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Effective Business Modeling for Selection of Gigabit Service Delivery Technologies

A Technical Paper prepared for SCTE/ISBE by

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Abstract

Consumer demand for faster data rates and increased consumption is driven by new technology and applications such as ultra-high definition (UHD) televisions and over-the-top (OTT) viewing options, as well as by marketing and competition. The Access Network can meet increased demand and consumption with a variety of technologies including Ethernet Passive Optical Network (EPON), Gigabit Passive Optical Network (GPON), and Data over Cable Service Interface Specification (DOCSIS). However, the process of selecting which of these technologies and supporting infrastructure to use is complex. The service provider must evaluate the technical merit and cost effectiveness of a given technology when applied to different deployment scenarios present in their network.

It is typical for functional areas involved in selecting technologies and vendors for the service provider's network to work in isolation from one another. Engineering, Finance, Supply Chain, and Operations are all participants in the technology selection process, but many times they do not speak the same language. Frequently, this results in an inefficient use of time, a slow and confusing decision-making process, and occasionally, a sub-optimal and more costly technology choice, due to misaligned objectives or misunderstood requirements.

To avoid a sub-optimal decision outcome, it is critical for all stakeholders to have a common understanding of the decision-making process and the objective to be achieved by making the decision. Defining a single cost metric or set of metrics to normalize solution costs across technologies and vendors enables decision-making participants from all functional areas to understand the decision options and how those available options align with the decision objective.

In this paper, we will propose and describe a standardized cost modeling methodology for performing financial analysis on network solutions and their related in-home components. The paper will demonstrate how to identify, aggregate, and analyze requirements, bills of material (BOMs), and other data to develop models for various sample use cases, eventually calculating a single cost metric to use for comparison across technologies and vendors.

We will also include reference architectures for the access network and in-home network, considering today's technologies and the technologies expected to be available in the near future.

Introduction

1. The "Need for Speed" Landscape

On March 30, 2011, Google officially announced their plan to bring ultra high-speed broadband to Kansas City, Kansas. Since then, "need for speed" has become synonymous with 1 Gbit/sec Internet speeds delivered over fiber technology and to the premises. On December 12, 2012, Google cemented this seismic shift in speed expectations by announcing their plan to offer GoogleFiber as a product in cities throughout the U.S.

Figure 1 is a compilation of highest data rate offerings by different service providers in the North American market. In this Figure, downstream trends are indicated by solid lines and upstream trends are indicated by dashed lines [1]. At the time of this paper's writing, Comcast has already made 2 Gbit/sec service available via fiber and 1 Gbit/sec broadband service available in select markets using DOCSIS 3.1. Comcast is further discussing the next phase of multi-gigabit speed with a blended tool kit of both hybrid fiber coax (HFC) and fiber-based technologies. Applying Nielsen's Law of Internet Bandwidth, by the year 2020, it is conceivable for residential broadband to be in the 10s of Gbit/sec and new market dynamics enabled by next generation access technology prompting service providers to reach the 100 Gbit/sec speed frontier shortly thereafter.

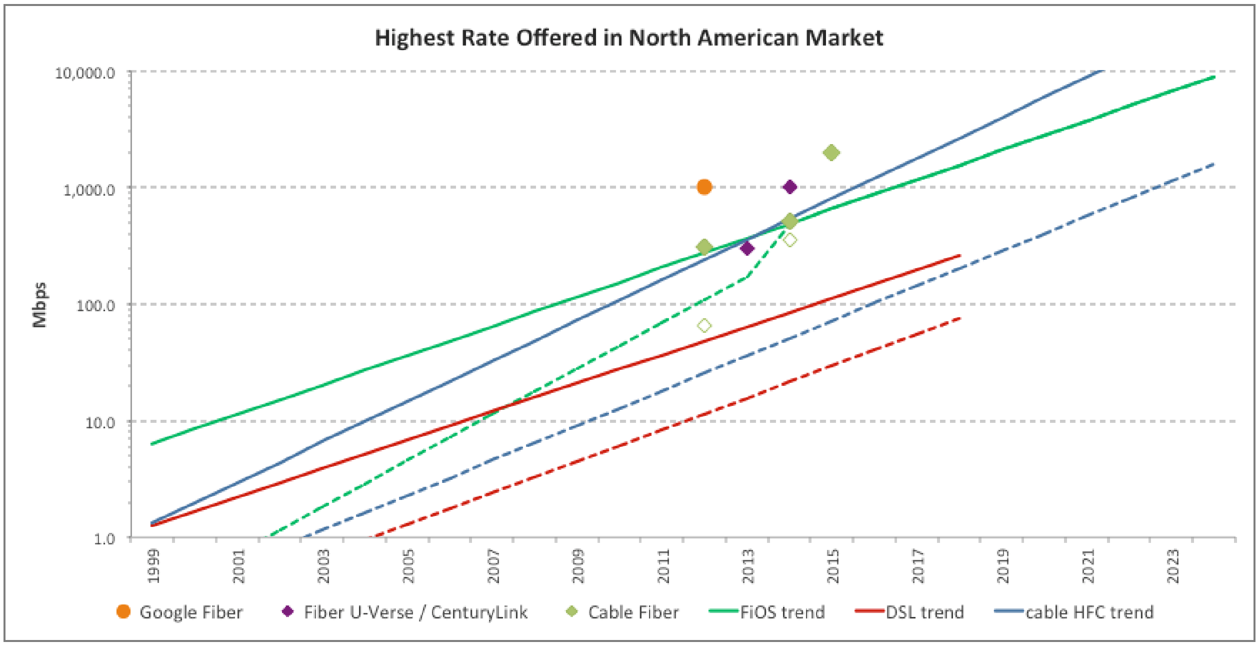


Figure 1 - Maximum North American data rate offerings [1]

2. Related Work

Literature on cost models for the communications and technology industries in peer-reviewed journals or other forums is surprisingly lacking. We found no papers presenting cost models in the SCTE archives and only one similar paper in the IEEE archives. [2] describes a cost model of fiber to the x (FTTx) vs. Worldwide Interoperability for Microwave Access (WiMAX) networks, as well as a technical breakdown of the network and cost model, but the paper neglects the aspects of cost modeling related to communicating across multiple disciplines within an organization. [3] describes a method of optimizing costs in a wireless access network- a valuable addition to any cost modeling methodology.

Beyond these papers, the reader is recommended to read or reference publications such as [4], [5], [6], [7], [8] for additional resources on data analysis, cost modeling, data visualization, and their cross-functional uses.

Content

3. Scope of Paper

There are numerous costs associated with building out, adding on to, or changing access network technologies, including Capital Expenditures, Operating Expenses, and other Total Cost of Ownership (TCO) considerations. We will list many of these costs so the reader may also consider them and choose which to add to their own model(s); however, the “how-to” model in the case study will be limited in scope to specific costs listed in the model assumptions and will primarily focus on Capital Expenditure aspects of access network technology choices.

This paper will serve as a foundation for a “how-to” guide for analyzing different technology options based on various use cases in a way that can be understood by all stakeholders involved in the decision-making process, including (and especially) those non-engineering stakeholders whose support is necessary for final decision-making and funding of access network technology purchases.

The goal of this paper is to describe a standardized cost modeling methodology that can be used to evaluate various access network technologies to satisfy the requirements of a particular deployment scenario in the service provider’s network. The purpose of this standardized modeling process and the metrics it produces is to enable all stakeholders to have a common understanding of the decision-making process and the criteria by which to evaluate available technology options in order to make an informed, effective, and efficient deployment decision in a non-siloed, cross-functional manner.

With this paper and its associated cost models, we will attempt to answer the following questions:

1. How can one determine which access network solution is most cost effective, given a particular set of requirements?
2. How can the capabilities and costs of different access network technologies and vendor solutions be normalized for comparison in a way that is understandable by both engineers and non-engineers alike for the purposes of more efficient and effective decision-making?

4. “Need for Speed” Drivers

To meet market pressure for the “need for speed”, service providers must upgrade their access networks to meet consumer demand for ultra high-speed broadband. This increased demand results primarily from:

1) Increased consumption driven by new technology and applications (e.g., OTT and IoT applications,4K/UHD & VR content delivery)
2) Competition from new industry entrants providing gigabit speeds
3) Changing customer expectations of the “new normal” for high-speed internet (e.g., broadband and mobile customers)

Since the requirement to upgrade access networks to provide gigabit speeds is unavoidable, each service provider must decide which technologies to use to achieve these ultra high-speeds and under what circumstances to use a given technology or architecture.

5. Current-State Decision-Making Processes

Many service providers take a siloed approach to decision-making. Often this siloed approach is not intentional, but rather a default state companies adopt in the absence of a push toward cross-functional decision-making.

