Proactive Network Maintenance for EPoC

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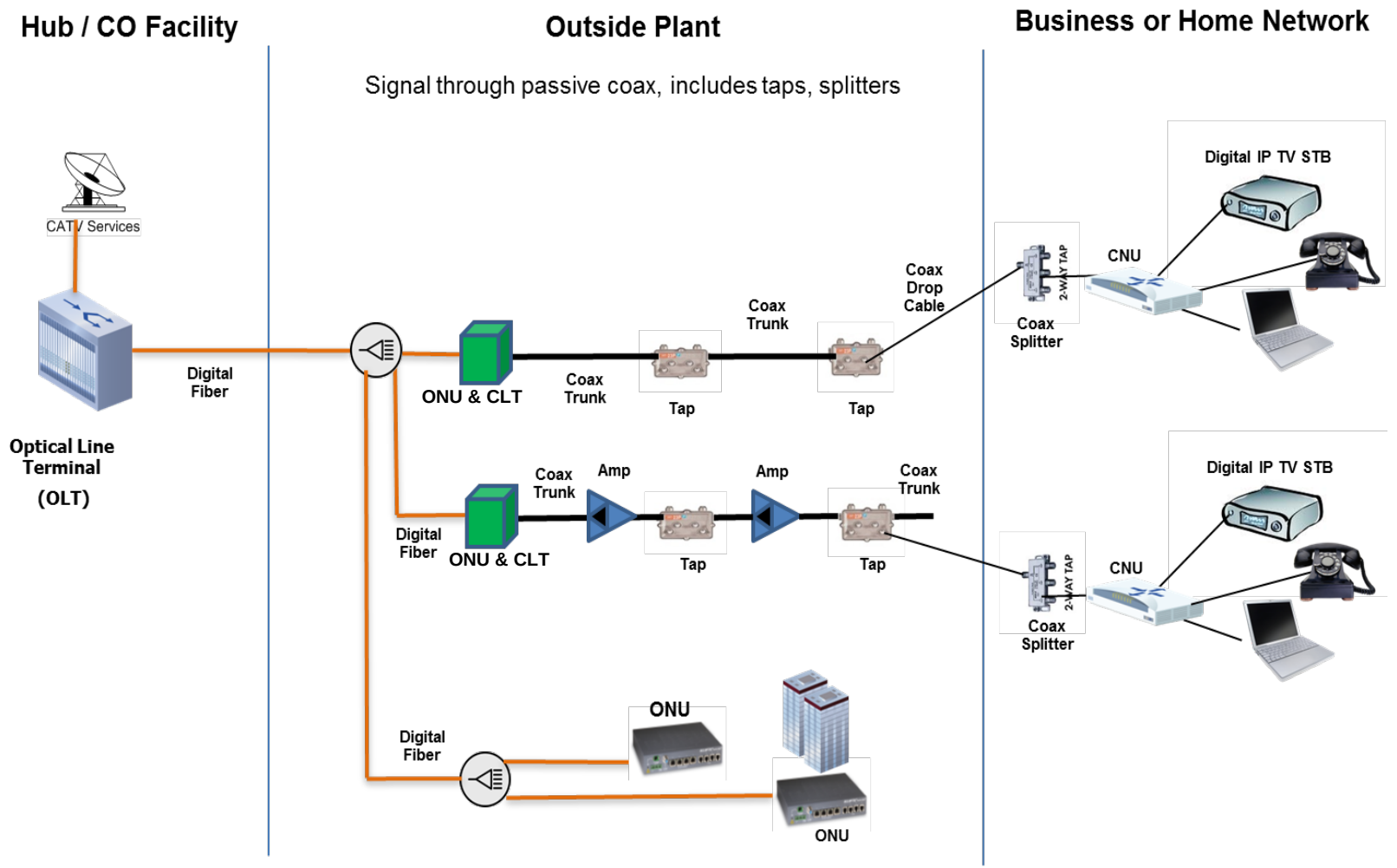
SUMMARY

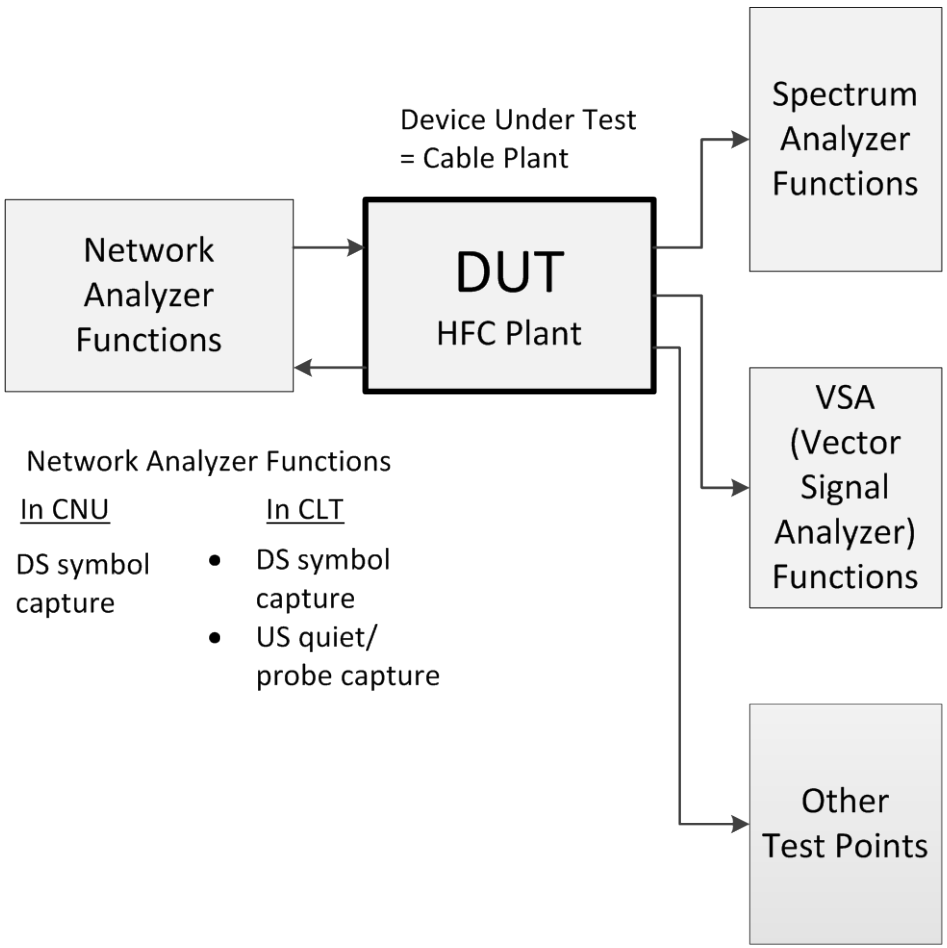
- Cable operators require remote visibility into operation of cable plant and equipment
- Insert test points into CLT and CNU to enable characterization and troubleshooting of HFC plant
- Provide characterization of cable plant response, linear and nonlinear, and noise/interference evaluation
- Suport remote proactive troubleshooting of plant faults
- Goal is improved reliability and maximum throughput from well-maintained plant

EPOC SYSTEM DIAGRAM



Source: EPoC Architecture Specification

TEST POINTS FOR HFC PLANT



Spectrum Analyzer Functions

In CNU
- Full-band spectrum
- NPR notch

In CLT
- Triggered spectrum

VSA Functions

In CNU
- US pre-equalizer and DS equalizer coefficients
- Constellation display
- RxMER vs subcarrier

