HFC Evolution

The Best Path Forward

An Operational Practice prepared for SCTE•ISBE by

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Introduction

The majority of MSOs have an N+X outside plant architecture. Assuming that Fibre to the Premises (FTTP) is the final state of the plant, there are varieties of approaches being considered by each provider to increase bandwidth (BW) in the meantime to compete with fibre-based services. Some are considering a leap directly to a fully passive state (N+0), whereas others are considering reducing amplifier cascades gradually, with a passive state in mind. At Shaw we are contemplating an initial move to N+2, meaning the plant is going to be split directly to an N+2 state from its current architecture.

In this paper an analysis has been carried out to evaluate the potential advantages and disadvantages of going directly to a passive (N+0) architecture versus reducing amplifier cascades to a mid-point (N+2) prior to going to N+0, with a long-term goal of FTTP in mind, in both cases. This is assuming that Full Duplex DOCSIS (FDX) will be developed in a cascaded environment in the near future.

Due to the fact that business as usual (BAU) node splits, based on plant congestion, are not scalable, they have been excluded from the comparison.

Based on the current downstream capacity offerings and projected future growth, the difference in capacity between an N+0 and N+2 plant has been evaluated while taking into consideration the various new technologies that will be deployed in the near future.

Furthermore, a net present value analysis has been provided for the transition from N+2 to N+0. At its current state, 75% of Shaw's plant consists of nodes with a longest cascade of 5 or less amplifiers. Depending on when the transition to N+2 or N+0 is projected to occur, a relative estimate for the net present value of the costs has been provided, based on the sample plant selected.

Based on the analysis shown in this paper, assuming that Full Duplex DOCSIS (FDX) is developed in a low-cascade architecture such as N+2, the results show that moving to N+2 → N+2 FDX → N+0 FDX has a lower total cost of ownership (TCO), in comparison to moving directly to N+0 FDX.

Content

1. Scope

In order to quantify the differences between various deployment strategies, two major categories have been considered in this paper:

1. Downstream plant capacity and peak utilization analysis
2. Overall cost and net present value analysis

These are both based on the assumption that the ultimate state of the plant will be FTTP and all other deployments strategies are in-between stages to increase plant capacity to be able to compete with fibre based services.

2. Analysis

2.1. Utilization and Capacity Analysis

In order to provide a utilization and capacity estimate, the various plant stages should be elaborated on.

Currently Shaw's plant is primarily N+X. In this paper the primary focus is on the 75th percentile of the largest number of amplifiers in cascade, which is N+5. Assuming this is the current state and FTTP being the final stage of the plant, the in-between stages have been considered to be:

N+5 → N+2 → N+2 FDX → N+0 FDX → N+0 Extended Spectrum DOCSIS → FTTP

This paper analyses the feasibility of moving to an N+2 FDX environment prior to moving to N+0 FDX. The assumptions for a cascaded environment FDX plant has been described in section 2.1.1.7.

Prior to outlining the details of these analyses, the assumptions for this analysis have been outlined below:

2.1.1. Assumptions:

2.1.1.1. Plant Bandwidth:

The following assumptions have been made regarding the capacity of N+X and N+0 plant

1. Maximum plant BW for N+2 has been assumed to be 1GHz
2. Maximum plant BW for N+0 has been assumed to be 1.2GHz

Although some of the amplifiers in the plant today are not 1GHz, the assumption has been made that the 750MHz and 860MHz amplifiers are going to be swapped out for 1GHz versions to increase plant BW and take full advantage of DOCSIS 3.1 and Orthogonal Frequency Division Multiplexing (OFDM) carriers.

2.1.1.2. Spectrum:

The capacity analysis in this paper considers the end state of the spectrum for each architecture. This means that IP TV is assumed to have been deployed.

2.1.1.3. Available Capacity vs Peak Utilization:

In order to satisfy the peak utilization, the overall available spectrum capacity requirement has been analysed in the two scenarios below:

- Double the peak utilized amount (worst case scenario) or 100% buffer case
- 50% more than the peak utilized amount (realistic case) or 50% buffer case

2.1.1.4. OFDM Modulation Order:

In order to have a basis for capacity calculations, all OFDM carrier modulation orders are assumed to be 1024QAM. This is based on the plant characterization tests and field observations that we carried out as a part of D3.1 deployment. Anything above this, namely 4096QAM, is considered "extra capacity" and will not be used in the capacity calculations demonstrated in the below sections. This is due to the fact that 4096QAM may not be achievable in certain portions of the plant.

