4/0.4 |
| Mean latency | 172/203 | 482/488 | 414/431 | 516/584 | 429/446 | 199/199 |
| Sigma latency | 211/243 | 537/514 | 423/443 | 487/485 | 623/651 | 245/225 |
| Median latency | 87/88 | 278/295 | 263/261 | 372.436 | 170/166 | 113/138 |
| Max latency | 1199/1154 | 2558/2432 | 2361/2075 | 2325/2258 | 3174/2534 | 1406/1427 |
| FD throughput (bps) | 268 | 282 | 266 | 263 | 261 | 271 |

Repeaters or mesh essential

CSMA does not help DSSS

Self-cancellation significantly reduces packet loss and latency, improves throughput

# Simulation Results: DSSS vs. SWiG Level 1

15 nodes in a 6km x 6km x 600m uniform distribution

| DSSS, NSC, no CSMA | 0 repeaters | 1 repeater | 2 store & forward | 4 store & forward | 2 Mesh | 4 Mesh |
|---|---|---|---|---|---|---|
| Fraction messages lost | 0.4/0.3 | 0.3/0 | 0.3/0 | 0.2/0 | 0.3/0.03 | 0.4/0.2 |
| Mean latency | 2.7/47.5 | 3.1/29.2 | 3.2/33 | 3.5/22 | 3.1/37.9 | 2.7/56.8 |
| Sigma latency | 0.9/200 | 1.3/74 | 1.5/89 | 1.9/57 | 1.3/99.1 | 1.1/191 |
| Median latency | 2.8/2.9 | 2.9/3.6 | 2.9/3.6 | 3.1/3.8 | 2.9/3.8 | 2.7/3.1 |
| Max latency | 5/2197 | 6.8/577 | 10.1/757 | 12/607 | 9.6/997 | 8.5/1566 |
| FD throughput (bps) | 271 | 345 | 342 | 348 | 325 | 277 |

| Primitive SWiG, NSC, CSMA | 0 repeaters | 1 repeater | 2 store & forward | 4 store & forward | 2 Mesh | 4 Mesh |
|---|---|---|---|---|---|---|
| Fraction messages lost | 0.5/0.5 | 0.5/0.4 | 0.5/0.4 | 0.5/0.5 | 0.4/0.4 | 0.6/0.6 |
| Mean latency | 169/184 | 341/342 | 341/342 | 708/706 | 543/564 | 160/156 |
| Sigma latency | 227/230 | 437/400 | 432/400 | 706/750 | 514/527 | 149/155 |
| Median latency | 93.0/90.0 | 177/197 | 177/197 | 451/420 | 377/401 | 112/94.3 |
| Max latency | 1804/1120 | 2386/1896 | 2386/1896 | 3094/3111 | 2615/2162 | 700/749 |
| FD throughput (bps) | 22.5 | 22.9 | 22.9 | 19.8 | 24.1 | 19.5 |

DSSS plus store-and-forward or mesh significantly reduces packet loss and latency, improves throughput

