Problem statement

When developing a long-term access network transformation plan, network operators tend to focus on demand growth as the key trigger for upgrades. While accommodating demand growth remains a key driver for upgrading a network, in reality other triggers may enforce a different upgrade strategy and alter the preferred upgrade path and the required investment profile. Hence to select a suitable upgrade strategy, it is imperative to understand the robustness and sensitivity to input assumptions against a complete set of relevant upgrade paths.

Definition level set

Network upgrade triggers can be grouped into four main categories:

Long-term access planning is dynamic. Many factors around us (including COVID-19) influences the plan. How to cope with the changes due to:

- Growth variations
- Product roadmap plans
- Strategy alignment, and
- Operational realizations

1. **Growth triggers**: Year over Year (YoY) demand growth will continue to be an important trigger. Given the uncertainty of future growth levels (such as the growth changes due to working from home during the current COVID-19 situation), doing extensive what-if analysis is an absolute must to get the access upgrade strategy right. Furthermore, growth profiles can vary drastically from one urban morphology to another. It is therefore imperative to define a representative set of growth profiles assigned at the lowest level of granularity.
2. **Product/service roadmap triggers**: Another key set of triggers for the access network transformation are the introduction of new services and new service tiers. A straightforward example is the introduction of higher bandwidth tiers over time (see example in Appendix A for the roadmap used in this use case). Less obvious examples are the introduction of new services that drive additional demand above YoY bandwidth growth such as moving video delivery from QAM to IP based, home security monitoring etc.
3. **Strategic alignment triggers:** Forcing an aggressive upgrade to FTTH is an example of a strategy trigger.
4. **Operational triggers**: Optimizing construction efficiency by moving from a just in time upgrade strategy to geographically clustered upgrade strategy is an example of operational trigger.

To illustrate the main take away of this application note, we selected few examples to include what-if sensitivity on growth triggers, basic product triggers and service triggers. The examples are chosen for illustrative purposes only. They are not a representative set for in-depth network transformation analysis.