The effective throughputs calculated for the 1024QAM OFDM carriers have been shown below. Note that this is a conservative estimate based on field observations:

Table 1 – 1k QAM Bit Rate

Modulation Rate	Effective Throughput (Bits/s/Hz)
1024QAM	7

2.1.1.5. DS Compound Annual Growth Rate:

At Shaw we have experienced a 36% CAGR.

2.1.1.6. Remote PHY (RPHY):

For the purpose of plant progression in this paper, an assumption has been made that the in-between stage of the plant consists of an RPHY node and amplifiers. The final stage of the plant being N+0, will have FDX nodes.

Further to the assumption mentioned above, the N+2 plant has been broken down into two categories:

- An N+2 plant where RPHY nodes and amplifiers will be deployed, but no FDX will be available to them
- A case has also been assumed for FDX deployable in an N+X environment (N+2 in this case). This has been further explained below.

2.1.1.7. Full Duplex DOCSIS:

The capacities for FDX have been based on the assumption that it will be fully deployed in the FDX band (108MHz – 684MHz), by the time plant reaches an N+2 state.

Please note:

- Currently FDX is only being discussed in an N+0 environment
- An assumption has been made for FDX deployable in a cascaded environment. Considering the complexities that would be present in this type of plant, the achievable modulation order has been assumed to be 256QAM.

Table 2 – 256 QAM Bit Rate

Modulation Rate	Effective Throughput (Bits/s/Hz)
256QAM	5

2.1.2. Results:

DOCSIS technology has advanced significantly in recent years, improving the spectral efficiency in the DS and US. This analysis has been based on peak utilization and the available spectrum to be able to provide the capacity and BW to satisfy the peak utilization.

The peak utilization per node is gathered at Shaw bi-monthly. The method of calculating the peak utilization is:

$$\begin{aligned} Peak\ Utilization \\ &= Number\ of\ available\ carriers\ \times Capacity\ of\ carriers\ (Mbps) \\ &\times maximum\ \%\ utilized\ Sampled\ Every\ 5\ minutes \end{aligned}$$

Based on the historical data available, the 75th percentile of the peak utilization for the past 5 years was calculated. The results produced a starting point of 508.66 Mbps in peak utilization. Referring to assumptions section 2.1.1.3, the capacity requirement for each scenario can be calculated as:

- 100% Buffer Case: 1017.3 Mbps
- 50% Buffer Case: 763 Mbps

Based on this, assuming a 36% CAGR, the graphs below can be produced to estimate the capacity required in the future:

