Phoneline Home Networking Technology

Technology - Leveraging Standards

- Only protocols that have been extensively tested for many years in real use are ready for large scale deployment
- HPNA has chosen IEEE-802.3 layer 2 networking
  - Uses 802.3 framing & Ethernet CSMA/CD MAC behavior
- Guarantees
  - Interoperability between equipment from multiple manufacturers
  - Support for networking standards, particularly IP suite

Technology - QoS Support

- HN applications such as transport of digital audio, video and voice (IP telephony) drive the need for QoS
  - Latency in voice connection must be controlled below 10 to 20 ms for voice quality to be maintained
- HPNA 2.0 has an aggregate throughput of 10Mbps
  - Adequate for many application scenerios
  - Burst loads presented by TCP transfers between PCs without QoS makes the network unable to meet the latency & guaranteed bandwidth service requirements
- HPNA 2.0 MAC layer introduces 8 priority levels & an improved collision resolution technique

Technology - Robustness

- Ad hoc home wiring topology results in
  - Reflections & frequency-dependent channel transfer functions
  - Uncharacterized & highly variable wire transmission parameters especially at higher frequencies
  - Telephone instruments on the same wiring that present a wide range of frequency-dependent impedance
  - POTS signaling & ringing which produces significant transients
  - Impulse noise coupled from AC power wiring that is seen on many phonelines
  - RF ingress & egress particularly in the amateur RF bands
- Phonelines are robust supporting up to 500 feet of phone wire between devices connected to RJ-11 jacks

Technology - Performance

- Rating of up to 10Mbps
- HPNA 2.0 with a self-describing frame format with PHY-level signals directly control equalizer training & demodulation

Technology - PHY Layer Privacy

- Powerline & wireless technologies allow users to share the same physical medium
  - Encryption at the link level helps attain a degree of privacy equivalent to the phone line
  - Requires some user user key configuration thus defeating the plug-and-play objective
- Privacy in phone wires is not a substitute for true cryptographic security

Technology - Future Safeness & Cost

- Future safeness
  - Once installed home networks remain in place for several years
  - Home networks interfaces become embedded in appliances and impossible to replace
  - Good HN technologies build future generation interoperability into current generations
- Cost
  - Home networks should be at consumer prices with few, additional requirements of external components

Phoneline HN Technology

- Based on HomePNA 2.0 - the de facto industry standard
- Easy to use
  - User must install the software, set up the network through both the software settings & physically connect to the phone jack
- Security is excellent
  - Each home has a unique phone circuit (phone number) from the phone company's CO

Critical Aspects of the Phoneline HN Technology

- Foundation is based on Ethernet technology
  - Packet based architecture
- Spectral compatibility
  - Allows the network to coexist with other telephone services and emerging broadband Internet access
- High performance encoding scheme