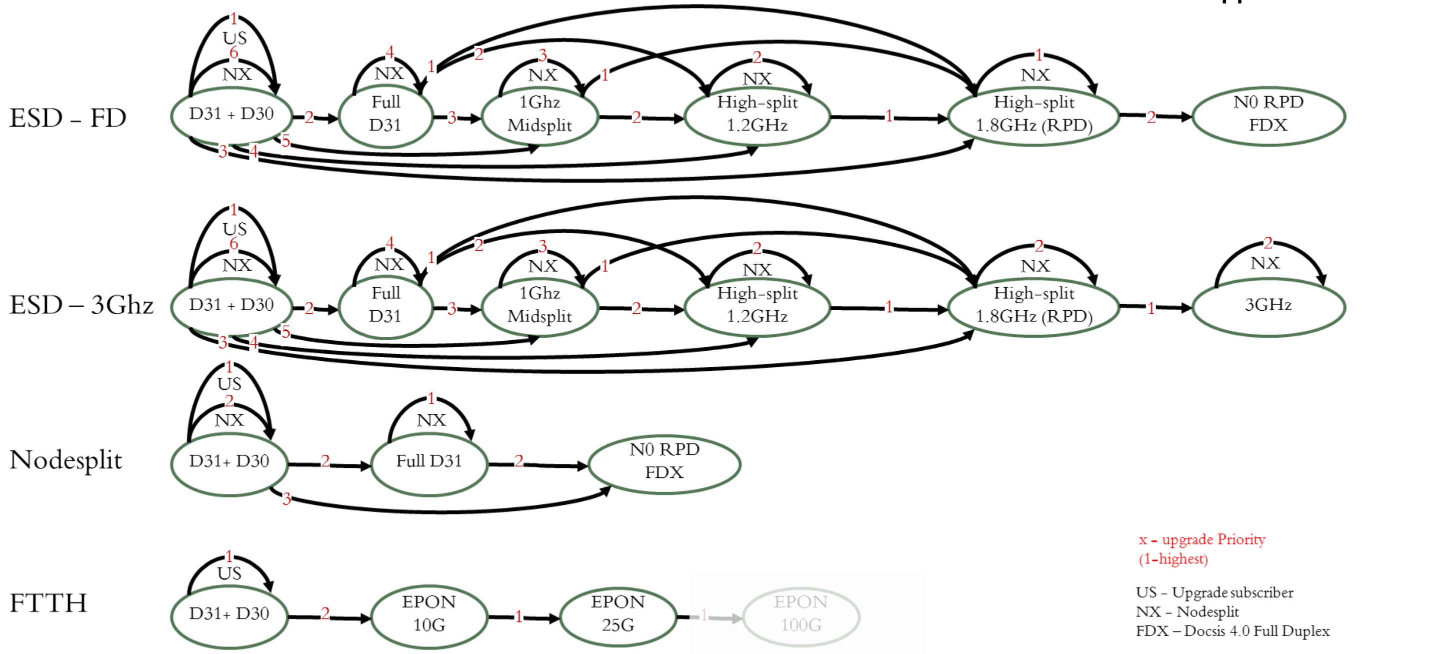
Analysis set-up

For clarity of the results the analysis is done on a small brownfield network with the following key assumptions:

- One facility with 50K HHP across 108 N+X DOCSIS 3.1 (D3.1) capable nodes with mixed D3.0 and D3.1 subscribers
- Demand growth of 40% downstream and 30% upstream
- Technology and product roadmap assumptions as shown in Appendix A, and
- Transition to FDX is possible at only in N+0 configuration.

To ensure that the results obtained are representative, this analysis is also conducted on a one million homes passed network. The large-scale exercise is omitted in this application note as they are in line with the single facility results.

To show the impact of different types of triggers and the sensitivity of upgrade paths to input parameter levels, it is important to look at a long-term evolution with different upgrade scenarios. The upgrade paths modelled in AP-Jibe for this analysis are representative versions of upgrade strategies considered by many service providers today for their HFC access infrastructure. The four upgrade paths used are shown in the figure below.



Brief description of AP-Jibe approach

Four upgrade scenarios are configured in AP-Jibe using technology, cost and resource definitions based on our industry analysis. For each scenario a baseline 10-year quarterly analysis is run with only growth-based upgrade triggers. In the baseline models a node is considered due for upgrade if the demand is over 70% of the capacity. In the second phase, for each of the baseline scenarios three variations were created and analyzed by changing or adding individual input parameters. These three scenarios are as follows:

1. **What-if on growth rate**: For the first variation both upstream and downstream growth rates were increased by 10% in both directions, to 40% YoY for upstream and to 50% YoY for downstream. This variation shows the importance of doing what-if sensitivity analysis on an input parameter, such as the growth. Note: for a complete transformation plan analysis, what-ifs could be done on important input triggers and constraints.

2. **Product roadmap requirement**: In the second variation additional upgrade triggers are introduced to analyze the capability of the upgrade path to deliver on a roadmap for increased top-tier bandwidth services. The triggers are set-up as best-effort triggers. That is, if an evolution path cannot accommodate a product tier at a certain point in-time the trigger will remain active until the time it is accommodated. A bandwidth tier triggers an upgrade if the headroom on an interface (capacity – demand) is less than 1.2 times the requested bandwidth in the downstream direction and 1.1 times in the upstream direction. This represents a typical engineering rule enforced to ensure customers Quality of Experience (Refer to – “Simulating the impact of QoE on per-service group HSD bandwidth capacity requirements,” by Tom Cloonan, Jim Allen, Mike Emmendorfer).

3. **IPTV introduction**: To illustrate a more indirect impact of product requirements, a third variation looks at the impact of migrating customers over time form QAM based video to IPTV based video.

Results and Observations

Caution: These results are based on our high-level assumptions for illustrative purposes only. Actual results may vary based on each operator's environment.

Before looking at insights gained from the analysis, let's start with a summary of the results of the scenarios and scenario variation brought together in a single table.