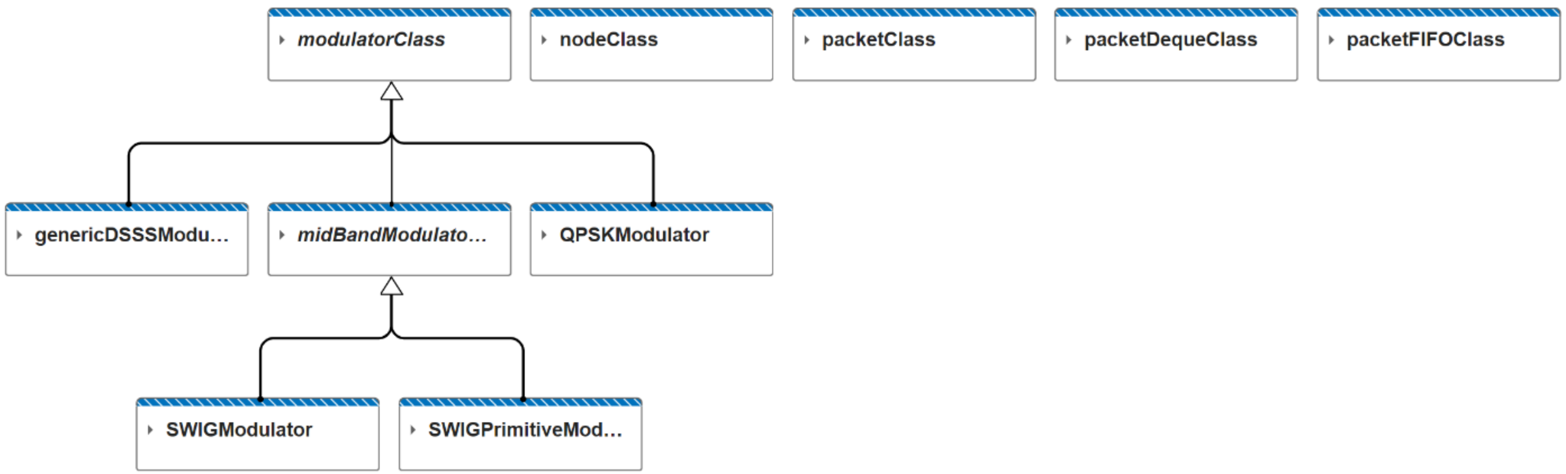
# Simulation Results: Simultaneous FD and HD

8 nodes in a 2km x 2km x 200m uniform distribution

| HD Simulation | SWiG Level 1 | DSSS, SC, no CSMA |
|---|---|---|
| FD fraction of messages lost | 0.07/0.06 | 0.03/0 |
| FD mean latency | 8.1/9.8 | 1.5/3.6 |
| FD sigma latency | 13/14 | 0.5/9.8 |
| FD median latency | 4.3/2.6 | 1.4/1.6 |
| FD max latency | 112/64 | 5.7/62 |
| Overall FD throughput | 20.7 | 222 |
| FD throughput when HD unused | 20.9 | 222 |
| FD throughput when HD in use | 16.5 | 219 |
| HD throughput | 8667 | 8532 |
| HD fraction of packets lost | 0.04 | 0.05 |

FD and HD operations can coexist

# Network Simulation Software : Classes defining protocol



# Network Simulator Software : Class methods defining protocol

**nodeClass**

- Properties
- Methods
  - ACKasNeeded
  - addTransmittedPackets
  - forwardMeshAsNeeded
  - forwardStoredAsNeeded
  - getDelay
  - getLocation
  - getModulator
  - getUnacknowledgeMessages
  - handleFDConfigurationChan...
  - handleReceivedACKS
  - handleReceivedFDConfigurat...
  - handleTimedOutACKS
  - isSending
  - nodeClass
  - pushPacketsToSend
  - receivingPackets
  - run
  - scheduleHDChannelEvent
  - sendAsNeeded
  - setBandwidthFraction
  - setCenterFrequency
  - setMeshRouteTable
  - setModulator
  - setStoreAndForwardTable
  - validatePackets

***modulatorClass***

- Properties
- Methods
  - *attenuation*
  - getBandEdges
  - getBandOverlapFraction
  - getBandwidth
  - getBandwidthFraction
  - getCenterFrequency
  - getCSMA
  - getDuplex
  - getMaxInterferenceIn_dB
  - *getModulatorType*
  - getPacketDuration
  - getPacketLength
  - getPreambleDuration
  - isHDModulator
  - isPreambleCollisionFatal
  - modulatorClass
  - *packetValid*
  - resetModulator
  - setBandwidthFraction
  - setCenterFrequency

**packetClass**

- Properties
- Methods
  - copyElement
  - getData
  - getDestination
  - getHop
  - getIDack
  - getIDsend
  - getModulator
  - getPacketDelay
  - getPacketDuration
  - getPacketStart
  - getResponseRequired
  - getSource
  - packetClass
  - setHop
  - setModulator
  - setPacketDelay
  - startPacket

# Network Simulation Software

- Available at GitHub:
  - git@github.com:QinetiQ-US/SWiG.git or
  - https://github.com/QinetiQ-US/SWiG.git