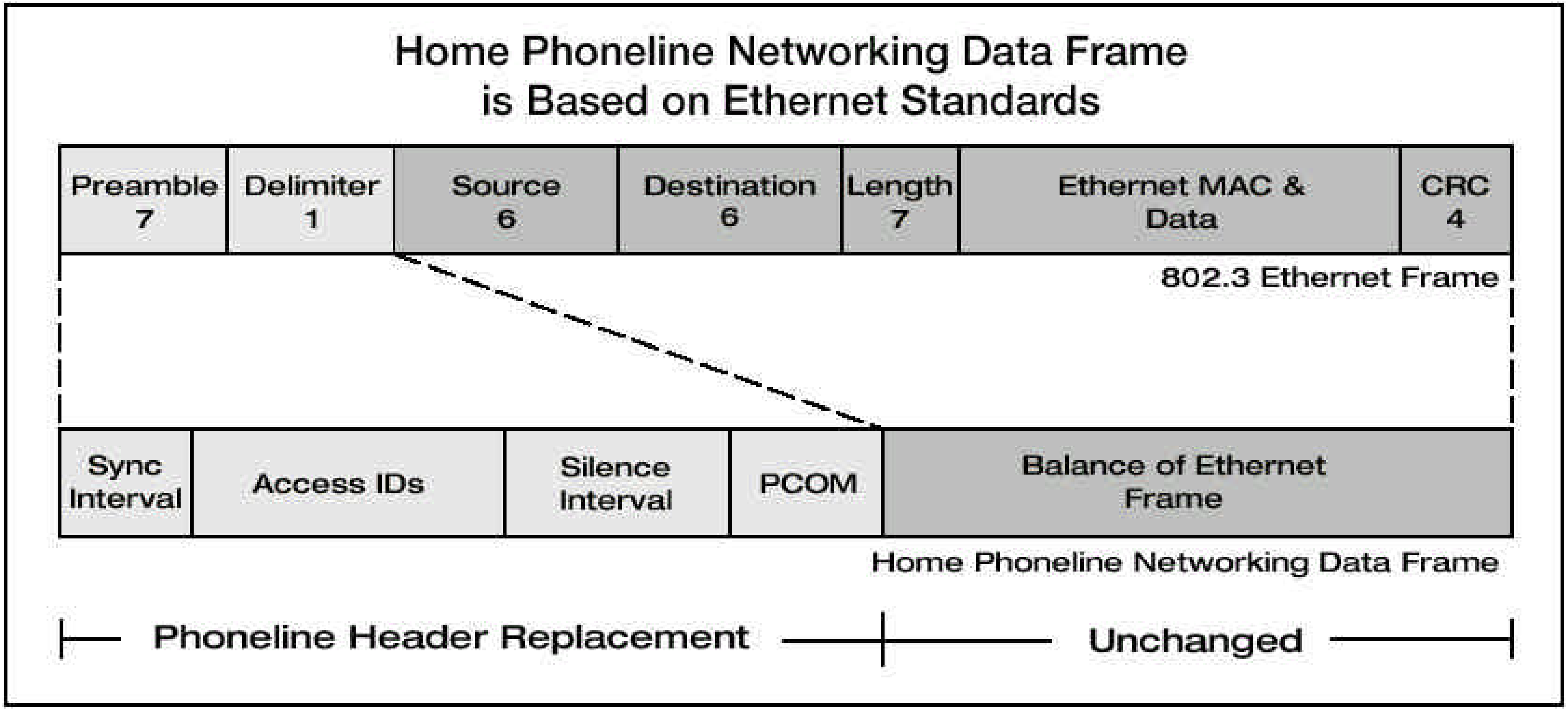
Leveraging Ethernet Technology

- Home phoneline networking technology uses standard Ethernet technology
  - It is adapted to overcome challenges of the home phoneline environment
  - Enables phoneline HN to leverage the tremendous amount of Ethernet-compatible software that exists today while meeting the needs of the home environment
- IEEE 802.3 compliant MAC
- CSMA/CD as access method for sharing the baseband signal on the home network bus
  - Carrier Sense Multiple Access with Collision Detect

CSMA/CD

- When a station has data to send, it first listens to the channel to see if any other station is transmitting
- If the channel is busy, the station waits until it becomes idle
- Collisions occur when 2 stations listen for traffic, hear none, and then transmit simultaneously
  - This causes both transmissions to be damaged
  - Stations must retransmit at some later time
- Back-off algorithm determines when the colliding stations should retransmit

Leveraging Ethernet Technology



Source: Intel Corporation

The home phoneline networking data frame is based on Ethernet standards with a specialized header

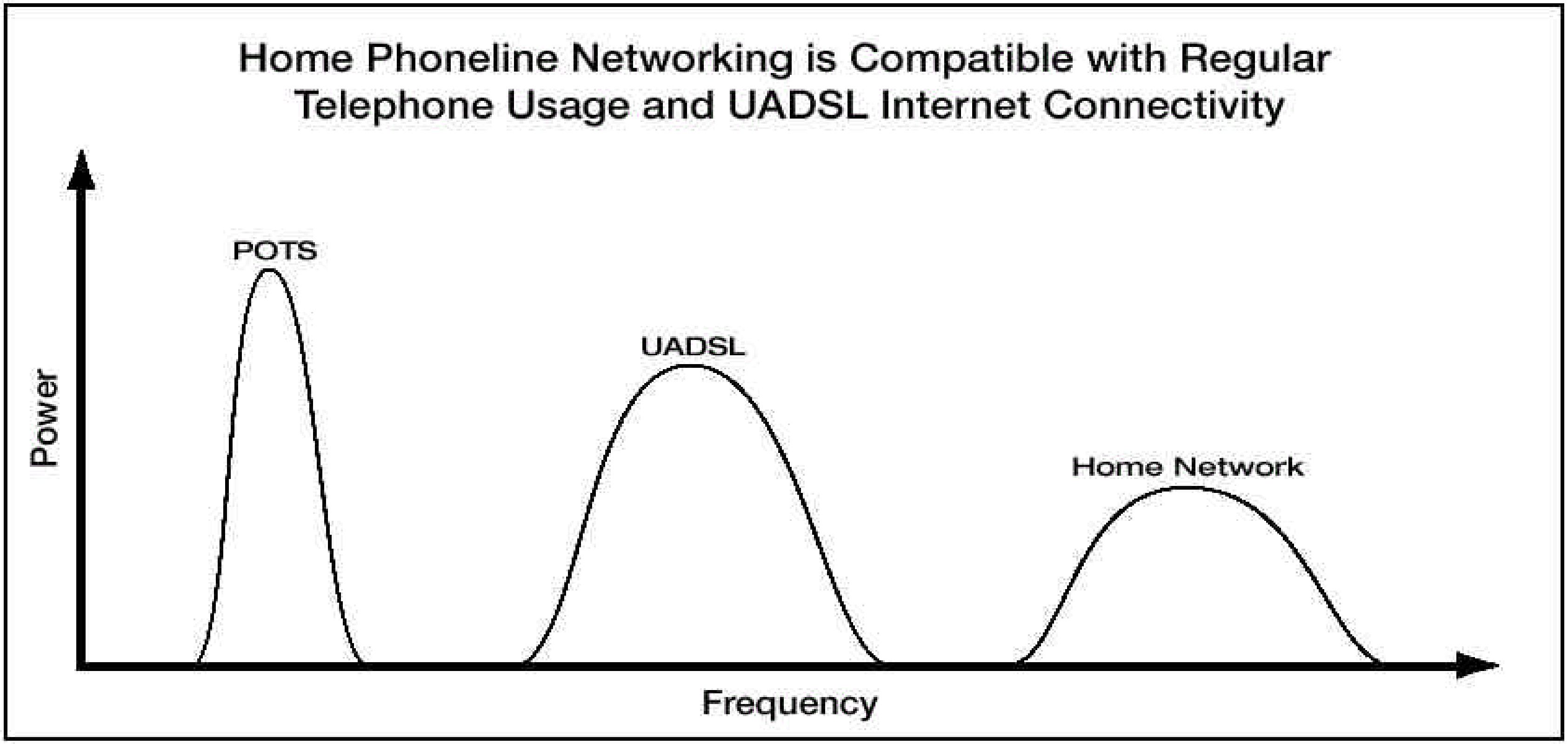
Leveraging Ethernet Technology

- Data originating from applications within the PC
  - Formed into standard 802.3 Ethernet data frames
  - Passed to the phoneline PHY
    - PHY circuitry strips off the first 8 octets of the Ethernet frame (preamble & delimiter fields) and replaces it with a PHY header designed specifically for phoneline networking
- Receiver - Reverse is executed
  - PHY is used to establish the validity of the frame
  - PHY header is stripped off & replaced by a IEEE 802.3 compatible preamble & delimiter field
  - At this point the PHY can pass the frame to a standard Ethernet controller for passage to upper layer applications

