PNM CPR

INVENTOR:

JASON W. RUPE

Description

By creating measures of the amount of risk taken by cyclic prefix (CP) settings and rolloff (R) period settings, comparing to estimates of the amount of bandwidth taken or liberated by the settings of these CP&R settings, one can set policy, optimize, and implement procedures to adjust these settings in real time, triggered by events, or periodically as needed, to optimize risk and manage capacity of available bandwidth. Note this is separate from but can be implemented in concert with other resiliency capacity mechanisms including profiles in DOCSIS.

This enables dynamic cyclic prefix and dynamic rolloff period settings, thought dynamic cyclic prefix may carry more utility.

Cyclic prefix and rolloff period settings are defined in DOCSIS to be finite, but could be more granular if defined so, or may be in other specifications. But in any case, as they relate to digital communications, there are finite number of settings. Therefore exhaustive search is possible for any digital communication specification but is reasonable for DOCSIS.

One can manage these in a few ways. Some direct methods include (with method flows described but not fully constructed yet):

> 1) setting CP to max with RP at max for the most resiliency, and monitor capacity, then reduce CP and RP as needed to manage risk as capacity becomes constrained, noting that capacity demand can be bursty whereas CP and RP settings address issues that should be more static. When capacity is grown by taking CP and RP too far based on risk models, or policy for CP and RP settings, address with action that may include maintenance, node splits, adding frequencies to the band plan, and other solutions.
>
> 2) Running a procedure with CP and RP settings at high then backing them down to levels just higher than the existing impairments (reducing until impairments found then raising just above, which may require telemetry to determine which CP or RP is hitting a limit, then adjusting the limited one higher and reducing the other until it hits a limit then adjusting it higher to get the settings) would provide the initial settings for current impairments in the network, then monitor for the impairments and adjusting up as needed. This assumes that either other resiliency mechanisms (like PMA) will adjust to correct for bit errors, or the service will suffer until detected, identified, and then CP and RP adjusted to manage. This method requires monitoring the CP and RP limits, which are stochastically impacted by demand bustiness, so that further action can be triggered including but not limited to maintenance, node splits, frequency additions, and more.
>
> 3) Selecting CP and RP settings that are sufficient for a section of plant (all CM on an R-PHY node, etc.) and possibly typical for ease of implementation and

management, along with sufficient bandwidth as a starting position, then monitoring capacity, demand business (parametric, statistical, pdf, cdf)

PNM is a cable specific concept of fault management. This idea transforms PNM into a general fault management concept by creating the process for using traditional PNM (field impairment maintenance) and other proactive maintenance activities to address resiliency directly, specifically the resiliency mechanisms of CP and RP.

In any optimization approach, the monitored parameters are in pairs determining the capacity against demand (bandwidth, echo resiliency, channel interference resiliency and bit loading).

In some of the optimization approaches one or more of these limits are at the highest setting so does not need monitoring of the headroom but only the demand because any time the setting is insufficient, action is required.

In each case, for each monitored parameter, a risk model or probability of exhaust is useful for optimization.

When a capacity limit is exceeded, resiliency is challenged so that another resiliency mechanism must assist, or service is impacted (always the case with bandwidth).

If adjustments to the resiliency-capacity tradeoff cannot restore service, or risk of service impact is too great (based on a cost-benefit model, service level agreement, service policy, specification limit, or statistical process control limit for examples), then some sort of maintenance is required. In short term, PNM is likely the solution as RP can be extended if there is sufficient CP, and CP can be extended if there is sufficient bandwidth, which is most quickly and-or preferably addressed by removing any echo impairments if they exist,

or next by changing the bit loading on frequencies that overlap guard bands or adding bandwidth by adding channels or changing channel plans or adjusting the bandwidth usage [including FDX],

or last by engineering node splits or technology upgrades.