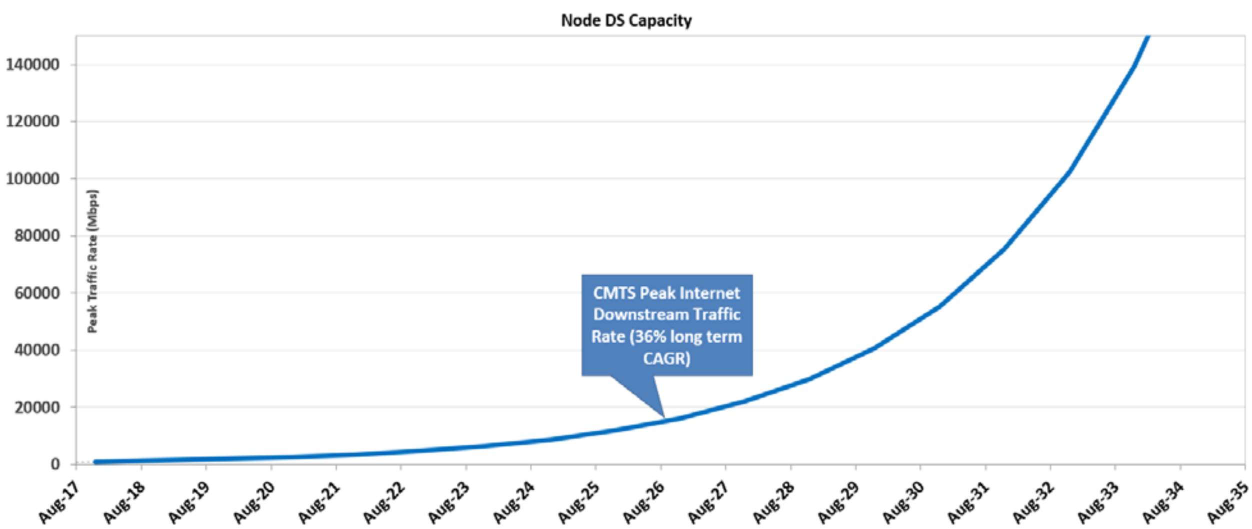

Figure 1 – Node DS Capacity –100% Buffer Case

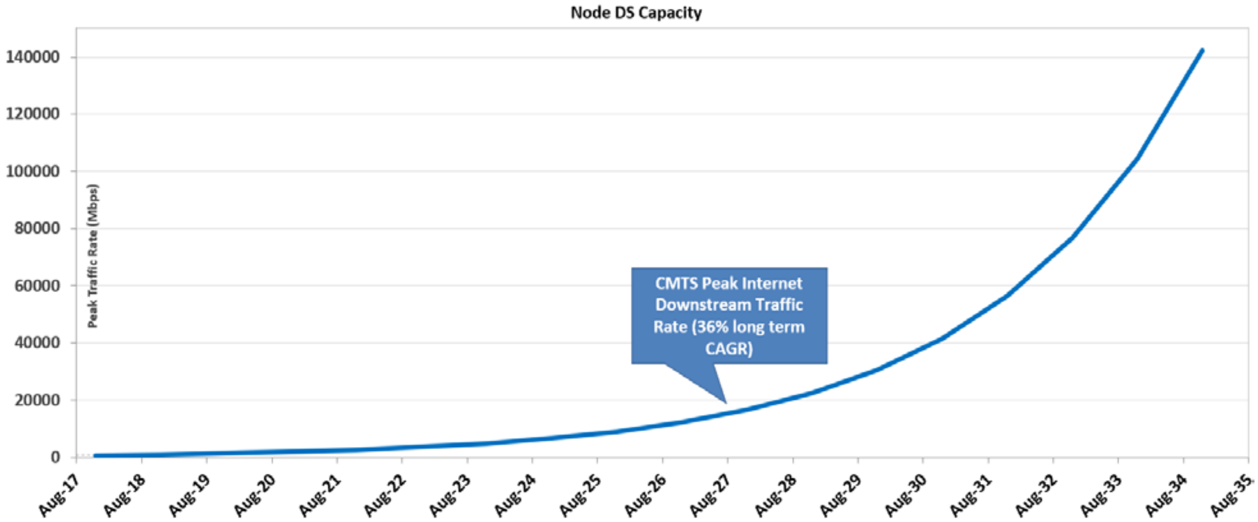

Figure 2 – Node DS Capacity – 50% Buffer Case

To be able to estimate when Shaw needs to reach each capacity point, the potential overall spectrum capacity in the various available stages needs to be estimated. The current Shaw spectrum plan has been shown below:

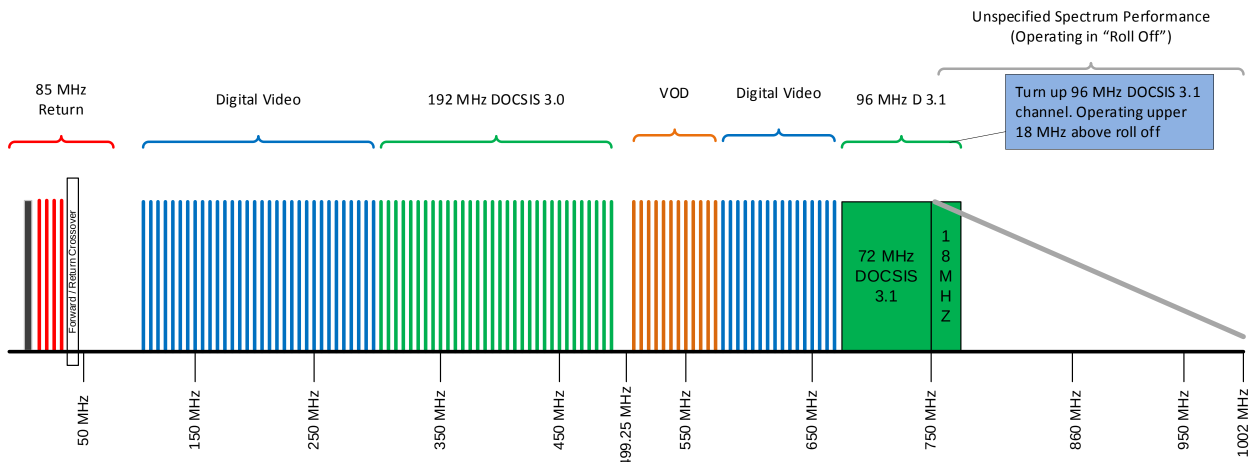

Figure 3 – Current Shaw Spectrum Plan

Transitioning to N+2 plant, the spectrum has been projected to look as below:

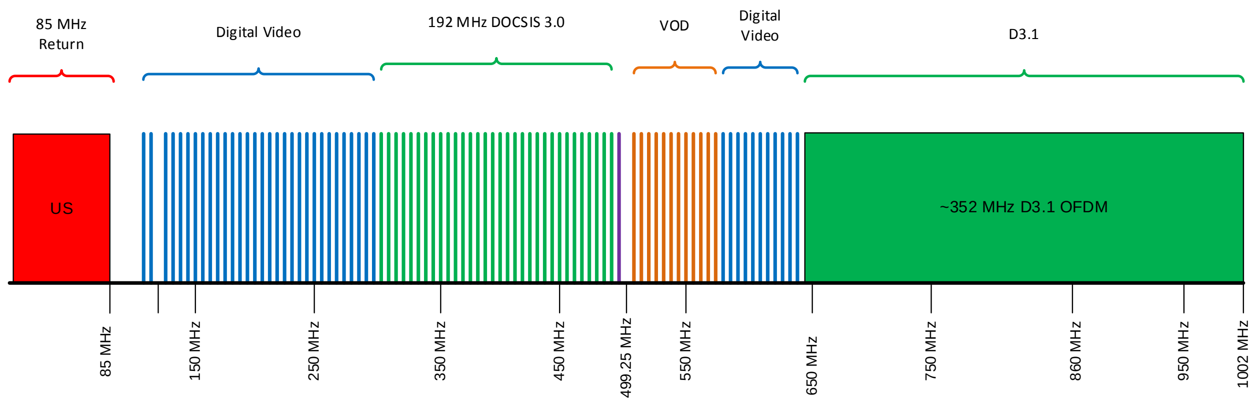

Figure 4 – Projected Shaw N+2 Spectrum Plan

Based on this and the D3.1 OFDM carriers starting at 648MHz, the capacity for N+2 plant can be estimated as:

$$Shaw\ N+2\ Capcity = D3.0\ Capacity + D3.1\ Capacity = 32 \times 36Mbps + 2465Mbps \cong 3.6Gbps$$

DS/US Capacity: 10/1

DS Tier: Gigabit Services

Referring to the assumptions section 2.1.1.7, if FDX is to be developed in any N+X environment, the spectrum has been assumed to look as demonstrated below:

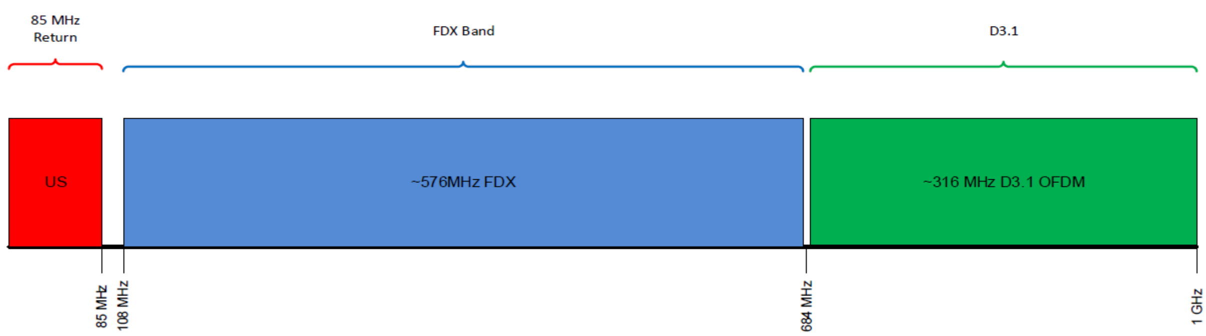

Figure 5 – Projected Shaw N+2 FDX Spectrum Plan

Based on the assumption of 256QAM achievable in the FDX DS band, as an end state, the capacity can be estimated as:

$$Shaw\ N+2\ FDX\ Capcity = FDX + D3.1\ = 2880Mbps\ + 2212Mbps\ \cong 5\ Gbps$$

DS/US Capacity: 1.5/1

Tier:

- Gigabit symmetrical services

or

- Multi-gigabit DS & gigabit Upstream (US) Services

Transitioning to N+0, the spectrum has been assumed to look as below:

