FSAN Interoperability Efforts: Building toward G-PON Interoperability

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ABSTRACT

The Full Service Access Network's (FSAN) Interoperability Task Group (TG) addresses interoperability between PON systems. Recently, the TG has focused on Gigabit Passive Optical Network (G-PON) system interoperability between Optical Line Terminations (OLT) and Optical Network Terminations (ONT) of different vendors, which has leveraged the lessons learned from Broadband Passive Optical Network (B-PON) interoperability. The TG members have made progress with interoperability by analyzing the International Telecommunications Union-Telecommunications (ITU-T) Recommendations to develop test plans and demonstrate implementations that work across multiple vendors' OLTs and ONTs. This article defines interoperability and conformance and describes the FSAN's Interoperability Program to develop common test plans. It describes recent and planned G-PON interoperability demonstrations, as well as current challenges facing the industry.

INTRODUCTION

The FSAN Interoperability TG mission is to develop technical specifications to distribute voice, video, and data services to broadband subscribers worldwide. To expedite this mission, the industry is looking at the key next steps in broadband access deployment. The abovementioned services need to be delivered simultaneously and economically including traditional voice, Time Division Multiplexing (TDM), and Radio Frequency (RF) video, along with newer services such as Voice over IP (VoIP) and Internet Protocol Television (IPTV).

G-PON is a broadband optical access system that consists of an Optical Line Termination (OLT) and several Optical Network Terminations (ONTs) connected via a tree and branch ("point-to-multipoint") Optical Distribution Network (ODN) topology. Time division multiplexing technology is used in the downstream (OLT to ONT direction) of transmission and time division multiple access (TDMA) is used in the upstream (ONTs to OLT) direction of transmission to share the available bandwidth among up to 64 ONTs connected to the ODN. The prevailing G-PON system implementation is a 2.488 Gb/s downstream and 1.244 Gb/s upstream using Ethernet as the layer 2 technology, with or without the RF wavelength overlay for multi-channel broadcast video. Throughout this article, for simplification, the term ONT is used instead of Optical Network Unit (ONU), as they are functionally equivalent.

Part of the solution to mass deployment is fine-tuning the technology implementation to extend the interoperability from the physical layer through the service level, thus enabling ONT portability across networks and broadening product choices and availability. FSAN advancements toward this objective include streamlining and standardizing interoperability testing practices. While efficient standardized testing practices are a necessary first step, interoperability testing based on these practices must be embraced industrywide by equipment suppliers, independent test laboratories, and network operators, and applied to products early in their life cycle in order to have the greatest positive impact on the broadband marketplace. These impacts include:

- Reduced product implementation costs
- Economical introduction of new system versions
- Mitigated network operator risks, such as the need for field fixes
- Fostered competition for delivering commoditized ONTs
- Benchmarks for fairly comparing G-PON products in the marketplace
- Validated industry standards

Not only has FSAN member companies taken the role of defining operator requirements and developing technical contributions to seed the International Telecommunications Union-Telecommunications (ITU-T) Recommendations (standards), it has extended its role on interoperability. The recent addition of independent test laboratories as Interoperability TG members has helped propel the interoperability efforts.

DEFINITION OF INTEROPERABILITY

CONFORMANCE AND INTEROPERABILITY

G-PON equipment interoperability is considered from the perspective of network element (NE) interworking, which is between OLTs and ONTs

