Requirements for Reliable Communications in HFC Based Broadband Data Networking

Paul Nikolich
Broadband Access Systems, Inc.

Abstract

This paper will briefly address the reliability performance requirements of the Broadband Data Networking transmission system cable modem termination systems (CMTS), and HFC plant). In the context of this larger perspective, it will specifically illustrate the critical importance of a maintaining a high availability CMTS. For example, failure of a single CMTS downstream port will affect hundreds of subscribers. The service objective is to keep downtimes below 53 minutes a year (99.99% available.)

This paper will then focus on techniques that can be applied to maximize the availability of the Cable Modem Termination System. Mechanisms that increase availability are redundancy, high mean time to failure and low mean time to restore. A fully distributed, no single point of failure architecture also enhances reliability.

This paper will be of interest to all cable operators interested in understanding the impact of deploying high availability advanced services and how that translates into infrastructure equipment requirements.

OUTLINE:

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3) An HFC network Failure Model
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1. Introduction:

Broadband Data Networking has tremendous potential to become a key source of revenue for cable operators by enabling the delivery of not only Best Effort Data services, but of Packet Voice and Packet Video services as well. However, along with the revenue potential comes the increased expectations by the consumers for high availability of these new data, packet voice and packet video services. Hence operators must ensure their networks are 'high availability' with performance similar to what the telephone company objectives are today: 99.99% uptime.

2. Service Availability 101:

Service Availability is defined as the percentage of time that service is available. This value is a function of the number of network elements between the service 'source' and the service 'sink', how these elements are interconnected and reliable these elements are. Each network element can be assigned a mean time between failure (MBTF) and a mean time to restore (MTTR). It is assumed these parameters are assigned during the 'steady state' portion of their life cycle, and not early on when there is a high 'infant mortality' or late in life when 'wearout' becomes a factor.

Availability, A, of one specific network element is defined as

$$A = MTBF/(MTBF+MTTR)$$

Obviously, for each network element, it is desirable to make the MTBF as high as possible and the MTTR as low as possible to maximize the availability.

Conversely Unavailability, U, is defined as

$$U = 1 - A$$

$$U = MTTR/(MTBF+MTTR)$$

When network elements are connected in series, any one-network element failure results in service unavailability. In this case, the total availability (A_{total}) of the network segment comprised of series elements is equal to the product of the individual availabilities.

For example, if network element one (NE1) with availability A1 is in series with network element two (NE2) with availability A2, the total availability is

$$A_{total} = A1*A2$$

If A1 = A2 = 0.99 (99%) the resulting A_{total} is 0.98 (98%) and the total unavailability is

$$\begin{aligned} U_{total} &= 1 - A_{total} \\ &= 1 - 0.98 \\ &= 0.02 \text{ (or 2\%)} \end{aligned}$$

When network elements are connected in a parallel redundant fashion, any one-network element failure will not result in a service disruption. In this case, the total unavailability (U_{total}) of the parallel network elements is equal to the product of the individual unavailabilities. Assuming NE1 and NE2 above are in parallel, the resulting

$$U_{total} = U1*U2$$

If U1 = U2 = 0.01 (or 1%, note this is equivalent to availabilities A1 and A1 above), the total unavailability is

$$\begin{aligned} U_{total} &= 0.01*0.01 \\ &= .0001 \text{ or } .01\% \end{aligned}$$

$$\begin{aligned} A_{total} &= 1 - U_{total} \\ &= 1 - .0001 \\ &= 0.9999 \text{ or } 99.99\% \end{aligned}$$

In summary, implementing redundant network architectures along with maintaining high MTBF and low MTTR in the network elements will help cable operators achieve the very high availability targets (for example 99.99% or 53 minutes of downtime per year) for their networks.

3. An HFC network Failure Model:

Armed with an understanding of how to calculate service availability for a network, a model of the HFC network for failure analysis can now be constructed. Figure 1 illustrates a typical HFC network. The Cable Modem Termination System (CMTS) is connected to the Internet via a conventional 100Mbps Ethernet port. The CMTS connects to the HFC network via its downstream and upstream RF interfaces. The downstream interface is connected to an fiber transmitter via the combiner, the optical signals sent down 10 miles of fiber to the Fiber Node, where the signals are converted to RF and transmitted into the neighborhood via a series of trunk and line amplifiers over 75 ohm coaxial cable. The signals are tapped off the coax and brought through a drop cable into the home where they are routed to the television and cable modem subsystems in the home. Signals sent upstream from the cable modem to the CMTS follow the reverse path illustrated in Figure 1 through an independent fiber return.