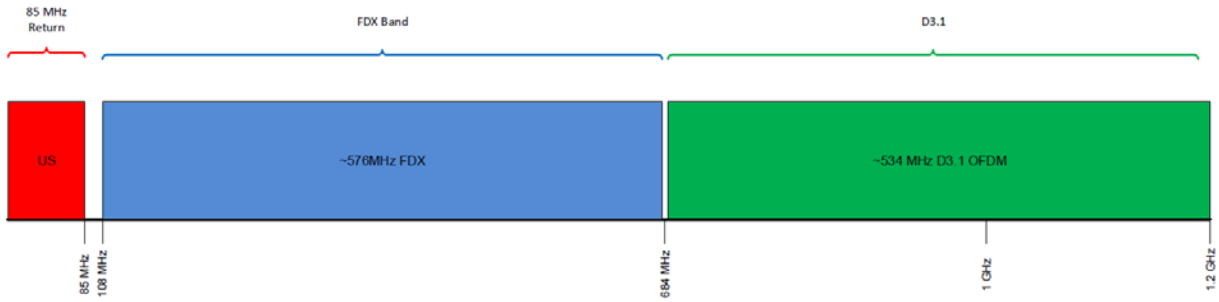

Figure 6 – Projected Shaw N+0 Spectrum Plan

Based on this, the capacity can be estimated as:

$$Shaw\ N+0\ Capcity = FDX + D3.1\ = 4032Mbps\ + 3738Mbps\ \cong 7.8Gbps$$

DS/US Capacity: 2/1

Tier:

- Gigabit Symmetrical Services

or

- Multi-gigabit DS & gigabit US Services

Assuming no drastic changes will occur in the DS peak utilization and Shaw deploys extended spectrum DOCSIS (ESD), the spectrum will look as below:

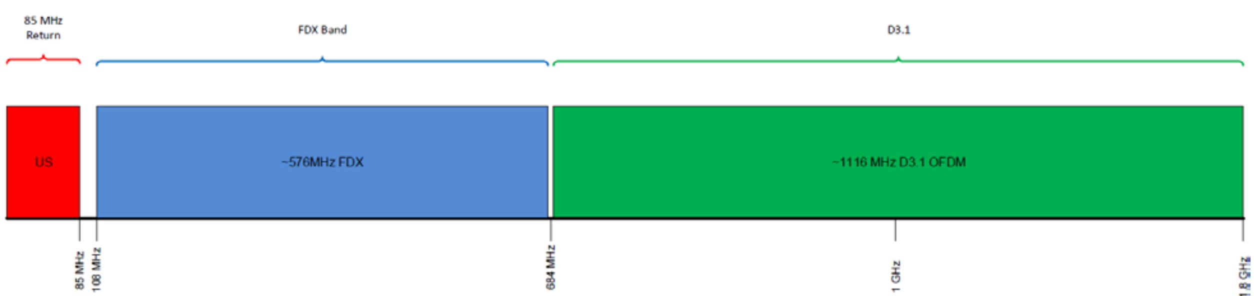

Figure 7 – Projected Shaw ESD Spectrum Plan

Based on this, the capacity can be estimated as:

$$Shaw\ Extended\ Spectrum\ N+0\ Capcity = FDX + D3.1\ = 4032Mbps\ + 7812Mbps\ \cong 12Gbps$$

DS/US: 1/1 (assuming static FDX US)

Tier: Multi-gigabit Symmetrical Service

Note that Figure 7 is not evaluated in this paper. It is simply inserted as a point of discussion for future architectures, as ESD gains more traction in the industry.

The capacities calculated above will be analyzed in detail in section 2.2.2.1 where they will be inserted in the capacity trends discussed earlier in this paper.

2.2. Net Present Value Analysis:

In this section the details of the net present value analysis, based on the progression of the plant has been provided.

The sample plant (VC-819C) that was selected for this paper consists of the parameters below:

Table 3 – Node Parameters

	Homes Passed	Trunk Amp.	Distr. Amp.	2 Way Tap	4 Way Tap	8 Way Tap	2 Way Splitter	3 Way Splitter	4 Way Splitter	Directional Coupler
VC819C	350	3	18	0	54	13	4	3	2	4

The node above was selected based on the 75th percentile of the largest number of amplifiers in cascade, in the top 3 biggest regions in Shaw. The reason why homes passed was not considered for the selection of this node is due to the fact that focusing on the number of amplifiers provides a more challenging environment for the node to be split down to N+2 and/or N+0, in comparison to focusing on homes passed (HP), due to the density factor. In other words, focusing on the number of amplifiers in cascade provides a reasonable-worst-case scenario.

The map for the selected node has been shown below:

Figure 8 – VC819C

The progression of this plant was planned in such a way to:

1. Go to N+0 from the current state
2. Go to N+2 from the current state, then N+0

The assumptions below were taken into consideration for this analysis:

2.2.1. Assumptions:

2.2.1.1. Plant Design:

- The N+2 plan was designed with N+0 in mind, this means that some of the N+2 node locations overlap with future N+0 locations. This lines up with Shaw's current node split strategy.
- In the N+2 design, the nodes are not optimized for reach. This means that the nodes were not centralized, and plant turn-arounds were avoided.
- The N+0 plan was designed to optimize the node location with minimal coaxial work required. This means existing amplifier locations were used to accommodate future node locations.