In CLT
- US equalizer coefficients

Network Analyzer Functions

In CNU
- DS symbol capture

In CLT
- DS symbol capture
- US quiet/ probe capture

Other Test Points

In CNU
- FEC statistics
- Histogram

In CLT
- Impulse noise statistics
- FEC statistics
- Histogram

- **Each test point will be described at end of slide deck**

CABLELABS PROACTIVE NETWORK MAINTENANCE (PNM) WORKING GROUP

- **Approach**
  - Collect equalization coefficients and other metrics
  - Measure wideband spectrum
  - Analyze to locate impairments in cable plant
- **Track record**
  - Reliably finds impairments in cable plant -- often before outage occurs
  - High-resolution spectrum
  - Strong reception by MSOs

***InGeNeOs** = **In**telligent **Ge**neration-**Ne**xt **O**perational **S**ystems*
Working Group at CableLabs, fka Proactive Network Maintenance (PNM)

PNM HISTORICAL TIMELINE

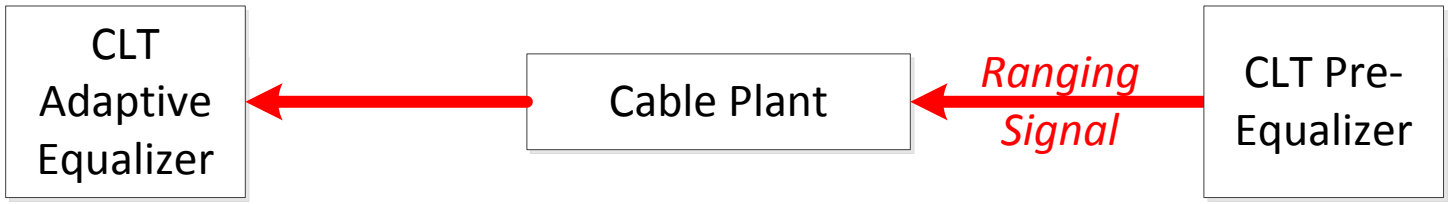
- **Upstream adaptive equalization**
  - DOCSIS 1.1, circa 1999
- **CableLabs Proactive Network Maintenance WG**
  - 2007
- **Comcast Scout Flux Tool**
  - November 2009
- **Spectrum Analysis MIB definition**
  - Late 2012
- **Comcast Flux / Spectra Tool**
  - March 2013

PNM TOOL IMPLEMENTATIONS ACROSS CABLE INDUSTRY

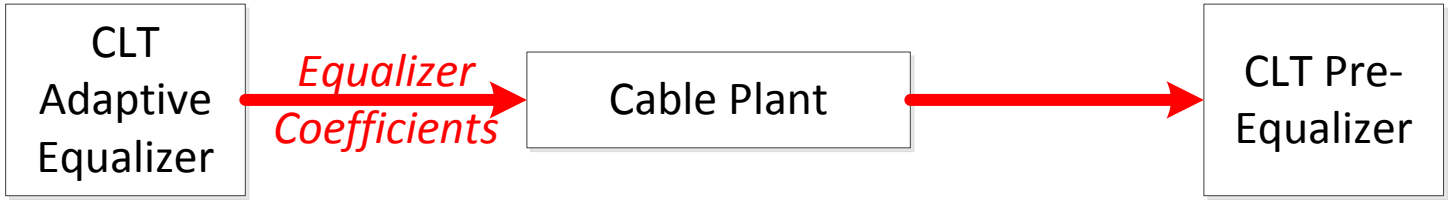
- CableLabs – Pre-EQ / SA Reference
- Charter – DRUM / Node Slayer
- Comcast – Scout Flux / Spectra
- Cox – Edge Health
- Motorola – Pre-EQ Response Tool
- Rogers – F-Finder
- Time Warner Cable - ROI / Unified

UPSTREAM PRE-EQUALIZATION STEPS

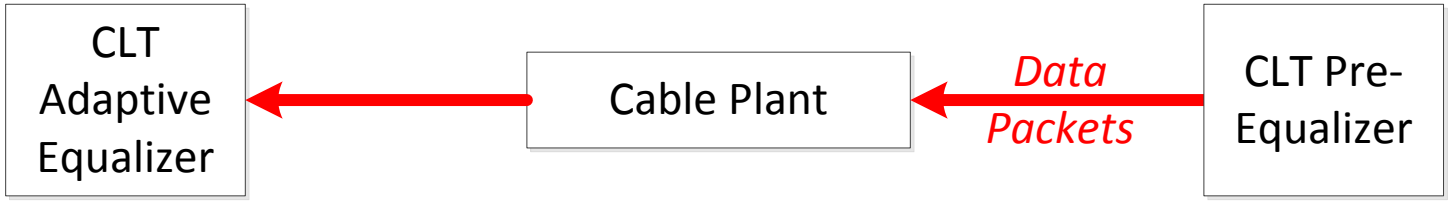
1) ***Adapt*** *Headend Equalizer to Channel*



2) ***Copy*** *Coeffs Into Pre-Equalizer (Update Periodically)*



3) ***Send*** *Data Traffic Upstream*

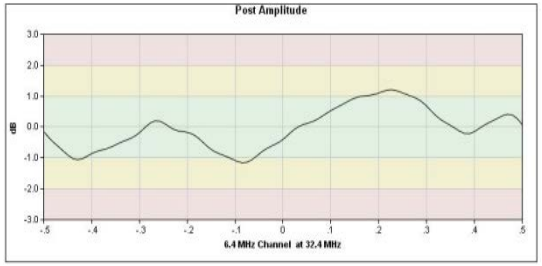


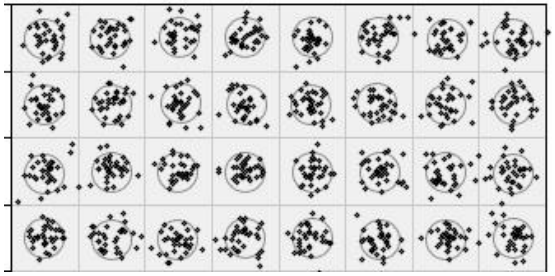
PRE- AND POST-EQUALIZERS

CNU pre-equalizer does most of correction

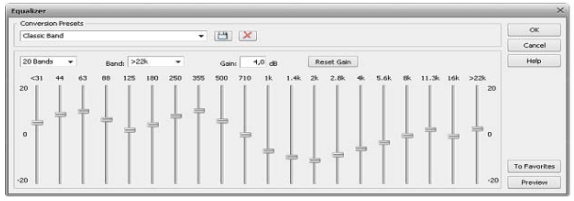
CLT post-equalizer cleans up residual

Pre-Equalized Frequency Response

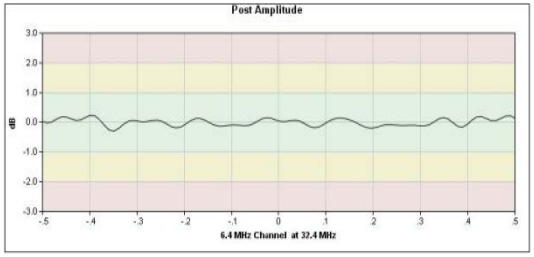


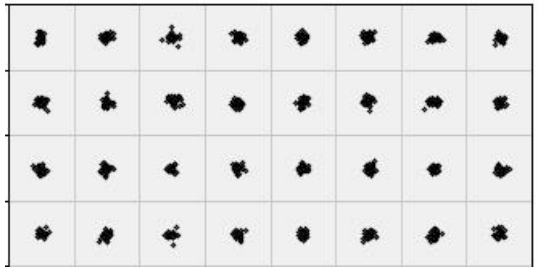


Equalizer



Post-Equalized Frequency Response





Source: Comcast (Larry Wolcott)

