The Generic Access Platform

What's in it for me?

A Technical Paper prepared for SCTE•ISBE by

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Introduction

1. What is the Generic Access Platform?

Simply stated, the Generic Access Platform is an outdoor housing enclosure that can be built in a number of ways to address multiple applications.

When a Distributed Access Architecture (DAA) was being discussed as a new approach to the way Cable and Telecommunications operators could redistribute the new components of either purely optical or Hybrid Fiber-Coaxial (HFC) networks it became apparent that DAA would lead to a much greater number of network access devices being placed in the outside plant portion of the access network. Since most outdoor components are strand mounted or pedestal mounted within the United States and cabinet mounted in many other parts of the world, this in turn leads to a greater diversity of equipment vendors producing and deploying a variety of different types of equipment. Today, MSOs deploy strand-mounted amplifiers, numbering tens of millions, but these are limited to just a few vendor designs. DAA introduces the concept of remote physical layer nodes to convert deeper penetrated digital fiber into HFC radio-frequency spectrum, closer to customer's homes than previous network design and deployment approaches.

Additionally, the GAP housing can be used for other applications beyond just an RF node. It is also intended to standardize the housing design for other outdoor equipment; 4G & 5G Small-Cells radios, Wi-Fi Access Points, remote OLTs and ONUs to support EPON and GPON networks, Edge-Compute Nodes and other smart-city applications such as IoT radios, traffic-light and pedestrian monitoring, and smart-sensing, as shown in Figure 1. In fact, the GAP housing can be used to accommodate multiple functions in the same housing (considering some thermal and power constraints) such as being an RPD with an IoT radio included for example. This greatly reduces the need for multiple node housing on the same coaxial strand.

There has been a progression from simple HFC amplifiers to a myriad of network-edge applications, combined with an increase in the available bandwidth across a network. Many techniques for increasing bandwidth, such as node-splits, also requires additional components that need to be housed outdoor.

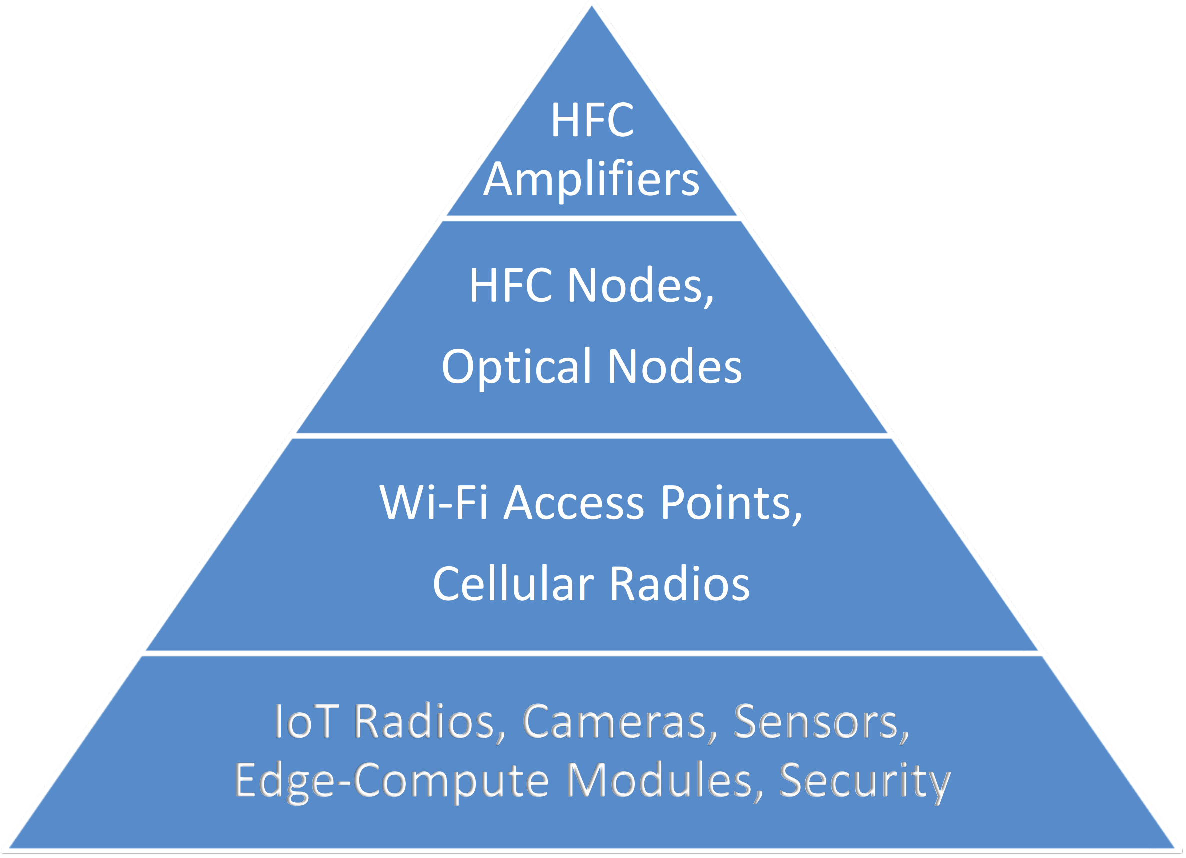


Figure 1 - An Increasing number of application devices over time, which could be housed in a GAP enclosure.

However, operational complexity arises from having so many applications. Ina conventional approach the solution for each application will be provided by multiple vendors, each with a custom design, and each inside a custom housing enclosure. Technical momentum will drive a high rate of replacement for these new technically advanced “nodes”. The innovation cycle will become very challenging for cable and telecommunications service providers because the rate of deployment, and extraction to and from the field will rapidly increase over time. Each custom housing cannot be re-used at the end of its useful life, where the end of the useful-life could be a consequence of technology upgrades or component failures in the field.

The Generic Access Platform is designed to address the life-cycle challenges by producing a single housing that can be re-used for the same initial purpose, be upgraded to a new technology for the same functional purpose, or be completely repurposed as new device for a new technical function.

Content

2. Why a change in design philosophy becomes the new advantage

2.1. Distributed Access Architecture (DAA) - Enabling components deeper into the network.

DAA has a number of advantages:

- Network efficiency
- Increased network capacity and simpler outside plant maintenance
- Supports Node evolution with Remote PHY, Remote MAC-PHY and Remote 10G EPON or GPON OLT
- Better end-of-line signal quality, higher modulation rates, higher bit-rates
- Better spectral efficiency, more wavelengths per fiber
- Operational and capital expenditure benefits
- Reduced headend power, space and cooling requirements
- Hub consolidation
- Add QAMs without changing the RF combining network
- IP convergence
- Extend IP network to the node
- Alignment with FTTx build-out
- Ability to leverage standards-based interconnectivity and economies of scale
- [1] [2]

The GAP housing does not aim to replace any DAA technologies. In fact, it encourages the development and deployment of DAA technologies in a standardized way. The GAP housing enables a standardized approach to the hardware enclosure. It can;

- Reduce the number of custom designed and manufactured housings.
- Address the market needs ahead of a large growth in outdoor equipment predicted by DAA and Smart-City applications.
- Reduce operational expenditure for Cable and Fiber Main Service Operators, and Telecommunications companies.
- Increase longevity for deployed housing due to re-purposing rather than housing replacement.
- Increase availability and ability to integrate advanced technologies within a modular approach.
- Facilitate inter-operability between different vendor technologies.
- Introduce a common industry-wide approach to outdoor deployed devices.
- Increase access to market-share for new technology providers.
- Reduce the need for multiple node housing on the same coaxial strand.

2.2. Why will node housing become more common?

The following section describes how the number of housing increases over time due to a number of factors.

2.2.1. HFC Bandwidth increases

The compound annual growth rate (CAGR) of user-demand for bandwidth is approximately 43-45%, which is driving service operators to divide nodes, as shown in Figure 2.