2.2.1.2. Node and Amplifier Costs:

Given that this analysis assumes the plant to be in its final stage for each of the items mentioned above, the nodes and amplifiers are assumed to be RPHY/FDX capable nodes and amplifiers. The cost of the node and amplifiers have been outlined below:

- FDX Node: Approximately twice as expensive as an optical node
- FDX Amplifiers: Approximately the same cost as an optical node

Note: Head-end/Hub costs have not been included in any of the estimates.

2.2.1.3. Net Present Value (NPV) Rate:

For the NPV analysis, the discount rate has been assumed to be 8%.

2.2.2. Results:

The plant design for each case has been demonstrated below:

N+0 Design:

Figure 9 – VC819C N+0 Design

Each coloured circle in the figure above is a future node location, with its boundary highlighted.

Total Node count: 9

<u>N+2 Design</u>

Figure 10 – VC819C N+2 Design

Total Node count: 3

N+2 to N+0 Design:

Figure 11 – VC819C N+2 to N+0 Design

Total Node count: 10

The build cost for each case has been shown in Table 4. Note that the N+2 design has been split to two categories. Non FDX N+2 and FDX N+2. The reason behind this is the fact that the FDX amplifiers will be more expensive than the non-FDX (RPHY) versions, as mentioned in the assumptions above.

The table below outlines the overall build cost for each case:

Table 4 – Build Cost for Each Plant Design

Design	Build Cost (1000$)
N+2 (non-FDX)	77
N+2 (FDX)	120
N+2 to N+0 (FDX)	242
N+0 (FDX)	298

Assuming a fixed yearly budget, from the table above shows that:

- N+2 non-FDX can be reached 3.5 times faster in comparison to N+0
- N+2 FDX can be reached 2.5 times faster in comparison to N+0

In order to carry out a net present value analysis, the dates where the projected capacity trends meet the required capacity demands, for each case, should be estimated.

2.2.2.1. Updated Capacity Trend:

Referring back to Figure 1 and Figure 2, they can be updated respectively, based on the resulting number of nodes in each design scenario, in the section above. The starting points for the 100% and the 50% buffer cases can be calculated as:

- 100% Buffer Case:
  - $N + 2\ Starting\ point = \frac{1017.3}{3} = 339.1\ Mbps$
  - $N + 0\ Starting\ point = \frac{1017.3}{9} = 113.03\ Mbps$
- 50% Buffer Case:
  - $N + 0\ Starting\ point = \frac{763}{3} = 245.33\ Mbps$
  - $N + 2\ Starting\ point = \frac{763}{9} = 84.77\ Mbps$

These can be entered into figures 1&2, as demonstrated below:

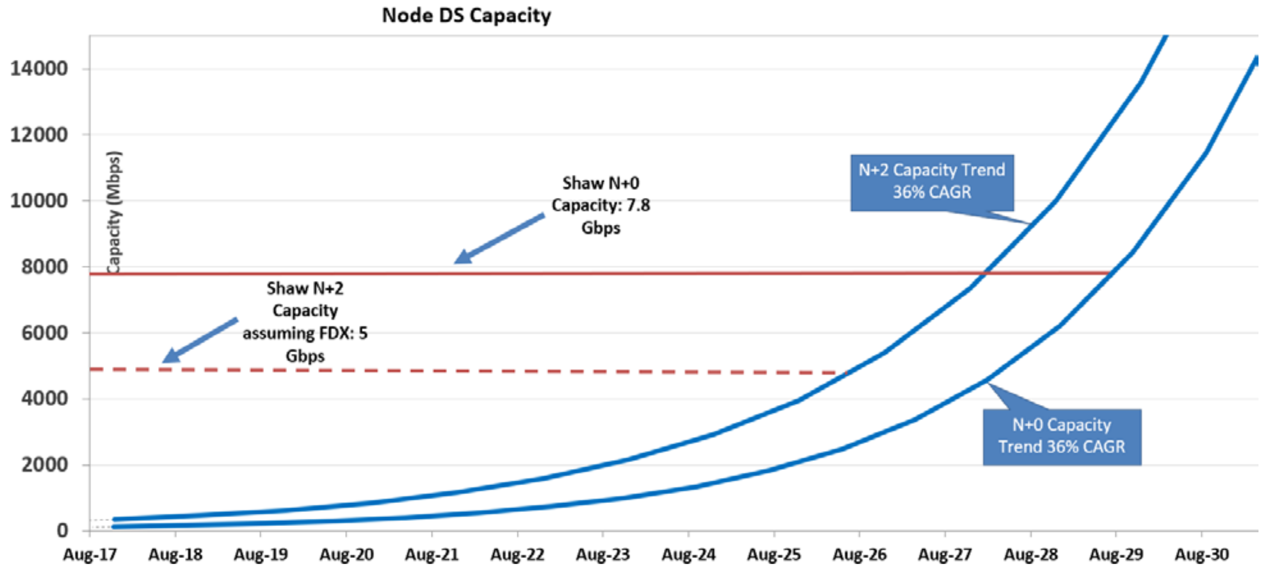

Figure 12 – Updated Capacity Trend – 100% Buffer

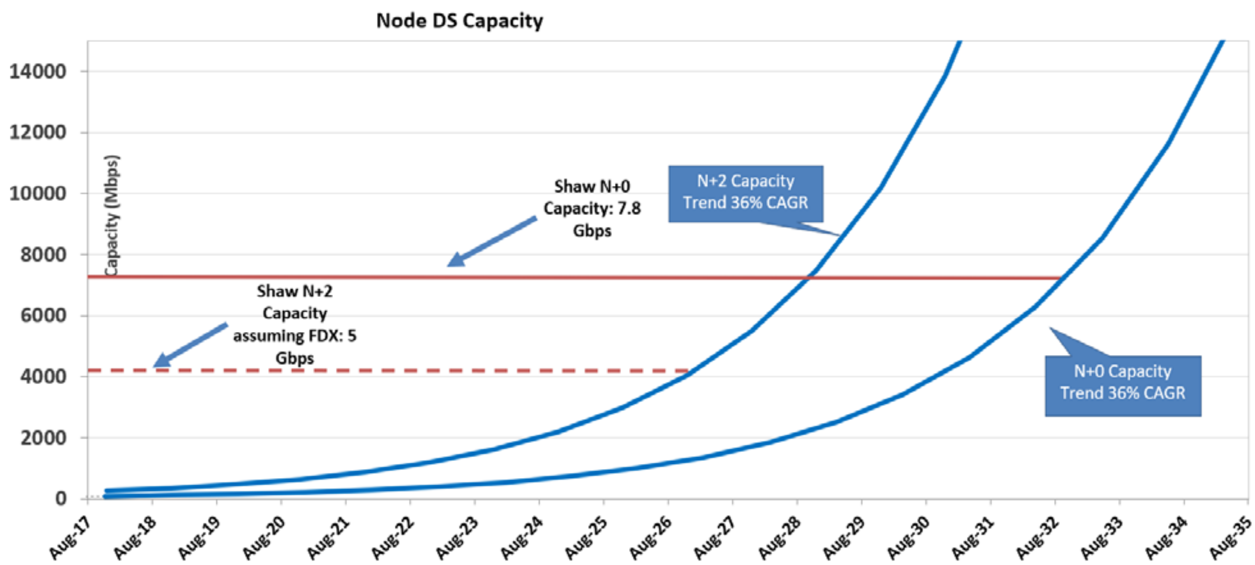

Figure 13 – Updated Capacity Trend – 50% Buffer

From Figure 12 and Figure 13, the dates where capacity trends will reach N+2 FDX for each buffer case can be estimated. These have been demonstrated in the table below:

Table 5 – Capacity Trend Summary Table

	Date	
Case	100% Buffer	50% Buffer
N+2 FDX	2026	2027
N+0 FDX	2029	2032

The dates above can be utilized to estimate the net present value of each scenario:

Table 6 – NPV Analysis – 100% Buffer Case

	NPV	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
N+2 (FDX)	$281,000	$77,000	$43,000	0	0	0	$242,000
N+0 (FDX)	$298,000	$298,000	0	0	0	0	0

Table 7 – NPV Analysis – 50% Buffer Case

	NPV	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
N+2 (FDX)	$269,000	$77,000	$43,000	0	0	0	0	$242,000
N+0 (FDX)	$298,000	$298,000	0	0	0	0	0	0

In the tables above the $242,000 for moving to N+0 has been placed in 'year 6' and 'year 7' for the 100% and 50% buffer cases, since in Figure 12 and Figure 13, the capacity trend will reach the N+2 FDX limit by 2026 and 2027 respectively. Also note that the $120,000 for moving to N+2 FDX has been broken down to an initial $77,000 to move to N+2 and an additional $43,000 to be spent the year after, since the technology is estimated to be available at that time.