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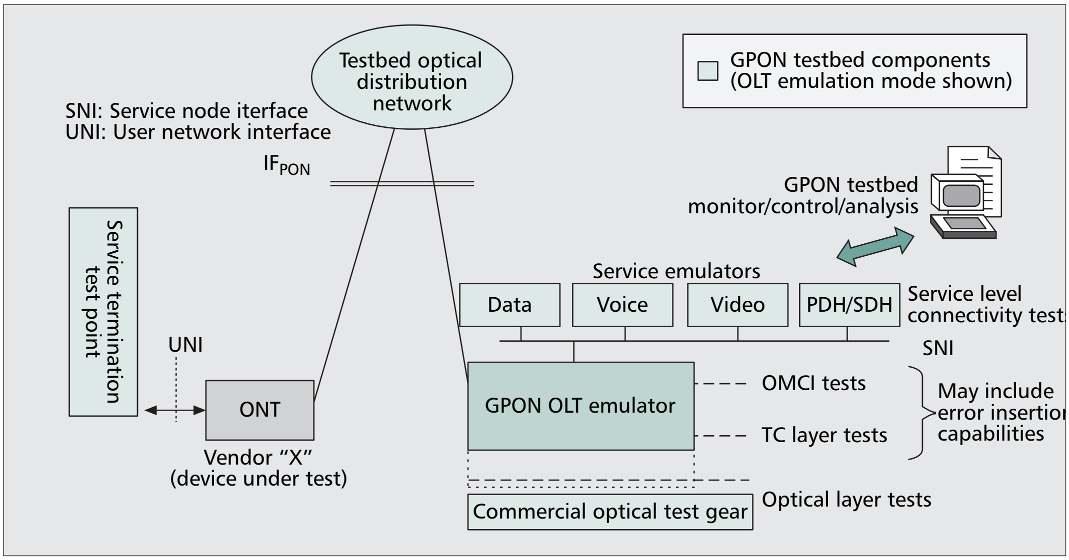

■ **Figure 1.** *Conformance testing of G-PON.*

At the test laboratories, the tests are conducted to determine if the equipment passes each applicable test. Ultimately, the passing of the tests depends on how well services are delivered to the subscriber.

in the context of this article. NE interworking is segmented from the end-to-end operational deployment environment, in contrast to network integration testing.

The road to interoperability begins with a strong set of technical specifications. For G-PON, there are internationally ratified standards referred to as the ITU-T G.984 series of Recommendations [1–4]. As with any technical specification, as G-PON products are implemented, ambiguities and potential gaps in the technical criteria are discovered. A number of ambiguities have been addressed by the editorial clarifications, including the "Implementers' Guide for ITU-T Rec. G.984.3." [5]

Interoperability assessment is typically performed in two phases: paper analysis and laboratory testing. The paper analysis phase is based on the completion of Protocol Implementation Conformance Statement (PICS) documents of two or more network elements. The PICS is a tabular checklist that is used to indicate what criteria of the standard has been implemented in the vendor products [6]. The PICS identifies the implementation's completeness relative to the underlying technical specifications. In addition, a PICS analysis guides the scope of the subsequent laboratory testing phase.

The second phase of interoperability assessment is laboratory testing. FSAN has addressed laboratory testing in two areas:
- Conformance testing
- 1:*N* interoperability testing

The European Telecommunications Standards Institute (ETSI) defines conformance testing as the activity of determining to what extent a single implementation conforms to the individual requirements of its base standard. In contrast, interoperability testing is the activity of assessing whether end-to-end functionality of two or more communicating NEs is as required by the underlying system specifications.

For conformance testing, a universally recognized, well-characterized, reference implementation is utilized to assess how well the NE under test complies with criteria defined in the referenced technical specifications. This is conceptually illustrated in Fig. 1, whereby an ONT is assessed for conformance to the G.984 Recommendations using a conformance "test bed" that includes a "G-PON OLT Emulator." A similar test environment to that of Fig. 1 would be used to assess OLT conformance, but instead using an ONT Emulator device with the OLT as the device under test.

Because G-PON vendors have various interpretations of Recommendations manifested in their implementation of their OLT and ONT products, FSAN has undertaken interoperability assessment through 1: 1 and 1:*N* interoperability testing. The 1:1 and 1:*N* interoperability testing analyzes how well an NE under test interworks with another implementation, not an agreed upon reference. A 1:*N* interoperability testing setup for G-PON is illustrated in Fig. 2.

FSAN test plans address the interoperability requirements for OLTs and ONTs by describing how to conduct tests through establishing the passing criteria and performance reporting, and by specifying how to set up the test laboratories. At the test laboratories, the tests are conducted to determine if the equipment passes each applicable test.

