Comparing Technologies: DMT vs. QAM

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Agenda

- Brief Intro
- Technical Merits
- Market Merits
- Summary

Defining the selection before us…

- VDSL line code choice should be based on:
  - Technical Merits
    - Various parameters compared including Application/protocol stack integration, Power consumption, and Density
  - Market Merits
- Additionally, we must remember we are defining an Ethernet PHY, not a DSL

Brief Intro

- **DMT**
  - Discrete Multi-Tone
  - subset of Multi-Carrier Modulation - MCM
  - Found in ADSL
    - About 7.5M lines installed (Cahners In-Stat, OECD)
    - 8 years to get interoperability
- **QAM**
  - Quadrature Amplitude Modulation
  - subset of Single Carrier Modulation - SCM
  - Found in Cable modems
    - About 8.5M installed (Cahners In-Stat, OECD)
    - 2 years to get interoperability
  - Found in 100BT2/1000BT
    - Many 10s of millions installed

QAM and DMT Modulation Techniques

- QAM and DMT are 2 classes of modulation techniques that have both found application in DSL
- QAM is a generalization of PAM techniques, a subset of single carrier modulation (SCM). Five level PAM used in 100BaseT2,1000BaseT (802.3 2000 30.3.2.1.2)
- QAM - in VB modems, HDSL, SDSL, SHDSL, IDSL, RADSL, Ethernet, cable modems, direct satellites, etc.
- DMT - in ADSL, certain wireless applications

QAM for VDSL

- 4 independent QAM bands, 2 for upstream, 2 for down, plus Band 0
- Standards bodies conclusion: 4 bands optimal for mixture of VDSL service types and loop lengths
- Specification enables bandwidth optimization within each band (current QAM technology in use)

DMT for VDSL

- Each band divided into hundreds of 4 kHz sub-bands
- Each sub-band carries a narrow QAM signal
- Bandwidth optimization and frequency division duplexing occur by zeroing many (half) sub-bands

Version data and installed base

- DMT
  - No version data available on DMT VDSL
  - No installed base
- QAM
  - Third and or fourth generation now coming available
  - Across whole VDSL family
    - Shipments of over 1M chipsets in 2001

Technical Merits Comparison

- QAM versus DMT performance: stationary noise
- QAM versus DMT performance: bursty noise
- Field Experience
- Implementation and Practical Effects
- Standards Support
- Performance Summary

QAM vs. DMT Performance: Stationary Wideband Noise Case

- QAM / DMT performance virtually identical, when using worldwide band plans
- Reason: QAM DFE averages input SNR while DMT averages bits per sub-channel - very similar
- Fully accepted in peer-reviewed academic context:
  - B. Saltzberg, “Comparison of Single-Carrier and Multitone Digital Modulation for ADSL Applications,” *IEEE Comm Magazine*, Nov. ‘98.
  - L. Vandendorpe, “Asymptotic Performance of MMSE MIMO Decision-Feedback Equalization for Uncoded Single Carrier and Multicarrier Modulations,” IEEE International Conference on Communications 1998, Atlanta, GA, June 1998.
- Notched channel comparison: See “Practical Effects”

QAM vs. DMT Performance: Stationary Narrowband Noise Case

- QAM DFE nulls narrowband ingress, automatically and almost immediately, with no loss beyond that dictated by Shannon theory limit
- DMT reduces constellation in effected channels
  - Requires use of windowed FFT for effective performance; VDSL specific (not used in ADSL), requires more overhead
  - Requires handshaking and negotiation to adapt to new continuous interferer
  - Slower and less robust than automatic QAM DFE approach
- QAM has advantage for this case

QAM vs. DMT Performance: Bursty Noise Cases

- 6 burst noise cases: (High, Moderate, Low) levels with x (Narrowband, Impulse) noise types
- Comparative performance varies with case
- Results highlight the time/frequency domain duality of QAM/DMT: When one line code excels for a particular case, the other line code excels for the dual case

High, Moderate, and Low Noise Levels

- By definition, in the following performance comparison table, for the given channel:
  - *Low level narrowband* is the max ingress level which does not cause QAM symbol errors
  - *High level narrowband* is the min ingress level which saturates the ADC
  - *Moderate level narrowband* refers to levels in between
  - *Low level impulse* is the max impulse level which does not cause DMT sub-channel errors
  - *High level impulse* is the min ingress level which saturates the ADC
  - Moderate level impulse refers to levels in between
- Narrowband ingress and impulse noise are duals

Burst Noise Field Experience

(Not all bursty noise scenarios are likely in the real world)

Noise Case	QAM Result	DMT Result	Advantage	**Likelihood**
Low Level Narrowband	No pre-FEC errors	Correctable errors made	QAM	Common
Moderate Level Narrowband	Errors extended by DFE tracking time, deeper iÕleaver required to correct	Correctable errors made, same as low level NB case	DMT	Uncommon
High Level Narrowband	Analog common-to-differential canceler required	Analog common-to-differential canceler required	Tie	Very Uncommon
Low Level Impulse	Correctable errors made	No pre-FEC errors	DMT	Very Common
Moderate Level Impulse	Correctable errors made, same as low level impulse case	Impulse errors extended by DMT spreading, deeper iÕleaver required to correct	QAM	Very Common
High Level Impulse	Same as moderate level	Same as moderate level	QAM	Uncommon