PLANT FAULT LOCALIZATION USING PRE-EQUALIZER TAPS

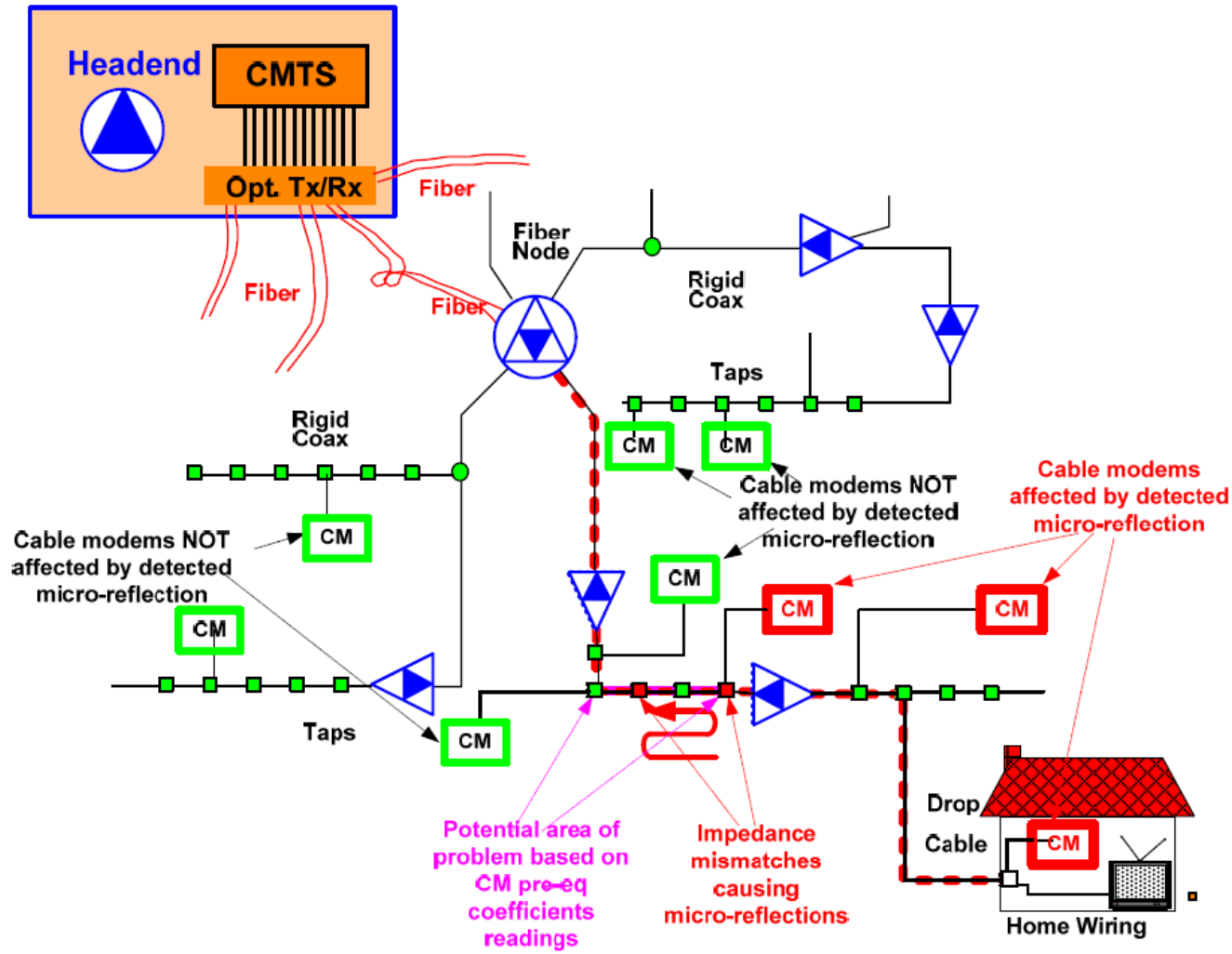


Figure 22 - Correlation of Topology with Distortion to Provide Fault Localization

