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
- Support remote proactive troubleshooting of plant faults
- Goal is improved reliability and maximum throughput from well-maintained plant
EPOC SYSTEM DIAGRAM

Hub / CO Facility

Outside Plant

Signal through passive coax, includes taps, splitters

Business or Home Network

Source: EPoC Architecture Specification
Each test point will be described at end of slide deck
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** = Intelligent Generation-Next Operational Systems
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
- 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
CNU pre-equalizer does most of correction

CLT post-equalizer cleans up residual

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

Source: PNM Best Practices Document

MR = micro-reflection
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

Before:

- Frequency (MHz)
- Level (dB)

After:

- Frequency (MHz)
- Level (dB)
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

Network Analyzer Functions
- DS symbol capture
- US quiet/probe capture

DUT
HFC Plant

Device Under Test = Cable Plant

Spectrum Analyzer Functions
- Full-band spectrum
- NPR notch

VSA Functions
- US pre-equalizer and DS equalizer coefficients
- Constellation display
- RxMER vs subcarrier

Other Test Points
- FEC statistics
- Histogram

Spectrum Analyzer
Functions

VSA
(Vector Signal Analyzer) Functions

Other Test Points

In CNU
- Triggered spectrum

In CLT
- US equalizer coefficients

In CNU
- Full-band spectrum
- NPR notch

In CLT
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In CLT
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**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

- 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)

- Notch fills in with intermod products
POSSIBLE OFDM DS SPECTRUM REPORTING TRANSACTION

CNU Measures the SNR for each of its subcarriers.

CLT does not need to run a timer; if no response from CNU, CLT will retry when convenient.

ODS-REQ

ODS-RSP (subcarrier ID = 0, SNR vector)

ODS-RSP (subcarrier ID = 1920, SNR vector)

CLT remembers SNR vectors for later processing.

Source: Hesham ElBakoury
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
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
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.
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
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)
Thank You