Peaceful Co-existence: Spectral Compatibility

- Ensure compatibility with other communication services within the home
  - Home phoneline networking must work with voice & emerging UADSL (universal asynchronous DSL) data services
- Home phoneline networking uses filtering technology - Frequency Division Multiplexing (FDM)
  - Allows simultaneous operation of multiple services over single pair of wires
  - In POTS bandwidth is segregated into channels for each type of traffic - power, analog voice, digital information (audio, data & video)

Peaceful Coexistence: Spectral Compatibility



Source: Intel Corporation

Spectral usage of three services (POTS, UADSL & home phoneline networking) share the same line by operating at different frequencies

Spectral Compatibility

- Frequency Division Multiplexing (FDM)
  - Each communications service is assigned a frequency spectrum different from all others
  - Using frequency-selective filters devices using one type of service can exchange information without interference from other services that communicate in another frequency band
- Frequency range
  - Home network operates between 5.5MHz - 9.5MHz
    - Passband filters attenuate frequencies below 5.5MHz very rapidly to eliminate interference very rapidly to eliminate interference with other potential services sharing wire
  - Standard voice communications operate in 20Hz - 3.4kHz
  - UADSL services occupy 25kHz - 1.1MHz

High Performance Encoding

- Home phoneline networking technology uses time modulation line coding method
  - Developed & patented by Tut Systems
  - Increases data throughput
  - Allows reliable transmission of data over the unknown cabling system of home phone wiring at 1Mbps
  - Incorporates an adaptive circuit
    - Can dynamically correct for varying environmental conditions characteristic of residential phonelines

High Performance Encoding

- Both transmit & receive circuits continually monitor line conditions & adjust settings accordingly
  - The receiver circuit of the PHY layer adapts to the varying noise levels on the wire
  - The transmitting circuit is adapting output signal strength to match requirements of other receivers
- 'Squelch' algorithm sets the minimum & maximum signal levels
  - The receiver can filter out extraneous noise that otherwise might compromise data transmission & reception

HomePNA 2.0 Specification

HPNA 2.0 Spec Introduction

- HPNA 2.0 defines the PHY & MAC layers for a system
  - PHY-layer payload transmission rates of 4 - 32 Mbps with throughput rates equivalent to 10Base-T Ethernet
    - Provides ability to extend transmission rates to over 100 Mbps
  - Rate adaptive transceivers
    - Optimize data rates and packet error rates for dynamically varying channel conditions on a per-packet basis
  - Frequency Diverse QAM techniques provides robust communication over highly frequency selective channels

Spec Introduction (contd.)

- IEEE Std 802.3 “Ethernet” MAC
- Compatibility with IEEE Std 802.3 MII
- Backward Compatible with HomePNA 1M8
  - Allows interleaved transmissions at 1 Mbit/s rates and 10M8 compatibility mode rates
- Compatibility with other phoneline services such as POTS, V.90, ISDN and G.lite
- Spectrum notching for compatibility with Amateur Radio services

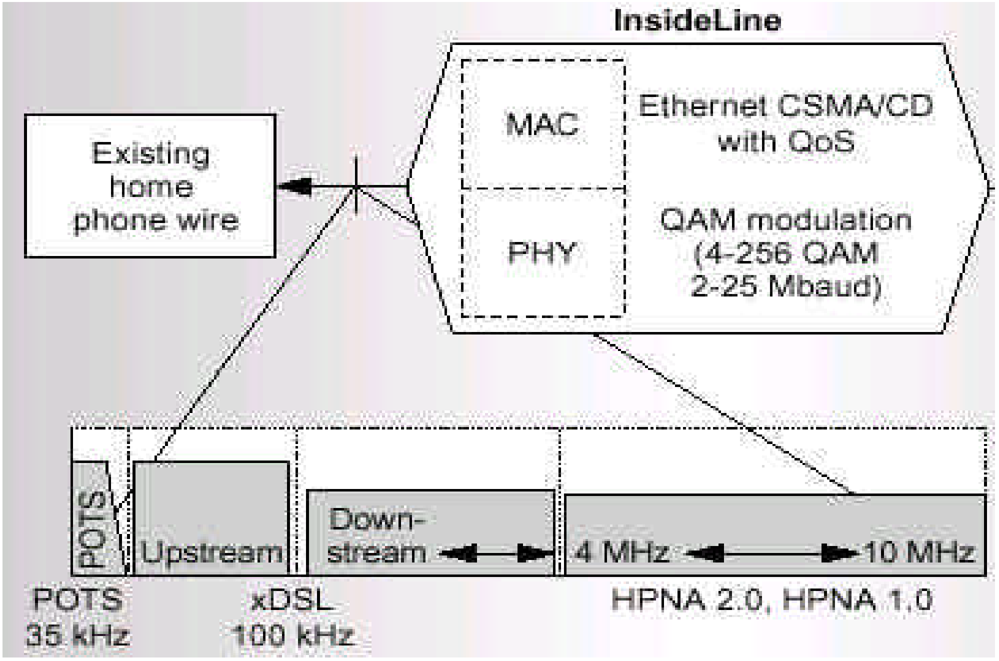
HomePNA Protocol
Network Stack and Responsibilities