Source: PNM Best Practices Document

MAINTENANCE RESPONSE VS. ECHO LEVEL

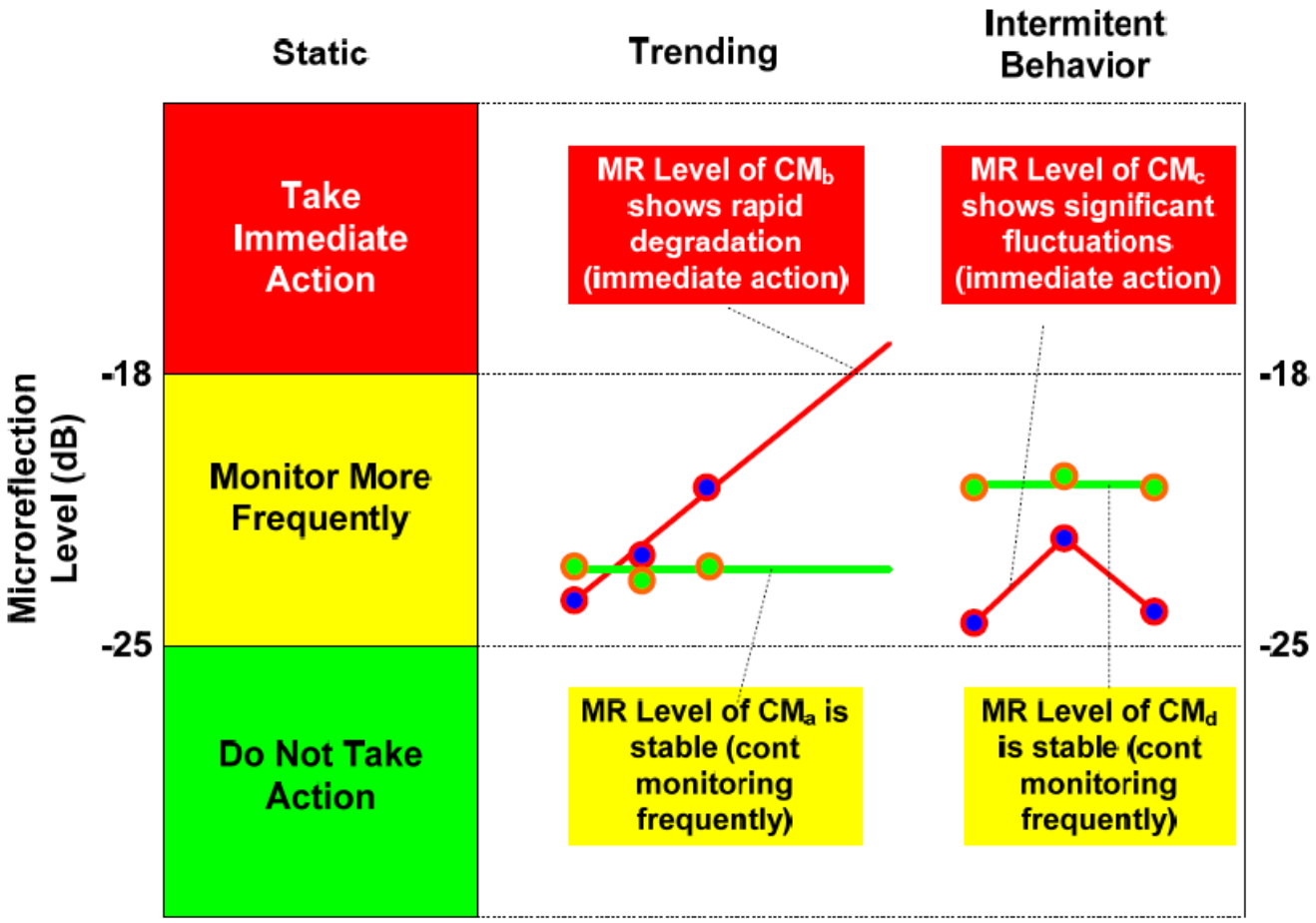


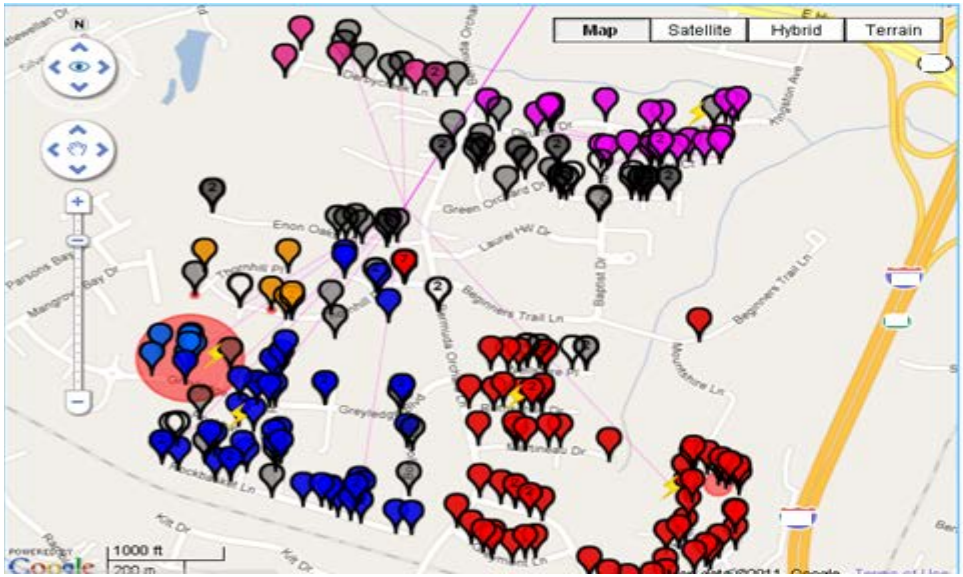
Figure 28 - Severity Classification Mechanisms

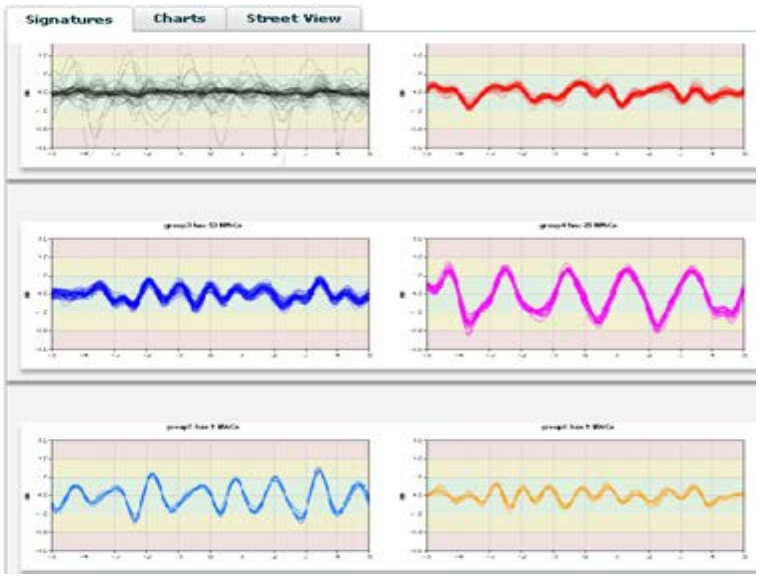
MR = micro-reflection

Source: PNM Best Practices Document

SIGNATURES AND GROUPING

- **Use signature clustering to locate common plant faults**

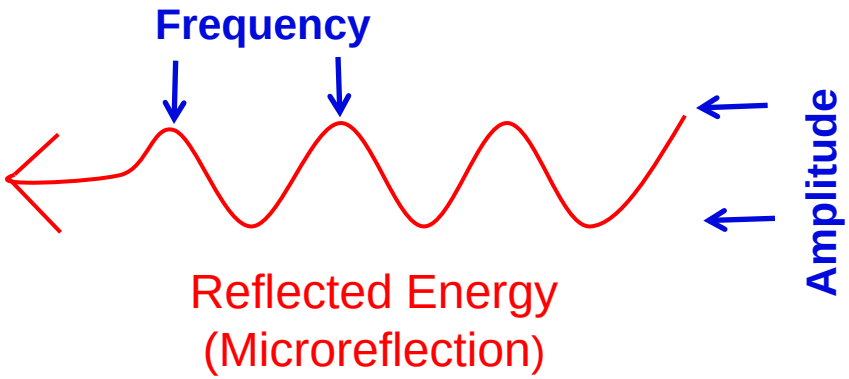


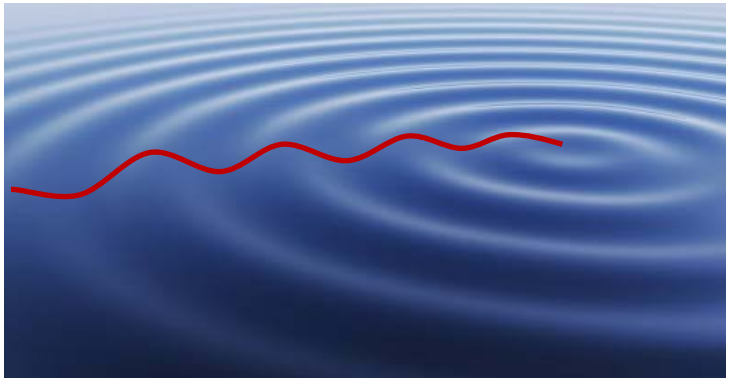


Source: Comcast (Larry Wolcott)

CALCULATING DISTANCE TO FAULT

- **Equalizer response provides precise echo measurements so distances can be calculated**
- **Time-Domain Reflectometer (TDR) functionality**