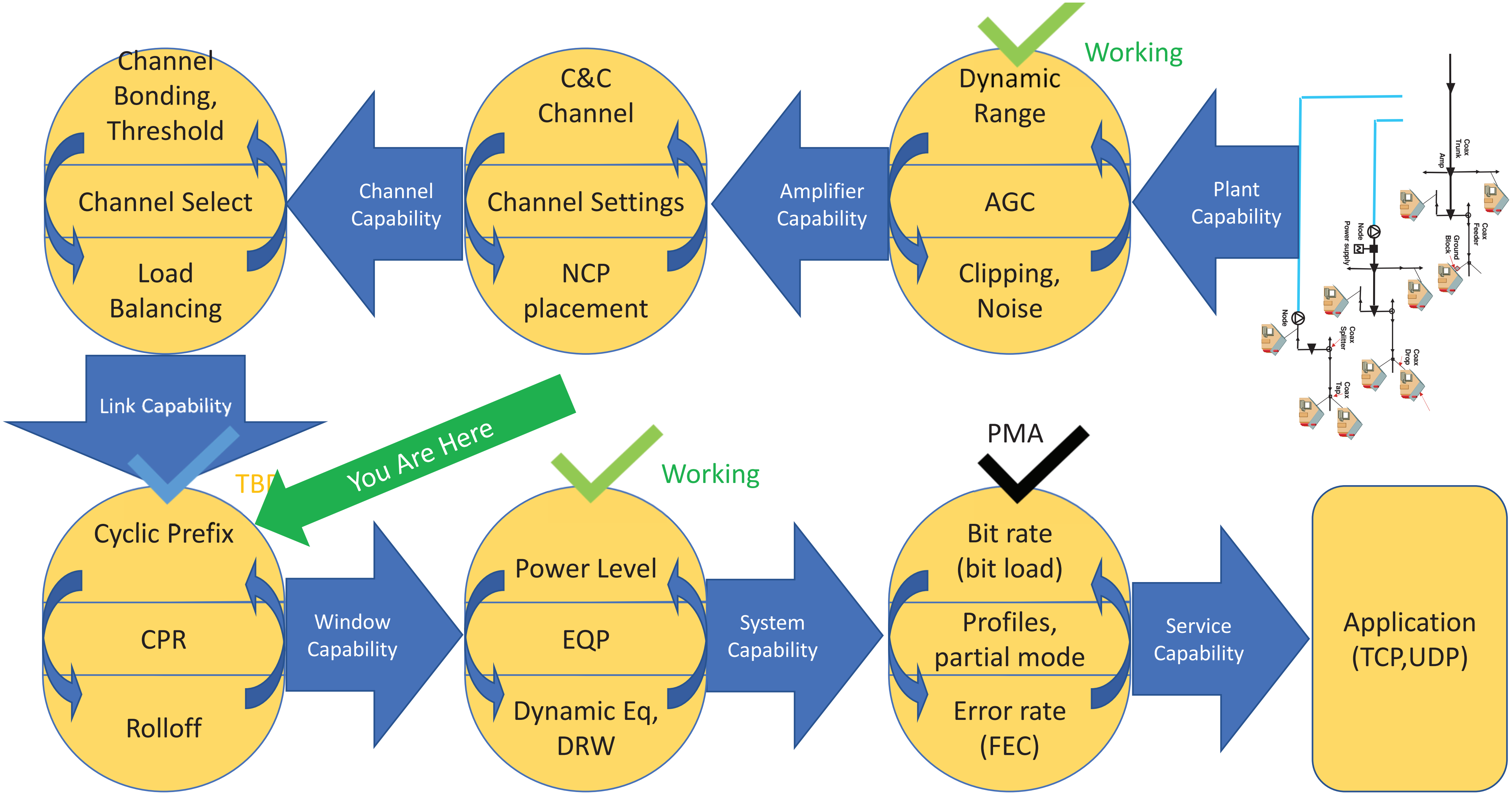
Note that the preference for these actions is up to the decision of the implementer operator.

Background

Many operators do not consider the tradeoffs involved in managing the CP and RP dynamics and their impact on capacity; many just use the default settings. Some operators are starting to question whether optimizing these settings may free up bandwidth for service such that it is worthwhile. Defining the problem and procedures for managing these parameters is important and timely.