A siloed decision-making process can begin in any functional area. Figure 2 depicts examples of possible starting points: perhaps Engineering learns of a new technology it can deploy to improve network efficiency. Marketing devises a campaign to sign up new customers by offering a new product or service, but forgets to consult Engineering or Operations before launching the campaign. In another example, a service provider may fall into the Engineering/Supply Chain technology trap: a vendor contacts Supply Chain offering a reduced price on a product and because Supply Chain's goal is to save money, it may order this equipment without confirming whether Engineering and Operations need it or if it still meets the company's technical needs.

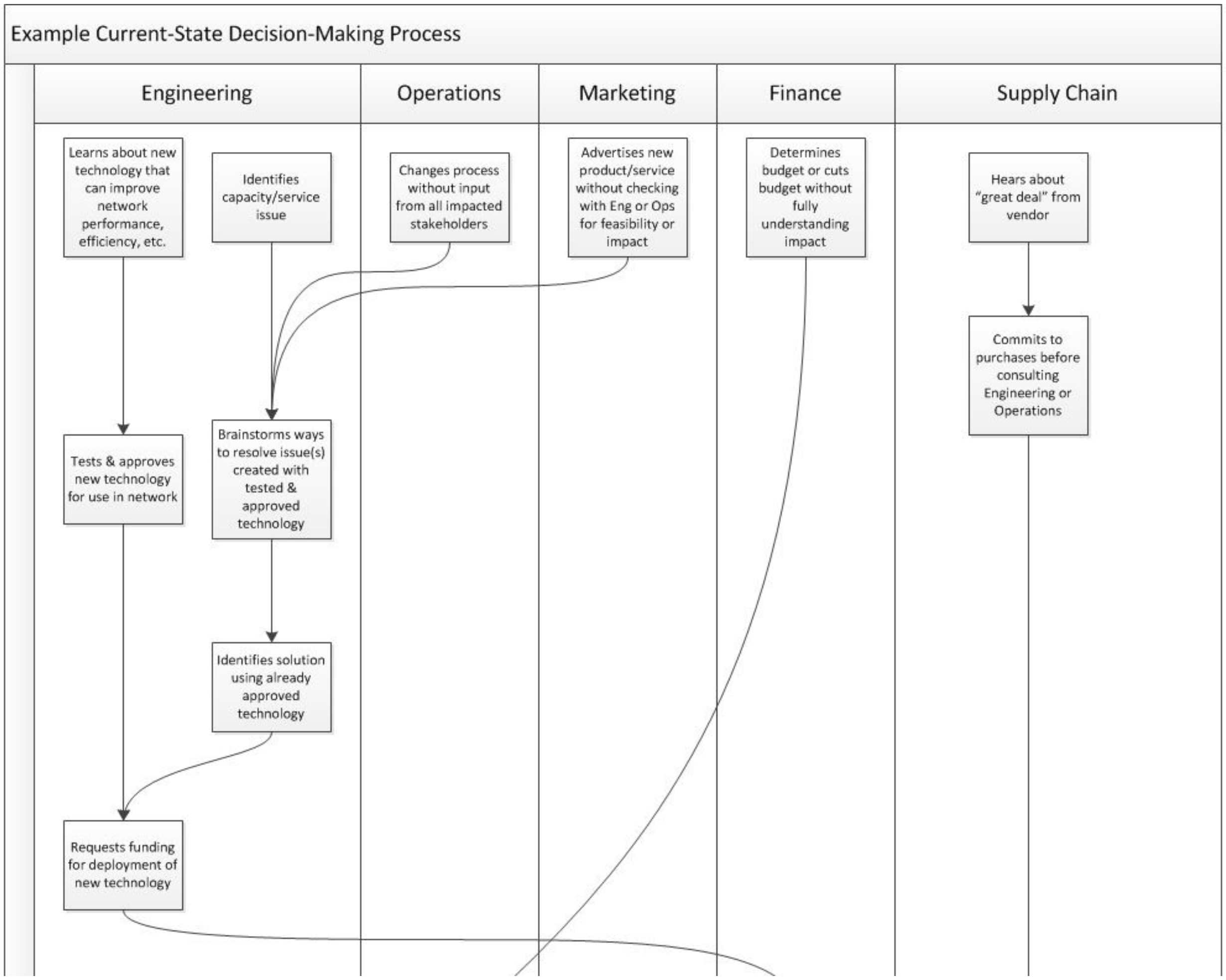


Figure 2 - Example Decision-Making Process – How It Starts

Once a siloed decision-making process has begun, it is difficult to bring functional areas together and get "back on track". Often communication issues and misunderstandings compound as other functional areas attempt to catch up with the silo that kicked off the process in an attempt to make up for not having been involved earlier in the decision-making process.

Figure 3 demonstrates the miscommunication and misunderstanding loop that can occur between Engineering and Finance around budget and funding. Becoming stuck in this loop is a common cause of inefficiency in technological decision-making. Engineering and Finance organizations are comprised of individuals with very different backgrounds and expertise and the two organizations may have different or even conflicting objectives, so it can be difficult for them to understand each other and align on a path forward. It may sometimes feel as though a translator is needed to help these two groups communicate.

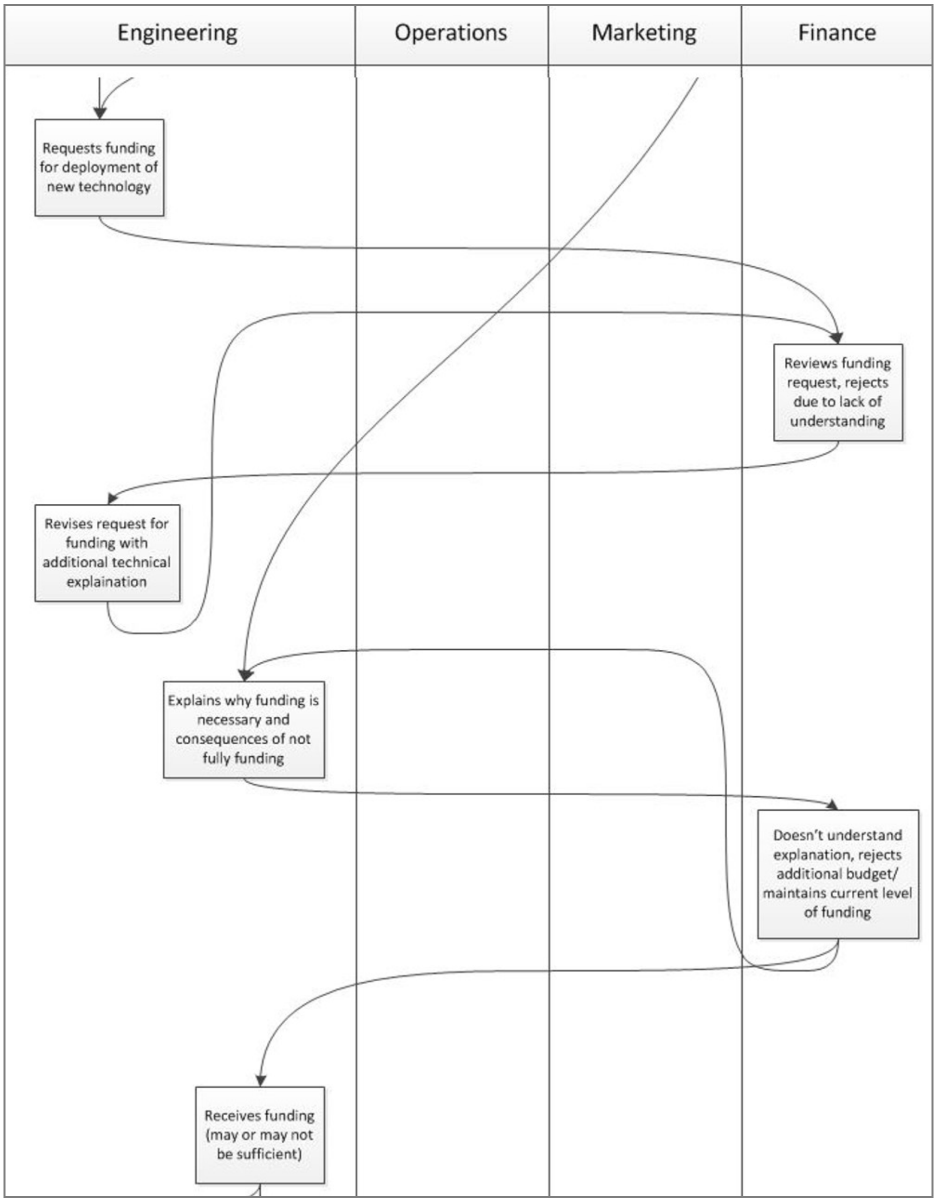


Figure 3 - Example Decision-Making Process – The Finance/Engineering Loop

In Figure 4 of our example current-state decision-making process, the fact that a siloed decision-making process leads to suboptimal outcomes becomes clear: in each case, the functional areas that did not initiate the process experience dissatisfaction with the outcome of the decision.