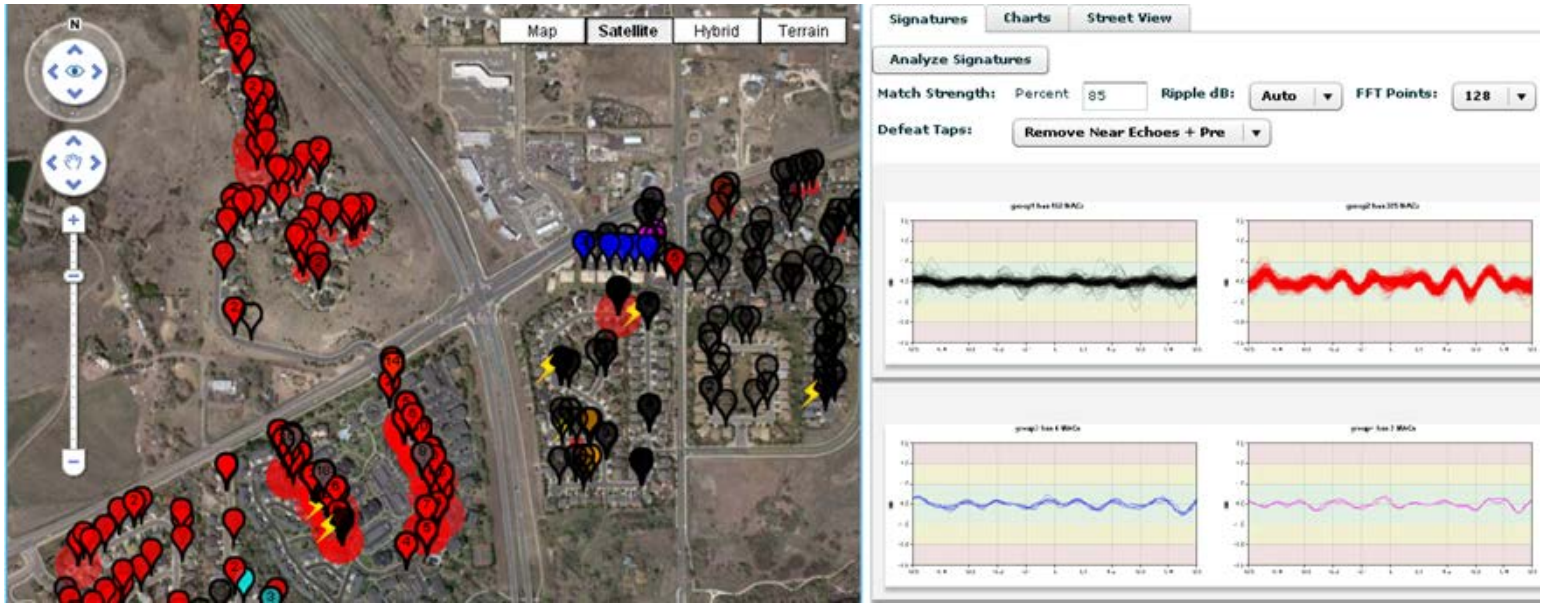




Source: Comcast (Larry Wolcott)

TDR FAULT LOCATION EXAMPLE

- **Cable fault is one of the reflectors in a “cavity” consisting of at least 2 reflectors**
- **Measure TDR distance from one end of cavity: line amplifier, etc.**



Source: Comcast (Larry Wolcott)

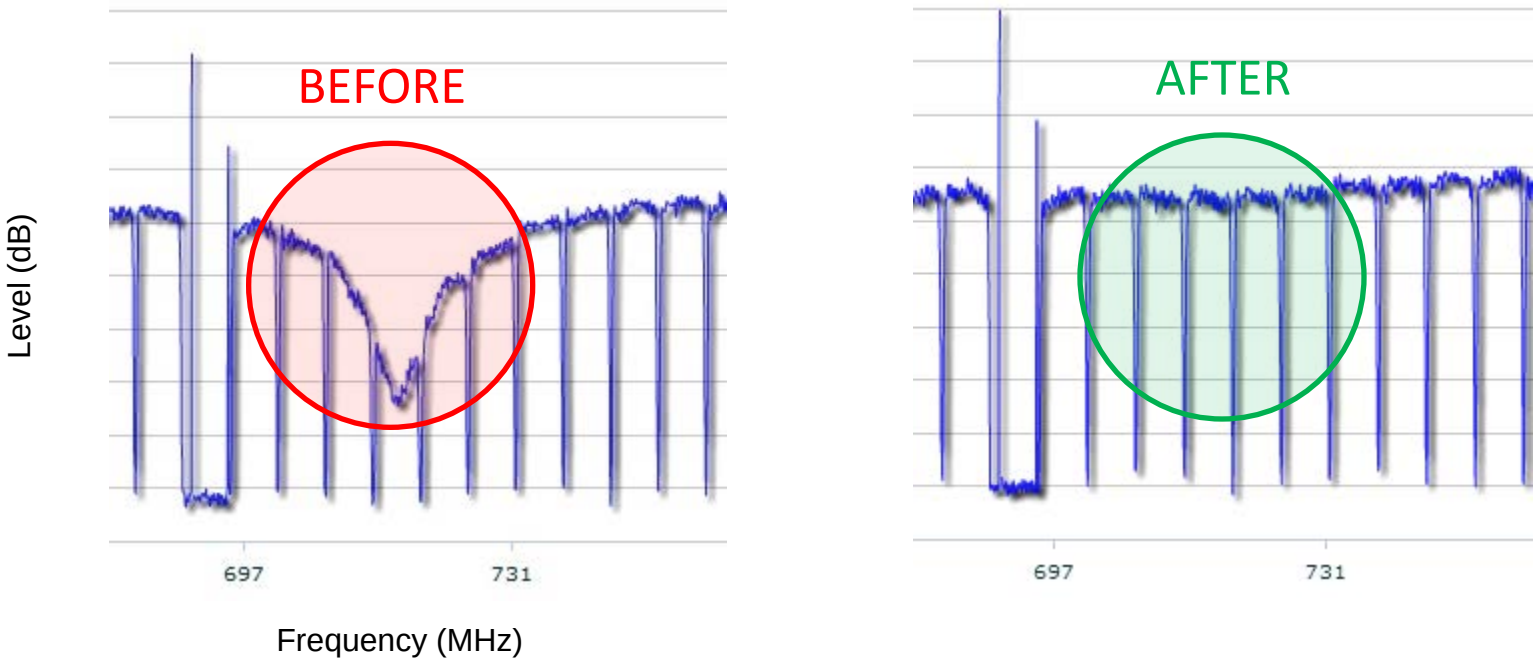
FIXING BROKEN BURIED CABLE

BEFORE

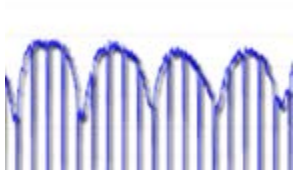
AFTER

Source: Comcast (Larry Wolcott)

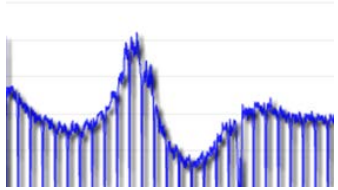
SPECTRUM BEFORE AND AFTER CABLE REPAIR



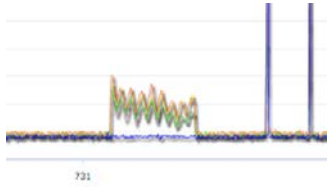
FAULTS DETECTABLE WITH FULL-BAND SPECTRUM ANALYZER IN EVERY CPE (CNU)



