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Application Note

Adding Analog Noises to the DOCSIS 3.0 Cable Network

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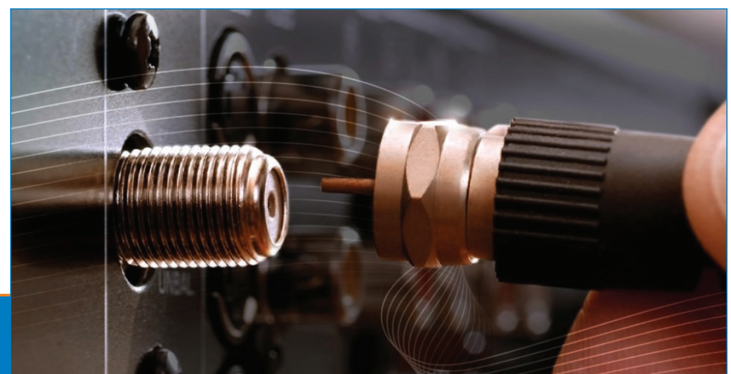

Abstract

Injecting Additive White Gaussian Noise (Gaussian Noise) of varying power from Noisecom noise generators into the cable network is an effective way to assess the extent of cable network's ability to cope with Gaussian Noise interferences of varying intensity. In this application note, we highlight area where Gaussian Noise should be added to examine its impact and uses some of the signal quality metrics to assess the health of the DOCSIS network.

DOCSIS 3.0 network

Demands for more efficient bandwidth utilization and expanding channel capacity bring about higher order of QAM transmission on the cable network which takes either the form of all-coaxial or Hybrid Fibre/Coaxial (HFC) cable network.

The benefits of adopting DOCSIS 3.0 standard are higher data rates; additional subscriber capability, better bandwidth utilization, high-quality IP video and the ability to carry IPv6 addresses. Added capacity through channel bonding enables expansion of high quality video, voice and business data services. For example, a cable network with 256 QAM transmission will carry 2 HDTV channels rather than just 1 with 64 QAM in a 6 MHz (North America) or 8 MHz (Europe) channel spacing and still be able to add on more high-speed data cable services such as video-on-demand, internet access and additional digitized cable channels onto existing cable network built for analog video services.

Figure 1 shows the elements in the provisioning of DOCSIS (Data-Over-Cable Services Interface Specifications) services.

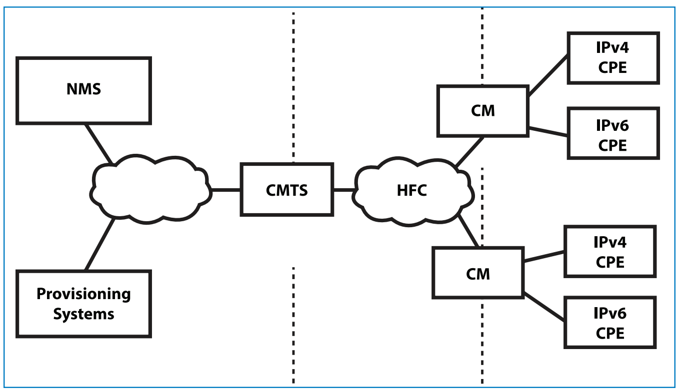

Figure 1: *DOCSIS network*

These elements allow transparent bi-directional transfer of Internet Protocol (IP) traffic between cable system head-end and customer locations, over an all-coaxial or HFC cable network as in Figure 2.

Cable Modem Termination System (CMTS) and Cable Modem (CM)

CMTS connects operator's back office and core network with the cable network, forwards packets between these two domains and between upstream and downstream channel over the cable network. At subscriber locations, CM is a modulator-demodulator device that provides complementary functionality to the CMTS to enable bi-directional data communication on the DOCSIS network.

CNR, SNR and RxMER

Injecting Gaussian Noise into the cable network in baseband domain which is prior to modulation for broadcast (pre-modulation) can affect both the RF domain (post-modulation) and baseband domain (post-detection) of the cable network between cable system head-end and customer locations. In the baseband domain, the signal quality metric provided by CMTS and CM that is used to assess the impact of added Gaussian Noise on the health of the DOCSIS network is Signal to Noise Ratio (SNR) while in the RF domain, the signal quality metric provided by CMTS is Carrier to Noise Ratio.

While cable operators continue to implement the DOCSIS 3.0 standard, they are also obliged at this moment to provide a mixed of analog and digital contents in their network, though the number of analog contents is expected to reduce gradually.