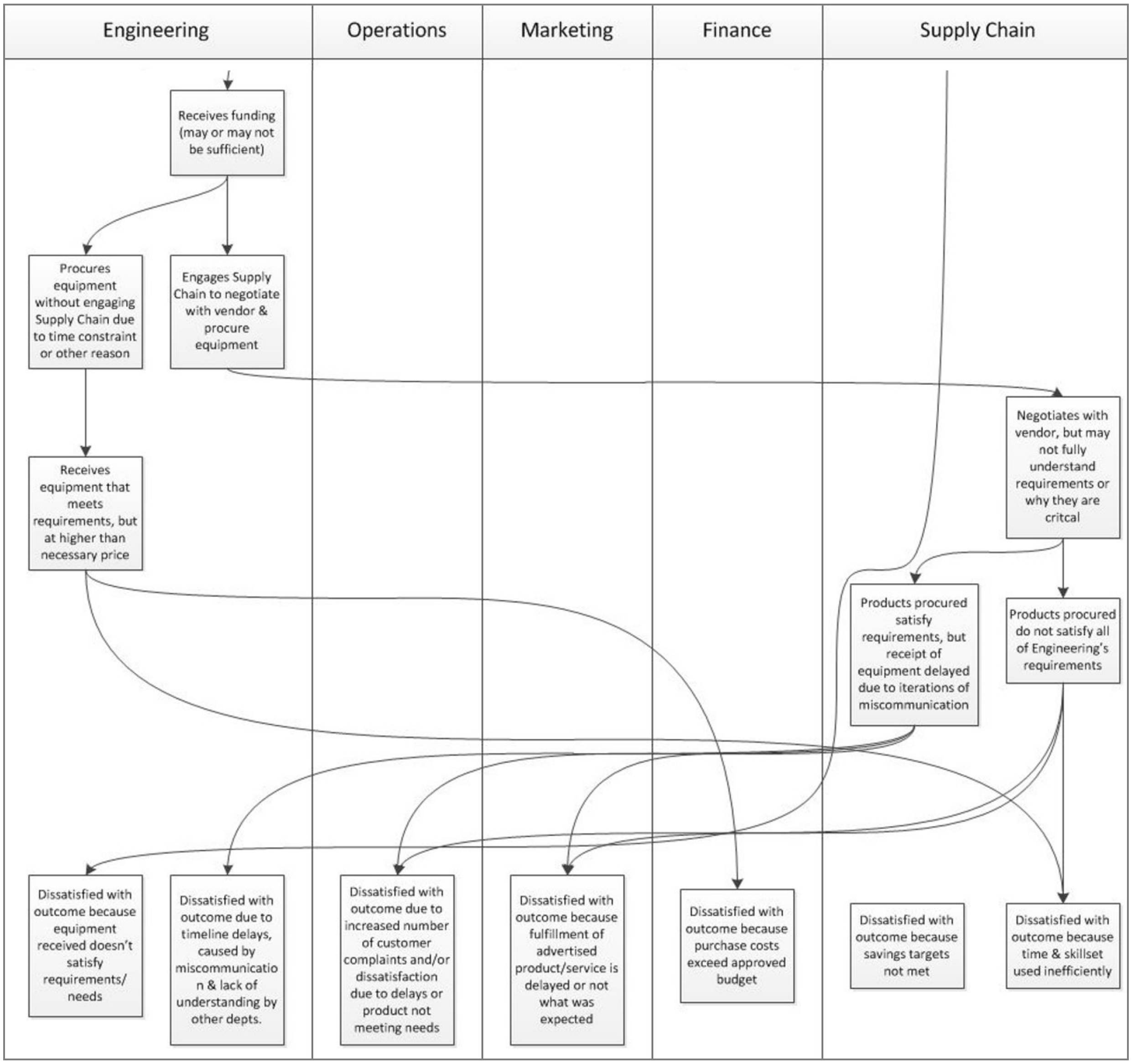


Figure 4 - Example Decision-Making Process – Results

In addition to individual functional areas experiencing dissatisfaction and suboptimal outcomes as a result of a siloed decision-making process, the company as a whole experiences inefficiencies by spending time on non-value added activities, paying more than necessary for products and services, or experiencing increased costs through rework, extended timelines, or reduced customer service.

An environment where decisions are made in isolation only exacerbates the typical miscommunication and misunderstandings which arise when functional areas interact. In each example above of suboptimal outcomes, one can see that if only the various functional areas had interacted, collaborated, and understood each others' needs earlier in the decision-making process, the poor outcome could have been avoided or its impact reduced.

6. Recommended Decision-Making & Modeling Process

The primary goals of our proposed decision-making process are to improve decision outcomes, to reduce suboptimal technology choices, and to avoid higher than necessary costs. In support of these overarching goals, there is also a secondary objective related to the access network cost modeling methodology which is the foundation of this decision-making approach: develop a cost per measure of capacity metrics by which technologies and vendor solutions can be normalized and compared, and which are understandable to all stakeholders.

While we cannot claim the techniques described in this paper will solve all issues related to access network decision-making, we do propose ways to reduce the miscommunication, misunderstandings, and misalignment of objectives between functional areas in order to create a more efficient and effective decision-making process.

Whether the cross-functional team involved in the access network decision-making process is created formally or informally, is recommended the team contain representatives who are empowered to make decisions for their functional areas. Participation and input from the following areas is recommended: Engineering, Operations, Supply Chain/Procurement, and Finance.

In order to more effectively and efficiently drive the decision-making process, at least one person on the cross-functional team should have an understanding of the technical **and** business requirements, as well as financial and data modeling concepts. This person can be an engineer with financial skills, a finance or supply chain person with a good understanding of technology, or a member of a dedicated analytics team – the key is that this person has a combination of skillsets: 1) a basic understanding of the access network technologies involved and the ability to communicate with Engineering, 2) a basic understanding of finance and the ability to communicate with Finance representatives, and 3) an understanding of and ability to implement data modeling best practices to create the analysis on which the cross-functional decision will be based.

This individual will be responsible for bringing the various functional areas together – not as a project manager, but as a communicator and data modeler. This individual will also be responsible for ensuring all requirements and needs are heard, shared, and incorporated into the decision-making analysis in a way that representatives from all functional areas can understand. This individual, because of his/her understanding of multiple functions, can serve as a translator between functional areas and reduce the time spent in these non-value added activities.

It is preferable to make the decision cross-functionally, because to optimize the decision, one needs to consider both the set of technical solutions that best fit the deployment scenario requirements **and** the cost of each technical solution compared to the other proposed solutions, as well as across vendors. The decision making process must be a collaborative effort; otherwise the probability of a suboptimal outcome is high.

There should also be a project sponsor on the team with the authority to weigh tradeoffs between functional areas and make a decision in the event that the optimal choice benefits the company as a whole, but has an outcome which is not ideal for a particular area and the cross-functional participants are unable to reach agreement.

In summary, to reduce the probability of a suboptimal decision-making outcome, we recommend the following steps for creating an effective decision-making team:

1. Identify the functional areas potentially impacted by the decision early in the decision-making process.
2. Identify representatives with decision-making authority from each area to participate in the process.
3. Designate a project sponsor with the authority to weigh tradeoffs between functional areas and make a decision in the event that a certain course of action benefits the company as a whole, but has an outcome that is not ideal for a particular functional area.
4. Understand the potential impacts of the decision to each functional area and how those impacts fit (or do not fit) with that group's short-term and long-term objectives.
5. Agree upon an objective (i.e., a preferred end-state) and a preliminary strategy to achieve this objective.
    a. Example objective: To deliver gigabit speeds to our customers for the lowest TCO, while also being mindful of impending technology changes and technological obsolescence.
    b. Example strategy: Model the costs of different technology and vendor options that meet technical requirements; then negotiate with the vendors whose technology most closely aligns with our requirements and whose costs are reasonable and within range of our budget.

7. Decision-Making & Modeling Process Steps

The first step in an effective decision-making process is to identify the decision to be made, the objective, and an initial strategy. This may sound simple, but it is not uncommon to get part way though a project and discover different functional areas involved had different ideas about the objective and the decision to be made. It is best to state the decision and the objective to be achieved by making this decision up front to reduce misunderstandings and misalignment of expectations.