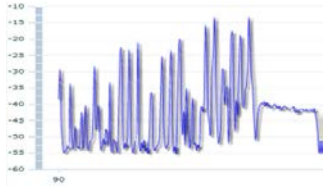
Reflections



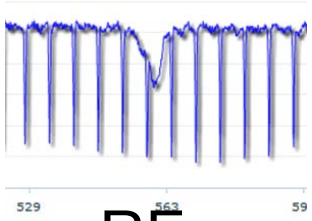
Resonant Peaking



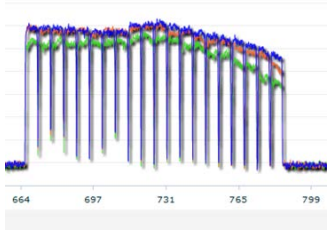
4G LTE Ingress



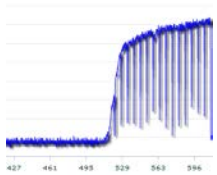
FM Radio Ingress



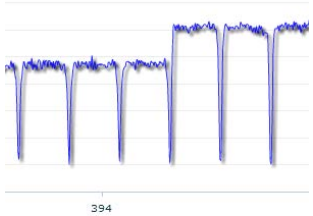
RF Notches



Roll-off



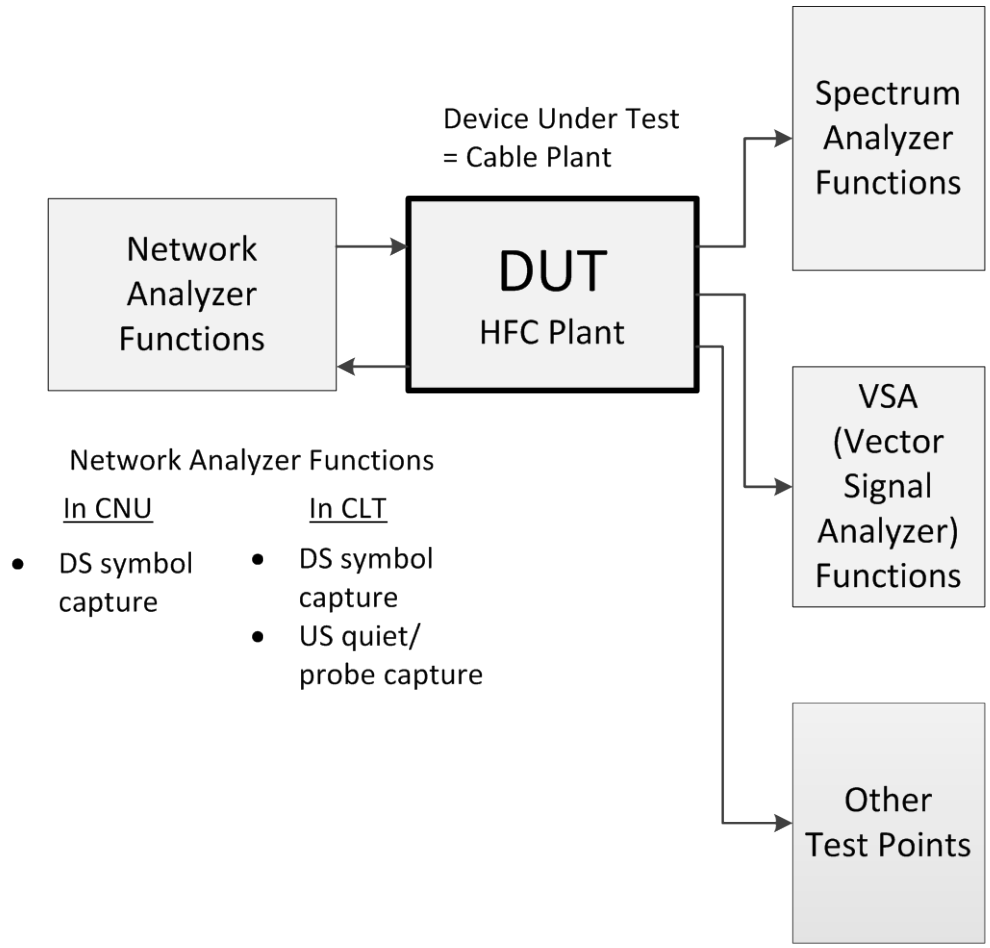
Filters



Adjacency

Source: Comcast (Larry Wolcott)

DESCRIPTION OF PROPOSED PNM TEST POINTS



Spectrum Analyzer Functions

In CNU
- Full-band spectrum
- NPR notch

In CLT
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VSA Functions

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In CLT
- US equalizer coefficients

Other Test Points

In CNU
- FEC statistics
- Histogram

In CLT
- Impulse noise statistics
- FEC statistics
- Histogram

PNM DOWNSTREAM TEST POINTS

- **Symbol Capture: Capture wideband OFDM symbol at input and output of cable plant, solve for plant response**
  - Requires Trigger Message to synchronize capture at CLT and CNU, using PHY Link Channel (PLC) as a timing reference
  - Alternatively, can define downstream probe and quiet symbol analogous to upstream
- **CPE Spectrum Analyzer: Power spectrum of full downstream band**
- **Noise Power Ratio (NPR) Measurement: Examine spectrum of notch to see intermods and ingress**
- **Channel Estimate: Linear response of channel at CNU receiver**
- **Constellation Display: Shows impairments to QAM constellation**
- **Receive Modulation Error Ratio (RxMER) Per Subcarrier: Profile of SNR at receiver slicer vs frequency**
- **FEC Statistics: Codeword error ratio for each profile in use by CNU; CRC-40 error statistics**
- **Histogram: Shows nonlinear channel effects**

PNM UPSTREAM TEST POINTS

- **Capture for Probe Symbol: Send wideband probe symbol through cable plant, solve for plant response**
- **Capture for Quiet Period : View underlying noise floor when no desired signal is being transmitted**
- **Triggered Upstream Spectrum Analyzer: Power spectrum of full upstream band**
- **Impulse Noise Statistics: Power and duration of impulse events exceeding programmable threshold**
- **Equalizer Coefficients: Pre- and post-equalizer, giving linear response of cable plant**
- **FEC Statistics: Codeword error ratio for selected user; CRC-40 error statistics**
- **Histogram: Shows nonlinear channel effects**

FEC STATISTICS PROVIDED

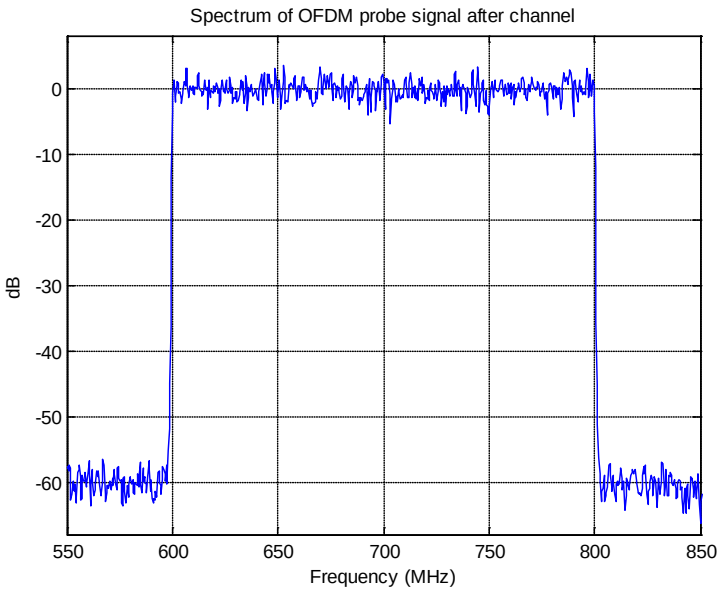
- **Uncorrectables: Number of codewords that failed CRC-40 checksum, and number of total codewords**
- **Codeword error ratio vs time (seconds): CER in 1-second intervals for rolling 10-minute period**
- **Codeword error ratio vs time (minutes): CER in 1-minute intervals for rolling 24-hour period**
- **Short-term statistics: Report results when M errors have occurred or N codewords have been processed, whichever comes first**
- **RED/YELLOW/GREEN summary CNU status: Colors to be defined based on thresholds**
- **Upstream statistics are per-user; downstream are per-profile**