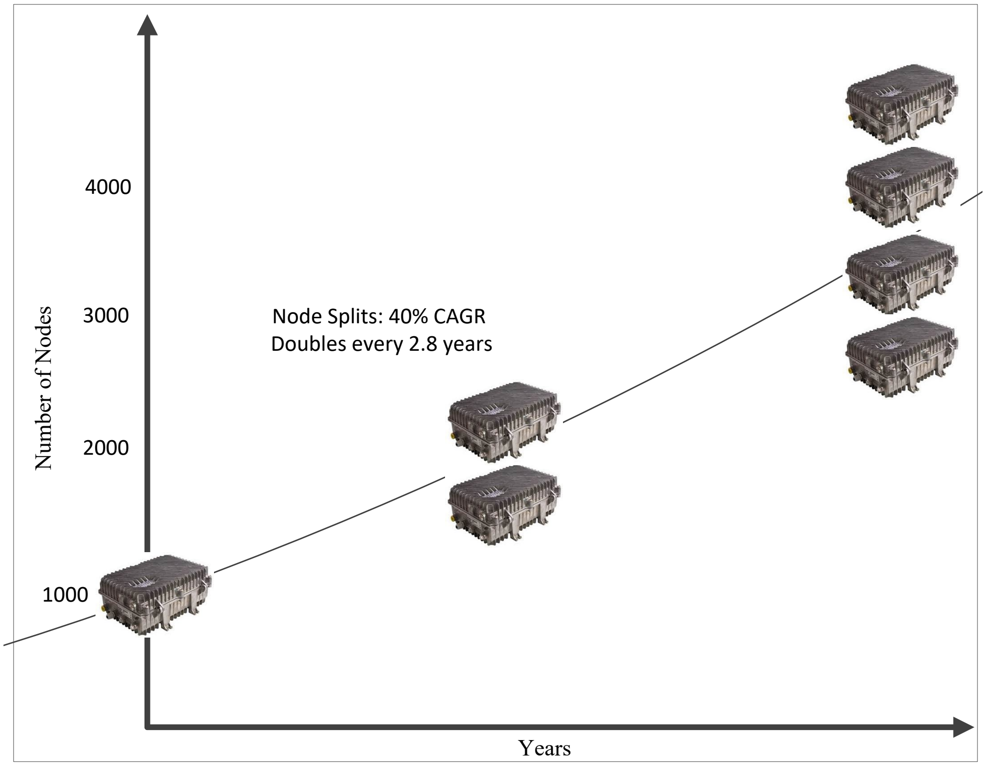


Figure 2 - Bandwidth Compound Annual Growth Rate increases the number of Nodes

2.2.2. Deeper into the Network with Optical Nodes

The deployment of optical nodes, especially in the trend towards N+0 network architecture, will also increase the number of deep-fiber optical links and hence fiber nodes.

2.2.3. Emerging Cellular Markets

As the cellular market expands into the Citizens Band Radio Service (CBRS) band 48 at 3.5GHz, a greater number of new cellular nodes are needed to bring those services closer to the customer. Developments are on-going within the mobility market to design and deploy Radio Access Network (RAN) Small, Pico and Femto-Cell radio nodes into this emerging infrastructure, as shown in Figure 3.

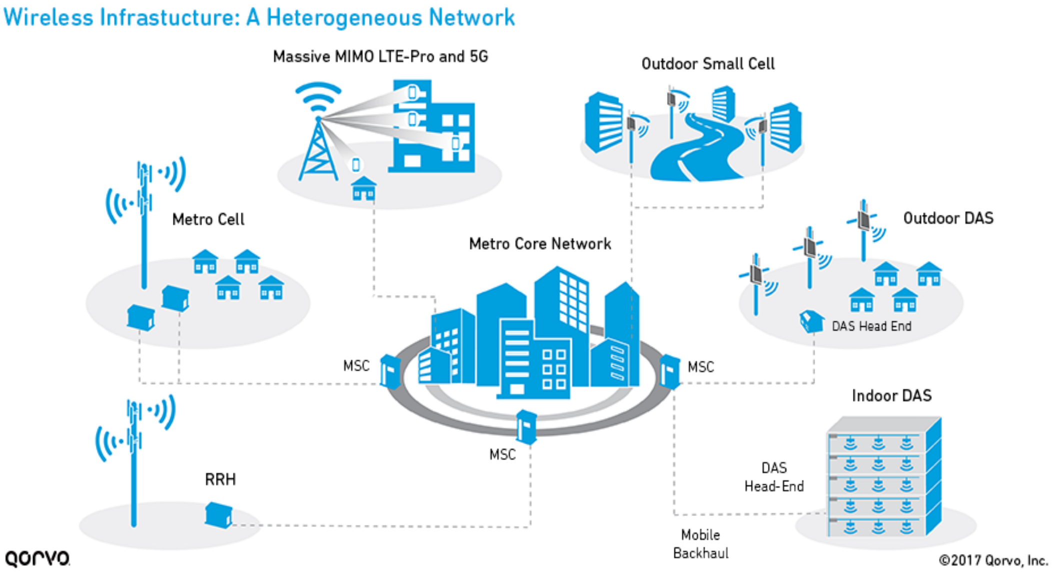
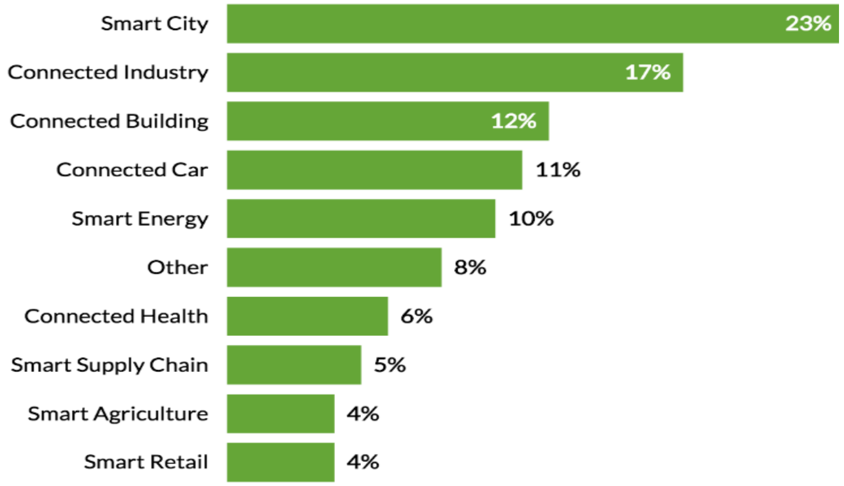


Figure 3 - Expansion of Cellular Networks

[3]

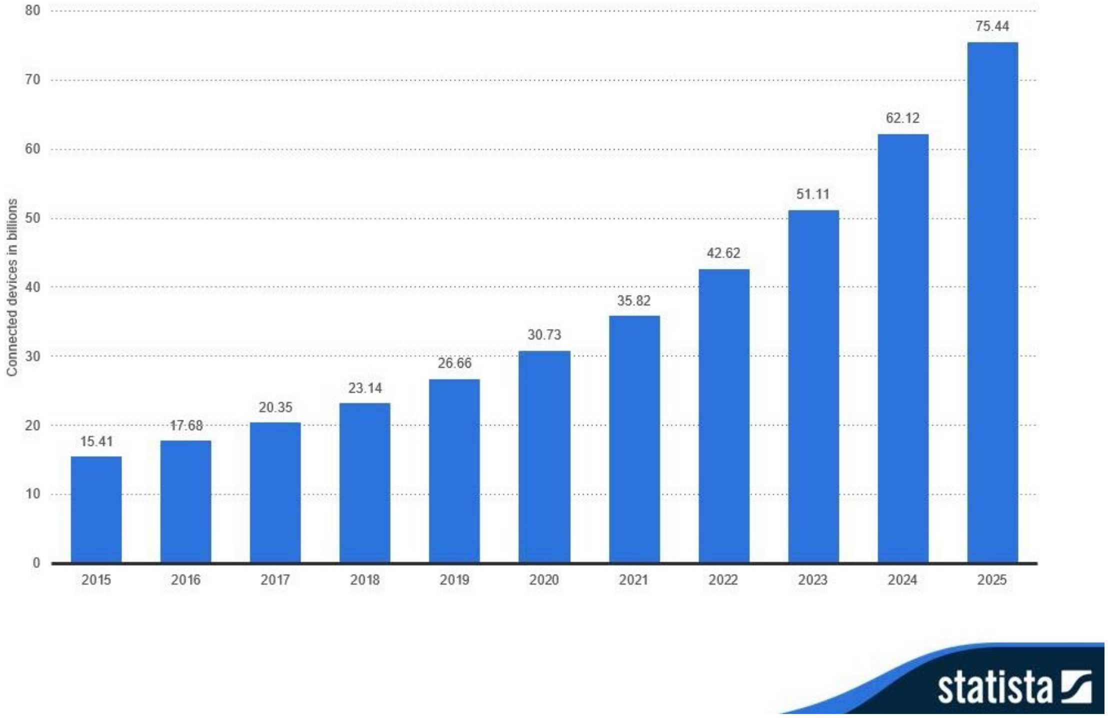
2.2.4. *Smart-City Applications*

Additional housings will be needed for Smart-City applications to enable sensing and monitoring devices such as IoT radios and surveillance cameras. These monitoring and sensing applications are still emerging but there is no doubt that they will continue to increase in number and will drive the need for more network node connection points. Higher traffic capacities and lower latencies are normally achieved by placing nodes closer to the user groups or customers. Data published by Priceonomics, Figure 4 and Statista, Figure 5 shows the emerging market shares for different IoT categories, by market segment, and predicted growth for IoT devices which could be used as a proxy for the relative growth in new technology node devices.



