Creating an optimal access transformation plan – Understanding the problem

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What is the problem?

How do I create an implementable optimal access transformation plan, that gives me the most "bang for the buck"?

This first paper in the series looks at the process to get to the insights needed to define an optimal network transformation plan.

What's next:

- Tuning the selected optimal transformation strategy
- Applying constraints to create realistic plans
- Zoom in and refine with targeted deployment strategies

Key Takeaways

In this paper we observe:

- The optimal upgrade strategy is not intuitive
- The mathematically least cost solution is not necessarily deployable
- The greedy algorithms reflecting different upgrade strategies can create near optimal implementable transformation plans
- The lifespan of the network goes beyond the plan, future safeness must be a key factor in strategy selection

Key words: Access planning, optimization, strategy, speed tier, finance, operations

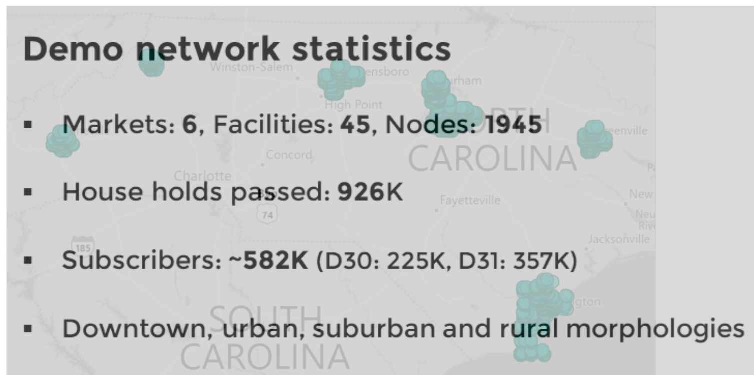
What is the problem?

Telecommunication networks are going through major transformations to meet insatiable bandwidth demand growth and to release new product speed tiers to stay competitive. Especially the access part of the network is affected the most by the changing requirements and it contributes to 90% of the yearly CapEx investments [1],[2]. Carefully planning the access network transformation is fundamental for a telecom operator's success. This requires a systematic approach to answering a lot of what-if questions with strong tool support, as discussed in previous papers [3],[4],[5].

After doing all the work using access transformation tools such as AP-Jibe [6] a solid plan will emerge. But the leaders and stakeholders will have a nagging question that remains – ***is this access transformation plan the optimal plan***? In this paper, we will show how to answer this question using a realistic HFC network transformation plan as an example.

The sample topology setup

The access network we used for this paper is an (imaginary) HFC network in the state of North Carolina, as shown aside, with characteristics that represent the current state of a typical cable operators' network. We took special care to select access **node characteristics** (such as type of customers, aerial versus underground, densities) in downtown, urban, suburban and rural morphologies.



Growth profiles (YoY)

	US	DS
Piedmont	30%	40%
Mountains	25%	35%
Coastal	30%	35%
Business heavy	32%	42%

One of the key inputs to any access transformation network model is the assumption on **subscriber demand growth**. For this paper, we kept the demand growth model relatively simple by assuming constant year-over-year growth without subscriber acquisition assumptions. As shown in the figure, we did include market-based differentiation and a special growth profile for nodes with a high density of business customers.

In terms of upgrade triggers (refer to the ***"When are access upgrades performed?"*** insert), to keep the results simple and easy to interpret, we modeled a simple utilization threshold trigger-based model and did not include any product or QoE triggers [7]. Note that the process used in this paper can also be applied to other triggers or a combination of multiple triggers.

The key part of building any access transformation plan is prioritizing the upgrade options one wants to consider. To create an optimal solution, we needed to include all possible upgrade options for each state of a node. In this paper, we included the possibility of different types of upgrades a cable operator might consider. These options include:

When are access upgrades performed?

Utilization threshold based trigger: Upgrade a network element when utilization reaches a predefined percentage of capacity (e.g 70%).

QoE based trigger: Upgrade a network element when a user can no longer burst consumption up to a predefined level.

Product trigger: Similar to QoE based triggers, with predefined level based on maximum speed tiers of the product roadmap.