- PHY layer
  - Framing, scrambling, symbol mapping, modulation
- MAC layer
  - CSMA/CD
  - Collision resolution
- MII (media independent interface)
  - MAC-PHY interface
- Link layer protocols
  - Rate negotiation, link integrity, link ARQ, capability announcement

HomePNA 2.0

- Current 2.0 spec was introduced in late 1999 by HPNA
  - This revised spec is backward compliance with the 1.0 spec
- Throughput rating of 10Mbps
  - Products show an active throughput in 7-8Mbps range
  - Sufficient for most home networking applications
    - Not sufficiently fast for users engaged in streaming video applications
- HPNA 2.0 spec can support up to 25 PCs, peripherals & other network devices

View of the HPNA 2.0 Stack & Spectrum



Source: 2000 IEEE, HPNA 2.0

HPNA 2.0 System from Point of View of the Network Stack and Frequency Spectrum

Physical Layer

- System is FDM on the same wire as used by the std. analog phone service & splitterless ADSL
  - Analog telephony uses low part of the spectrum - below 35kHz
  - ADSL uses spectrum up to 1.1 MHz
  - HPNA selected 4 to 10 MHz band
    - Lower limit of 4 MHz makes it feasible to implement the filters needed to reduce out-of-band interference between HPNA & ADSL
    - Modeling phone networks shows the spectrum above 10 MHz to be have wider & deeper nulls caused by reflections
    - Cross talk between phone lines increases with frequency
      - Analog front end is harder to implement at higher frequencies
    - Choice of 4-10 MHz only overlaps a single amateur radio band (40m) which simplifies ingress & egress filtering

Physical Layer

- HPNA 1.0 uses pulse position modulation (PPM)
  - This technique adapts to the modulation rate
- HPNA 2.0 uses quadrature amplitude modulation (QAM)
  - Get more throughput in the same bandwidth
  - Achieve greater robustness
- Both techniques are used
  - Because the channels may have very deep nulls & multiple nulls in band

Physical Layer

- The transmitter may vary the packet encoding from 2-8 bits/symbol on a packet-by-packet basis
  - This is instead of having a fixed number of bits/symbol
  - A packet header is always encoded at 2 bits/symbol so that every receiver can demodulate at least the packet's header
  - System uses a fixed 7MHz carrier freq. & can operate at either 2 or 4 Mbaud with modulation encoding of 2-8 bits/symbol
    - Base symbol rate is 2 Mbaud
      - At this rate, the system has a peak data rate ranging from 4 to 16 Mbps
      - Overhead reduces the actual throughput the system can achieve
    - In practice, to achieve performance equivalent to 10Base-T Ethernet, a packet must be sent at 6 bits/symbol

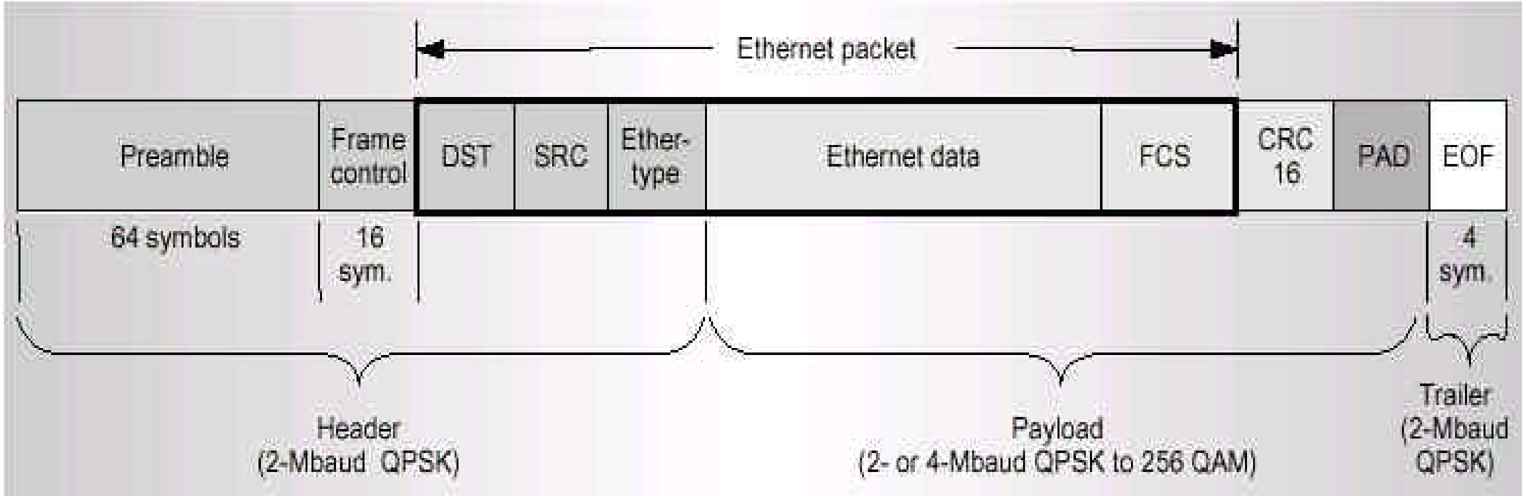
Frequency-Diverse QAM

- HPNA 2.0 implements a modified version of QAM at its 2-Mbaud rate called frequency-diverse QAM (FDQAM)
  - The nature of channel nulls can be such that even rate adaptation down to 2 bits per symbol is not sufficient to guarantee that the packet can be received
  - In a traditional QAM system, if there is an extreme null (i.e., one with which the equalizer can't cope) in the band, the system will fail to operate
- HPNA 2.0 allows for a higher performance 4-Mbaud mode, which achieves peak data rates up to 32 Mbps & through-put above 20 Mbps
  - In cases where the channel nulls are not particularly deep