[4]

Figure 4 - Categories for Connected devices in emerging markets



[5]

Figure 5. Internet of Things (IoT) connected devices installed base worldwide from 2015 to 2025

The GAP housing aims to limit the number of housing styles by making available a modular, upgradable and re-usable housing that can accommodate one or more node functions at any time. The approach will provide a uniform outdoor enclosure platform for a variety of different types of devices.

2.3. An opportunity to Unify DAA Components

The predicted growth in strand-mounted technologies will put a strain on overhead plant infrastructure. Most service operators in the United States are confined to using strand (see Figure 6) or pole mount equipment due to problems with getting permits to use city-owned street-level mounting positions.

The GAP housing will help to alleviate the amount of strand-mounted infrastructure by combining two or more box solutions, or collections of associated strand-mount devices into a single enclosure. An example would be an outdoor Wi-Fi Access Point backhauled by a strand-mount DOCSIS cable modem. Both items could be co-located inside the same housing if designed in a modular form factor. Other application technology use-cases are shown in Table 1.

[6]

Figure 6 - An example of current strand-mount DAA applications housings

A modular form-factor allows for an even higher potential for integration. Multiple new functions could be achieved in the same node. For example, a traffic monitoring camera or CBRS small-cell could be incorporated along with a Wi-Fi AP with DOCSIS modem backhaul within the same housing. This benefits strand-loading from a reduced weight perspective and lower power consumption, compared to using two separate node enclosures.

Table 1 - Potential uses for a GAP housing enclosure

DOCSIS	R-PHY	R-MAC-PHY	vRouter	LoRA WAN	Wi-Fi
DAA	Traffic Monitoring	Edge-Compute	Security Cameras	Environmental Monitoring	R-ONU
PON	DWDM	Coherent Fiber	R-OLT	CBRS	FWA
DPI	Surveillance	Smart-Network Diagnostics	Earthquake Detection	Edge-Caching	Flood Detection

2.4. Improvements in end-of-line Signal Quality

There are a number of advantages to the DAA architectural approach. One of the advantages is to use digital optics to deliver digital signals that are converted by the remote PHY device (RPD) to analog radio frequency signals such as OFDM and QAM used by coaxial cable systems, as well as those used by 4G, 5G, Wi-Fi and IoT radio applications. In the cable case, the elimination of noise and distortions produced by conventional analog intensity modulated optical links from the hub to the optical node will result in a higher MER at the end-of-line and consequently higher QAM modulation orders can be used such as 4K-QAM, 8K-QAM, and potentially 16K-QAM.

3. GAP is a more modular design approach

The GAP enclosure present a very different lifecycle compared to the traditional node design. Technologies become housed in custom designed modules using a common modular form factor, as shown in Figure 7.

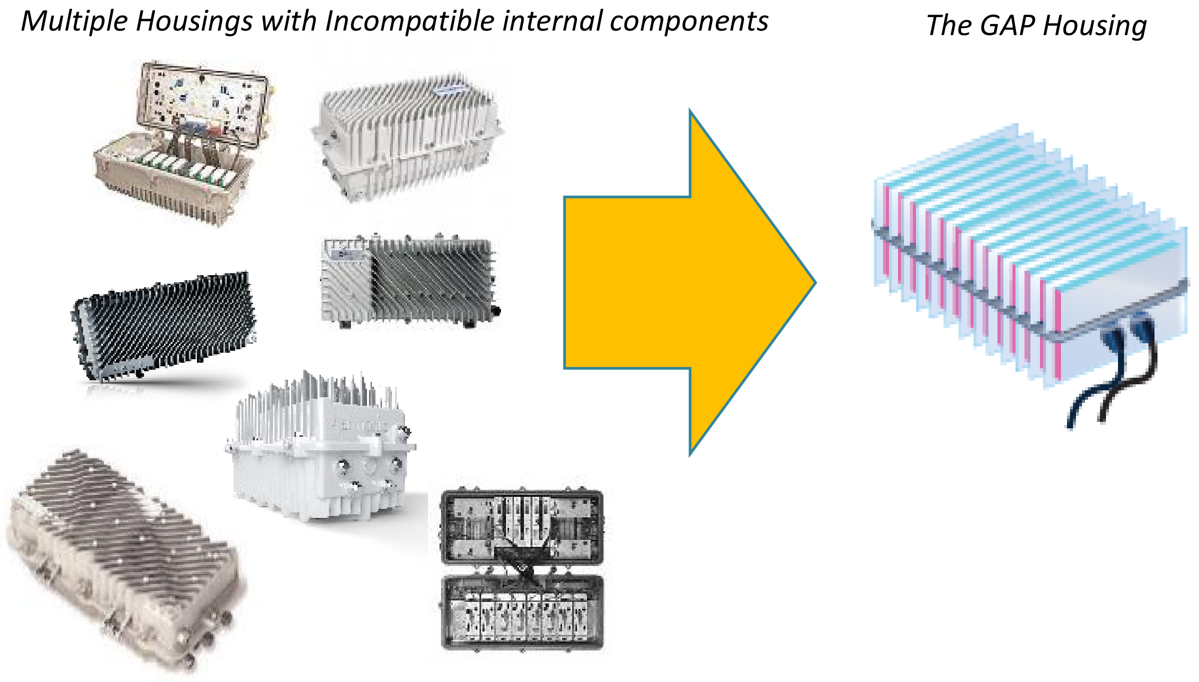


Figure 7 - A modular approach reduces the number of styles.

Modules are mechanically supported by the housing which also provides thermal dissipation for up to 220W of input power. Power is distributed to each module through a backplane that modules plug into. The proposed design also offers a high-speed (PCIe) and a low-speed (I2C) bus for module-to-module data transfers and module management functions.

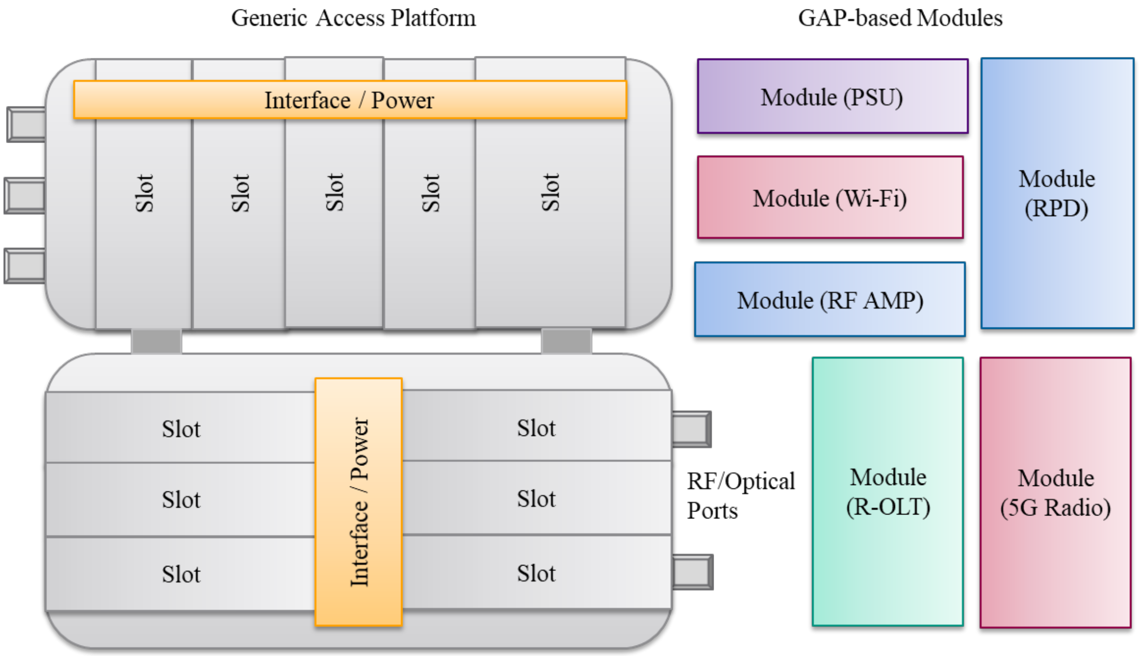


Figure 8 - A modular approach to node design

The external ports are basic threaded entry holes that can support either RF entry ports up to 3GHz capability, optical fiber entry, or shielded-Ethernet cable. A fourth option is for any RF port to be used to connect an array of antenna, mounted on the external surfaces of the housing via mounting spigots. This is to support outdoor Wi-Fi, CBRS and IoT applications requiring MIMO arrays. The internal RF interconnections remain customized as they are very application dependent so as to allow flexibility for module to module connections that go beyond the basic backplane requirements.