Using the example of an access network transition to providing gigabit service, the steps for gathering information and constructing a model are as follows:

1. **Document Network Architecture:** Document current state and future state network architecture to support transition to gigabit service delivery.
2. **Document Technical Requirements:** Document technical requirements necessary to achieve gigabit service delivery.
3. **Identify Gaps:** Identify and document gaps/changes required to move from current state to future state network architecture, as well as any network constraints.
    a. Example constraints: legacy equipment installed in network, locational variables (e.g. rural vs. urban deployment, hub space limitations).
4. **Identify Technologies:** Identify technologies to bridge gaps and meet technical requirements associated with upgrading the network.
    a. Note: for the remainder of this list, we assume a model is being created to compare EPON and DOCSIS solutions to each other; however, this same modeling methodology can be applied to any technical solution where there is not a 1-to-1 relationship of capacity (i.e., amount of service/function provided) across technologies or vendors.

5. **Develop Model – Enter Technical Requirements, Assumptions, and Inputs:** Structure the model so it is easy to use and easy for decision-making process stakeholders to understand. Add relevant technical requirements, assumptions, and other inputs.
6. **Identify Relationships:** Identify the relationships between equipment components and requirement fulfillment.
7. **Create Bills of Material**: Based on requirement fulfillment and technology/equipment-specific constraints, create a BOM to represent the "standard configuration" for each technology, use case, and vendor option under consideration.
    a. Note: We acknowledge there will be variation in configurations deployed throughout the network, but for modeling and cost comparison purposes one must identify a configuration to best represent the network as a whole.
8. **Calculate Units of Capacity:** Identify, quantify, and calculate the units of capacity provided by the standard configuration (e.g., gigabits per chassis).
9. **Create a "Cost Equivalency Metric":** Use solution-specific data (e.g., number of ports, number of line card slots) to normalize costs between technologies and vendors and calculate an equivalency metric, such as cost per measure of capacity (e.g., cost per gigabit) to serve as a way to compare all technologies and vendors under consideration for the access network solution in an apples-to-apples manner.
    a. This cost equivalency metric is how representatives from all functional areas can understand and compare solution and vendor options. It is a metric everyone can use for comparison without functional expertise in a certain area. There are no further conversions or calculations needed to understand the options available to the company for upgrading its access network to provide gigabit service.
10. **Enhance Model:** Once a cost equivalency metric is created for the technology equipment under consideration to be the foundation of the access network upgrade, the model can be expanded to include maintenance costs, outside plant (OSP) buildout/upgrade costs, access termination equipment (ATE) and customer premises equipment (CPE) costs, energy and critical infrastructure costs, or any other ancillary costs important to the decision-making team.
    a. The key to maintaining the usefulness and cross-functionality of the model is to include these additional decision-making cost factors in a normalized way so they are comparable across technologies and vendors.
    b. To support vendor negotiations, it is recommended these additional cost factors be calculated separately from each other, as it is likely Supply Chain will consider different vendors for different aspects of the transition to gigabit service.
11. **Summarize & Present:** Summarize model outputs for presentation to ensure understanding of costs, other metrics, and tradeoffs to facilitate decision-making. Use data visualization techniques to convey model output information in an audience-specific manner.

8. Data Modeling Best Practices

There is no single right way to build a cost model, but there are some ways which are more effective, efficient, and communicative than others. There are entire courses, books, and even degrees focused on Data Modeling. We will give a simple and brief overview of some basic concepts and best practices for building an effective and dynamic model to analyze access network technology and vendor options to facilitate decision-making. For the purposes of this paper, we will assume the model is being constructed in MS Excel, since this is the most widely used ad hoc analysis tool.

- **Structure** – Organize your workbook and data logically, grouping like inputs & outputs together. Group and order the tabs of your workbook so information is easily accessible. Keep all your data and analyses for the project in one workbook.
- **Labels** – Name your columns and rows with headers which are meaningful and easily understandable to your audience (e.g., instead of "price" use "price per unit"). Label your tabs with meaningful names as well and group them in a logical way.
- **Inputs** – To create a dynamic model, enter model inputs and quantitative assumptions only once, then reference these inputs in formulas throughout the model. This will enable you to easily change an input or assumption and calculate an updated output.
- **Assumptions** – List all assumptions in the model (quantitative & qualitative). It is best to have all assumptions and inputs near each other in the model for rapid retrieval and ease of updating.
- **Identification** – Use pre-determined text colors to indicate the source of information in a cell. For example, use text colors to indicate when a cell:
  - Contains a hardcoded number
  - Pulls from/references another sheet
  - Results from a formula/calculation (choosing black for formulas is recommended, since most cells will be formula driven in a model)
- **Colors** – Use colors sparingly and wisely. Too many colors or too much color will render the colors meaningless. Using colors to indicate meanings counter to common understanding will also create confusion (e.g., using red to indicate a good/positive outcome might not be intuitive to someone viewing the model).

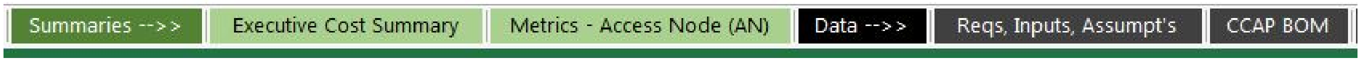
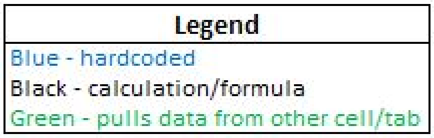


Figure 5 - Example Tab Labels & Color Usage



Legend
Blue - hardcoded
Black - calculation/formula
Green - pulls data from other cell/tab

Figure 6 - Example Cell Color-Coding

To learn more about data concepts and modeling, please see the "Related Work" and "Bibliography & References" sections for a more comprehensive list of suggested resources.

9. Case Study

We will now walk through a case study using the decision-making & modeling process steps described so far in the paper. In this case study, there is a decision to be made about the technology to deploy in a small suburban area in order to deliver 1Gbit/sec today, 2 Gbit/sec in the near-term future, and 5 Gbit/sec by 2020. We will focus on three areas of the Access Network – OSP, the Access Node, and Access Termination Equipment, as these are often the largest cost drivers of the decision and usually must be made in tandem, as the choice of technology for one limits the choices for the other.

The primary objective in this case study is to build a 1 Gbit/sec capable network based on fiber with the highest probability of technical success at a reasonable cost for the purpose of identifying and evaluating the gaps in operationalizing such a network and for the purpose of identifying areas for further development and optimization. The decision to be made is which technology to use for the Access Node and Outside Plant.

The cost model will compare the costs associated with different Access Node, Outside Plant, and Access Termination Equipment/CPE technologies in order to facilitate making a decision that supports the objective stated above.

9.1. Step 1: Document Network Architecture

Cost models are often used to compare one solution to another. For example, a service provider might need to upgrade the access network in a particular area to support a new service tier. Multiple technical solutions may exist and a cost model is used to assist in the decision of which technical solution to choose.

The problem with cost models in these situations is that the various technical solutions are not always easy to compare due to inherent differences in the technology and implementation. There is often no one-to-one relationship between the solutions making them simple to compare. It is, then, helpful to describe a reference network architecture that normalizes the description of the technology for the purposes of modeling and discussion among the stakeholders.

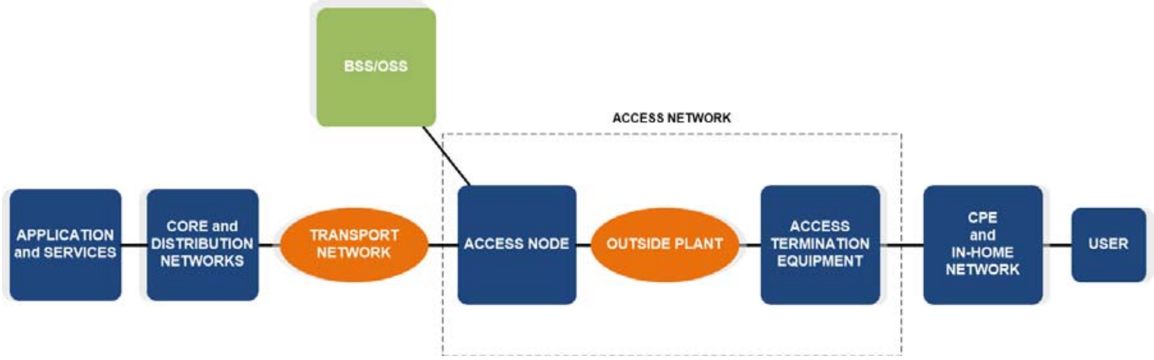


Figure 7 - Proposed Reference Network Architecture

The architecture consists of the following major components:

- The **User** is the stub network to which Internet access (high speed data (HSD)), voice services, video services, and other services are provided.
- **CPE & In-Home Network** is the set of networking devices (such as routers, switches, Wi-Fi access points, etc.) located at the customer site and the interconnections between those devices that are used to distribute HSD, voice and video within the customer premises.
- The **Access Network** is the network which provides the user access to the service provider’s network. The Access Network is responsible for moving customer data from the user to the Core and Distribution networks. The Access Network consists of the Access Node (AN), Outside Plant (OSP) and Access Termination Equipment (ATE).