Frequency-Diverse QAM

- Signal is frequency diverse, motivating the name FDQAM
  - The baud rate is less than half the filter's width
  - Output signal has 2 (redundant) copies of the baseband signal
    - In a traditional QAM system, a single copy of the baseband signal is sent & received
  - One copy of the signal will still make it through
    - On channels with a low SNR ratio, where a large part of the spectrum is severely attenuated, FDQAM works robustly in many cases where uncoded QAM would fail
    - Such channels are common on home phone lines
  - Simplified protocol enables robust performance over time-varying channels
  - Unlike other methods of handling severe channels, in FDQAM does not require the transmitter to have knowledge of the channel characteristics

Frame Format



Source: 2000 IEEE, HPNA 2.0

- Frame includes
  - Preamble, frame control, 802.3 Ethernet frame, CRC16, padding and EOF (end-of-frame) sequence

Frame Format Fields

- Preamble
  - 64-symbols at the beginning of the frame
  - It supports robust carrier sensing & collision detection, equalizer training, timing recovery & gain adjustment
- Frame control
  - 8-bit frame type which follows the preamble
  - Following the frame type is an 8-bit field that specifies the modulation format (bits per symbol, for example)
  - There are other miscellaneous control fields in frame control including an 8-bit CRC header

Frame Format Fields

- IEEE 802.3 Ethernet frame
- CRC-16
  - Cyclic Redundancy Check
  - It covers the header and payload, & reduces the undetected error rate for severely impaired networks
- Padding and EOF sequence

Frame Format - Key to Operation

- The first 120 bits of the frame are sent at the most robust 2-Mbaud, 2-bits/symbol rate
- Any station able to demodulate a packet can do it at this encoding
- Even if the payload is encoded at a rate (bits/symbol) that the receiver can't demodulate, it will be possible to demodulate the header
- In this situation, the receiver sends a rate request control frame (RRCF) to the sender, asking it to reduce the number of bits/symbol or the symbol rate

Frame Format - In Practice

- System starts out sending at 2 bits/symbol
  - Unless the receiver sends an RRCF, asking for future packets to be sent at higher data rates
  - Several algorithms can be used to determine when to send RRCFs and to estimate the channel capacity using an approximate SNR and bit error statistics
  - The rate adaptation algorithm can optimize the rate used when sending to multicast and broadcast groups

Medium Access Control (MAC)

- HPNA 2.0 is a CSMA/CD system
  - Like the standard IEEE 802.3 Ethernet
- HPNA 2.0 introduces 8 levels of priority and uses a new collision resolution algorithm called distributed fair priority queuing (DFPQ)
- Using the Ethernet MAC does not guarantee any real service
  - Voice telephony requires a low-latency network service, and streaming audio or video applications require a guaranteed bandwidth service

MAC - Access Priority for VoIP

- Different access priorities with the VoIP station having a higher priority than best-effort file transfer traffic
- HPNA 2.0 accomplishes access priority by organizing the time following the interframe gap into an ordered series of priority slots
  - Access priority lets software define different service classes
    - Such as low-latency, controlled-bandwidth, guaranteed-bandwidth, best effort, and penalty
    - Each uses a different priority level

MAC - Access Priority for VoIP

- Within a given priority level, HPNA 2.0 uses a new algorithm for collision resolution
  - Each station keeps track of a back-off level & after a collision, randomly chooses to increment the back-off level by 0, 1, or 2
  - During a collision resolution cycle, stations incrementally establish a partial ordering
  - Eventually, only one station remains at the lowest back-off level and gains access to the channel

MAC - Access Priority for VoIP

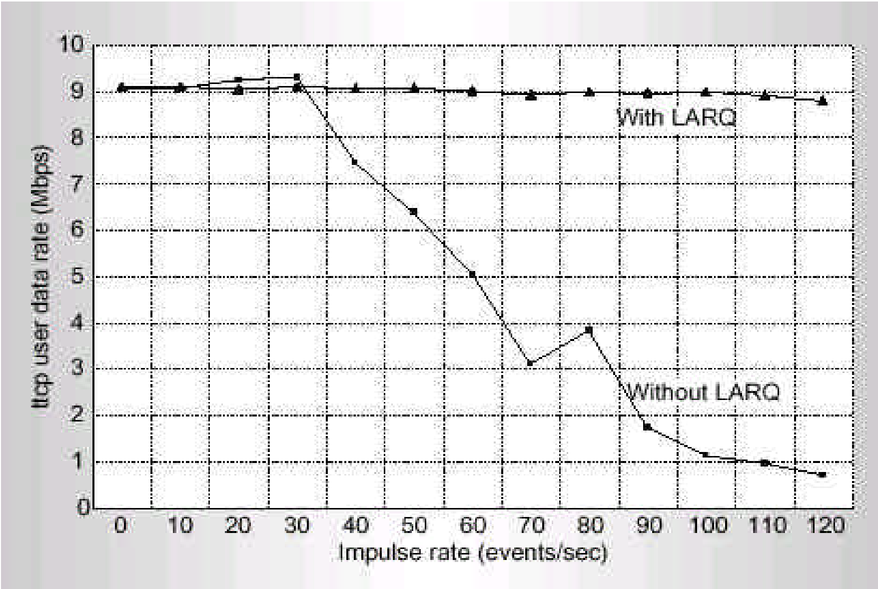
- In practice & even on saturated networks, HPNA 2.0 behaves very well
  - Unlike traditional Ethernet it does not exhibit the capture effect
  - As the offered load increases, Ethernet experiences delays of hundreds of frame times for several percent of transmission attempts
  - When compared with the Ethernet delay, the HPNA 2.0 access latency distribution reveals a negligible tail beyond twice the minimum time to service each active station, even at high offered loads