3.1. Modular Components with upgradability

- Housing: A clamshell design that can be re-purposed. Mechanical design features such as replaceable RF gaskets, silicone weather seals and removable entry/exit ports.
- A modular High-Speed Data backplane: A PCIe 5.0 based interconnect bus. As technology advances this backplane can be single part upgraded to PCIe 6.0 and so on.
- Module Slots: These remain the same width are interchangeable between the lid and the base, for flexible system design options.
- Power Supplies: Standardized voltage rails. Located in a position that optimizes cooling and thermal dissipation for heatsinking. Can be customized for some applications.
- Power-plane: A modular, replaceable, PCB that interfaces power to the modules though fixed and optional voltage rails.

3.2. A Traditional Node Lifecycle

A traditional node design is based on a single-use design philosophy that results in a single deployment and eventual disposal after a relatively short service life, as shown in Figure 9.

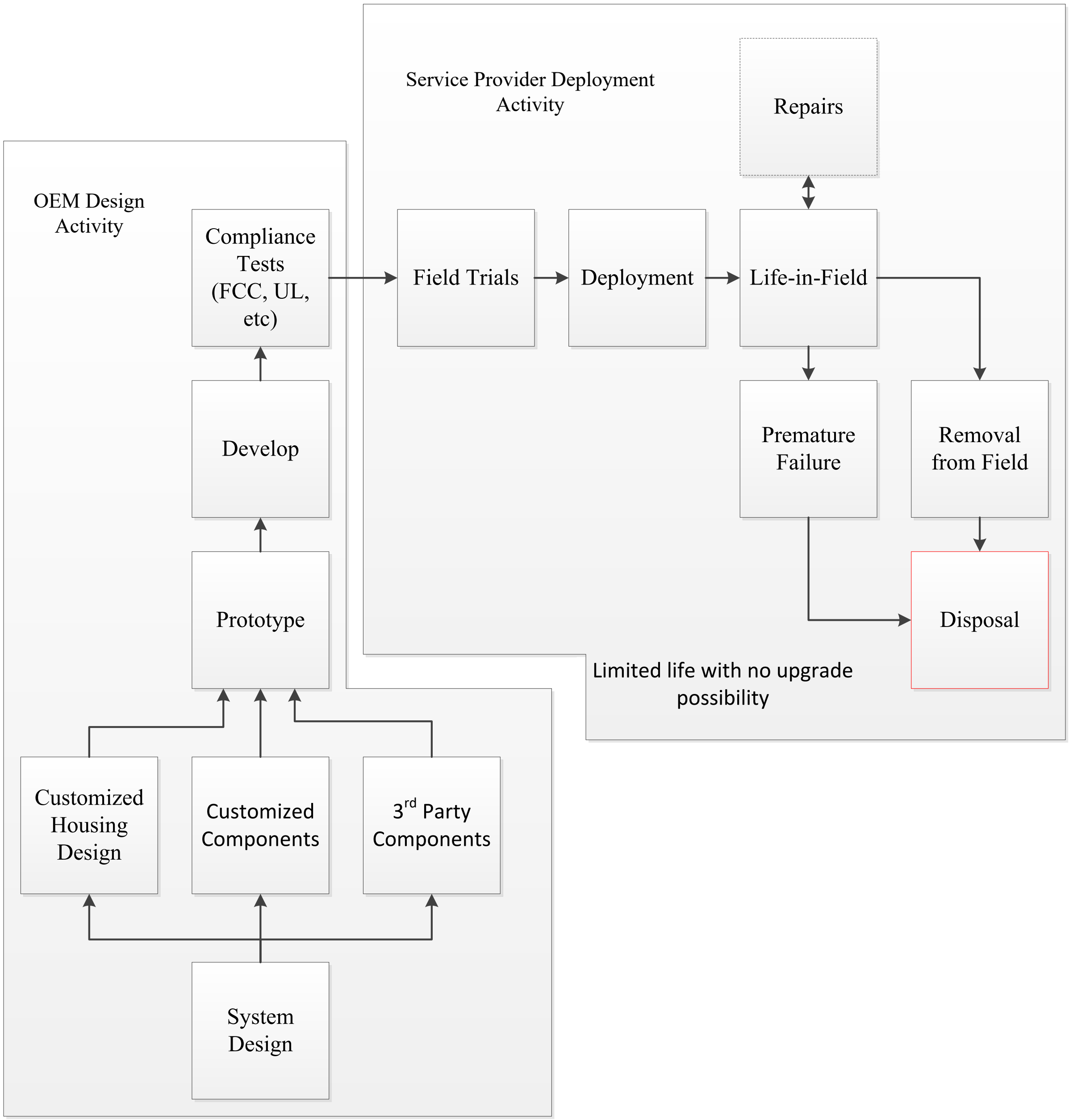


Figure 9 - Lifecycle for a typical node.

At present, DAA devices such as nodes begin as a custom design, using specially developed components such as an optical transceiver, embedded CMTS, power-supply, and various RF modules and connections. Once developed and tested for applications and regulatory compliance, the final design moves onto a field trial phase. After successful trials and any subsequent improvements, the device is deployed to the field, where it may go through some infrequent repairs, but ultimately gets removed from the field and has no further use, leading to disposure of the hardware, at a capital loss to the service operator. Only very recently has the idea of an upgradable node housing become more popular, with some node vendors already starting to propose re-usable housings.

An analogy for the GAP housing is the personal computer. The first personal computers of the 1970's and 1980's were customized designs that integrated all of the necessary components such as the CPU board with on-board memory, a visual display unit and a keyboard. It became apparent that the rate of development was being slowed by the sequential design work needed integrate all of the new, technically-advancing components. The solution derived in 1985 was to produce the Advanced Technology (AT) form-factor motherboard with common interfaces that could be housed in a standard chassis. The AT motherboard could be equipped with plug-in sub-components such as LAN/WAN cards, memory modules, disk interface cards and other peripheral devices. [7].

Development then centered on the incremental improvement to each of the peripheral modules. Over the following years, the motherboard capabilities were increased but there remained a backwards compatibility in terms of supported interface standards. The development process moved from a single vendor being the only developer, to a multi-developer environment with a higher rate of new product availability. The GAP project is essentially leveraging a similar approach except that cadence is being exchanged for the ability to develop technical functionality while retaining as much existing hardware as possible, thereby lowering the operational expenditure for service providers. By 1995, the AT form-factor was revised into the Advanced Technology eXtended (ATX) motherboard which continued the upgrade path for the next generation PC industry. [8]

3.3. The GAP Lifecycle

A GAP-based node design is based on a multiple-use design philosophy where the housing and modules are re-used and therefore will have a much longer service life, as shown in Figure 10.