	Cost ($, M)				NPV ($, M)				Are the needs met?			
	NS-FD	ESD-FD	ESD-3G	FTTH	NS-FD	ESD-FD	ESD-3G	FTTH	NS-FD	ESD-FD	ESD-3G	FTTH
Base Case	66.0	33.0	28.6	35.7	34.1	17.5	15.7	29.8	Yes	Yes	Yes	Yes
Aggressive Growth	66.2	65.4	43.6	35.4	38.6	32.4	23.8	30.9	Yes	Yes	Yes	Yes
IPTV Migration	65.9	32.9	28.5	39.3	34.5	17.6	15.8	31.1	Yes	Yes	Yes	Yes
Product Roadmap	51.5	38.8	40.8	40.4	31.4	24.4	25.6	34.2	Partial	Partial	Yes	Yes

Roadmap	NS+FD	ESD-FD	ESD-3G	FTTH
1G/100M	No	Yes	Yes	Yes
2G/1G	No	Yes	Yes	Yes
5G/1G	Yes	Yes	Yes	Yes
10G/2G	No	No	Yes	Yes

Some observations on the summary table:

1. Cost and NPV observations: Impact of growth rate changes and increased product needs will drastically impact the cost profiles. This can be explained by the amount of headroom that is created when a node is upgraded. The smaller the headroom in an upgrade step the more frequent upgrades needs to be performed.

    a. Organic node splits to reach full duplex has both higher cost and NPV: Cost of construction dominates the frequent node splits. Lower NPV (relative to cost) indicates investments are spread out.

    b. Aggressive growth will force ESD options look less attractive from cost point of view: Increased growth seem to force the ESD option to migrate faster into future options.

    c. FTTH has higher NPV but lower variance across scenarios: Construction related upgrade costs in FTTH happen in earlier years forcing the Cost and NPV higher but with little variance to support future needs (such as increased growth and better product offering) due to the headroom created by FTTH.

2. Roadmap support observations: Not all upgrade paths can support the requested product roadmap. In a competitive market not being able to introduce a product tier can result in significant subscriber and revenue loss. **Note:** With some upgrade paths not being able to accommodate and thus ignoring the products triggers, the cost comparison shown in the table for the product variation is no longer apples to apples.

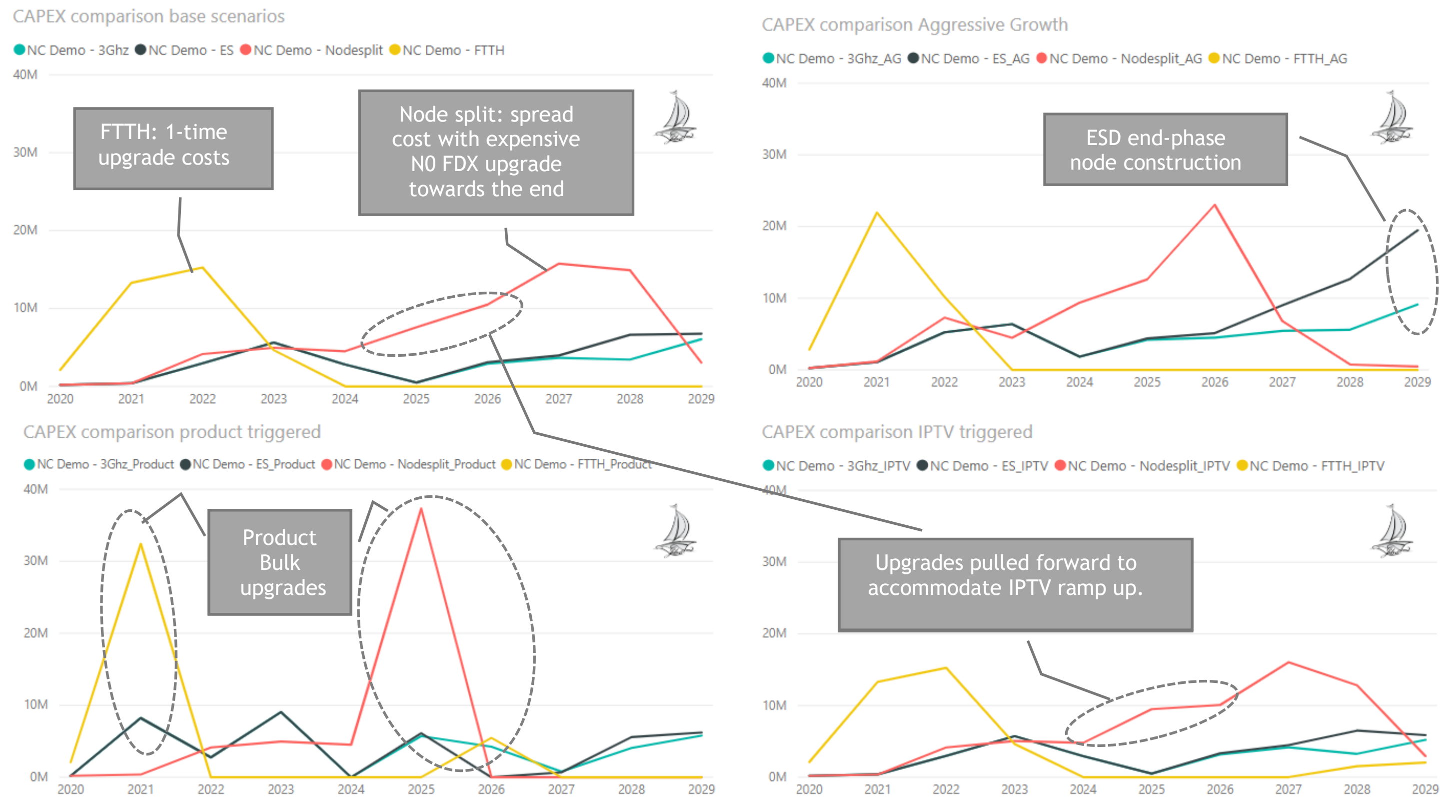
    a. Organic node split will not support the roadmap plan (as required in Appendix A): This is mainly due to the upstream capabilities and in later years the downstream capabilities. For example, maximum upstream capacity with nodes in full D3.1 is 124Mbps, the 100Mbps upstream product tier cannot be supported as it requires 110 Mbps of headroom and even small nodes have more than 14 Mbps of upstream demand.