RxMER MEASUREMENT

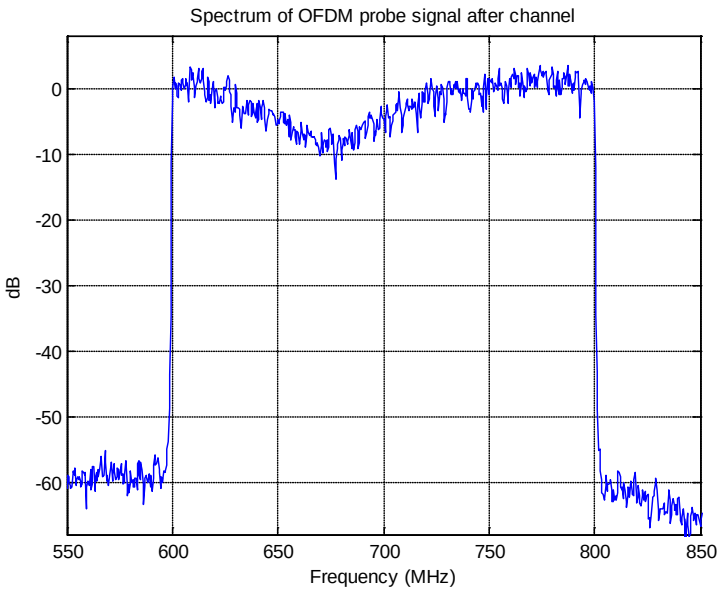
- **Receive modulation error ratio (RxMER) is a measure of the average size of the “noise ball” surrounding each QAM constellation point (cluster variance).**
  - It is reported in dB for each subcarrier frequency.
- **RxMER is measured using the scattered pilots, which visit all subcarriers.**
  - Pilots are not subject to symbol errors as data subcarriers would be.
  - This gives an accurate MER measurement over a wide dynamic range.
- **RxMER is defined as the ratio of the average power of the equalized QAM constellation to the average error-vector power.**
  - The error vector is the difference between the equalized received pilot value and the known correct pilot value.
- **The noise power of zero-valued subcarriers is also measured, and is expressed as an equivalent unequalized RxMER value.**

EXAMPLE: WIDEBAND PROBE/CAPTURE

Wideband probe at input to cable plant



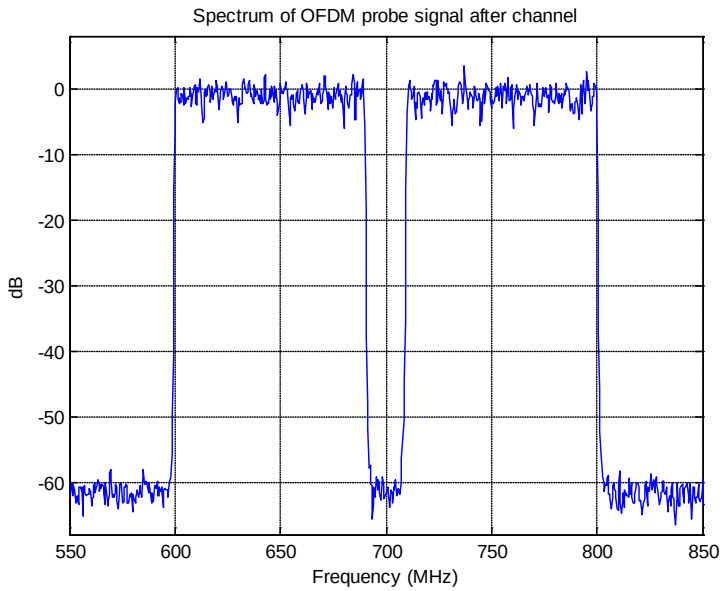
Wideband probe at output of cable plant



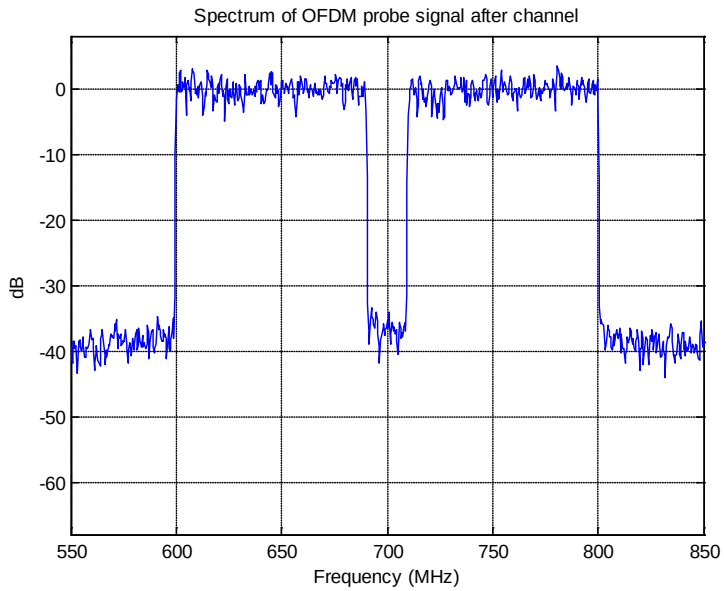
- With known input and output samples, channel can be characterized including linear and nonlinear effects (compression, laser clipping, intermods(CSO, CTB), common path distortion, ingress, group delay, plant leakage, …)
- Probe may be special probe symbol (upstream) or captured normal OFDM data symbol (downstream)

EXAMPLE: NOISE POWER RATIO (NPR)