- **Outside Plant (OSP)** is that portion of the network that connects the ATE to the AN. The OSP generally consists of various types of cable, connectors, attenuators, amplifiers, splitters, power supplies, and other components necessary to fulfill its function
- **Transport Network** is the set of network links, routers, switches, optical and other platforms that supply connectivity between the Access Network and the Core and Distribution Networks. The Transport Network may be as simple as a fiber optic jumper between the Access Node and an upstream router.
- The **Core and Distribution Network** is the network that connects one or more access networks to one another and to the Internet. The Core Network is responsible for moving the user's data from the access network to systems and servers within the operator’s network or to the Internet.
- **Applications & Services** is the set of applications and tools that are accessed by the user over the operator’s network and the interconnections that operator provides. Examples include (but are not limited to) voice switches and gateways, video servers, web sites, and email servers.
- **B/OSS (Billing and Operational Support Systems)** are the systems that, among many functions, enable the network to be provisioned, configured, monitored and managed and for customers to be added to the network and to be billed for their access to the network.

The focus of this paper is the access network. The access network is responsible for moving a user's data (voice, Internet access, and video traffic) from the user's site to the core and distribution network (upstream traffic) and from the core and distribution network to the user's site (downstream traffic).

DOCSIS, EPON, GPON, dedicated fiber, coarse wavelength division multiplexing (CWDM) and other technologies are typically used in the access network to carry packetized digital data such as Internet access and voice. Increasingly, video is being carried in packetized digital format over these same technologies, but there is a significant deployed base of legacy quadrature amplitude modulation (QAM)-based video distribution systems, which calls for continued use of HFC or, in all-fiber networks, RF Overlay or RF over Glass (RFoG).

Our reference network architecture decomposes the access network into an access node (AN), which is similar to the access node defined in the Broadband Forum’s TR-025 and the access terminal equipment (ATE), which is similar to the network termination equipment described in TR-025. The AN could be an optical line termination (OLT) for an EPON network or a cable modem termination system CMTS/CCAP in a DOCSIS network. Similarly, the ATE would be an EPON optical network unit (ONU) or a DOCSIS cable modem. Other access technologies would equally fit into this model.

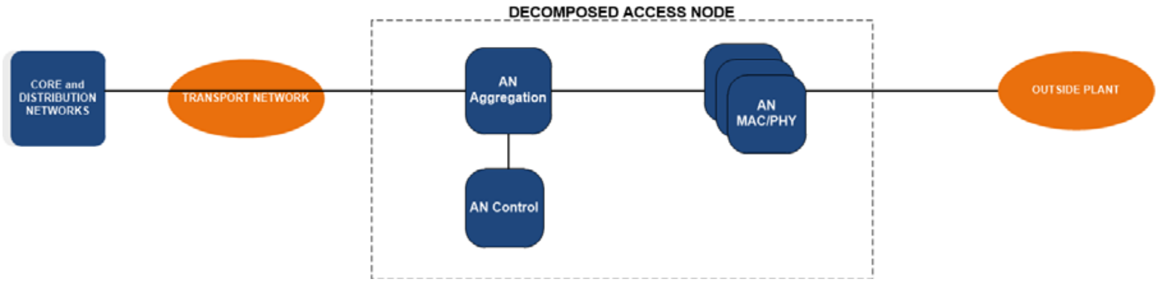


Figure 8 - Decomposed Access Node

Distributed architectures, described in [11], [9], [10] and many industry publications, are emerging and gaining favor in many operators' networks. Further decomposition of the Access Node is warranted to accommodate this additional complication. Our proposed reference model of the AN in a distributed architecture is shown in the figure above. In this architecture, the AN is composed of the AN media access control (MAC), AN physical layer (PHY), AN Aggregation, and AN Control blocks.

- The Access Node MAC is the component of the Access Node which implements station addressing, frame creation and recovery, and controls access to the transmission medium.
- The Access Node PHY is the component of the Access Node which implements the physical connection to the outside plant cabling and also implements the signaling (typically optical or electrical) on the physical cable.
- Access Node Aggregation is the portion of the Access Node which aggregates one or more AN MAC/PHY components. In a distributed architecture, the AN Aggregation might be an Ethernet switch. In a centralized or collapsed architecture the AN Aggregation is likely to be a combination of a system backplane and switching fabrics.
- Access Node Control is the component of the Access Node which facilitates configuration and provisioning of the AN and usually implements protocol functionality required to interact with external systems (routing protocols for example).

Each of these elements potentially becomes a cost contributor in the financial modeling and comparison. In a centralized model, each of these functions collapses into a single cost center versus several cost centers. In this case study, we will use a centralized architecture.

9.2. Step 2: Document Technical Requirements

In this case study, we are modeling the deployment of 1 Gbit/sec to a small suburban development of 150 single-family units. All utilities and telecommunications services are required to be underground within this development.

The network must support 1Gbit/sec Internet access, voice services, and video service. HSD must reach a 5Gbit/sec service tier by the year 2020. This project will apply a simple 2x capacity threshold to the chosen access network technology.

Voice service is based on an existing Session Initiation Protocol (SIP) infrastructure (voice over IP). Set-top box-based video is a required service in the offering, but the delivery method will depend on the selected technology.

9.3. Steps 3 & 4: Identify Gaps and Solution Technologies

In this case study, engineering design has determined that either a single-node HFC network or a pre-terminated fiber cable system will satisfy the requirement to provide 1 Gbit/sec service today, and we will include each option in the model to guide decision-making.

Applying a 2x capacity threshold to a 1 Gbit/sec service offering requires that the selected technology support 2 Gbit/sec today and 10 Gbit/sec by the year 2020.

The predominant method for offering HSD today is DOCSIS 3.0 over existing HFC networks. Using widely available DOCSIS 3.0 devices would require more than 32 downstream channels (192 MHz of spectrum) at 256 QAM to reach 2 Gbit/sec capacity. Expanding DOCSIS 3.0 beyond 32 channels is a not a probable technical solution and it is difficult to operate a typical HFC plant at a standard that allows single carrier 256 QAM to be viable.

These difficulties led to the development of DOCSIS 3.1. DOCSIS 3.1 is more efficient in its use of spectrum on the typical HFC network. However, DOCSIS 3.1 CPE is barely available and the industry is still working out a roadmap that allows DOCSIS 3.1 to be deployed to support 10 Gbit/sec. The current status of DOCSIS 3.0 and DOCSIS 3.1 in the market will force any real cost model to account for an upgrade from DOCSIS 3.0 to DOCSIS 3.1 in the 3-5 year timeframe.

Passive optical networks (PONs) have been used since the late 1990s. As is commonly understood in the industry, there is a near equal market share between EPON, an IEEE 802.3 standard, and GPON, an ITU-T standard. In their most predominant forms EPON and GPON support 1 Gbit/sec and 2.5 Gbit/sec capacities, respectively. Both standards have evolved to support capacity of 10 Gbit/sec and higher.

GPON (2.5 Gbit/sec) could meet the requirements of our example development in the short term but would need to be upgraded in the 3-5 year timeframe. 10G EPON (10 Gbit/sec) is available immediately and would meet the current and the year 2020 requirements. Similar to the DOCSIS case, a thorough cost model would need to compare the cost of a 10G EPON solution to the cost of upgrading the GPON solution.

There are many variations on the DOCSIS and PON options. This case study chooses a centralized architecture that contains all components of the AN in a hub site. Many centralized and decentralized options exist in PON; however, exploring these options is beyond the scope of this paper, but [9], [10] are good sources for additional detail.