    b. ESD+FD option has issues with 10G offering: Downstream 10G product needs will force further expansion of spectrum to 3Ghz.

    c. FTTH has a clear path of low-cost upgrades to requested product roadmap: Headroom created by 10G EPON will sustain the product needs, only introduction of 10G tier will force a technology refresh without construction impact.

While this high-level analysis gives some intuition on the sensitivity of scenarios and ability to support additional requirements, to truly understand the difference between the upgrade approaches, a comparison of key results over time is needed. The two key indicators shown in this application note are CAPEX per year and construction mileage per year. The pictures below show the comparison of the variations in the four upgrade paths.

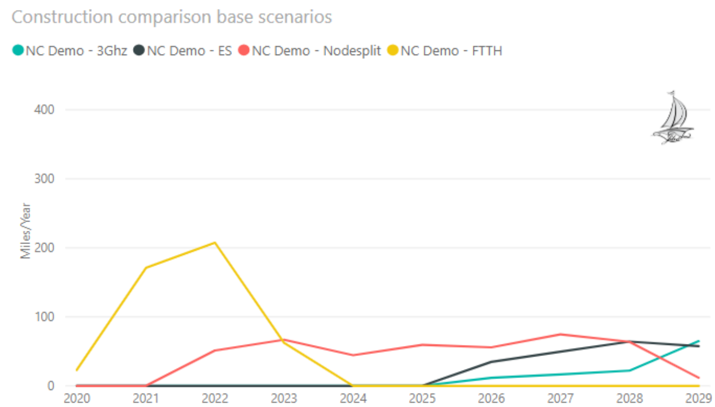
The following CAPEX comparison graphs provide a quarterly view on the investment profiles required to accommodate the scenario parameters. Here are some of the observations for each of these transformation paths:

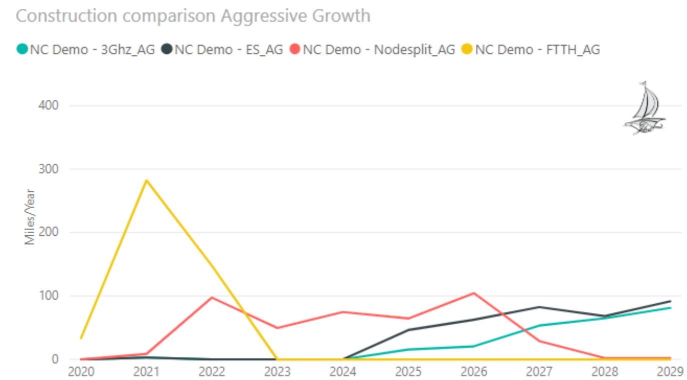


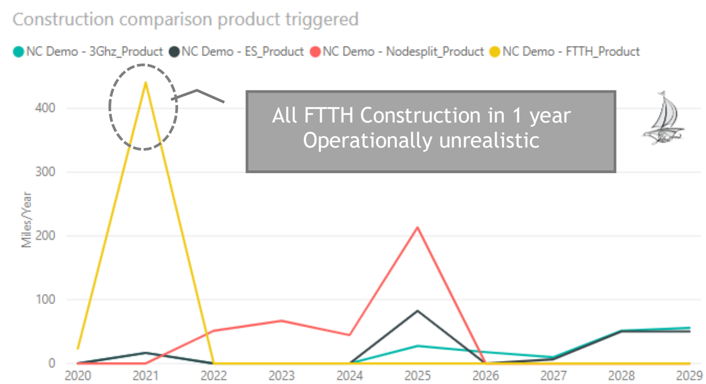
FTTH: With this scenario of moving nodes to 10Gig symmetrical technology, the first time an upgrade is performed significant headroom is created. As a result, in the basic growth-based scenario, the first upgrade is the only action required in the full 10-year period and thus all costs are incurred in the earlier years. In addition, with the enormous amount of headroom created by the first upgrade future requirements (except for 10G product tier) and aggressive growth have limited to no impact on the cost profile. In other words, the risk profile and input sensitivity of this scenario is extremely low. The 10-gig product tier in 2026 forces a technology upgrade to the next generation FTTH technology.

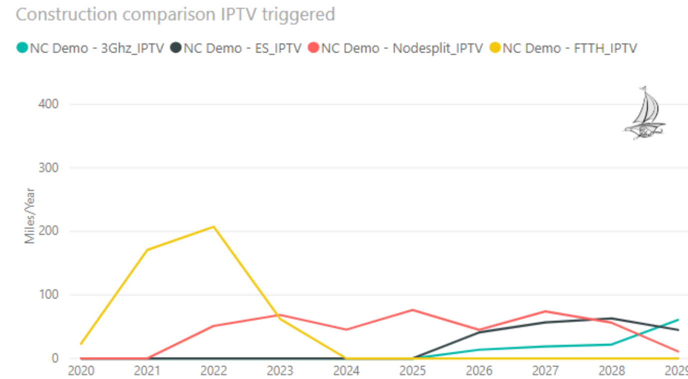
ESD: Both extended spectrum scenarios show very similar results with upgrade cost spread out over the 10-year period. The tail end shows an increase in cost specifically in the ESD-FD scenario as the last upgrade step requires many nodes to be split to N+0 fiber deep configuration. In the base case only a very small number of nodes run out of the capacity with 1.8Ghz option. In the aggressive growth scenario, the tail end cost of the ESD-FD option is clearly visible. In terms of product triggers the costs show clearly the bulk upgrades required each time a new product tier is introduced. It is also worth noting that the ESD-FD scenario does not support 10G product introduction and thus cost comparison for the product trigger scenario after 2026 is not completely valid for the ESD-FD scenario.

Node Split: The node split scenario represents a just in time approach with smaller increase of capacity each upgrade step (two-way split rather than larger segmentation). As a results costs are more smoothly distributed over the 10-year period with a higher upgrade frequency per node. The higher peak towards the tail end is driven by the fiber deep and expensive N+0-FDX upgrade step. The biggest problem with the node split scenario is the failure to support the product roadmap in any meaningful way. The cost shows a full bulk upgrade to the final N+0-FDX configuration as soon as it becomes available. This option is four years late for the 2021 product requirement, two years late for the 2023 product requirement and no upgrade option available to fulfill the 2026 product requirement.









The construction comparison graphs give further insights on the operational sensitivity of the different upgrade paths.

FTTH: Only one-time construction is required. Future upgrades are pure node technology and CPE technology upgrades. Here a significant upfront construction activity is anticipated which may not be feasible.