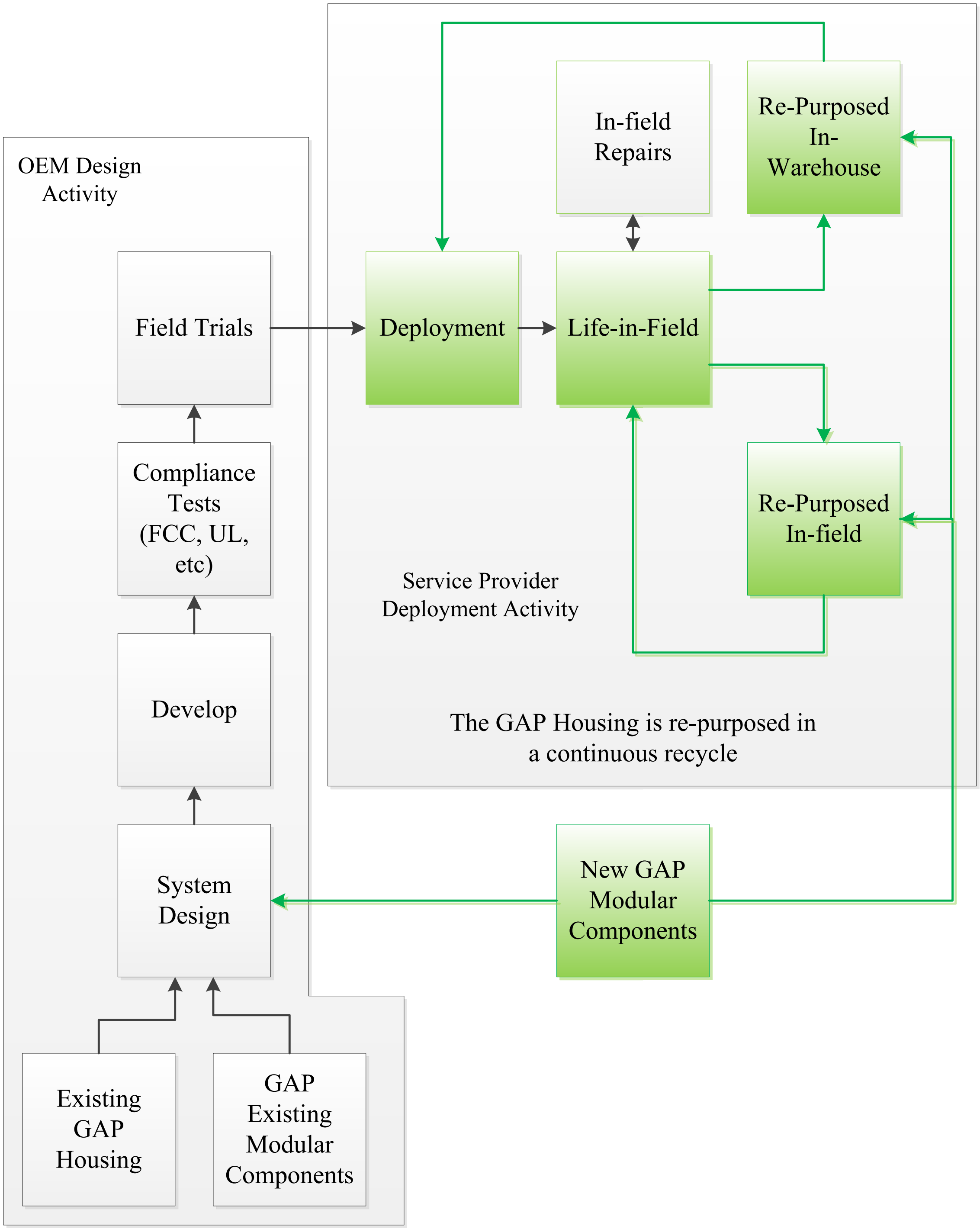


Figure 10 - Lifecycle for a GAP Node or any GAP enclosure.

One of the aims for the GAP housing is to make use of a modular approach, to design and deploy nodes and other DAA equipment. This approach has the following benefits;

- Reduced system design time because the whole enclosure is no longer a custom design.

- The enclosure can be re-used by repaired more easily by replacing failed or damaged modules.
- The enclosure can be re-used by refitting it with new modular components.
- The technical function of a GAP housing can be incrementally upgraded or completely repurposed as a new technical function.
- It is an easier technology upgrade if only certain modules or technology functions need to be upgraded.
- Repurposing, repairs and re-fitments can be done without having to remove the housing from the strand, thereby making it easier to maintain at a lower overall operational cost.
- Modules can be re-warehoused and re-used in other application housings.
- It is a better model for sustaining new technology deployments into the field, especially where both the volume and specialty of those technologies is rapidly increasing, which offers some future-proofing between network access upgrades.

Longevity in the field can only be achieved by a GAP enclosure if it offera high degree of flexibility for the adoption of any particular set of new technologies. It must be designed to be upgradable if it is to adequately fulfil this role into the future. Today, it must be able to house DOCSIS3.0/3.1 with a 1.2GHz spectrum for example, but also accommodate DOCSIS4.0, Extended Spectrum DOCSIS and Full-Duplex technologies, up to 3GHz capability.

4. Examining the Economic Differences

4.1. The Traditional Node

4.1.1. From a node vendor perspective;

Each generation of node does bring new technologies and a more advanced set of features, and this is an essential part of the reason for deploying new nodes. Traditional nodes require a large amount of engineering expertise to design and construct. Currently, nodes are developed in a flow similar to those shown in Figure 9. A group of system designers are needed to define all of the individual components needed for any node or application housing. These components are usually housed in individual modules to isolate certain functions from a power or RF perspective, or simply to divide up the design work among multiple design engineers or design and production companies. Mechanical engineers produce the overall structure, while individual teams customize and optimize the engineering to meet performance and cost objectives. Each module is effectively designed from scratch, and each set of modules that make up any node are discarded with each generation of housing. Similarly the housing style is also discard and recreated between generations. There is very little re-use of the previous design, especially the mechanical components.

These design cycles increase the amount of design effort needed to produce each generation.

4.1.2. From a service provider perspective;

Each new node technology is anticipated to need a large operational expenditure, in addition to a capital expenditure, in order to do a network access plant upgrade.

The initial phase focuses on specification work conducted between silicon vendors, node-providers and service providers. The next phase consists of a lengthy period of prototype work (1-2 years) and a period of design verification, software feature upgrades and field trials (1-3 years), that results in a deployable product. The overall development and deployment cycles are very lengthy and cumbersome.

The preferred method for network access upgrades is to do them incrementally. Usually upgrades are performed service group by service group rather than attempting a large-scale or nationwide upgrade. This is because the service-group approach requires a lesser initial capital expenditure, uses less service technicians at any given point in time, and spreads the capital expenditure over a longer period of time. Another preferred approach is to take a longer term view of each service group upgrade by installing equipment that will enable that site not to have to be revisited within a 5-8 year period after an upgrade takes place. This means the future phase must have already been contemplated, planned and resourced ahead of any upgrade. With the traditional node architecture the amount of prior planning is limited to what the current generation of technology can offer. The traditional node is deployed and the network remains constant for a long fixed duration, typically greater than 8 years, until the next generation becomes available. At that point the traditional node is disposed of and entirely replaced and disposed of.

A GAP housing can be re-used many times by replacing either damaged or failed modules, subject to normal AFR rates, or be upgraded using new function modules. In either case, the housing will last considerably longer. There will be some housings that will need to be replaced due to physical damage such as from natural disasters, lightning or accidental connector damage, for example, but the quantity will be very low compared to the total deployed population. For this reason, a low in-field disposal rate of 0.1% was used in the cost-model.

4.2. The GAP Approach

4.2.1. From a node vendor perspective;

The GAP housing constitutes a different design philosophy compared to a traditional node design. The intention is to re-use as much as possible from a previous GAP node or device housing. A system design is still needed for the new components as these will most likely be the new technology and will involve some design effort to produce them in a GAP modular form-factor. The rest of the system will likely re-use existing power supply modules, backplane and the enclosure.

This new approach means the traditional node vendors migrate from being a complete system design and production entity, and instead become a producer of modules. They retain the module design and new technology development aspects however. They preserve their intellectual property is their traditional core areas. The modular approach allows those vendors to use modules from other vendors, such as the PSU or RF interface modules.

Additionally, it open the node market to new OEMs, to build sub-sections of a complete node such as an iCMTS as a new module. Further, the GAP approach allows a market entry option to new companies that want to take on either the system design, build, test, compliance, complete node construction or some combination of these roles.