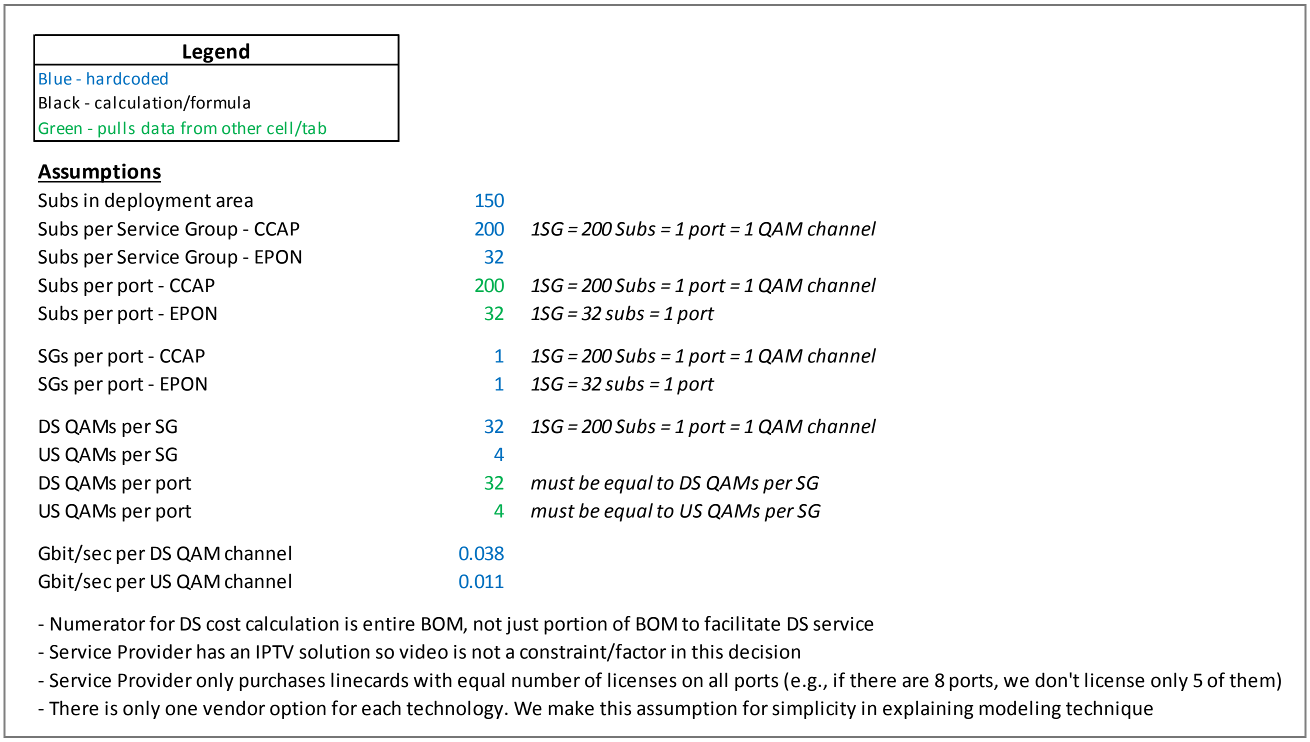
In this case study, we assume voice and video are either excluded from the product offering (HSD-only), or they are offered in a way that does not directly impact the HSD service (e.g., traditional QAM video over HFC). An alternative example for a PON-based offering - if an IP-based solution for traditional linear video were not available, then RFoG might be used and the cost of the RFoG components (ONU, transmitters and receivers) would need to be incorporated into the cost model.

Due to constraints of time and space, this case study focuses only on delivery of Gigabit HSD. If the service provider needs to deliver traditional linear video and voice services, the additional architectural and network elements would need to be included in the cost model. This could be added in a future version of the model developed for this paper.

9.4. Step 5: Develop Model – Enter Technical Requirements, Assumptions, and Inputs

To begin building the model, enter the technical requirements that are relevant to your calculations (Remember: to build a dynamic model, enter each input only once and link to that input using formulas), assumptions, and other inputs. An example of the inputs relevant to this case study and one way to organize them is shown in Figure 9.

Some recommended assumptions and inputs to include when building a model such as the one in this case study are shown in Figures 9 and 10. Note the assumptions list contains both quantitative and qualitative assumptions. Additionally, notes and clarifications about the quantitative assumptions and inputs are included to the right of the cell containing the value itself. These notes are helpful for both the model-maker and reviewers to understand how the inputs and assumptions are measured, as well as any constraints and relationships which may exist between values.



Legend
Blue - hardcoded
Black - calculation/formula
Green - pulls data from other cell/tab

Assumptions

Subs in deployment area	150	
Subs per Service Group - CCAP	200	*1SG = 200 Subs = 1 port = 1 QAM channel*
Subs per Service Group - EPON	32	
Subs per port - CCAP	200	*1SG = 200 Subs = 1 port = 1 QAM channel*
Subs per port - EPON	32	*1SG = 32 subs = 1 port*
SGs per port - CCAP	1	*1SG = 200 Subs = 1 port = 1 QAM channel*
SGs per port - EPON	1	*1SG = 32 subs = 1 port*
DS QAMs per SG	32	*1SG = 200 Subs = 1 port = 1 QAM channel*
US QAMs per SG	4	
DS QAMs per port	32	*must be equal to DS QAMs per SG*
US QAMs per port	4	*must be equal to US QAMs per SG*
Gbit/sec per DS QAM channel	0.038	
Gbit/sec per US QAM channel	0.011	

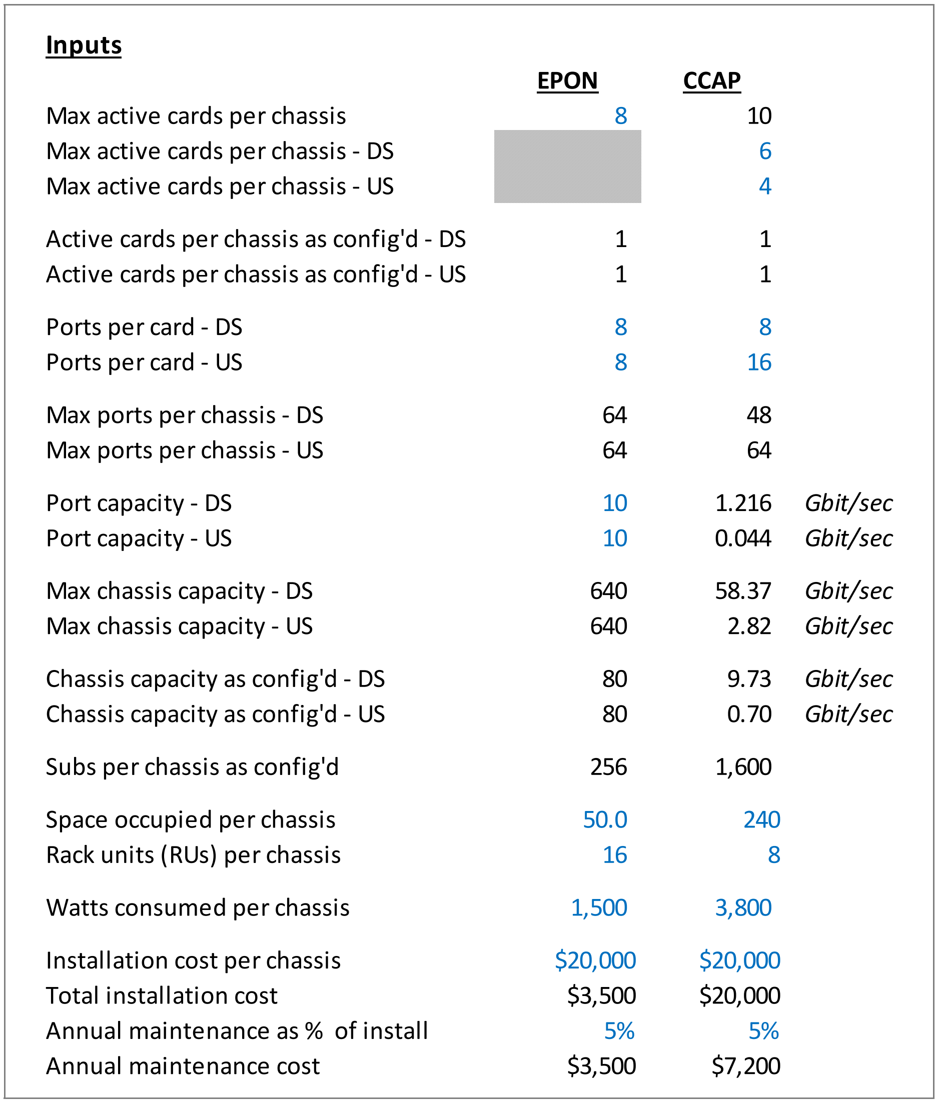
- Numerator for DS cost calculation is entire BOM, not just portion of BOM to facilitate DS service
- Service Provider has an IPTV solution so video is not a constraint/factor in this decision
- Service Provider only purchases linecards with equal number of licenses on all ports (e.g., if there are 8 ports, we don't license only 5 of them)
- There is only one vendor option for each technology. We make this assumption for simplicity in explaining modeling technique

Figure 9 - Sample Model Assumptions

It is also important to note that for the sake of simplicity and explaining the decision-making process and modeling technique, we've included an assumption that only one vendor is available for each of the technology solutions being considered. We recognize that in most cases there will need to be a comparison not only of technologies, but of multiple vendors who can provide each technology.