Even though there are differences between Hybrid Fiber Coax Network shown in Figure 1 and the telephone local exchange carrier (LEC) architecture that is used to deploy fiber to the curb, for the purposes of developing a failure model they can be viewed similarly[1]. The LEC criterions are defined in a document called Generic Requirements for Fiber-in-the-Loop Systems[2] (TA-909). TA-909 defines the maximum annual outage objective to be less than 53 minutes (99.99% availability). Note that this is an objective, and is not necessarily what the LECs are achieving.

TA-909 makes the assumption that certain failures are not included in their model:

- failures of utility power
- failures of switching equipment (in the cable operator's case this is head end equipment)
- failures in cabling from the curb into the home (in the cable operator's case this includes the drop cable, splitters, set top box, cable modems, televisions, PCs, etc.)

In this paper, we will look at the contribution of the head end equipment to the overall service availability, but we will not address power failures or failures that occur from the tap into the home.

4. Analysis of the HFC Failure Model:

All of the MTBF numbers shown in this paper assume that the equipment is operating in 'mid-life steady state'. It is during mid-life that the MTBF values are the highest; infant mortality has ended and wearout has not begun.

Note that dominant source of downtime in the network are the DOCSIS CMTS (120 minutes) interface. The chassis controller and 100BaseT Ethernet interfaces also have significant contributions (24 minutes). Also shown in Table 1 is what happens to the downtime when the CMTS, Ethernet interfaces and chassis controllers are run in 1+1 redundant modes--the downtime drop to less than 0.01 minutes per year per module. The overall chassis downtime reduces from 171 minutes per year to just over 3 minutes per year--a significant reduction. Clearly it will be a requirement for cable operators that must deploy highly reliable services to utilize equipment that is capable of running in a redundant mode.

Each of the network elements depicted in Figure 1 has a specific MTBF and MTTR as shown in Table 2. All of these values are taken from the ADL study[1] except for the values used for the CMTS subsystem. The CMTS subsystem values are based on estimates of equipment with similar complexity.

Figure 2 is a graphical depiction of the downtime on a per network element basis. Figure 2 also illustrates the downtime of a set of network elements together; the CMTS system both in redundant (3 minutes) and non-redundant (171 minutes) modes. The downstream fiber (15 minutes), upstream fiber (16 minutes), trunk coax/amplifiers (22 minutes) and feeder coax/amplifiers (19 minutes) are shown. (Note the y-axis is on a log basis.) The grand total of for the entire HFC network, assuming the CMTS is running in redundant mode is 76 minutes per year--clearly higher than the stated goal of 53 minutes per year.

One method of reducing the downtime to less than 53 minutes a year will be to place redundant paths in for the downstream (15 minutes) and upstream (16 minutes) fiber runs. This has the potential to reduce the downtimes to fewer than 1 second per year, bringing the total system downtime to approximately 46 minutes per year--well within our goal.

Of course the benefits of redundancy come at a price, it roughly requires a doubling of investment in the CMTS and Fiber infrastructure portions of the network.

5. Conclusions

It is possible to provide highly available HFC network systems, with downtimes of less than 53 minutes per year--better than what the local exchange carriers have as an objective--but it will require the deployment of redundant systems both in the head end (CMTS) and in the fiber plant.

Also remember that the effect powering, drop cables, in home cabling and equipment were not included in this analysis--these factors must be considered when caclculating the service objectives the from the end user perspective.

[1] Failure Modes and Availability Statistics of HFC networks, Stu Lippoff, Arthur D. Little, HFC '96: High Integrity HFC Networks, SCTE and IEEE Comm Soc.

[1] Generic Requirements of Fiber-in-the-Loop Systems, Telcordia TA-NWT-000909, Issue 2, December 1993.