ESD: Construction is only required towards the tail-end of both ESD scenarios, as all initial upgrade steps are purely node and CPE technology upgrades. Construction during the tail-end for ESD-FD is required due to the N+0 state requirement for FDX. Construction for the ESD-3GHz is due to coax refresh at 3Ghz spectrum range and larger 3Ghz nodes running out of capacity requiring node splits to meet the demand.

Node Split: As expected this option shows a smooth construction profile, trailing of at the end when all nodes are in N0 state.

Conclusion

Massive impact of different triggers on the access transformation strategy advises that when planning a long-term strategy consider more than simple growth-based plan. This will help the operators direct their multi-billion-dollar investments wisely.

While analyzing “black and white” transformation scenarios gives a directionally correct understanding of the different options, they do not represent an implementable transformation plan. Many iterations will be needed to combine key elements of transformation paths to converge onto a plan that accommodates the complex set of real-world requirements and the implementation constraints.

The AP-Jibe toolset gives you the capability to quickly and easily adjust upgrade scenarios and analyze limitless number of what-ifs with easy to configure transformation triggers and constraints.

For more information on this application note contact us at contact@fpinno.com or +1-919-444-2270

Appendix A: Detailed scenario assumptions

The following table outlines some key Extended Spectrum technology assumptions used in this application note.

<table>
<tr><th>Name</th><th>Description</th><th>Upstream Capacity (Mbps)</th><th>Downstream Capacity (Mbps)</th><th>Year Available</th></tr>
<tr><td>D3.0</td><td>Spectrum = 1Ghz (Upstream 45Mhz)
Docsis 3.0: 16 downstream channels
3 upstream channels</td><td rowspan="2">93</td><td>684</td><td>2017</td></tr>
<tr><td>D3.1</td><td>Spectrum = 1Ghz (Upstream 45Mhz)
Docsis 3.0: 16 downstream channels
Docsis 3.1: 1 x 192Mhz downstream block
3 upstream ch. shared with 3.0</td><td>1500</td><td>2017</td></tr>
<tr><td>Full D3.1</td><td>Spectrum = 1Ghz (Upstream 45Mhz)
Docsis 3.1: 2 x 192Mhz downstream block
4 upstream channels</td><td>124</td><td>3000</td><td>2017</td></tr>
<tr><td>1 Ghz Midsplit</td><td>Spectrum = 1 Ghz (Upstream 85Mhz)
Docsis 3.1: 2 x 192 Mhz downstream blocks</td><td>450</td><td>3000</td><td>2021</td></tr>
<tr><td>D31 Highsplit 1.2 Ghz</td><td>Spectrum = 1.2Ghz (Upstream 204Mhz)
Docsis 3.1: 3 x 192 Mhz downstream block</td><td>1300</td><td>4500</td><td>2022</td></tr>
<tr><td>D31 Highsplit +1.8 Ghz</td><td>Spectrum = 1.8Ghz (Upstream 204Mhz)
Docsis 3.1: 8 x 192 Mhz downstream block</td><td>1300</td><td>11000</td><td>2023</td></tr>
<tr><td>FDX</td><td>Spectrum = 1.8 Ghz
Full Duplex symmetric configuration</td><td>10000</td><td>10000</td><td>2025</td></tr>
<tr><td>ESD 3 Ghz</td><td>Extended spectrum to 3 GHz</td><td>5000</td><td>25000</td><td>2025</td></tr>
</table>

The following table outlines the maximum tier product roadmap offered by the operator over a 10-year period.

	2021	2023	2025	2026
Downstream	1 Gbps	2 Gbps	5 Gbps	10 Gbps
Upstream	100 Mbps	1 Gbps	1 Gbps	2 Gbps

The following table outlines the IP Video penetration and consumption assumptions

HD Bandwidth: 6 Mbps
4K Bandwidth: 15 Mbps

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
IP Video Penetration (% Subs)	0%	0%	10%	20%	30%	50%	50%	50%	50%	50%
Streams per Video sub	0	0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
HD %	1	1	1	1	0.9	0.8	0.7	0.6	0.5	0.4
4K %	0	0	0	0	0.1	0.2	0.3	0.4	0.5	0.6
Average BW per Sub Needed	**0**	**0**	**1.5**	**3**	**5.2**	**9.8**	**10.9**	**12**	**13.1**	**14.3**