Ultimately, the passing of the tests depends on how well services are delivered to the subscriber. For G-PON in particular, the testing involves a technical analysis of how well one or more (*N*) commercial ONT implementations interwork with an OLT implementation, including the satisfying of a set of system performance, service delivery, and management requirements using the OLT's element management system (EMS).

Purpose and Objective of Interoperability

The purpose of interoperability is to attain more uniform product implementations of ITU-T Recommendations and validate the Recommendations by testing. Through the efforts of the Interoperability TG, more common interpretations of the Recommendations are achieved

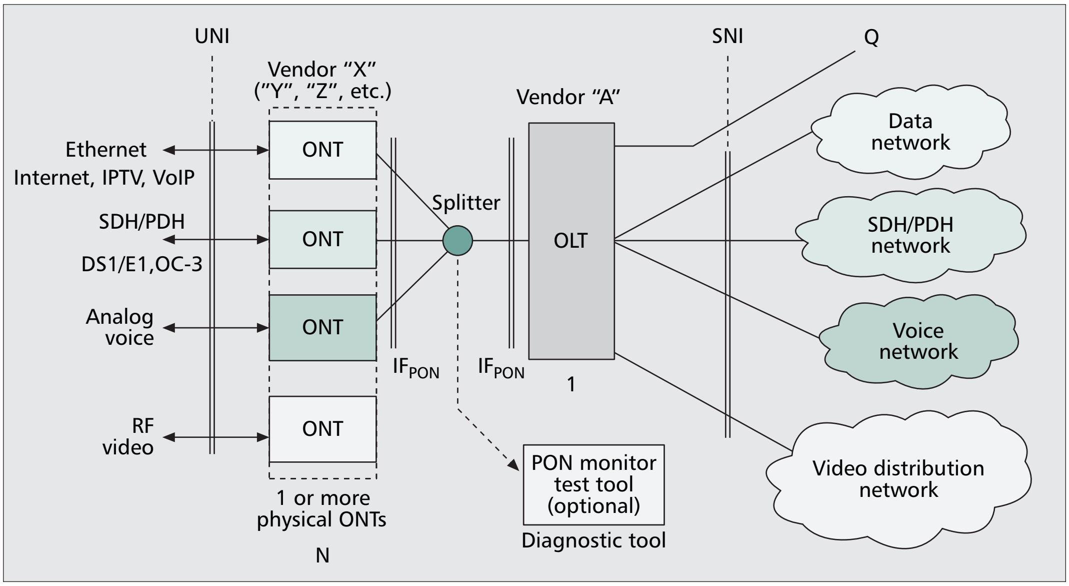

Figure 2. *1:*N *interoperability testing of G-PON.*

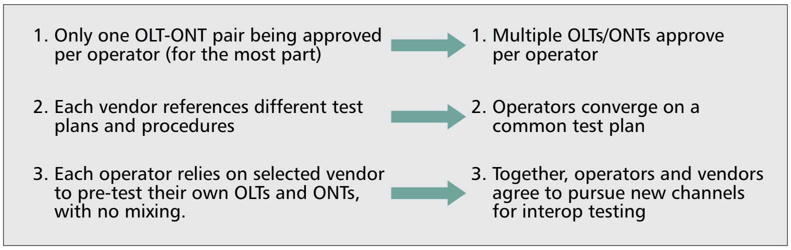

Figure 3. *Industry changes with interoperability.*

through the development and employment of test plans. This enables the interoperability of OLT and ONT products from multiple vendors, so they could interoperate across the same G-PON system.

By addressing interoperability early in the product implementation process, operators will be able to manage the provisioning and maintenance of a larger selection of ONTs as well as OLTs (Fig. 3).

Interoperability Goals

The Interoperability TG charter is to guide the industry's efforts for ubiquitous OLTs and ONTs of multiple vendors that function well together. The objective is to develop PICS documents and interoperability test plans and employ a program to demonstrate PON testing. Other goals of the Interoperability Program include guiding related FSAN activities and interoperability test events.

Benefits of FSAN's Interoperability Program

The FSAN Interoperability Program provides the structure to eventually enable operators and vendors to streamline multi-vendor G-PON installation and maintenance — all for an improved broadband subscriber experience — "right out of the truck."