4.2.2. From a service provider perspective;

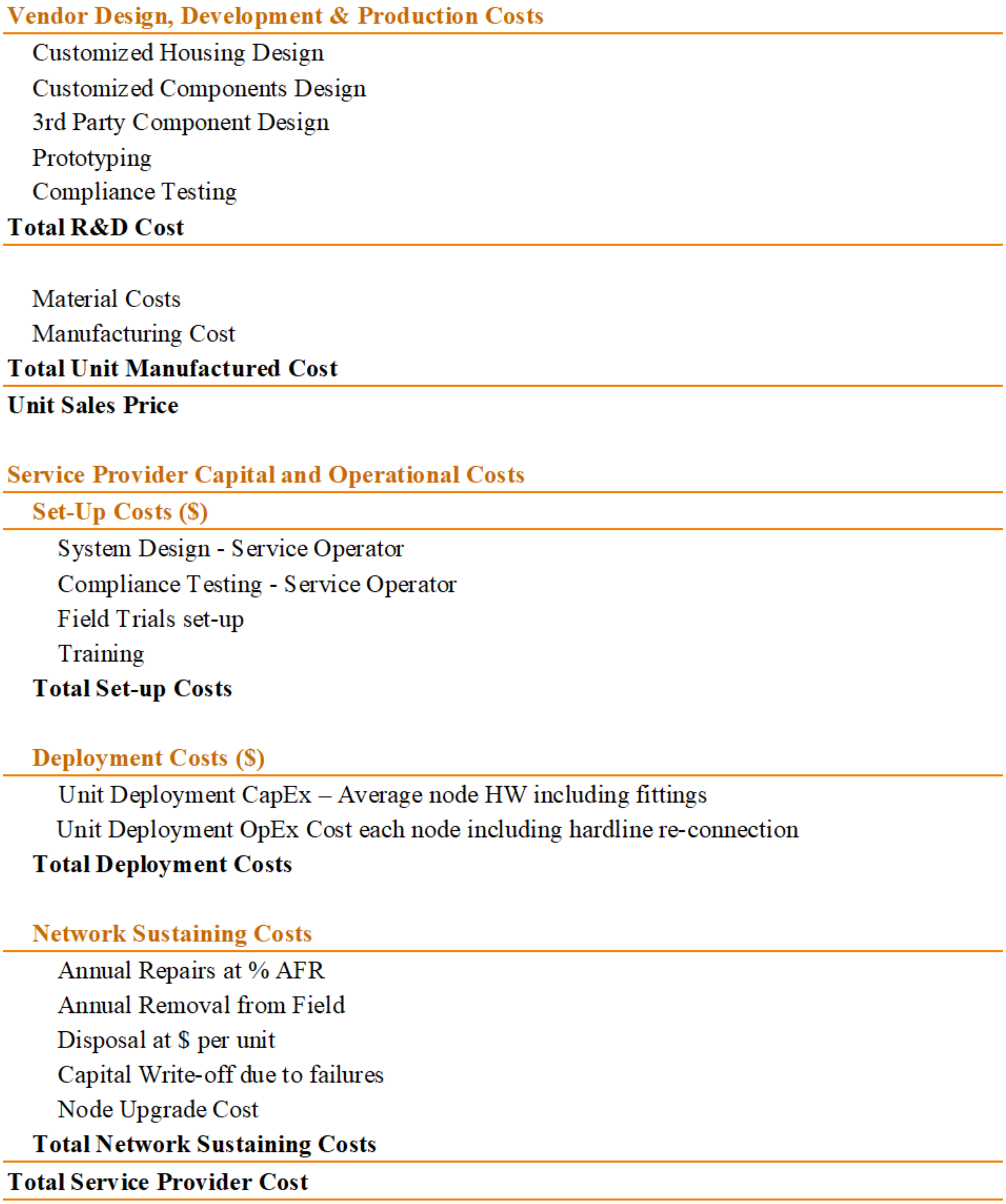
The service provider has the potential to take on the system design role which may be advantageous to the larger service providers, but there is also the option for a traditional node vendor to take on the system design role on behalf of a service operator. The service operator also becomes the system integrator and is ultimately responsible for the technical and compliance testing, although there is also the option for any 3rd party to perform these roles as an additional service.

Why would a service operator take on the role of being the system designer? The answer to how much or which areas of involvement depends on the complexity of the node design. For a new function or design, the traditional node vendor or OEM produces the new module specification using the GAP enclosure and module specification as a basis. The OEM produces an ‘encapsulated’ module that a service provider can then integrate with other existing modules currently in inventory. For example, a service operator might already have stock of GAP housings, suitable GAP module PSUs and RF interface modules, and these can be put together by a service operator system designer who adds a new iCMTS module recently introduced by an OEM. In this example, the OEM would have designed the iCMTS taking into account already available system components, i.e. existing modules vital to the final design. The service operator might also take on the compliance and testing aspect of the final node design.

For a mature design, the components are already well understood and relatively easy to integrate to produce a variation on an existing GAP node design. Some system level design is needed but a new node with extended functions can be produced without going back to the very beginning of the design process.

4.3. Comparing GAP versus Traditional Node Costs

The analysis was done by breaking down the factors that go into both the OEM’s or vendor’s design and production costs, and the service operators deployment and network infrastructure sustaining costs. Each are separately broken down in Figure 11.



Vendor Design, Development & Production Costs

- Customized Housing Design
- Customized Components Design
- 3rd Party Component Design
- Prototyping
- Compliance Testing

Total R&D Cost

- Material Costs
- Manufacturing Cost

Total Unit Manufactured Cost

Unit Sales Price

Service Provider Capital and Operational Costs

Set-Up Costs ($)

- System Design - Service Operator
- Compliance Testing - Service Operator
- Field Trials set-up
- Training

Total Set-up Costs

Deployment Costs ($)

- Unit Deployment CapEx – Average node HW including fittings
- Unit Deployment OpEx Cost each node including hardline re-connection

Total Deployment Costs

Network Sustaining Costs

- Annual Repairs at % AFR
- Annual Removal from Field
- Disposal at $ per unit
- Capital Write-off due to failures
- Node Upgrade Cost

Total Network Sustaining Costs

Total Service Provider Cost

Figure 11 - Cost factors for nodes

4.3.1. Assumptions used in the model

Two economic models were created; one for a traditional node and a second for a GAP node. The following assumptions were used in each:

- A traditional node would need to be designed from scratch.
- A GAP node would re-use an existing housing design, and all other components except one major module would change with each node design iteration.
- The deployed-node failure rates would be the same for each, at a 2% AFR.
- A failed node of any type would need to have all hardline connections replaced during the exchange.
- A traditional node in-field exchange would need each hardline connections to be re-terminated, whereas a GAP node would not.
- Node warehousing and site permitting costs were excluded because they are broadly the same for both housing types.
- The node upgrade cost assumes the majority case of one module (see Figure 17 for other assessments).

4.3.2. Comparing the cost factors for the design and production (R&D)

An analysis of the node vendor or OEM's cost structure can be seen in Figures 12 and 13 below. Note that the vertical scale are the same in both figures, giving a view of relative costs.

Figure 12 - Traditional node: vendor design, development and production costs by factor

The customized component design represents the largest cost, followed by the development and prototyping cost. A significant cost factor is the housing which in the case of a traditional node, is customized for each application, and is not re-usable across different applications. Compliance testing is costly because it involves development and testing all of individual components that make up the node.

In the case of a GAP-based node the same factors apply but in different degrees of cost. There isn't customized housing design because a standard GAP housing design is being utilized. Third-party component design is also not a factor. Compliance testing is now done by the service provider, or its system design agent, so no longer figures as a cost item. There is still the need to develop the main application module where the mechanical aspects are also standardized using the GAP form-factor. A cost still exists for prototyping, which is less given the reduced scope of electrical and mechanical changes.