Link Layer Protocols

- Home networks using no-new-wires technology have another problem : impulse noise
  - On phone wires, impulse noise exists due to phone ringing, switch-hook transitions, & noise coupled from the AC power wiring
  - Fortunately, the impulses tend to be short and destroy only a single packet
  - There are coding techniques that might reduce the number of packets destroyed by impulses
  - HPNA 2.0 has however chosen to use a fast retransmission mechanism called limited automatic repeat request (LARQ)

Link Layer Protocols - LARQ

- LARQ is implemented (in software) at Layer 2
- Because it only operates on a single segment of the network, it is very effective in hiding packet erasure from TCP/IP



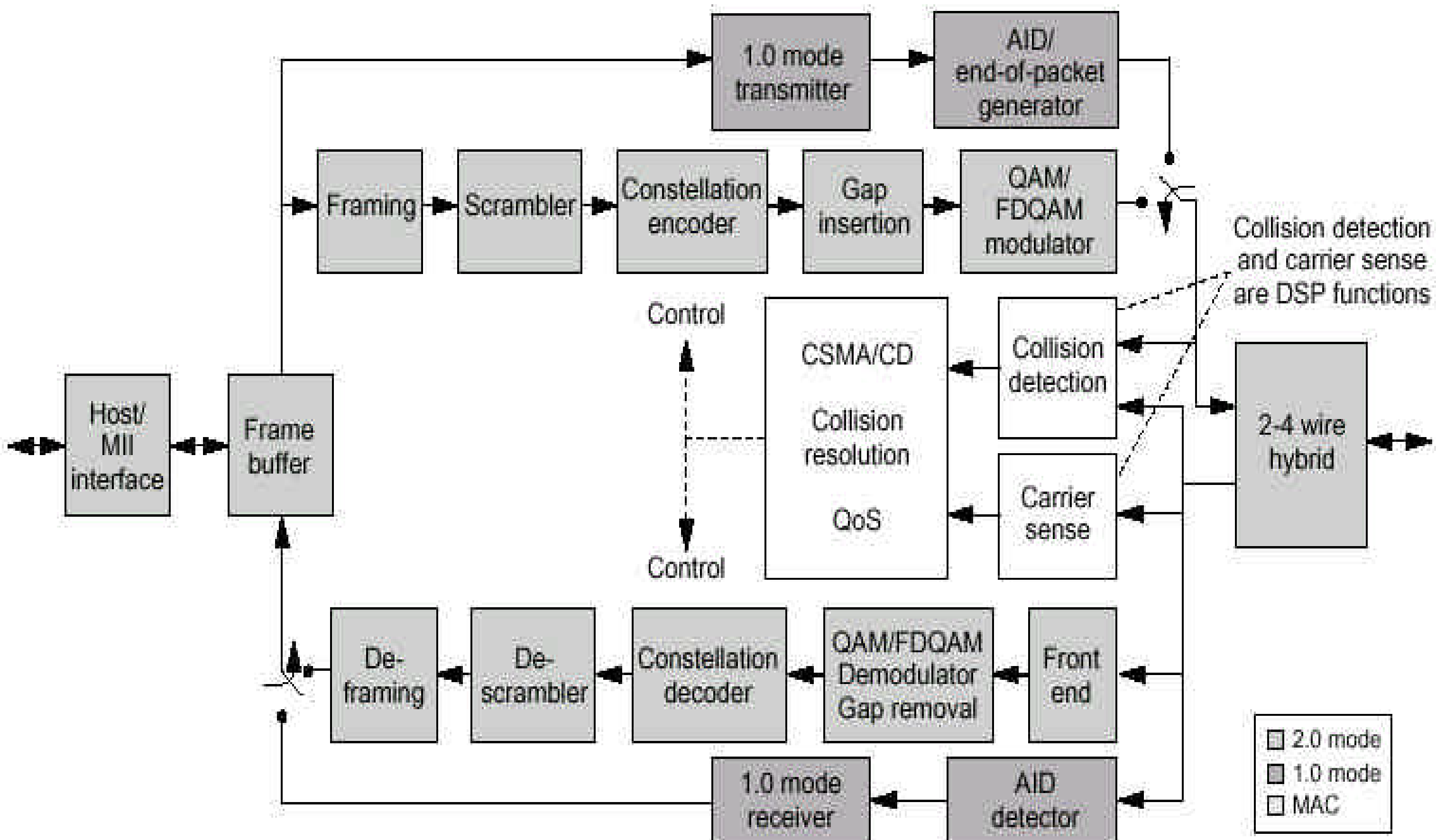
Source: 2000 IEEE, HPNA 2.0

User-level Throughput versus Impulse Noise Events/sec

Link Layer Protocols - Link Integrity

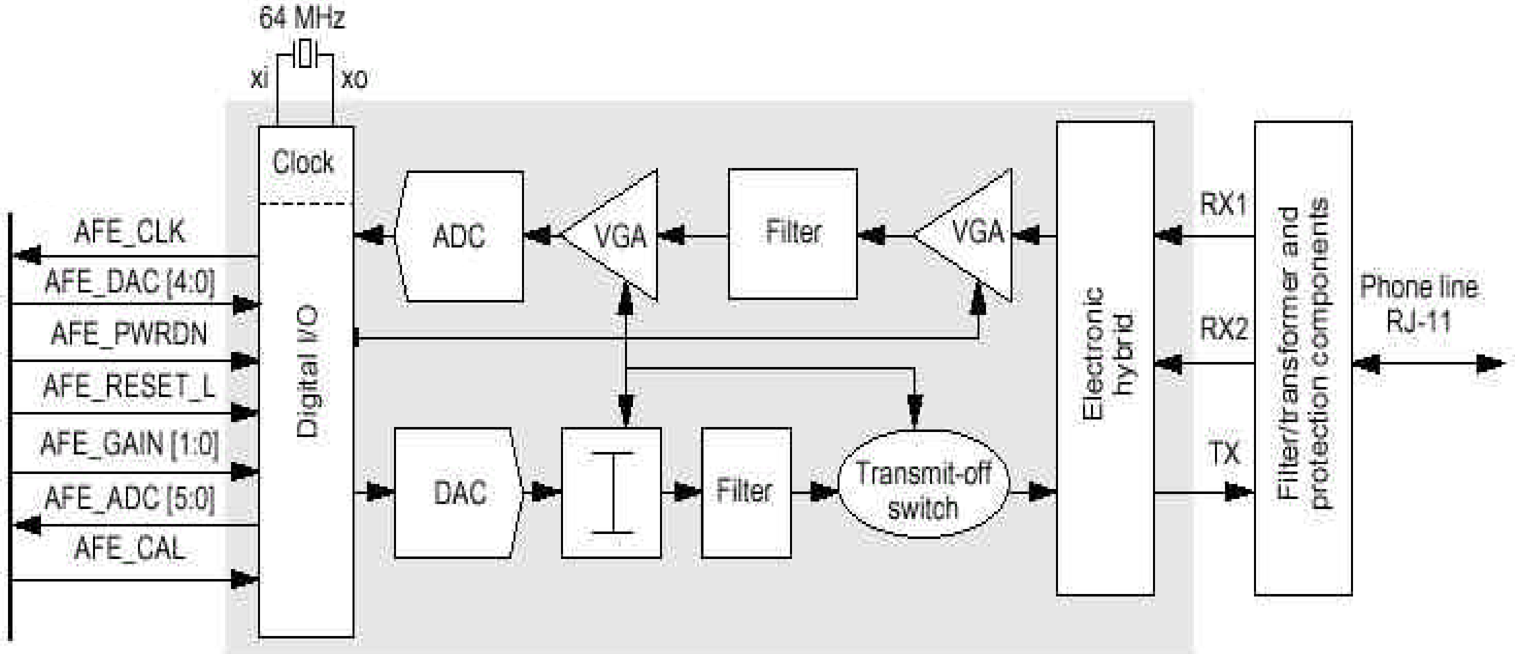
- HPNA 2.0 implements a link integrity mechanism
  - It can be implemented either in hardware or at low levels of a software driver
  - It provides a quick & easy way for the end user to determine if the network has basic connectivity
  - Link integrity frames are sent once per second, unless there is traffic on the wire, in which case a reduced number of frames may be sent

HPNA 2.0 MAC/PHY Block Diagram



Source: 2000 IEEE, HPNA 2.0

HPNA 2.0 Analog Front End Block Diagram



Source: 2000 IEEE, HPNA 2.0

HPNA 2.0 Technology

- Tut Systems & Epigram (Broadcom Corp.) are the alliance's initial technology providers
- Comparison with IEEE1394/FireWire specification