The key benefits to the industry are:
- Improved manufacturing efficiency
- Faster introduction of products and services
- Reduced operations costs

For operators, the Interoperability Program could lead to lower costs for testing, procurement and storage of ONTs.

Program Scope

The Interoperability Program scope consists of interoperability test plans and a process to employ them. This goes beyond the development of traditional PICS and Implementers' Guidelines. With the focus on G-PON system development and implementation, interoperability test plans leverage lessons learned from B-PON testing.

To facilitate the Interoperability Program, FSAN has invited independent testing laboratories to host test events and project manage demonstrations of the compatible multivendor equipment.

Test Setups

The FSAN Interoperability TG has produced a set of test cases, which are being compiled into test plans. These test cases address both B-PON and G-PON across the following functional layers:
- Physical media dependent (PMD) sublayer
- Transmission converge (TC) sublayer
- Layer 2
- ONT management and control interface (OMCI)
- Application layer functionality

The applicable test cases can be employed for G-PON interoperability or B-PON interoperability based on the vendor implementation, in particular, with the layer 2 test cases that address Ethernet and ATM.

For each of the functional layers, the test cases address the following areas:
- Optical compatibility verification
- ONT turn-up and management

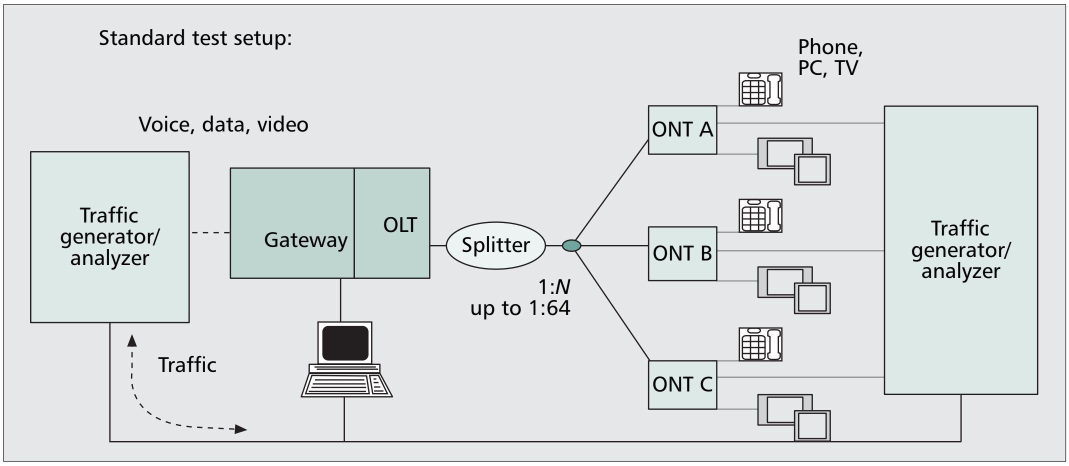

Figure 4. *Standard test setup testing multiple services.*

Developers and designers approach the challenge to interpret and implement relevant ITU-T Recommendations from their own perspectives. With FSAN's quest to commoditize G-PON OLTs and ONTs to an acceptable level for interoperability, a balance is needed to allow for vendor innovation and differentiation.

- Service-related functionality
- System and performance tests
- Fault recovery

Each area consists of test cases that are designed to verify the interoperability between OLTs and ONTs of different vendors and ensure successful support of services. For example, the optical compatibility verification test cases prove fundamental PMD and TC layer conformance in order to ensure that subsequent interoperability test results are not biased by physical layer issues or nonconformances.

ONT turn-up and management test cases verify ONT ranging and registration, as well as OMCI compatibility. These tests also verify provisioning, performance management counters, and alarms.

Service-related functionality test cases verify the ability of the OLT and ONT to offer voice, video, and data. This also includes testing of the interoperability service interfaces on the platforms such as Ethernet, DSL, and TDM.

System and performance tests cases verify interoperability with multiple ONTs of different model numbers or from different manufacturers that can be tested over a PON system.