Spectrum upgrades:

- Increase the upstream capacity through the mid split, high split, and full-duplex options
- Increase the downstream capacity by adding additional OFDM blocks or adding full-duplex blocks (can include the increase of the overall plant capacity by upgrading to 1.2 GHz or 1.8 GHz)
- Increase the capability of Fiber To The Home from XGSPON to NGPON2 or 100G PON

Node upgrades:

- Reduce the number of subscribers per node through node splits
- Reduce the number of subscribers per node through fiber deep options with N+0 FDX nodes
- Convert the HFC nodes to Fiber To The Home nodes

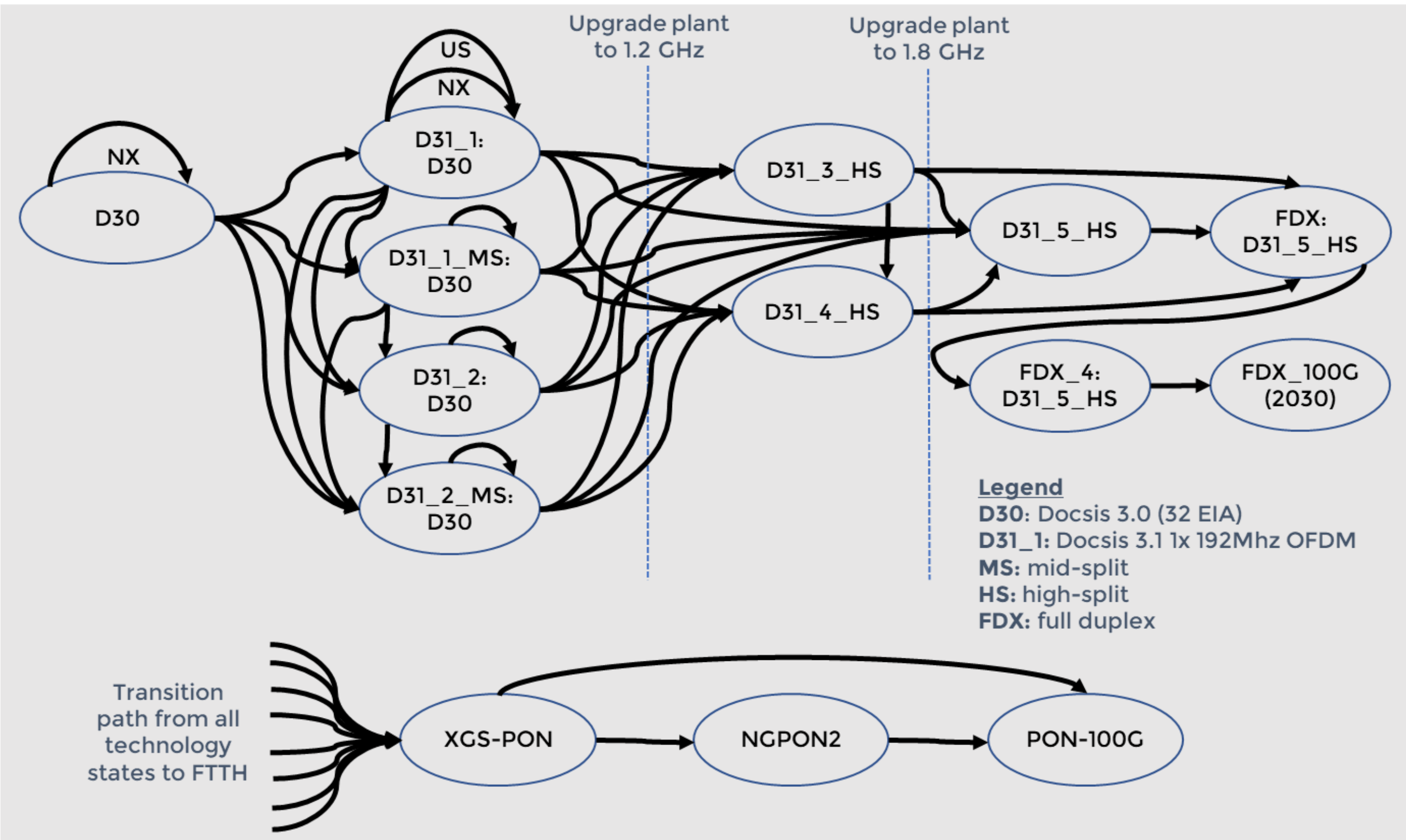


Figure 1 Different Hybrid Fiber Coax and Fiber To The Home access upgrade options considered in this paper

Figure 1 shows a graphical representation of all the upgrade options considered in the transformation plan used for this paper. The analyses used in this paper consider a 10-year quarterly plan.