While the "Assumptions" list contains data about the state of the network, the state of the deployment area, and company practices, the "Inputs" list is more detailed and focuses on information specific to the technology choices being compared. In addition to hardcoded inputs, the "Inputs" list also contains calculations based on those hardcoded inputs which will be used in formulas on other tabs.

In the example model for this case study, we've limited the inputs to the ones shown below; however, there are many more inputs and data points that may be relevant to making a decision. It is important to understand the objective, the decision to be made, and what will influence that decision so the most useful inputs specific to the scenario being evaluated can be selected.



Inputs

	EPON	CCAP	
Max active cards per chassis	8	10	
Max active cards per chassis - DS		6	
Max active cards per chassis - US		4	
Active cards per chassis as config'd - DS	1	1	
Active cards per chassis as config'd - US	1	1	
Ports per card - DS	8	8	
Ports per card - US	8	16	
Max ports per chassis - DS	64	48	
Max ports per chassis - US	64	64	
Port capacity - DS	10	1.216	*Gbit/sec*
Port capacity - US	10	0.044	*Gbit/sec*
Max chassis capacity - DS	640	58.37	*Gbit/sec*
Max chassis capacity - US	640	2.82	*Gbit/sec*
Chassis capacity as config'd - DS	80	9.73	*Gbit/sec*
Chassis capacity as config'd - US	80	0.70	*Gbit/sec*
Subs per chassis as config'd	256	1,600	
Space occupied per chassis	50.0	240	
Rack units (RUs) per chassis	16	8	
Watts consumed per chassis	1,500	3,800	
Installation cost per chassis	$20,000	$20,000	
Total installation cost	$3,500	$20,000	
Annual maintenance as % of install	5%	5%	
Annual maintenance cost	$3,500	$7,200	

Figure 10 - Sample Model Inputs

The inputs that are supplied to the model will depend heavily upon the model objectives. Listed below are some potential inputs to be supplied to a model, including ones not used in our example, but which could be useful depending on the decision to be made. The list below is not intended to be exhaustive and the model objective and network architecture should guide the model builder in cataloging the required inputs.

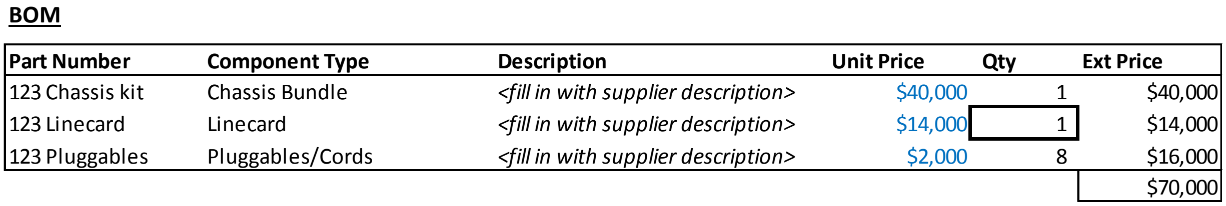
- Normalization Factor(s)
- Bills of Material
    - Cost per unit
    - Licensing Cost per time
    - Maintenance Cost per time
- Equipment Related

  - Chassis Physical Dimension (space)
  - Chassis capacity (US and DS ports)
  - Chassis Capacity (bits/sec)
  - Port Capacity (bits/sec)
- Electrical Requirements Minimum Service Tier (Downstream and Upstream)
- Maximum Service Tier (Downstream and Upstream)
- Subscriber Density
  - Geographic (HHP)
  - Per Port
- Cost of Spectrum Realignment
- Oversubscription Ratio
- Required Network Capacity
  - Access Network
  - Transport Network
  - Core/Distribution Network
- Growth Projections (subs and bandwidth and capacity)
- Penetration Rate
- Historical Data
- Take Rates (for each service tier, helps with capacity projection model)
- Customer Types (commercial vs. residential)
- Critical Infrastructure
  - Electricity Rates
  - Space/Real Estate
  - Environmental Treatment (heating/cooling)
- Labor Cost per hour per person
- Capacity Model Outputs
- Permitting Costs
- Pole Attachment Costs

9.5. Steps 6 & 7: Create Bills of Material

The inputs portion of Step 5 may be done in parallel with Steps 6 and 7, as some of the inputs may be related to the Bill of Materials for each technology and vendor that satisfies the Technical Requirements. Work as a team to translate the Technical Requirements into actual components for each technology and vendor under consideration. Document the equipment required for a "standard configuration" build, as well as the relationships between equipment (e.g., for every one unit of component X, two units of component Y are required) in your model. Using this information, you can calculate the total units required to satisfy the needs of the deployment.

In the example BOM below, each part required is clearly labeled using a part number and part description (first and third columns). In addition, the type of component is also listed (second column). A bold box is shown around the second item, the linecard, to indicate that it is the item that drives the calculations of other components in the BOM.



BOM

Part Number	Component Type	Description	Unit Price	Qty	Ext Price
123 Chassis kit	Chassis Bundle	*<fill in with supplier description>*	$40,000	1	$40,000
123 Linecard	Linecard	*<fill in with supplier description>*	$14,000	1	$14,000
123 Pluggables	Pluggables/Cords	*<fill in with supplier description>*	$2,000	8	$16,000
					$70,000

Figure 11 - Example EPON Bill of Materials[1]

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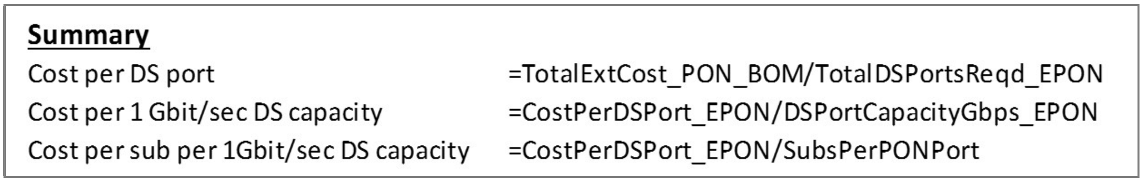
[1] Prices and quantities shown are illustrative and should not be interpreted to be actual prices negotiated, paid, or offered by or to any company

9.6. Steps 8 & 9: Calculate Units of Capacity & Create a "Cost Equivalency Metric"

Demonstrating Steps 8 & 9 is best done by showing a snapshot of the example formulas used in Excel for the case study. Using EPON as an example, we can use the following inputs to calculate the summary fields, pulling the total extended cost of the "standard configuration" from the Bill of Materials, as shown in the sixth column and last row of Figure 11.

- number of linecards needed to satisfy requirements
- number of ports per linecard
- downstream port capacity in Gbits/sec
- extended cost of required components from BOM



Summary	
Cost per DS port	=TotalExtCost_PON_BOM/TotalDSPortsReqd_EPON
Cost per 1 Gbit/sec DS capacity	=CostPerDSPort_EPON/DSPortCapacityGbps_EPON
Cost per sub per 1Gbit/sec DS capacity	=CostPerDSPort_EPON/SubsPerPONPort

Figure 12 - Calculation Examples

As discussed earlier, in order for this proposed decision-making process to be successful, a number of groups within the organization must weigh-in on the choice of technology to use for a given application and build. Each group has a different set of metrics that will influence their decision. Similarly, each portion of the access network has a set of metrics which are relevant to a decision in that portion of the network.

Listed below are some potential metrics to be output from a model. The list below is not intended to be exhaustive and the model objective and network architecture should guide the model builder in cataloging the desired outputs.