Fault tests verify that the system can recover from failures, including breaks in fiber connections and power outages.

With this broad range of types of test cases, it is preferred to have a few setup configurations that can support a large number of test cases. This increases the testing efficiency and facilitates the use of automation with test scripts.

The configuration shown in Fig. 4 illustrates a test setup that can be employed for testing the TC layer, OMCI, and services. Additional setups are required for optical and other system testing.

Key Issues

Separately, developers and designers approach the challenge to interpret and implement relevant ITU-T Recommendations from their own perspectives. With FSAN's quest to commoditize G-PON OLTs and ONTs to an acceptable level for interoperability, a balance is needed to allow for vendor innovation and differentiation. Furthermore, a vendor's desires for mass implementation of their own OLTs and ONTs also needs to be balanced with their need to interoperate with other vendors' products.

Aside from the business issues, the major technical issues that are being addressed include:

- Detailed aspects of the G-PON Recommendations have been interpreted differently.
- Options that are built into the G-PON that are linked with other Recommendations are not aligned.
- Deployment complexities and other areas of support have not been standardized.

Different Interpretations and Options

G-PON interoperability involves significant challenges due to the various vendor interpretations of Recommendations in their resulting implementations. Of the many challenges involved in G-PON interoperability, the most critical area of interoperability is the OMCI. OMCI allows for provisioning and ongoing management of the ONTs, which are subject to different vendor interpretations. It is a complex interface consisting of detailed performance management and alarming of the ONT by the OLT. Consequently, the complexity of the OMCI necessitates passing a long list of test cases to achieve interoperability.

In addition to the OMCI, the diverse implementations of G-PON can employ different options in G.984 Recommendations and a selection of other related standards and technologies to support the same type of service. For example, the quality of service (QoS) associated with a particular service may be achieved with Ethernet and IP technologies, within hardware and software of OLTs and ONTs. End-to-end QoS depends largely on agreement of a common framework between G-PON with Ethernet and IP for particular service requirements and their segregation, such as with the G-PON traffic containers (T-CONT).

At the ONT, services need to be given differentiated traffic handling based on the quality of service parameters such as packet loss, delay, and delay variation of the specific service. In the upstream direction of transmission, the OLT manages bandwidth assignment to the subtending ONTs with T-CONTs. Some ONTs have been implemented with a traffic model that effectively

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groups services with similar QoS requirements in a common set of T-CONTs, typically four or more T-CONTs per ONT. Other ONT designs utilize a single T-CONT structure, using priority queues within the ONT to fairly distribute the OLT allocated upstream bandwidth among the competing upstream traffic types. For each approach, the OLT needs to discover the T-CONT capabilities of the subtending ONTs via the OMCI and then fairly allocate upstream bandwidth between the ONTs on the ODN, based on the amount of waiting upstream traffic and the QoS characteristics associated with the waiting traffic. OLTs need to support ONTs with both types of traffic management models simultaneously on the ODN. Lab and field interoperability testing will play a critical role in verifying an OLT implementation's ability to provide this dual traffic-management-model support function. In particular, T-CONTs may be important for TDM services, because the OLT can minimize latency and jitter for the segregated TDM traffic.

In addition, one vendor's ONTs can be designed to achieve service quality levels at the G-PON Ethernet layer, while another vendor's OLT can be designed to solely employ IP for the same functions. Furthermore, service aggregation at the Ethernet or IP layers utilize 802.1D/Q priority codepoints (PCP) or DiffServ Codepoints (DSCP), respectively, to mark service quality levels within the ONT. Optionally, this service differentiation can be implemented using multiple queues per T-CONT, with strict priority or weighted fair queueing between the queues. The different interpretations of service quality can be manifested in various ways by Ethernet and IP service differentiation, which is intended to provide greater flexibility when multiple devices, such as Session Initiated Protocol (SIP) phones, IP video set-top boxes, and PCs, are connected to the ONT's Ethernet port.

Other Areas not net Covered in Standards

Because the G.984 set of Recommendations provides a framework for implementation, there are several items which have not yet been completely standardized, including TDM support and point-to-multipoint interactions.