Cyclic Prefix, Rolloff, and Impairments

What we can do with it, if we choose to…



Plant Capability
Working
Dynamic Range
AGC
Clipping, Noise
Amplifier Capability
C&C Channel
Channel Settings
NCP placement
Channel Capability
Channel Bonding, Threshold
Channel Select
Load Balancing
Link Capability
You Are Here
TBD
Cyclic Prefix
CPR
Rolloff
Window Capability
Working
Power Level
EQP
Dynamic Eq, DRW
System Capability
PMA
Bit rate (bit load)
Profiles, partial mode
Error rate (FEC)
Service Capability
Application (TCP,UDP)

CP-RP

- Table 55 from Phy, Table 7 from PNM

Table 1 - CMTS Proposed Configuration Parameters

FFT	Roll-Off Period Samples (N_{rp})	Taper Region (MHz)
4K	64	3.575
	128	1.875
	192	1.325
	256	0.975
8K	64	3.3375
	128	1.7125
	192	1.1625
	256	0.9875[1]

Table Note:

Note 1. The taper region of 0.9875 MHz is in accordance with the requirement for a minimum taper region of 1 MHz minus half subcarrier spacing. Achieving up to approximately 0.5 dB impact to the noise power in the adjacent spurious emissions integration region would allow a taper region of 0.8625 MHz, if the specification did not mandate the minimum taper region to be larger than this.

Table 7 - Upstream OFDMA Parameters

Parameter	2k Mode	4k Mode
Upstream Sampling Rate (f_{su})	102.4 MHz	
Upstream Elementary Period Rate (T_{su})	1/102.4 MHz	
Channel bandwidths	10 MHz, …, 95 MHz	6.4 MHz, …, 95 MHz
IDFT size (depending on channel bandwidth)	2048	4096
Subcarrier spacing	50 kHz	25 kHz
FFT duration (Useful symbol duration) (T_u)	20 µs	40 µs
Maximum number of active subcarriers in signal Values refer to 95 MHz of active subcarriers	1900	3800
Upstream Cyclic Prefix	0.9375 µs ($96 * T_{su}$) 1.25 µs ($128 * T_{su}$) 1.5625 µs ($160 * T_{su}$) 1.875 µs ($192 * T_{su}$) 2.1875 µs ($224 * T_{su}$) 2.5 µs ($256 * T_{su}$) 2.8125 µs ($288 * T_{su}$) 3.125 µs ($320 * T_{su}$) 3.75 µs ($384 * T_{su}$) 5.0 µs ($512 * T_{su}$) 6.25 µs ($640 * T_{su}$)	
Upstream window size	Tukey raised cosine window, embedded into cyclic prefix 0 µs ($0 * T_{su}$) 0.3125 µs ($32 * T_{su}$) 0.625 µs ($64 * T_{su}$) 0.9375 µs ($96 * T_{su}$) 1.25 µs ($128 * T_{su}$) 1.5625 µs ($160 * T_{su}$) 1.875 µs ($192 * T_{su}$) 2.1875 µs ($224 * T_{su}$)	

CP-RP

- CP and RP tables from Phy

Table 1 - Upstream Cyclic Prefix (CP) Values

Cyclic Prefix (µs)	Cyclic Prefix Samples (N_{cp})
0.9375	96
1.25	128
1.5625	160
1.875	192
2.1875	224
2.5	256
2.8125	288
3.125	320
3.75	384
5.0	512
6.25	640

Table 1 - Upstream Roll-Off Period (RP) Values

Roll-Off Period (µs)	Roll-Off Period Samples (N_{RP})
0	0
0.3125	32
0.625	64
0.9375	96
1.25	128
1.5625	160
1.875	192
2.1875	224

These tables 9 and 10 assume the sample rate of 102.4 Msamples/s.