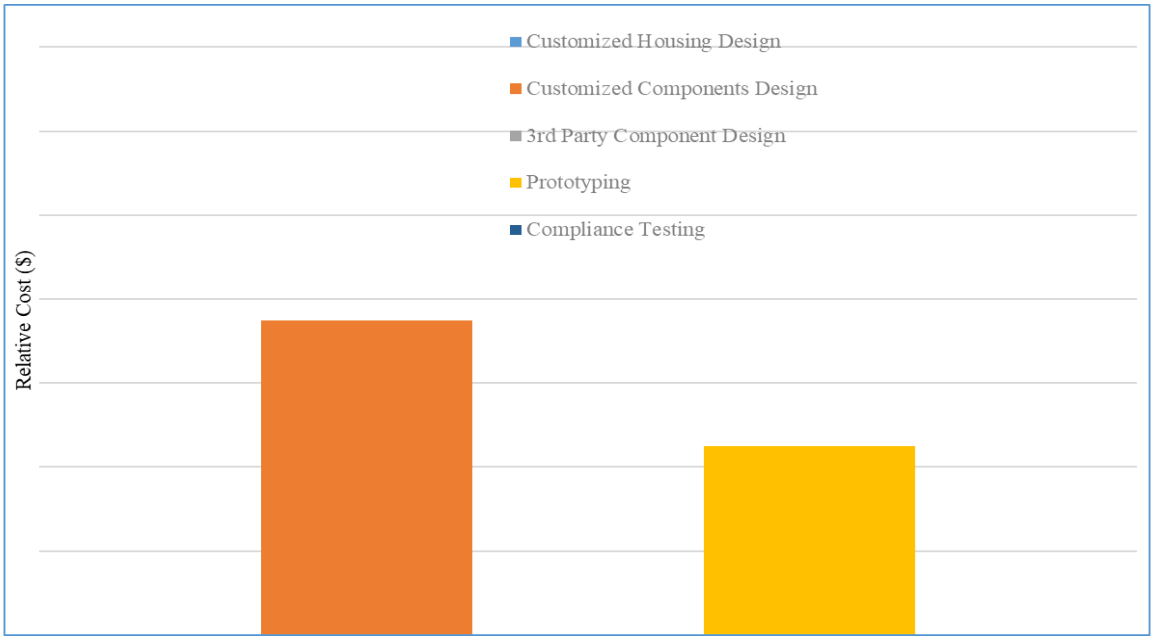


Figure 13 - GAP node: vendor design, development and production costs by factor

Overall, there is a large reduction design and development costs because of the large amount of component re-use when modules are available in a standardized form-factor. The use of a modularized approach does incur additional component costs however. A completed GAP node has a higher unit cost compared to a traditional housing. However, the impact of this increased costs be weighed against the lower overall cost for a service provider.

4.3.3. Comparing the deployment and network sustaining cost factors for the service provider

In this analysis a cost model created that compares the deployment and aspects for sustaining a network evolution for both a traditional and a GAP housing approach. Again, the same cost factors were assessed to compare their relative values.

In the case of the traditional node deployment, some of the costs such as system design and compliance testing are zero because these were part of the cost associated with the R&D phase above. Significant costs are experienced for training, deployment and repairs. Repair of a traditional node usually involve removing the node from a strand and replacing it with a new node. This means all of the hardline connections need to be replaced and re-terminated with a new connector – which adds significant time and cost. By far the greatest cost is the capital cost write-off associated with replacing a node either because it has reached the end of its functionally useful life as a technology, or due to annual field failures.

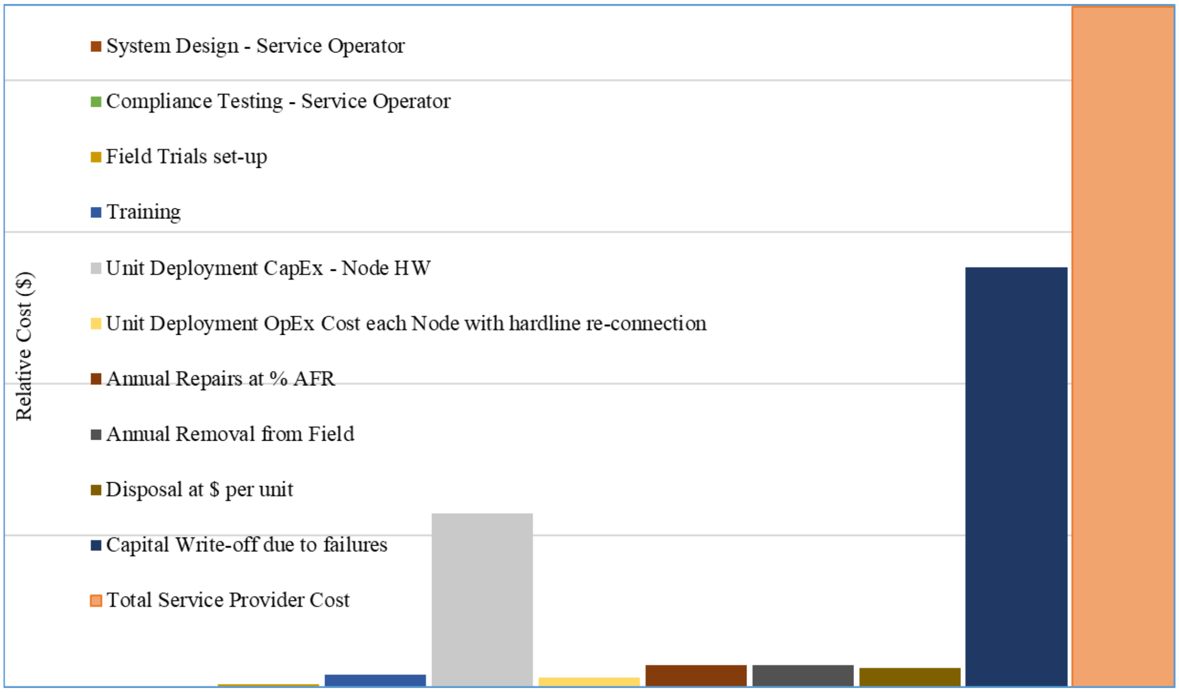


Figure 14 - Traditional node: service provider deployment and sustaining costs

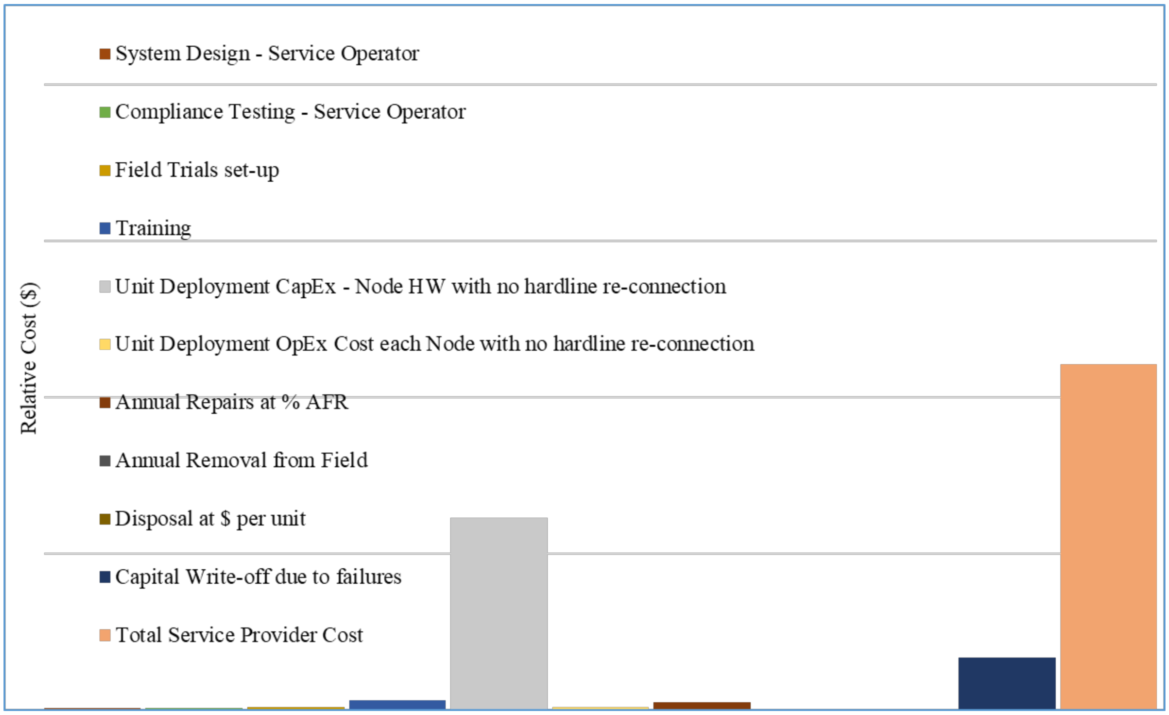


Figure 15 - GAP node: service provider deployment and sustaining costs

Both Figures 14 and 15 are drawn on the same relative cost scale for cost comparison purposes. The costs for deploying and sustaining GAP-based nodes are significantly lower as can be seen from the far-right hand bar; total service provider costs which is a cumulative total of the preceding bars to the left. The central bar indicating unit deployment capital expenditure is higher, by about 5% for GAP-based node compared to a traditional node, however the costs associated with deployment, repair and in particular, capital write-off costs are significantly lower. The cost-model assumes the same rate in deployed volume increase for both traditional and GAP nodes and the same rate of repair based on a 2% AFR. For GAP-based node deployment, the cost-model included an additional factor not include in the traditional node model. That is, 2% of nodes are being upgraded each year with new features by replacing old modules for new modules.