For example, the OMCI standard does not detail mechanisms to provide TDM services over Ethernet over GPON Encapsulated Mode (GEM) transport. When offering TDM or $N \times 64$ services, vendors have several choices, including TDM/GEM, AAL1 encapsulation, PWE3 (pseudo wire emulation edge-to-edge) encapsulation or MEF8 (Metro Ethernet Forum) encapsulation. When offering traditional voice service, vendors have a choice of using SIP or H.248 protocols.

In addition to TDM, the G-PON Recommendations do not address the complexities of a "rogue" ONT's potential to interfere with others over a G-PON system's point-to-multipoint shared ODN. Since up to 64 ONTs may reside on the same fiber in the ODN and share timeslots on the same wavelength for upstream traffic, the interoperability testing needs to address multiple ONTs, spanning different models and vendors connecting to an OLT.

As the industry begins to converge on implementation choices and defines test plans and other specifications to help fill the initial gaps, interoperability testing will become more comprehensive and streamlined.

Progress and Plans

The Interoperability TG has made significant progress with its test plan development and its demonstration at test events.

Test Plan Development

The path to building the FSAN Interoperability Program for G-PON relies on establishing agreed-upon test plans. The test plans have been derived from the G.984 series for the PMD and TC sublayers, OMCI and layer 2, as well as common technical specifications for higher layers through the service level. The process flow (indicated by the arrows) for FSAN to develop specifications and interoperability test plans is depicted in Fig. 5. The FSAN Interoperability TG membership is composed of operating companies, vendors or equipment manufacturers, and independent test labs. Representatives from these companies volunteer to serve in various functional roles, as outlined in the diagram. Their combined output feeds into test events and the ITU-T and serve as the guidelines to product development.

As already introduced in this article in the Test Setups section, the FSAN members have developed test plans based on the G.984 series of Recommendations. This consented compendium of FSAN member company contributions consists of test cases and describes the test procedures and expected results. For the most part, the test cases entail a pass or fail result, although there are a number of test cases that entail a range of acceptable levels for performance results, such as characterized throughput.

In addition, test plans that are comprised of specific test cases have been developed for the test events. The test cases for the test events are validated through putting them into practice. In this way, the test plans and vendor equipment, as well as test equipment, keep each other consistent and up to date. The test areas associated with the G-PON test events of the Interoperability Program are:

- TC layer demonstrations
- OMCI interoperability
- Service-level demonstration

For each of these areas, test plans are developed and test events are arranged by members of the Interoperability TG.

Test Events

During 2006, FSAN has provided an opportunity to push early G-PON implementations toward interoperability. Independent test laboratory members have hosted the G-PON testing events, for which vendors are invited to assess their G-PON product's progress toward interoperability early in the product lifecycle.

At the test events, OLT and ONT vendors have the opportunity to interconnect their G-PON products to those of other vendors. The test events have led vendors to make progress in