For analog content on analog carrier, the signal quality metric is termed as Analog baseband SNR while for digital content on analog carrier the signal quality metric is as Digital baseband SNR.

Analog baseband SNR refers to baseband video or audio signal either prior to modulation for broadcast (pre-modulation) or after demodulation of the RF waveform at the receiver (post-detection). It has been defined as the ratio of peak to peak analog video signal not including the sync, to the noise within the same bandwidth of video signal. Contributing sources to this noise include noise from studio cameras, transmitter or modulator, transport path, receiver and demodulator. These noise are measured in a bandwidth roughly the same as bandwidth of baseband video signal.

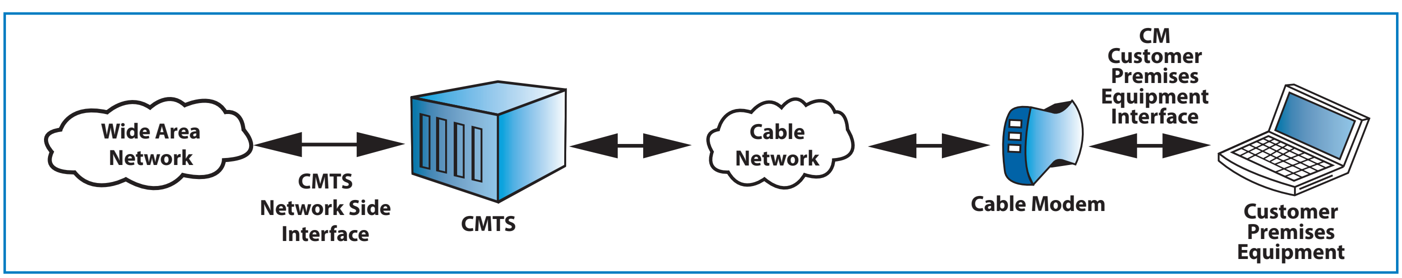

Figure 2: *Transparent IP traffic through the Data-Over-Cable System*

Analog baseband SNR is ideal for characterizing the overall picture quality seen by the end user. This parameter provided by the burst receiver in the CMTS, after the carrier has been demodulated to give a pure baseband, is termed Upstream SNR estimate while that provided by receiver in a CM or Set-top box (STB) is termed downstream SNR estimate.

For Digital baseband SNR which is applicable to digital content on analog carrier, we need to measure the QAM signal after demodulation up to its received constellation symbols. Hence, this parameter is more accurately termed as receive modulation error ratio (RxMER) which is defined as the ratio of the average constellation symbol power to average constellation error power, in dB. For digital channels, the RxMER reported by QAM receiver in CMTS after data is demodulated is termed Upstream RxMER while that reported by QAM receiver in CM or STB after data is demodulated is termed Downstream RxMER.

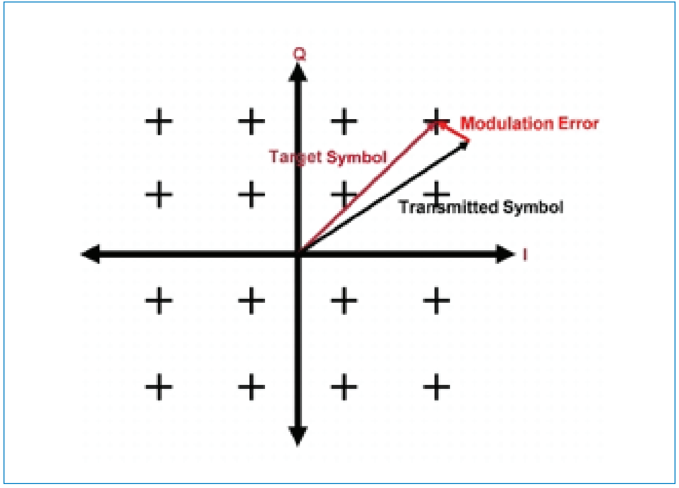

Figure 3: *Modulation error is a measure of quality of the communication link.*

RxMER

RxMER is a digital computation performed on digital elements in the receiver and a composite index of all QAM signal impairments as these demodulated symbols ultimately will either produce correct bits or bit errors at the receiver output after being processed by the Reed-Solomon FEC decoder. It is a direct measurement of digital signals modulation quality and hence a figure of merit for the quality of an RF QAM modulated signal. Any received demodulated symbols measured before the FEC decoder, is called un-equalized RxMER, while those after being compensated by the FEC decoder for in-channel response effects is called equalized RxMER. CM reports only equalized downstream RxMER whereas CMTS can either report equalized or un-equalized upstream RxMER.