NPR probe through clean plant

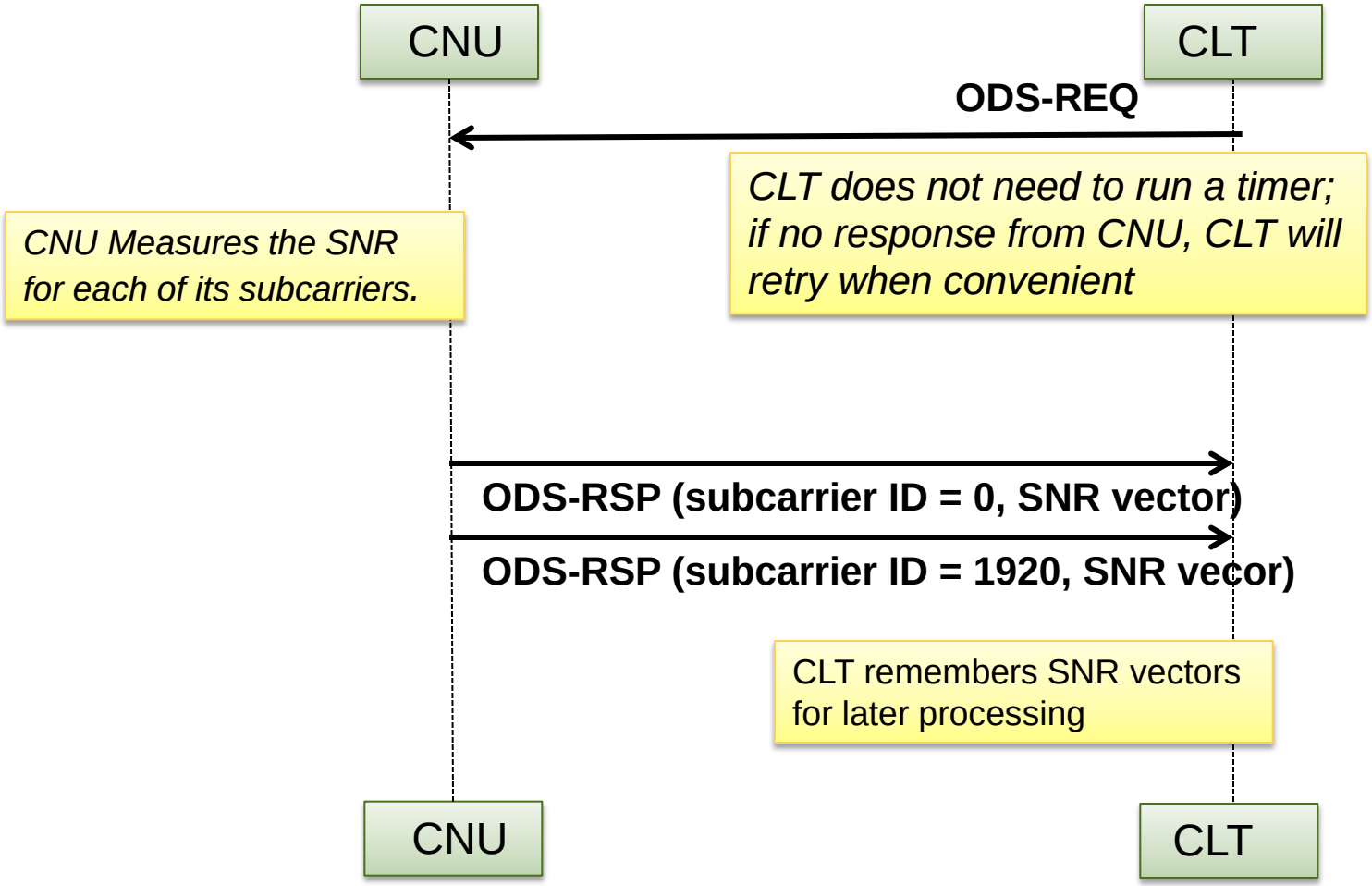


NPR probe after 3rd order nonlinearity



- **Notch fills in with intermod products**

POSSIBLE OFDM DS SPECTRUM REPORTING TRANSACTION



Source: Hesham ElBakoury

PNM OVERVIEW SUMMARY

- **Cable operators require visibility into plant and equipment performance**
  - PNM has been adopted as the approach
- **Provide characterization of cable plant response, linear and nonlinear distortions, and analysis of noise/interference**
- **Support remote proactive troubleshooting of HFC plant**
- **Goal is improved reliability, throughput and user experience**
- **Recommendation:**
  - Need to design-in test points in CLT and CNU that support PNM needs

IMPACT ON P802.3BN EPOC

- **To support PNM, P802.3bn EPoC would need to provide the following:**
  - RxMER measurement support in the CNU
    - Per sub-carrier, ratio of the average power of the equalized QAM constellation to the average error-vector power. For pilots, the error vector is the difference between the equalized received pilot value and the known correct pilot value.
    - Straightforward, specifics are T.B.D.
  - Performance monitoring, counters, measurements in CLT and CNU Rx
    - Upstream and Downstream FEC performance and other counters
    - Overview on next pages.
- **Additional consideration**
  - Add “Trigger” message in the downstream PLC and measurement support in CNU
- **Outside of the P802.3bn Specification**
  - OAM/eOAM messages for managing/gathering PNM statistics
  - Suggestion: CableLabs address this activity

IMPACT ON CNU RX - DOWNSTREAM

Overview – Specifics are T.B.D.:

- **The CNU would need to be capable of providing the following downstream performance metrics:**
  - Uncorrectable codewords: Number of data codewords that fail CRC-40 check
  - Correctable codewords: Number of data codewords that failed pre-decoding LDPC syndrome check and passed CRC-40 check
  - Unreliable PLC Codewords: Number of PLC codewords that failed LDPC post-decoding syndrome check
  - Total number of data FEC codewords
  - Total number of PLC codewords
  - Total number of MAC packets
  - Start and stop time of analysis period.
- **The CNU would need to be capable of providing the following downstream FEC summaries on each OFDM channel being received by the CNU:**
  - Codeword error ratio versus time (seconds): Ratio of number of uncorrectable codewords to total number of codewords in each one-second interval for a rolling 10-minute period (600 values).
  - Codeword error ratio versus. time (minutes): Ratio of number of uncorrectable codewords to total number of codewords in each one-minute interval for a rolling 24-hour period (1440 values).
  - Ending time of rolling period.

IMPACT ON CLT RX - UPSTREAM

Overview – Specifics are T.B.D.:

- **The CLT will need to be capable of providing the following FEC statistics for any single upstream user:**
  - Error-Free Codewords: Number of codewords that passed CRC-40 check
  - Uncorrectable Codewords: Number of codewords that failed CRC-40 check
  - Corrected Codewords: Number of codewords that failed pre-decoding syndrome check, but passed CRC-40 check
  - Total number of FEC codewords
  - Total number of MAC packets
  - Start and stop time of analysis period
- **The CLT MUST be capable of providing the following FEC summaries over a period of up to 10 minutes for any single upstream user:**
  - Total number of seconds
  - Number of errored seconds (seconds during which at least one unreliable codeword occurred)
  - Count of codeword errors (uncorrectable codewords) in each 1-second interval
  - Start and stop time of summary

IMPACT ON PLC - DOWNSTREAM

Overview – Specifics and adoption are T.B.D.:

- **Add a trigger message to the downstream PLC**
  - For synchronizing a measurement event between the CLT and group of CNUs
  - Perform a capture at a specific time aligned with the PLC frame
    - OFDM symbol time-domain data points equal to the FFT length in use
- **Can likely adapt D3.1 PLC Trigger for use in P802.3bn EPoC**

CONCLUSIONS FOR IMPACT ON P802.3BN

- **PNM is a requirement in the cable industry**
- **P802.3bn EPoC will need to participate in PNM**
- **Further proposal work should include**
  - Support for required downstream and upstream Rx measurements
  - Evaluation and consideration for use of the PLC trigger facility

SOME REFERENCES

- **Scout Flux / Spectra: Empowering Operations With Equalization and CPE Spectrum Analysis, Presentation by Comcast – Larry Wolcott, and Broadcom – Bruce Currivan (excerpts in this package)**
- **CableLabs DOCSIS Best Practices and Guidelines (excerpts used in this package)**
  - http://www.cablelabs.com/specifications/CM-GL-PNMP-V02-110623.pdf

Thank You