The costs used for all upgrade actions in this example are based on the default cost included in the AP-Jibe tool. These costs are averages based on extensive industry research by our team.

Different upgrade strategies

The upgrades shown in Figure 1 are the art of the possible. An operator can manually specify the priorities of the upgrades, as shown in Figure 2. This provides the best control to the upgrade strategy but can be very cumbersome and requires an in-depth understanding of the option priority impact.

Technology State	Sync State	Option-3	Option-4	Option-5	Option-6	Option-7	Option-8	Option-9	Option-10
D30	PARENT_SYNCED	Add D31	Add D31_2	Add D31_MS	Add D31_2_MS	D30 Analog NS			
D31_1	PARENT_SYNCED	Move D30 to D31	TT_D31_1to2	TT_D31_1to2_MS	CT_D31toD31_3_HS	CT_D31toD31_4_HS	CT_D31toD31_5_HS	D31_1 Analog NS	NT_XGSPON
D31_1_MS	PARENT_SYNCED	Move D30 to D31	TT_D31_1_MSto2_MS	CT_D31toD31_3_HS	CT_D31toD31_4_HS	CT_D31toD31_5_HS	D31_1_MS Analog NS	NT_XGSPON	
D31_2	PARENT_SYNCED	Move D30 to D31	TT_D31_2to2_MS	CT_D31_2toD31_3_HS	CT_D31_2toD31_4_HS	CT_D31_2toD31_5_HS	D31_2_MS Analog NS	NT_XGSPON	
D31_2_MS	PARENT_SYNCED	Move D30 to D31	CT_D31_2toD31_3_HS	CT_D31_2toD31_4_HS	CT_D31_2toD31_5_HS	D31_2_MS Analog NS	NT_XGSPON		
D31_3_HS	PARENT_SYNCED	TT_D31_3_HSto4_HS	TT_D31_3_HSto5_HS	D31_3_HS Digital NS	CT_D31_3_HS_add_FDX	NT_XGSPON			
D31_4_HS	PARENT_SYNCED	TT_D31_4_HSto5_HS	D31_4_HS Digital NS	CT_D31_4_HS_add_FDX	NT_XGSPON				
D31_5_HS	PARENT_SYNCED	D31_5_HS Digital NS	CT_D31_5_HS_add_FDX	NT_XGSPON					
EPON	PARENT_SYNCED								
EPON_100G	PARENT_SYNCED								
EPON_10G	PARENT_SYNCED								
Eth_100G	PARENT_SYNCED								
Eth_10G	PARENT_SYNCED								
Eth_1G	PARENT_SYNCED								
FDX	PARENT_SYNCED	Move D31 to FDX	NT_XGSPON						
GPON	PARENT_SYNCED								
NGPON2	PARENT_SYNCED								
XGS-PON	PARENT_SYNCED	TT_XPON_NGPON2							

Figure 2 Manually created access transformation upgrade options

As an alternative to the manual upgrade strategy, the operator who uses AP-Jibe can use different corporate strategies as a guiding principle to pick the best upgrade paths. The following are the three common classes of corporate strategies (implemented in the AP-Jibe tool with greedy algorithms, as explained in the insert "***Greedy versus exhaustive algorithms***"):

Kick the can down the road: In this strategy, when a node needs to be upgraded, the preference is to pick the lowest cost option that satisfies the upgrade requirements. This is the *lowest cost* greedy optimization algorithm in AP-Jibe.

Minimize network upgrade actions (capacity-based): In this strategy, when a node needs to be upgraded, the preference is to pick the viable option that provides the most added capacity to the node. That is because, intuitively, upgrade options that add the highest capacity will survive from upgrades the longest. Using this option mitigates the risk against unforeseen demand growth increases (e.g. the Covid-19 pandemic impact). This is the *highest capacity* greedy optimization algorithm in AP-Jibe.