  - Firewire is a high-speed technology requiring new optical fiber or high grade copper wiring throughout the home
  - Firewire technology is used for special applications requiring enormous amounts of bandwidth
  - HPNA will be widely popular for applications with multiple PCs & for those looking for existing wires solutions

HPNA 2.0 Technology

- Phoneline based home networking
  - Will ensure interoperable & coexistence with wireless, powerline, Universal ADSL/G.Lite & Ethernet networks
    - Co-exists with the new splitterless Universal ADSL standard
    - Fully compatible with the Ethernet MAC layer standard (IEEE 802.3 CSMA/CD)
    - Meets FCC requirements
  - Complement high speed Internet access technolgies such as cable modems, ISDN, xDSL, satellite
    - Ensures sharing Internet access with all other PCs or devices in the home simply by plugging into the telephone jack with an adapter or NIC

HPNA 2.0 Technology

- Does not require any hubs or new Cat 5 wiring
- Supports the complex, random-tree type of wiring typically found in the home
- Such an arrangement requires no special terminations, filters or splitters
- Provides QoS
  - Allows streaming audio, video & telephony over the same wires through which Internet access occurs

Key Consumer Applications Require HPNA 2.0

- High speed Internet access sharing
- High speed file sharing
- Peripheral sharing
  - Printer, scanner
- Voice over IP (VoIP)
- Multimedia
  - Streaming digital audio & video throughout the home
- Backward compatibility & support for applications supported by HomePNA specification 1.0