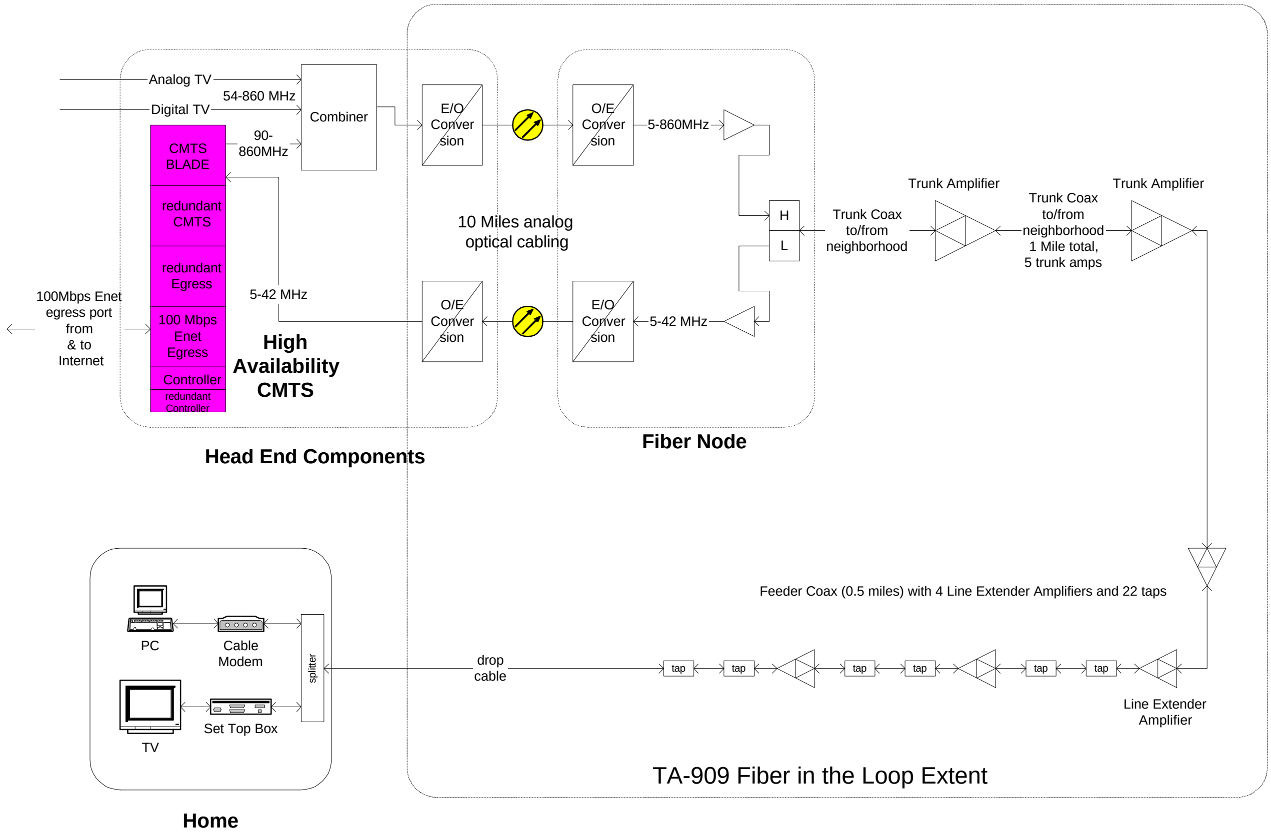

Figure 1 HFC Network Failure Model

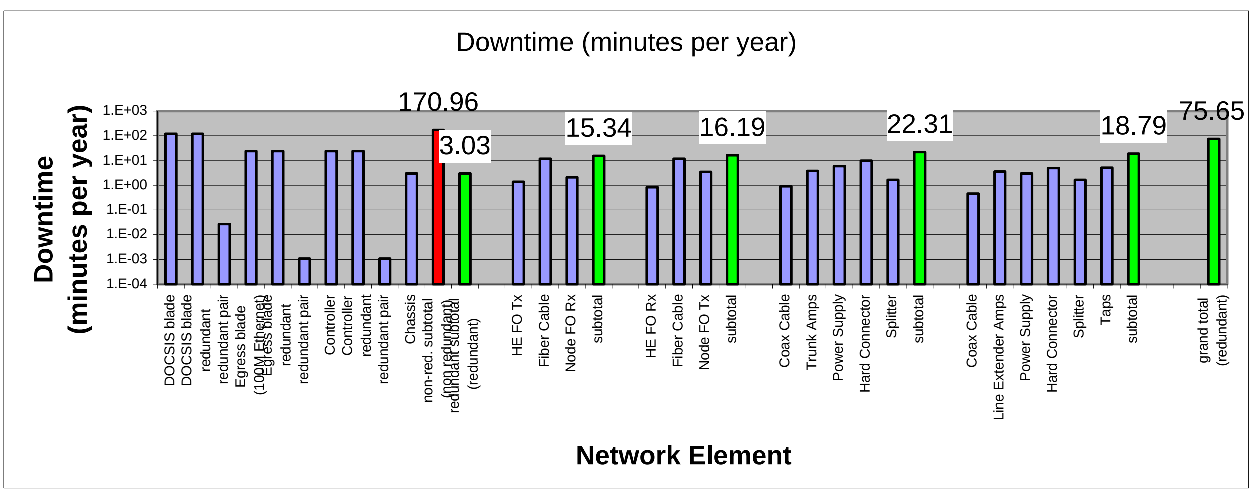

Figure 2 HFC Network Element Downtime in Minutes per year

Table 1 HFC Network Failure Mode Data

Network Segment	Network Element	Failure Rate (%/yr)	Number	MTBF (years)	MTTR (hours)	Avail	Unavail	Down-time (min/year)
CMTS	DOCSIS blade	100	1	1.0	2	0.999771742	0.000228258	119.97
	DOCSIS blade redundant	100	1	1.0	2	0.999771742	0.000228258	119.97
	redundant pair					0.9999999479	5.21019E-08	0.0274
	Egress blade (100M Ethernet)	20	1	5.0	2	0.99995434	4.566E-05	24.00
	Egress blade redundant	20	1	5.0	2	0.99995434	4.566E-05	24.00
	redundant pair					0.9999999979	2.08484E-09	0.0011
	Controller	20	1	5.0	2	0.99995434	4.566E-05	24.00
	Controller redundant	20	1	5.0	2	0.99995434	4.566E-05	24.00
	redundant pair					0.9999999979	2.08484E-09	0.0011
	Chassis	1	1	100.0	5	0.999994292	5.70773E-06	3.00
	non-red. subtotal (non redundant)					0.999674739	0.000325261	170.96
	redundant subtotal (redundant)					0.999994236	5.764E-06	3.03
Downstream link	HE FO Tx	2.33	1	42.9	1	0.99999734	2.65981E-06	1.40
	Fiber Cable	0.439	10	22.8	4.5	0.999977449	2.25509E-05	11.85