In an ideal condition where there is zero noise and zero ISI condition, error or noise vector at each symbol time is zero as all the symbols of the QAM digitally modulated signal continue to land exactly at the target point on the constellation diagram. As we mentioned earlier, in order to understand the system's immunity to noise we inject Gaussian Noise of increasing power into the RF path either after the QAM modulator or before QAM demodulator, to cause most of the symbol landing points to spread out from the target landing point of each symbol as in Fig 3 and observe that both RxMER value and FEC errors are getting worse from its original nominal value.

It is possible to effect varying degree of severity by injecting different band of analog noise, from targeting at specific downstream channel to whole of downstream spectrum when measuring downstream RxMER or at specific channel to whole of upstream spectrum for upstream RxMER.

These RxMER and FEC values are a good indication of the system immunity to increasing amount of Gaussian Noise and through data mining, stakeholders are able to gather the pattern and knowledge of deterioration and trending the pace of system deterioration that may ultimately serve as the driving factor behind the scheduling of corrective maintenance to reduce unexpected failures.

In situation when more Gaussian Noise is permitted to be added without affecting viewers, further increase of Gaussian Noise will degrade the RxMER and FEC values and cause disruption to the transmission unless the system responds by switching to a lower order of modulation appropriate for sustaining existing transmission with a lower data rate. At this new order of modulation, both RxMER and FEC values are expected to improve.

We also recommend adding Gaussian Noise to demodulator chipsets that incorporate noise cancelling algorithms in the demodulation of QAM signal. It is intended to assess the algorithms effectiveness in cancelling out the added Gaussian Noise.

Forward Error Correction (FEC)

RxMER has a direct relationship with the Bit Error Rate (BER) for a given order of modulation. BER has been the most used indicator to determine the quality of a cable network. Cable network which takes the form of either coaxial or Hybrid Fibre/Coaxial (HFC) is regarded as a bandwidth-limited linear path with various attenuation sources including white noise, interference and multi-path distortion.

Various imperfections starting from where the transmission signal originates is likely to cause signal degradation. Similarly, effects of cable network's downstream or upstream noise floor, in-channel frequency response (amplitude tilt and ripple, group delay variation and micro-reflections), phase noise of oscillator, receiver imperfections and upstream data collisions are all capable of affecting the modulation error of receive symbol constellation and causing its receiver to rebuild wrong amplitudes.

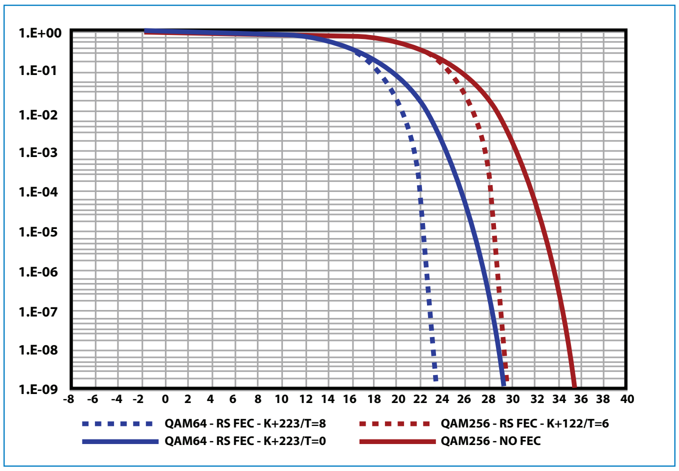

Figure 4: *BER vs SNR for downstream modulations*

Adaptive Equalization technique such as Reed-Solomon Forward Error Correction encoding (RS-FEC) is implemented in the CMTS and CM to mitigate the effects of a) micro-reflections causing amplitude tilt and ripple, group delay and frequency response problems, b) narrow-band ingress c) frequency response imperfections and d) group delay; by correcting the variation in phase and amplitude, albeit only small and within its limit.