Least cost per capacity: A middle ground strategy tries to lower the network upgrade frequency and provide some growth risk mitigation without always using the biggest upgrade step. This upgrade strategy picks the viable upgrade option with the least cost per added bit of capacity. This is the *least cost per bit* greedy optimization algorithm in AP-Jibe.

Recently operators have been focusing more network evolution strategies that combine demand growth with Quality of Experience (QoE) triggers [7] also refer to as K-factor triggers based on the formula:

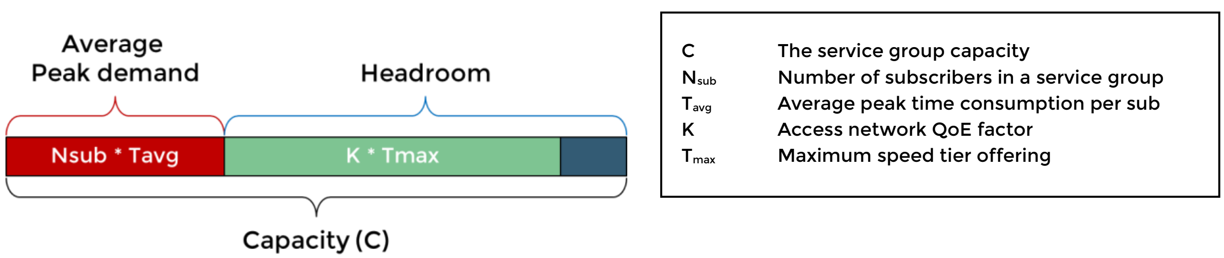


Figure 3 Quality of Experience based capacity allocation

> **Greedy versus exhaustive algorithms**
>
> Greedy algorithms: These are the algorithms used to select the optimal upgrade option based on the selected criteria. The option is selected without any knowledge of the future needs.
>
> Exhaustive algorithms: These algorithms evaluate all viable upgrade paths for the full duration of the analysis and pick the optimal path based on a optimization criteria such as minimize total cost.

K-Factor triggers are also commonly used to incorporate future speed tier roadmap requirements into the access transformation plan.

Upgrades based on K-factor triggers are driven by the available headroom (see Figure 3) on an interface or service group rather than the capacity available per subscriber on the network. It, therefore, makes sense to include alternative upgrade strategies that focus on headroom rather than capacity.

Minimize network upgrade actions (headroom-based): In this strategy, the preference is to pick the option that adds the most headroom to a node's interface. The maximum speed tier an operator can deploy on an access link is bounded by the available headroom. A higher headroom strategy is the best hedge against competitive threats. This is the *highest headroom* greedy optimization algorithm in AP-Jibe.

Least cost per headroom: In this strategy, the preference is to pick the option with the least cost per added bit of headroom. This is the *least cost per headroom* greedy optimization algorithm in AP-Jibe.

In its latest release, AP-Jibe includes the capability to select an algorithm that reflects one of these 5 upgrade strategies. This allows for an easy way to compare the impacts of the different upgrade strategies on the network transition plan.

Being able to compare results for these strategies side by side, creates very valuable insights and allows you to quickly refine your transformation plan and pick a strategy that is closest to your vision.

However, it still does not answer the question: **What is the optimal transformation model?** To answer the question, we need to create a reference point for the best solution given the customer demand growth parameters, transformation upgrade triggers, and available access upgrade options.

The most apparent optimization criteria for a network transformation are the total investment cost or the net present value of the total investment cost. With all the possible upgrade paths available in the model, it is possible for each node to **exhaustively** calculate all the viable upgrade paths and pick the path that offers the least investment (cost or NPV). For this paper, we defined two different such exhaustive criteria to determine what the *best solution* means:

- **The lowest NPV**: In this exhaustive optimization criteria, for every node in the network, pick the upgrade path that keeps the node compliant with the needs and has the lowest total present value for all the upgrade costs incurred during the analysis period.
- **The lowest cost**: In this exhaustive optimization criteria, for every node in the network, pick the upgrade path that keeps the node compliant with the needs and has the lowest total cost for all the upgrades incurred during the analysis period.