Figure 16 shows a hypothetical scenario where there is a cut-over to GAP-based housing node deployments in year 4, coincident with an increase in demand for application nodes beyond the traditional fiber/HFC type of node.

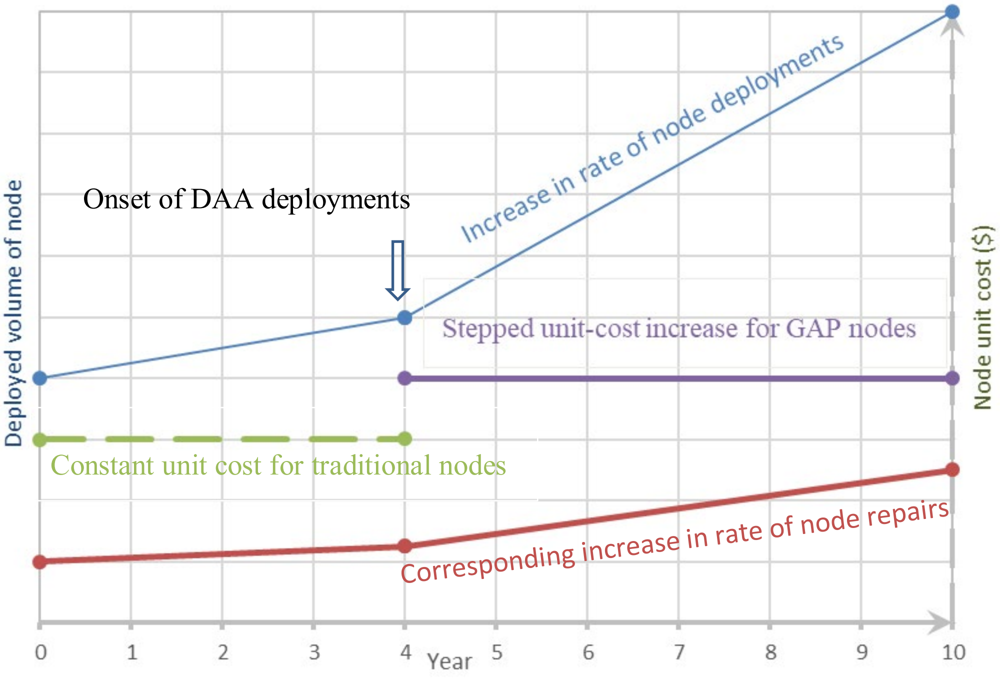


Figure 16 - Future traditional node deployed volume and cost over time

The cost analysis assumes that one module change only is needed to upgrade any GAP node to a new function, so it represents one of the lowest cost scenarios. In reality, there will be a blend of different options ranging from a single component or module upgrade through to a complete change of all of a GAP housing's contents. In some situations, it will be advantageous to remove and replace an entire lid or base that has been pre-built with the new modules in situ, thereby reducing the technicians in-field upgrade time. Figure 17 shows a typical blend and predicted percentage of these module exchanges. A further extension for this paper would be to examine the costs associated with re-building a lid or base with new modular components to create a new node function, taking into account the construction location costs, labor, warehousing and distribution prior to a technician doing an in-field GAP node exchange.

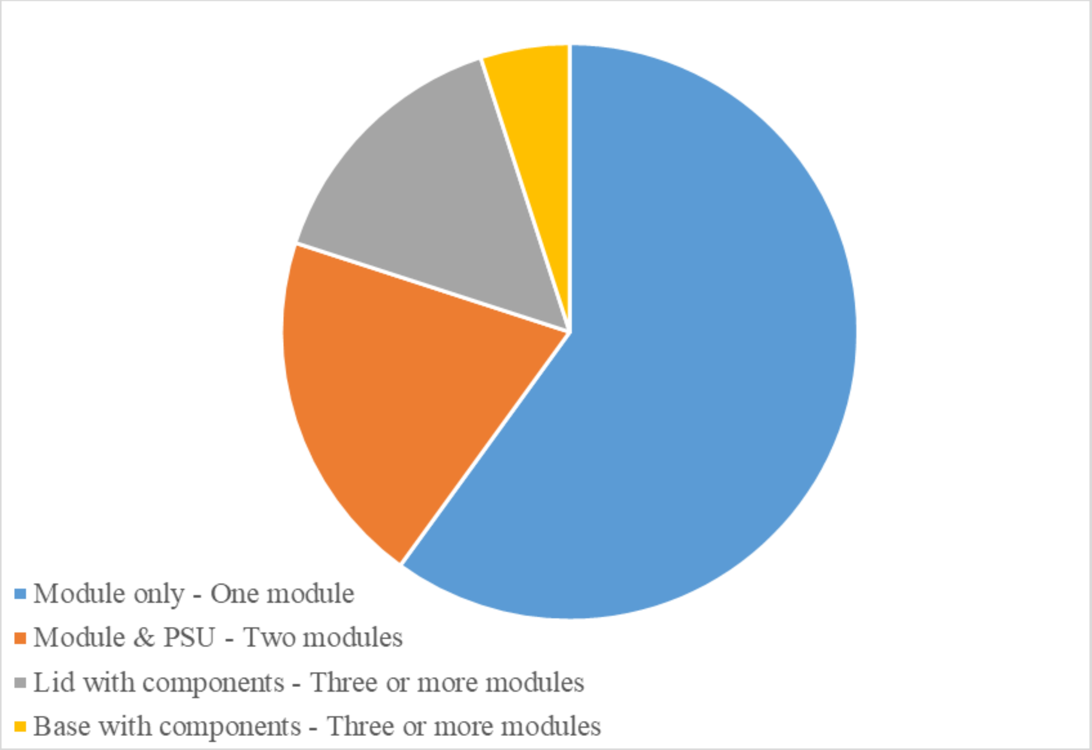


Figure 17 - Potential upgrade paths for GAP nodes

Conclusion

The Generic Access Platform (GAP) housing will change the way nodes are designed, developed and deployed into cable, optical and telecommunications networks. Network operators are on the cusp of a rapid increase in applications that are best suited for closer-to-the-edge node enclosures. GAP provides a means to deploy multiple types of nodes which are being created to address these new applications such as Wi-Fi, cellular, mobility, edge-compute and edge-storage.

The GAP housing offers the ability to use modularized and standardized components that will ultimately lead to operational cost reductions for service operators, while offering the ability to be upgradable to suit new technologies as they emerge. GAP nodes will have a longer in-field life and offer much reduced capital write-off when nodes need to be upgraded. Furthermore, the modular approach reduces the development time for new node features and provides a much faster time-to-market for node componenet vendors.

The cost-model shown in this paper reveals the design and development costs are also reduced for system designers and the vendor community. It enables an existing vendor to give greater concentration to their core competencies. The GAP modular approach also serves to allow the entrance of new node component vendors, as either node builders or modularized technology providers, such as for CBRS radios or edge-compute services.

Abbreviations

4G	fourth generation cellular network
5G	fifth generation cellular network
AFR	annual field failure rate
AP	access point
AT	advanced technology (form-factor)
ATX	Advanced technology eXtended (form-factor)
bps	bits per second
CAGR	compound annual growth rate
CBRS	citizens band radio
CMTS	cable modem termination system
DAA	distributed access architecture
DOCSIS	data over cable service interface specification
DWDM	dense wavelength division multiplexing
EPON	version e of a passive optical network
ESD	extended spectrum docsis
FTTx	fiber to the x, where x is curb, premise, or home
FWA	fixed wireless access
GAP	generic access platform
GPON	version g of a passive optical network
HFC	hybrid fiber-coax
HW	hardware
Hz	hertz
iCMTS	Integrated CMTS
IoT	internet of things
ISBE	International Society of Broadband Experts
LoRa	long range (radio wan)
LTE	long term evolution cellular network
MAC	media access control
MER	modulation error ratio
OLT	optical line termination
OEM	other electronic manufacturer
ONU	optical network unit
PC	Personal Computer
PHY	physical layer
RAN	radio access network
RMD	remote mac device
R-OLT	remote optical line termination
R&D	research and development
RPD	remote phy device
SCTE	Society of Cable Telecommunications Engineers
WAN	wide area network
Wi-Fi	a family of radio technologies commonly used for wireless local area networking

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