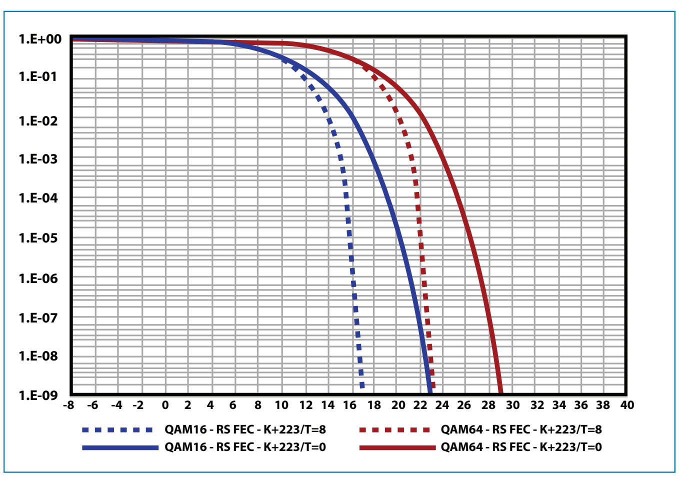

Figure 5: *BER vs SNR for upstream modulations*

Essentially, FEC encoding protects IP data and DOCSIS management messages against symbol errors caused by noise and other impairments by detecting symbol errors and then correcting them in order to reliably transport IP data traffic and to ensure data integrity and highest level of data throughput over the cable network. As such, FEC error is a measure of transmission quality and the best way of knowing how FEC improves the bit error rates is to examine the waterfall curve plot in Fig 4 and Fig 5.

As recommended, the minimum acceptable RxMER for error-free operation of a specific order of modulation is where the waterfall curve intersects the 1.E-08 BER line. A close look at the red family of curves in Figure 4 shows the relationship of BER and SNR for 256QAM modulation. At BER of 1.E-08, the red solid line show SNR of 35dB while the red dashed line show SNR of 29dB, demonstrating a 6dB gain from RS-FEC encoding.

In Figure 5, both red and blue solid lines show the relationship of-BER and SNR between 16QAM and 64QAM modulation. For a SNR of 22.5dB, the red solid line indicates BER of 1.E-02 for 64QAM modulation while the blue solid line indicated BER of 1.E-08 which is a better BER for the same SNR and FEC encoding using lower order of modulation.

Without FEC encoding; amplifier compression, intermittent connections, poor port isolation in combiner or splitter and noise such as impulse, ingress, thermal, and laser clipping would cause one or few packets to drop because of bit errors.

In the presence of many burst errors created in succession by impulse noise, FEC is unlikely to work well. These impulse noise induced errors can be addressed using interleaving which make burst errors to appear spread out before allowing FEC encoding to correct the errors. Interleaving is implemented on both the downstream and upstream to address this sort of impairment since the upstream, also known as return path, is also vulnerable to noise and related impairments.

There is a limit to the effectiveness of FEC encoding to correct errors in data transmission over unreliable communication paths. To establish this limit we inject Gaussian Noise at the inputs of QAM modulator and observe that both Interleaving and Equalization techniques continue to correct for symbol errors and maintain the BER value as noise power is increased gradually. At a particular noise power, errors that cannot be corrected will result in bit errors and a poor Modulation Error Ratio (MER).

CNR

CNR is another way to express the quality of a RF transmitted signal. It is a pre-detection measurement made on the RF signal in the RF distribution path and before the demodulator for characterizing the impairment of RF cable network or standalone device like an up-converter, using a spectrum analyzer.

For an analog TV channel in the cable network, CNR is defined as the ratio of the amplitude of a channel visual carrier to the amplitude of system noise in a specified noise power bandwidth which is the bandwidth of baseband video (4 MHz for NTSC & PAL) that modulates the channel visual carrier.
For a digital TV channel, CNR is the ratio of an average power level of the digitally modulated signal, also called digital channel power as measured in full occupied bandwidth of the digital modulated signal to the amplitude of system noise power in a specified noise power bandwidth which is the equal to the symbol or modulation rate used.

At a given CMTS upstream port, CNR for all CM is expected to be similar since CMTS manages the upstream transmit level of all CM to be within 1 dB amplitude difference among modems.

Noise amplitude at the CMTS upstream input port is expected to be the same for all modems sharing the return spectrum of that particular port. Typically, the upstream carrier power at the CMTS input port is nominally expected to be 0dBmV (1millivolt RMS into 75ohms = -48.75dBm). When there is noise in the RF plant that CMTS has to overcome, CMTS will get the CM to increase its upstream transmit power level so as to maintain the CNR at the desired value. One of the ways to verify these interactions between CMTS and CM can be by injecting Gaussian Noise at the RF plant and observing that the CNR value remains the same despite increasing power level of Gaussian Noise. At one point when CNR value starts to reduce, it would be when the CM upstream transmit power level has reached its maximum limit level.