Examples of Products that are Expected to Use the Technology

- PCs
- Modems (including cable, xDSL, satellite, analog)
- Network hubs
- IP telephones
- Digital TVs and set-top boxes
- Home security & automation
- Network appliances
- ‘Bridges’ to Ethernet, wireless, powerline, 1394, USB

Performance Requirements

- HPNA Spec 2.0 shall be capable of achieving nominal data rates of 10 Mbps over typical phonelines
  - Based on 10 Mbps 10BaseT Ethernet network
- Coverage over phoneline networks for HPNA spec 2.0 is defined as follows:
  - Achieve full rate throughput operation over at least 80% of home networks
  - Provide ability to connect, at no specified rate, in 100% of home networks
- Maximum internode distances are required to be greater than or equal to the HPNA spec 1.0

Performance Requirements

- Number of nodes supported on one network greater than or equal to HomePNA spec 1.0
- It is desirable that specifications feature adaptive capability above and below the nominal 10 Mbps rate
  - This allows optimization of throughput over the widest range of phoneline network topologies
  - This extends the coverage of homes served by HPNA spec 2.0 relative to the HPNA Spec 1.0
- It is desirable that specifications show scalability to future higher data rates well over 10 Mbps

Compatibility Requirements

- HPNA spec 2.0 addresses the physical and logical interface point between the phoneline and HomePNA network devices
  - This ensures interoperability between Promoter's/Adopter's home phoneline network products
- HPNA spec 2.0 should be electrically compatible with other services
  - POTS, V.90, ISDN & G.lite should coexist on the same phoneline

Backwards Compatibility With Earlier Specs

- HPNA Spec 2.0 specifies a mode for backward compatibility with HPNA Spec 1.0
  - The minimum requirement specifies a ‘fall back’ mode which selects operation of HPNA Specification 1.0 for all nodes
  - In a mixed network of HPNA Specs 1.0 and 2.0 nodes, all HPNA Spec 2.0 stations should communicate at their full 10Mbps rate
    - Regardless of the presence of HomePNA Spec 1.0 nodes
    - Without interfering with the HomePNA Spec 1.0 nodes

Interoperability

- With HomeRF products
  - HomeRF products work with HPNA-based products
    - TCP/IP is used in HPNA based products & HomeRF products fully supports TCP/IP
    - Consumer requires a bridge to interface the phoneline network to wireless HomeRF network
      - HomeRF SWAP spec defines this bridging
      - Vendors are currently developing future bridging products
- With Ethernet products
  - HomePNA is an Ethernet based technology and are seamlessly interoperable

So, Can We Use Powerlines for Home Networking?

Powerlines are also an Omnipresent, 'No New Wires' Solution!

XILINX®

Powerline Home Networking

- Uses existing power & electric lines in the homes
  - Quite similar to phoneline networks
- Several AC/power sockets/outlets in a home
- Powerline capabilities
  - Data rates up to 10Mbps are possible
- Low cost solution

Powerline Home Networking Pros

- Multiple power outlets can be fund in each room
- AC outlets are ubiquitous in virtually every existing home
- Powerline networking takes advantage of the unused capacity of the power cable to transmit data over the existing home power cabling
- Is capable of distributing data as fast as 10+ Mbps

Powerline Home Networking Cons

- Widely varying transfer response- frequency & attenuation
- Different types of noise impairments at unpredictable times
- RF jammers (particularly at night)
- Time delay spread (multipath)
- Usable bandwidth is not contiguous due to impairments or regulations
- Channel Adaptation is required to achieve high data rates and reliability

Noise Sources

- Switching power supplies
  - Rich in harmonics with oscillator 20Kh to > 1MHz
  - Conduct oscillator noise onto power line
  - Frequency often varies with load
- Universal series wound motors
  - Vacuum cleaners, kitchen appliances, drills
  - High repetition rate impulses

Noise Sources

- Light dimmers
  - Produce large impulses at 100-120 Hz
  - Large 20V to 50V impulses
- Power line intercoms
  - 3Vpp to 7Vpp from 150KHz to 400KHz
  - Large harmonics of about 30KHz bandwidth

Powerline Technologies

- X10
  - X-10 controllers send signals over existing AC wiring to receiver modules
  - X-10 power line technology transmits binary data using an Amplitude Modulation (AM) technique
- Intellon CEBus
  - Open standard that provides separate PHY layer specification documents for communication on power lines & other media
  - Data packets are transmitted by the transceiver at about 10Kbps employing spread spectrum technology
  - Uses a Carrier Sense Multiple Access/Collision Detection and Resolution (CSMA/CDCR) protocol to avoid data collisions

Powerline Technologies

- Echelon LONWorks
  - Provides a peer-to-peer communication protocol, implementing Carrier Sense Multiple Access (CSMA) techniques
- Adaptive Networks
  - Utilizes a hybrid token passing media access scheme as opposed to the peer-to-peer CSMA/CDCR schemes

Powerline Applications

- Industrial
  - Utility telemetering, automated storage, factory and machine automation, shipboard refrigerated container monitoring
- Commercial
  - Point-of-sale networks, public transit vehicles, residential LAN, vending machines monitoring

Issues to Overcome in Powerline HN

- Immature technology
  - Interference Issues
  - Low Speed and Attenuation
- Lack of standards
- Lack of consumer adoption
- Regulatory issues
- There is an added cost for the extra safety isolation needed with power connections
  - This type of modem is likely to remain significantly more costly than phoneline models but below the cost of wireless systems