It can be seen from both Tables 6 and 7 that N+2 FDX has a lower TCO by roughly:

- $17,000 in the 100% buffer case
- $30,000 in the 50% buffer case

2.2.2.2. A More Optimistic Approach:

So far, the parameters in this paper have been selected conservatively. Switching to a more optimistic approach, with the same method used above, the results can vary significantly. To demonstrate this, consider the parameters below, instead of the ones used so far:

- CAGR = 30%
- Buffer = 50%
- DS FDX N+X modulation order = 1k QAM
- Spectrum BW: 1.2GHz and 1GHz have been shown

As a result, the capacity trend has been shown below:

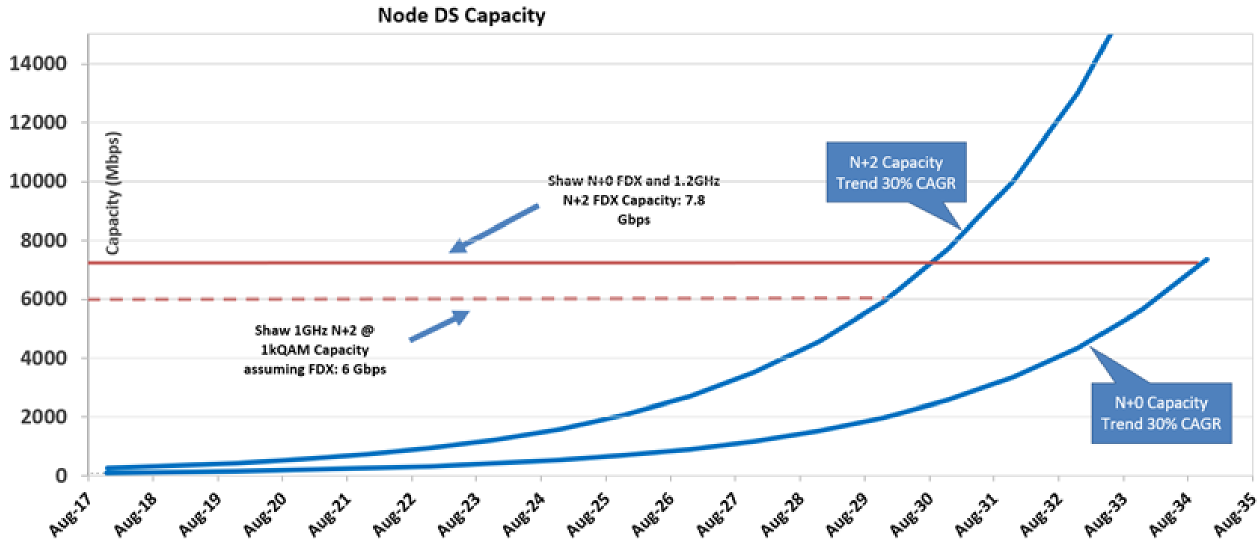

Figure 14 - Updated Capacity Trend – Optimistic Case

Based on Figure 14, the NPV table will be:

Table 8 - NPV Analysis – Optimistic Case

	NPV
N+2 (FDX)	$213,000
N+0 (FDX)	$298,000

It can be seen that adjusting the DS modulation order to 1kQAM in conjunction with adjusting the CAGR to 30%, as it's been decreasing, can reduce the overall cost of N+2 FDX by $68,000 in comparison to the 100% buffer and by $56,000 in comparison to the 50% buffer conservative cases.

Conclusion

According to the analysis carried out on the node, selected based on the 75th percentile of the largest number of amplifiers in cascade in Shaw's plant, and assuming that FDX is developed in an N+2 environment, moving to an N+2 FDX mid-point has a lower TCO, in comparison to moving directly to N+0 FDX. Furthermore, assuming a fixed yearly budget, N+2 can be reached 3.5 times and N+2 FDX 2.5 times faster, in comparison to N+0 FDX.

This was shown to be valid in the reasonable worst-case scenarios demonstrated, in which case, moving to N+2 FDX also provides Shaw with an additional 1.5Gbps in DS capacity, in comparison to N+2. This enables the capability of offering gigabit symmetrical services. Furthermore, moving to N+2 FDX secures Shaw's spectrum capacity until 2027, assuming we maintain a 50% buffer above the peak utilized speed and a 36% CAGR. This is prior to having to move to N+0 FDX to gain an additional 2.8Gbps in DS capacity.

Abbreviations

BW	bandwidth
BAU	business as usual
CAGR	compound annual growth rate
DS	downstream
DOCSIS	data over cable service interface specification
ESD	extended spectrum DOCSIS
FDX	full duplex DOCSIS
FTTP	fibre to the premises
HP	homes passed
NPV	net present value
OFDM	orthogonal frequency division multiplexing
RPHY	remote PHY
TCO	total cost of ownership
US	upstream