CNR value required to maintain the same BER value depends on the modulation format. More complex modulation formats require higher CNR to maintain the same BER value as illustrated in Fig 6 since more complex modulation format has higher symbol rate which is more susceptible to RF noise and interferences, resulting in packet loss or disruption to cable modem connectivity.

The typical average power of a digital channel at the input of CM is around 5dBmV thought it can range between -15 to +15dBmV. Nevertheless the total input power should be less than 40dBmV. By adding Gaussian Noise that equals the downstream spectrum (108 to 1002 MHz and 258 to 1218 MHz for initial DOCSIS 3.1) and of increasing power, we should expect the signal level at output of CMTS to increase so as to maintain the desired downstream CNR; otherwise bits errors and packet loss will worsen visibly and further increase of noise power would cause unreliable cable modem operation.

While cable network has sufficient headroom for Guassian Noise, its margin for it gets thinner as physical conditions of the cable network such as RF connection, cable insulation material, isolation between ports of each combiner and splitter etc start to deteriorate. A good practice that helps to track any trend of network deterioration is to keep records of the amount of Gaussian Noise used for each test cycle and compare it with past test cycles. By extrapolating these historic data, it is possible to trend the network condition for the next test cycle or next few test cycles so long as the future situation is consistent with past. Many a time the extrapolated result is used to initiate a corrective action and prevent an unexpected failure.

Result from past test cycles has greater relevance during the process of recovering the system back to operation after an outrage. It serves to guide the recovery process and as a benchmark on how well it has been managed and also provides a sense of whether any additional effort is needed before system can be fully operational.

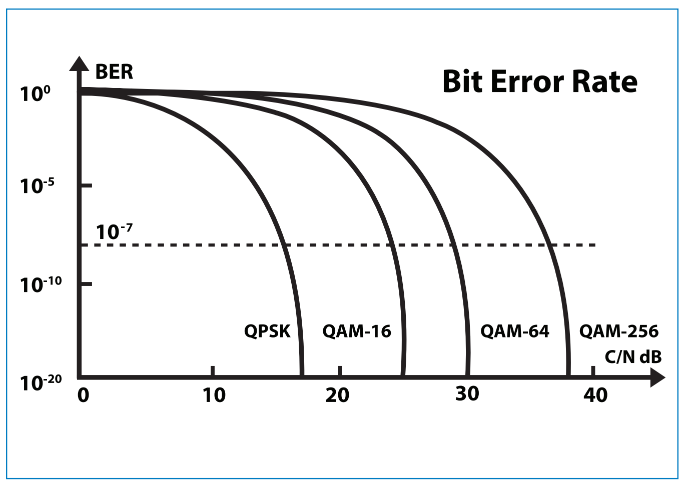

Fig 6: *Higher CNR to maintain same BER*

Conclusion

DOCSIS 3.0 and later versions allow high definition video, superb quality audio and higher speed data services to converge in the broadband cable network. To ensure existing network performance meets the agreed service Level, cable operators need to develop and implement test methodologies that establish the system's margin for noise impairment.

Injecting Additive White Gaussian Noise to either the baseband or RF path or both is an effective way to assess cable network immunity to noise interferences. The varying level of noise interferences as well as different frequency ranges emulates real-world signal degradation in a multi-channel environment which the DOCSIS network has to overcome. RxMER, BER, CNR and FEC are signal quality metrics we used to assess DOCSIS network reactions to every increment of noise impairment.

Gaussian Noise as wide as the upstream spectrum (5 to 85Mhz, and to 204Mhz for initial DOCSIS 3.1) and the downstream spectrum (108 to 1002Mhz and 258 to 1218Mhz for initial DOCSIS 3.1) rather than at specific channel bandwidth, is better able to subject the cable system to real world noise interferences across a broader spectrum with multi-channel operation. It effectively gauge how broad the upstream and downstream spectrum is truly usable since cable network responds to multi-channel interferences is different to specific channel interferences due to frequency limiting effects and un-uniform propagation delay across the frequency spectrum of the cable network. The narrower the upstream or downstream spectrum is usable for higher order modulation the lower is the data capacity and throughputs, and ultimately a cable network with low spectral efficiency.

Every reaction of DOCSIS network to each increment of noise impairment is indicative of the health of the cable network. It should serve the organization well during the process of recovering the system back to operation after an outrage or to initiate a corrective action and prevent an unexpected failure.

References

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