The optimized access transformation insights

With the setup and the upgrade strategies explained, we can compare the results side by side to develop relevant insights. Note that the results are very dependent on the scenario inputs, what upgrade strategy is favorable will depend heavily on the upgrade options that are being evaluated. It is therefore not the intention of this paper to draw specific conclusions, but rather focus on the process and type of insights gained by this type of analysis.

One key set of inputs not explained in this paper are the costs incurred for different transitions. The costs used in this example are the default costs included in the AP-Jibe tool. The costs are based on the extensive market research done by our team.

Results names used in all the graphs include the algorithm or optimization criteria used and are formatted as follows:

- …BestNPV: results are calculated using exhaustive node optimization algorithm using NPV
- …BestCost: same as above, but uses the total cost
- …LC: the lowest cost greedy algorithm
- …HC: the highest capacity greedy algorithm
- …LCB: the lowest cost per bit greedy algorithm
- …HH: the highest headroom greedy algorithm.
- …LCHR: the lowest cost per headroom greedy algorithm
- Scenario name starting with “All” contains the full state machine
- Scenario name starting with “HFC” contains the transition options to FTTH were removed

Side by side comparison of five greedy optimization upgrade strategies

Figure 4 shows the results of the transformation scenarios with different greedy optimization algorithms for a ten-year quarterly analysis.

The **lowest cost algorithm** requires the highest number of upgrade actions to the network (28K vs 2K) compared to the high capacity option. Looking at the total cost over the full 10-year period it is the most expensive of the solutions. After exhausting the spectrum upgrade options it favors node splits over the expensive upgrade to FTTH or N+0 FDX.

The **highest capacity algorithm** has the lowest number of upgrade actions (2K). Since the optimization option selects XGS-PON (the highest capacity option) from any state, it will be selected immediately requiring only the single upgrade for the network element in the ten years. As a result, to total cost is comparatively low but NPV is relatively high since all the expensive upgrades happen in the early years.

The **lowest cost per bit algorithm** favors larger spectrum upgrades in the early years and pushes the expensive upgrade to FTTH out to later years. As expected, the option limits the number of upgrades needed while pushing the very expensive upgrades to later years. NPV is significantly better than the highest capacity optimization while keeping total cost in check.

The **highest headroom optimization** in this scenario is the same as the highest capacity optimization.

The **lowest cost per headroom algorithm** is similar to the lowest cost per bit optimization that favors larger spectrum upgrades in the earlier years and pushes the expensive upgrade to FTTH out to the later years. The difference with the lowest cost per bit is that this optimization favors spectrum upgrades over node split actions compared to the lowest cost per bit algorithm. It can be observed in the middle of the footprint graph where nodes in the D31_2_MS state are split instead of upgraded to XGS-PON.

Figure 4 Access transformation comparison of five greedy optimization algorithms

How do the greedy algorithms fare compared to the exhaustive optimization analysis?

The greedy algorithms reflect the logical transformation strategies that align with the normal deployment behavior. The big question remains, how do these solutions compare to the minimum possible NPV or cost for this scenario? To answer the question one needs to compare the best path solutions (identified by the exhaustive search algorithms) with the greedy algorithms, as shown in Figure 5.

The **lowest NPV exhaustive optimization** solutions are used to calculate the optimal path on each node individually. Given the difference in the node characteristics (aerial versus underground, the composition of the subscribers, growth profiles, etc.) it is no surprise to see the different end states after the ten-year analysis. Given that the algorithm is trying to find the lowest NPV, it will favor

- smaller upgrades in the earlier years
- in the middle years, large step upgrades are favored for nodes that need higher capacity (to avoid intermediate regrettable upgrades), and
- the minimal possible upgrades to last till the end of the ten years in the later years.

While indeed the BestNPV offers the lowest net present value cost of all options, it is only marginally better than the LCHR (lowest cost per headroom) option and leaves the network in a state that will require more upgrades soon. Arguably, the LCHR option is a much better upgrade path. The other major concern with the BestNPV option is that by design it will create very divergent upgrade paths, which can be an operational and logistical nightmare.

A logical explanation for the smaller upgrade behavior in the later years is that the algorithm selects the path with the minimal NPV for the exact 40 quarters that are analyzed without considering the end state of the network. For a node, a cheaper upgrade that is viable till the end of the analyzed period will be selected over a more expensive upgrade that may provide a much longer lifetime for the upgrade. This effect (we call it the *Artificial Exit Phenomenon*) will be discussed later in the paper.