Upstream calculations for Cyclic Prefix and Rolloff selection

- CP = Cyclic Prefix
- FFT = Fast Fourier Transform
- GB = Guard Band (size)
- RP = Rolloff Period
- TR = Taper Region

Process

1. Select your FFT size (2k-FFT, 4k-FFT) based on needs and abilities, or do the following calculations for both and use the results to help with the decision. Depending on your CMTS, you may only be able to do 2k (50 MHz spacing). Note this can be generalized to higher FFT sizes if ever available.
2. Set the RP based on channel interference needs, with the RP translating to the TR for the FFT size (using Table 55 or Table 7 to relate RP to TR); calculate the bandwidth used as BW_{ofdma} + (BW_{sc} + TR)*n where n is 1 or 2 depending on how many SC-QAM are neighboring the OFDMA channel (one side or both sides). **The TR provides (input to) the needed guard band size, with $\boldsymbol{GB \geq TR}$.** Testing will reveal cases where $GB > TR$ (if ever).
3. Set the CP to be sufficient for the RP plus the longest echo to be protected: $CP \geq RP + CP_{echo}$ where CP_{echo} is the amount of CP required to cover the needed echo. Note this equation can be applied in units of microseconds or samples using Tables 9 and 10 to translate. Using microseconds as the units helps with translating the echo that is to be covered in terms of the velocity of propagation as CP_{echo} = 2*D_{ft} / *(VF*C) with the answer in time units, with VF in appropriate units. Note VF*C is often expressed in feet per nanosecond in the equation, so for microseconds remember to take the result and divide by 1000 to get CP in microseconds for use in the table. For hardline cable, $\frac{1}{\mathrm{VF*C}} \cong 1.17\ nanoseconds\ per\ foot$. For example, for a CP = 2.5 microseconds, D_{ft} = 1068 ft.

Efficiency

- Calculate the efficiency of the selected CP and RP, or calculate the efficiency of all combinations to determine the CP you want to use. In terms of spectrum, the efficiency can be thought of as $(BW_{ofdma} + n*BW_{sc})/(BW_{ofdma} + (BW_{sc} + GB)*n)$. But considering the time domain, more resiliency from the TR traded off with RP, and more resiliency from CP, the optimization becomes more interesting. Each transmission then has a CP including the RP added to it, so efficiency in time is approximately $T_b/(T_b+CP)$ when T_b indicates the transmission time of the carried bits. Note that this efficiency measurement approximates the maximum utilization of the bandwidth.

- Multiply the time and frequency efficiency equations to get a comparable efficiency over which to compare configurations.

Resiliency Management

- For a given selected configuration then, the limits to manage include the upstream utilization of the available bandwidth and the echo that can be canceled.
- A tradeoff between bandwidth need and echo appearance could then be considered.
  - Probability of a bandwidth burst that exhausts the system
  - Probability of an echo appearing that would impact bandwidth
  - Wouldn’t the former be far more likely than the latter?

Optimization

- Because there are finite choices, one can calculate the results for all combinations and select the ideal one.

<u>CP</u>

- It is possible to then pick a CP that covers less than the full potential set of echo possibilities, trading that risk for additional bandwidth to lower utilization.
- It is also possible to pick a CP that covers existing echoes
  - (starting largest and reducing until a problem is found then setting one level higher to assure echoes canceled),
  - then triggering this process again each time the plant is changed or indicated with a new echo (suffering until corrected).

<u>RP (GB)</u>

- Likewise it is possible to select a RP (GB) that is smaller to reduce the bit loading in certain effected frequencies but provide more bandwidth for other channels.

Decision making

In the decision making, considerations include the demand for the bandwidth (in terms of proportion of time) and the probability of an echo appearing that is greater than the CP based on estimates of the echo possibilities in the network.

1. If the echo is fully covered easily without concerns of bandwidth, then the operator could set the CP for best reliability and then monitor bandwidth utilization through upstream grant traffic.
2. If the echo cannot be fully covered due to upstream traffic needs, then a model of the probability of an echo appearing that is larger than can be covered by the selected CP is needed for estimating the reliability of the service provided. The appearance of an echo that cannot be covered by the CP will impact service as a profile shift, or may even result in bit errors if profiles cannot cover the fault.

Optimization

- Maximum resiliency then managed down as capacity needed.
- Maximum capacity with sufficient resiliency, managing resiliency up as needed.
- Standard but sufficient settings with monitoring of headroom for capacity against demand burstiness (probabilistic), as well as the resiliency provided for CP against echoes, and RP against channel interference and bit loading of the frequencies.

PNM-CPR

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