	Node FO Rx	1.396	1	71.6	2.5	0.999996016	3.984E-06	2.09
	subtotal					0.999970805	2.91945E-05	15.34
Upstream link	HE FO Rx	1.396	1	71.6	1	0.999998406	1.5936E-06	0.84
	Fiber Cable	0.439	10	22.8	4.5	0.999977449	2.25509E-05	11.85
	Node FO Tx	2.33	1	42.9	2.5	0.999993351	6.6495E-06	3.49
	subtotal					0.999969206	3.07938E-05	16.19
Trunk Coax	Coax Cable	0.439	1	227.8	3.5	0.999998246	1.75399E-06	0.92
	Trunk Amps	0.514	5	38.9	2.5	0.999992666	7.33442E-06	3.85
	Power Supply	2	2	25.0	2.5	0.999988585	1.14154E-05	6.00
	Hard Connector	0.28	16	22.3	3.68	0.99998118	1.88197E-05	9.89
	Splitter	0.13	7	109.9	3	0.999996884	3.11643E-06	1.64
	subtotal					0.999957561	4.24393E-05	22.31
Feeder Coax	Coax Cable	0.439	0.5	455.6	3.5	0.999999123	8.76997E-07	0.46
	Line Extender Amps	0.599	4	41.7	2.5	0.999993162	6.83785E-06	3.59
	Power Supply	2	1	50.0	2.5	0.999994292	5.70773E-06	3.00
	Hard Connector	0.28	8	44.6	3.68	0.99999059	9.40996E-06	4.95
	Splitter	0.13	7	109.9	3	0.999996884	3.11643E-06	1.64
	Taps	0.13	22	35.0	3	0.999990206	9.79442E-06	5.15
	subtotal					0.999964257	3.57429E-05	18.79
	grand total (redundant)						total	75.65