Outside Plant Metrics

- Total Cost
- Labor Cost per km
- Labor Cost per households passed (HHP)
- Labor Cost per Year
- Material Cost per km
- Material Cost per HHP
- Material Cost per Year
- Maintenance Cost per km per year
- Maintenance Cost per passing per year
- Critical Infrastructure
    - Electricity Cost per year
    - Real Estate Cost per year

Access Node Metrics

- Total Cost

- Cost per subscriber
- Cost per port
- Space required (cubic meters, width/depth in cm, height in RU)
- Capacity per RU (bits per second per RU)
- Capacity per subscriber (bits per second per sub)
- Capacity per HHP (bits per second per HHP)
- Electrical Load (Watts Consumed)
- Electrical Cost (Watts per year)
- Electricity Density (Watts per RU, Watts per sub, Watts per bits per second)
- Subscriber Density (Subscribers per RU)
- Total capacity (bits per second)
- Installation Cost per Unit

Access Terminal Equipment Metrics

- Cost per unit
- Electrical Cost (Watts per year)
- Space required (height, width, depth in cm)

Time Based Metrics

- Time Value of Money Cost of upgrading
- Time remaining in technology cycle (i.e., until technology upgrade is required to meet expected requirements)

9.7. Step 10: Enhance Model

In addition to calculating metrics for the Access Node portion of the decision, we will also need to consider an OSP cost equivalency metric, as well as the cost for ATE/CPE equipment, since those decisions are intertwined and, depending on the requirements, the choice of one may limit options for the other.

The same techniques used for modeling Access Node costs and creating an equivalency metric can be used for OSP and for Access Termination Equipment/CPE. It is also a good idea to consider TCO of a solution by including any known maintenance costs that could be material to the decision.

9.8. Step 11: Summarize & Present

The final step is to aggregate the metrics for each part of the model – in this case study, our primary metric is cost per subscriber, although there will be other metrics which also factor into the decision. A key secondary factor will be the oversubscription rate of each technology under consideration, as well as the length of time until the equipment will need to be upgraded to meet expected future speed demands. Again, the metrics on which the decision is based are determined by the objective– they will not be the same in all cases.

The Figure 13 shows a matrix of possible Access Node and OSP technology choices and their associated cost per subscriber to provide 1 Gbit/sec service today. The combinations shown are:

- EPON + Fiber – EPON as the transmission protocol with a Fiber outside plant (which is the only OSP supported by EPON).
- DOCSIS + Fiber – DOCSIS as the transmission protocol with a Fiber outside plant (which might be the case for an RFOG-based network).
- DOCSIS + HFC – DOCSIS as the transmission protocol with a traditional HFC outside plant.

This is the type of summary that could be provided, along with non-cost metrics, to executives so they could make an informed, data-driven decision.

Cost Comparison

Total Cost per Sub *(1 Gbit/sec service)*	EPON	DOCSIS
HFC		$1,500
Fiber	$2,000	$1,600

All-in cost = AN equip + AN install + AN maintenance + OSP labor & materials + ATE equip

Figure 13 - Sample Cost Comparison - Normalized Cost Metric[2]

In addition to this "all-in" cost per subscriber table, it is also useful to share the breakdown of the "all-in" number, so decision makers can see which components are the largest contributors to the total. This knowledge will help Supply Chain and Finance know where to focus their efforts when negotiating with vendors.

One way to depict this information is in a chart. In Figure 14 we can see that for the EPON solution, the biggest contributor to cost per subscriber is ATE unit cost.

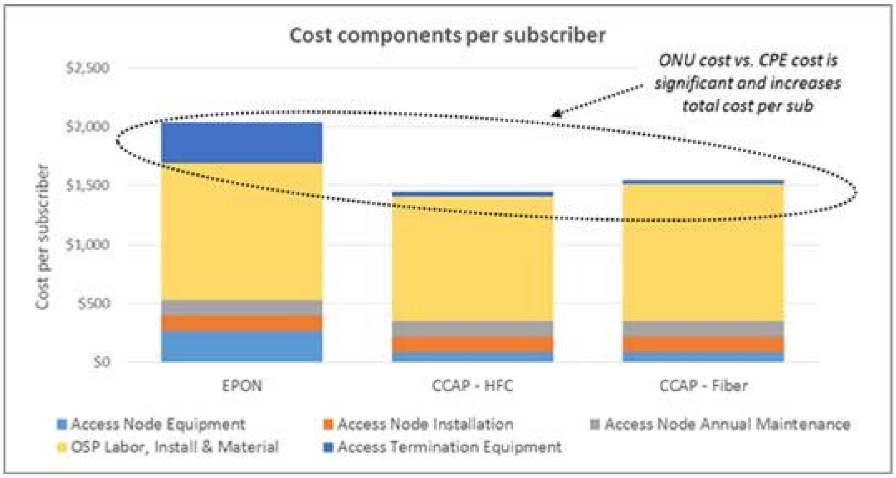


Figure 14 - Cost per Subscriber by Access Network Component

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[2] Summary costs shown are illustrative and should not be interpreted as being calculated from actual prices negotiated, paid, or offered by or to any company

Because the model we created is dynamic, it would be relatively easy to use an Excel Add-in such as Crystal Ball to see how the outcome would change if some of the inputs to the model were uncertain or had a range of possible values. Once the model is constructed and you become familiar with basic modeling techniques, there are endless possibilities for enhancements to improve the quality of decision-making even further by providing additional metrics, incorporating other variables (e.g., power costs, critical infrastructure costs), or by using data visualization techniques to make the existing information more understandable and easily usable by all functional areas participating in the decision-making process.

Conclusion

Based on the case study model outputs, there are several questions to consider in making a final decision:

1. Which solution has the lowest cost to implement today
2. Which solution has the lowest Total Cost of Ownership
3. How long will the solution meet the requirements before an upgrade or forklift/replacement is necessary
4. What level of oversubscription is tolerable today and in the future

Applying the business modeling described in this paper, Table 1 summarizes the results of the analysis process of three different access network solutions for gigabit service delivery.

Table 1 - Decision Factor Summary

Decision Factor	**Solution (Access Node + OSP)**		
	EPON + Fiber	**DOCSIS + Fiber**	**DOCSIS + HFC**
Cost per sub today to meet 1 Gbit/sec requirement	~25% higher than DOCSIS options	Low	Low
Upgrade(s) required to meet 2 Gbit/sec w/in next 1-2 years	None	Yes, upgrade to D3.1	Yes, upgrade to D3.1
Upgrade(s) required to meet 5 Gbit/sec w/in next 4 years (2020)	None	Unknown	Unknown
Current oversubscription rate	Low	High	High
Future oversubscription rate	Low-Med	High	High

Based on this analysis, a DOCSIS solution will not be able to meet the technical requirements of this case study (to deliver 1 Gbit/sec immediately, 2 Gbit/sec within the next one or two years, and 5 Gbit/sec by 2020) without an upgrade to DOCSIS 3.1. At the time of this paper's writing, the scope of hardware and software upgrades that will be required for a DOCSIS network to meet the 5 Gbit/sec requirement in 2020 are unknown. Therefore, although the cost per subscriber to deploy a DOCSIS solution meeting today's requirements has a lower cost, there are unknown future costs and technology challenges that could make it a more costly solution in the long-term. Choosing DOCSIS carries greater long-term risk because of these unknowns.

EPON, while 25% more expensive per subscriber to install today, avoids the future upgrade costs associated with a DOCSIS solution, as it is already designed to accommodate 10 Gbit/sec. By reviewing the breakdown of cost contribution by access network component in Figure 14, we can see the majority of the cost difference between DOCSIS and EPON is driven by the ATE.

By identifying the ATE as the component driving the price differential, we give Supply Chain and Finance an opportunity to negotiate with the EPON vendor to perhaps get closer to price parity with DOCSIS solutions on this component, while still maintaining the technical advantage and reduced risk of deploying EPON today and knowing it will meet capacity requirements for years to come.

In this way, by working collaboratively, obtaining input from all impacted functional areas, assessing the tradeoffs between technical requirements and costs, and having metrics that can be understood by all functional areas, the service provider can make an informed, cross-functional, data-driven decision on providing Gigabit service to meet today’s and tomorrow’s technical requirements and financial constraints.

Abbreviations

AN	access node
ATE	access terminal equipment
BOM	bill of material
B/OSS	billing and operational support systems
CCAP	Converged Cable Access Platform
CM	cable modem
CMTS	cable modem termination system
CPE	customer premises equipment
CWDM	coarse wavelength division multiplexing
DOCSIS	Data over Cable Service Interface Specification
EPON	Ethernet Passive Optical Network
FTTx	fiber to the x
GPON	Gigabit Passive Optical Network
HFC	hybrid fiber coax
HHP	households passed
HSD	high speed data
MAC	media access control
OLT	optical line termination
ONU	optical network unit
OSP	outside plant
OTT	over-the-top
PHY	physical layer
PON	passive optical network
QAM	quadrature amplitude modulation
RFoG	RF Overlay or RF over Glass
SIP	Session Initiation Protocol
TCO	total cost of ownership
UHD	ultra-high definition
WiMAX	Worldwide Interoperability for Microwave Access

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