Burst noise field conditions favor QAM

Practical Effects - SNR Averaging

- DMT requires constellation dense enough for highest SNR region, while QAM gets to average SNR variations, thereby requiring smaller constellations
  - QAM requires less analog and digital precision = lower power
  - QAM less sensitive to timing jitter, EQ imperfections
- DMT 11 bit limit = high SNR performance penalty
- QAM averaging penalty for low SNR amateur notches < 0.5 dB
- Duality again: High SNR vs. Low SNR

Practical Effects - Digital Duplexing

- Frequency Division Duplexing w/o use of analog filters
- Both QAM & DMT can use, but severe analog requirements
  - Without analog filters local echo 30 dB stronger than received signal
    - Effects Range, noise sensitivity, etc.
  - 5 extra ADC bits required; or accept very high quantization noise floor
  - Current cost/performance tradeoff strongly favors passive LC filters

Practical Effects - Digital Duplexing

- Claims that QAM cannot inherently do digital duplexing are disingenuous and misleading
- In fact, DMT cannot take advantage of analog splitting filters without suffering from out of band filter distortion. No such problem for QAM.

Standards Support

- Worldwide, Telcos committed to not repeating the DMT ADSL time-to-market/interoperability issues
- Standards bodies:
  - Want both QAM and DMT vendors developing standards-compliant systems
  - Market determining ultimate winner, or there will be spectrally peaceful coexistence

Blind Acquisition/Handshake

- DMT cannot do blind acquisition, QAM can
- DMT requires handshake to start up, needs a longer time to start
  - Handshake defined with HDLC and additional processing requirements
- QAM does not require handshake to start, faster start up

Power Consumption

- Standards call for max. 1.5W per VDSL port
- DMT suppliers do not have commercially available products on the market to compare
- QAM vendors now supplying singles at <1.5W/port and multi-port at <1W/port for <u>all components</u> needed in a design

Performance Summary - “Is it a Wash?”

- All things considered, for properly designed systems QAM and DMT performance are technically equal
- 10 years of QAM vs. DMT fighting boil down to:
  - Small (< 0.5 dB) differences in various continuous noise conditions
  - Bursty noise frequency/time domain duality trade-offs that cancel out
- QAM VDSL is the right choice
- Technical Reference: IEEE Communications article by Saltzberg from 1998 comparing the technologies

IEEE Communications November 1998

Comparison of Single-Carrier and Multitone Digital Modulation for ADSL Applications

Burton R. Saltzberg

Issue	Single-carrier	Multitone	Equivalent
Performance in Gaussian noise			X
Sensitivity to impulse noise (uncoded)		X	
Sensitivity to narrowband noise (uncoded)	X		
Sensitivity to clipping	X		
Sensitivity to timing jitter	X		
Latency (delay)	X		
Need for echo cancellation	X		
Computations per unit time		X	
Complexity of algorithms	X		
Cost and power consumption in analog sections	X		
Adaptability of bit rate		X	

Table 1. *Relative advantages of single-carrier and multitone modulation for ADSL.* X *denotes the system with better performance or lower cost.*

Densities

- DMT
  - No commercially available VDSL data
  - Per various web sites, single port ES only available, some rumors of Quads due out for later ES
- QAM
  - For commercially available chips:
  - 2-Band (EoVDSL)
    - Single and Octal
  - 3/4-Band
    - Singles
    - Multi-port (quad and octal)

Regarding Intellectual Property

- DMT
  - Requires IP licensing
  - Does this need to be addressed to the IEEE?
- QAM
  - Public Domain
  - No hidden costs
  - More in line with IEEE

Market Merits - Market availability, Interoperability

- DMT
  - No commercially available systems (TI has a chipset announced, no data on if single manufacturer has delivered systems, however the system vendor has dropped the product)
  - No interoperability
- QAM
  - 3 years commercial availability
  - Multiple system vendors have products
  - Interoperability targeted by end of 2002

Market Merits - Installed base

DMT

No established market data on commercially available DMT VDSL, extrapolate ADSL data?

- QAM
  - Could extrapolate from cable modems or 100BaseT and/or 1000BaseT, however there is data on QAM VDSL, including Ethernet over VDSL
  - Immediate availability, commercially available
  - Multiple sources drive costs down
  - Interoperability efforts
  - >1M QAM VDSL ports shipped in 2001, with >700K EoVDSL ports shipped

Market Merits - Relative Costs

Item	DMT	QAM	Advantage/Notes
Filters/Magnetics	Lower complexity so lower cost		DMT
Line Drivers	Higher complexity	Lower complexity so lower costs	QAM
AFE	Higher complexity and AD/DA	Lower complexity so lower costs	QAM
Digital	Same	Same	No advantage
Rest of circuit design	Higher power requirements	Lower power, less heat dissipation	QAM

Summary Findings

- Technical Merits almost balanced, QAM ahead
- Market Merits (as VDSL)
  - QAM is
    - In the market, commercially available
    - Has been tested
    - Defined interoperability effort