The **lowest cost exhaustive optimization** solution is very similar to the highest capacity strategy. It will strive to execute large transitions early, only executing a single upgrade for most of the nodes. The major difference between the HC and the BestCost solutions is that the BestCost will avoid large upgrades for nodes that can survive the ten years without expensive transitions.

Figure 5 A comparison of different transformative options using exhaustive and greedy algorithms

What is optimal and how to create a fair solution comparison?

From the observation on the BestNPV and the BestCost calculations, it is apparent that a straight comparison of different options for a fixed analysis period is going to be unfair if the different options leave the network in different end-states. This unfairness that is created by limiting the period of the analysis is what we called *The Artificial Exit Phenomenon* . Ideally, for a proper comparison of different optimization algorithms, we need a fairness factor that can capture the value of the exit state of the network. Unfortunately, we do not have such a magic formula - *yet*!

To illustrate the *Artificial Exit Phenomenon* even further we can look at the impact of the unfairness created due to the abrupt termination of planning by extending the planning horizon, as shown in Figure 6. In **Error! Reference source not found.**Figure 6, we show the BestNPV algorithm applied to the same network with the same rules but for extended analysis periods. The side-by-side comparison shows the BestNPV path for a 10-year, 12-year, 13-year, 14-year, and 15-year period.

Figure 6 Demonstrating the unfairness or *Artificial Exit Phenomenon* due to limiting the analysis period in later years

Note: the statistics shown in the top half are for the individual calculation period and are not normalized.

Looking at Figure 6, it becomes apparent that for the *lowest NPV optimization* calculation algorithm the end state is driving the optimal upgrade selections in the terminal years. This begs the question, what is considered the "best" path for the next ten years. Note that we do not build networks for a fixed period and they need to keep evolving. Therefore optimizing for a fixed duration makes no sense. The optimal solution should consider the future impact of the chosen upgrade path. This forces us to implement a fairness factor in the terminal years, which we will discuss in a later paper in the series.

Now that we identified the reference solution using a 15-year analysis horizon, we can bring the greedy algorithms back into the picture to find the optimal "deployable" strategy. The upgrade decisions made by the different greedy algorithms are purely based on node state, node attributes, and upgrade options available at the point of analysis and do not take future upgrades into account. This makes the process easier in the sense that a longer analysis period will not influence the upgrade choices made by the greedy algorithm. However, to compare algorithms against the BestNPV reference solution the same problem of the value of the end-state of the network still applies. This issue is resolved in the current paper by considering a 15-year analysis for a 10-year horizon.

In Figure 7, we use the BestNPV the BestCost solutions as a yardstick to measure the effectiveness of the greedy optimization algorithm. Note again that the greedy algorithms are the deployable solutions. Here are some of the observations:

Figure 7 Comparing different exhaustive and greedy alorithms for better insights

- We did not consider the BestNPV or the BestCost as valid deployment strategies as they are node-specific and are considered more for identifying a cost reference.
- Ths Highest Capacity greedy algorithm tracks the BestCost solution as the algorithm immediately forces to get the highest capacity solution with little regard to the cost of execution.
- The Lowest Cost per Bit algorithm gives a better option than the HC algorithm but increases the number of nodes due to selecting FDX for some of the non-business nodes.
- The Lowest Cost per Head Room tracks very closely to the BestNPV solutions and has the best cost results.

Conclusions

The goal of this first paper was to create a better understanding of what does it mean when the leaders ask the question **What is the best transformation strategy for my access network?** With the analysis shown in this paper, we created insights on what can be considered an optimal transformation strategy for a given scenario. Here are some of the recommendations for the operators to consider:

- Develop a mentality to analyze your long-term access transformation strategies
- Ask the right questions and evaluate the implications of your needs on your transformation, and

- Optimize the transformation strategy by evaluating and selecting the right upgrade strategies

The AP-Jibe toolset has the features to allow us to answer all these questions and more. Look out for future papers in this series with the answers !!

Any questions or thoughts reach out to luc@fpinno.com

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