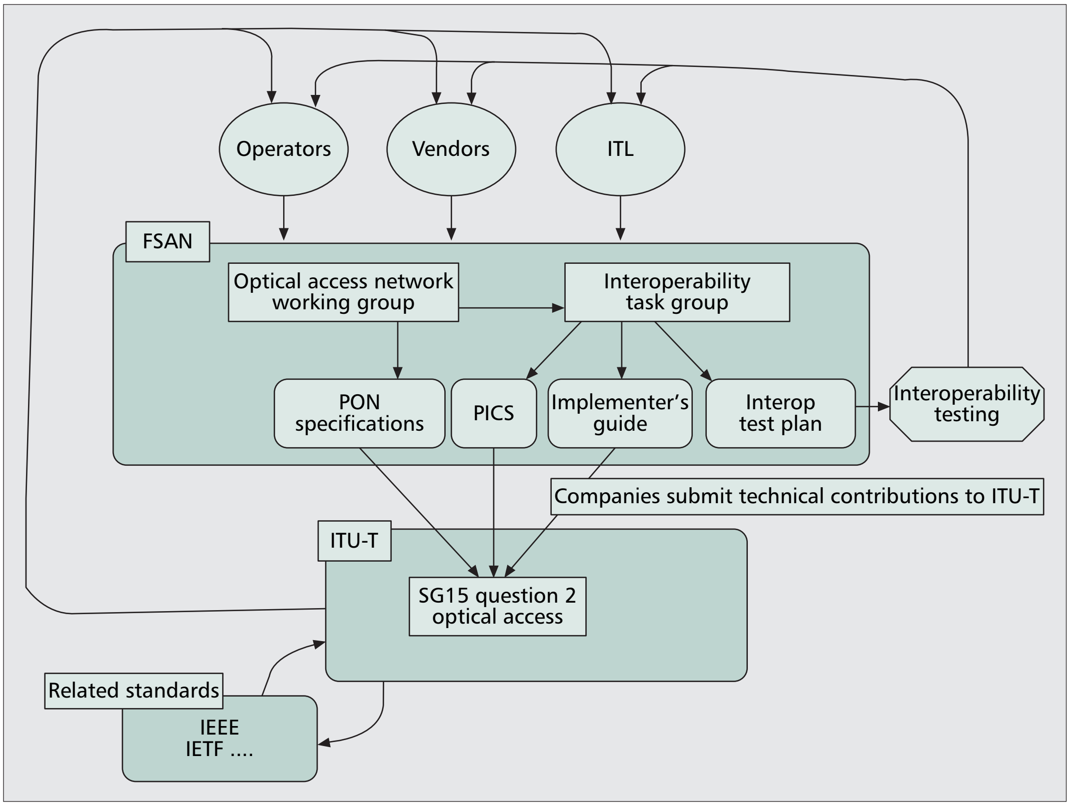

Figure 5. *Process flows in FSAN for developing G-PON interoperability.*

the alignment of their implementations, thereby progressing toward interoperability.

In January and May of 2006, FSAN moved G-PON interoperability forward with test events arranged for the interoperability of the TC layer. Some lessons learned so far include the identification of ambiguities and their clarification in the sequencing between forward error correction (FEC) and advance encryption standard (AES) described in ITU-T G.984.3. These clarifications can lead to the alignment of the different vendor implementations, so they work better together.

Building upon that achievement, the FSAN membership is gearing up to further demonstrate OMCI interoperability with more test cases, as well as developing new test cases for service-level demonstrations. Going forward, the test plans for the test events will build on test cases established for the OMCI messages. This will involve even more challenges to achieve success. Furthermore, the test events will focus on interoperability that links the OMCI with service-level tests. Forthcoming test cases and demonstrations include:

- VoIP employing H.248 or SIP standards implementations
- IPTV over Multicast
- TDM over G-PON Ethernet Management (TDM/GEM)

VoIP — One paramount service that needs to be supported over G-PON with interoperability is VoIP. There are two well-defined standard implementations to transport and configure VoIP: the ITU-T's H.248 and the IETF's SIP. With SIP, the OMCI and the configuration server based architecture are the standard alternatives to convey the operation of the ONT for VoIP. In addition, the VoIP user agent at the ONT needs to work in conjunction with a softswitch for voice service features.

IPTV over Multicast — The G-PON Recommendations allow for alternatives for the efficient implementation of IPTV over multicast, whereby a G-PON Port ID can be utilized. More specifically, the G-PON OMCI standard supports vendor implementation of a single G-PON logical connection associated with one Port ID or multiple G-PON logical connections segregated across more than one Port ID, in order to carry the video multicast traffic flows on the ODN. This involves options in how multicast groups or television channels can be mapped to Port IDs. Fortunately, the same IETF Internet Group Management Protocol (IGMP) can be implemented in these various vendor G-PON implementations, so that the OLT and/or ONTs can control the forwarding of video multicast flows in and out of the G-PON system.

TDM Support — As G-PON is deployed for business subscribers in addition to residential subscribers, legacy TDM continues to be a service that needs to be supported in an interoperable manner. This involves vendors integrating the same means of timing for TDM as well as other provisions for GEM for OLT and ONT interoperability. Further complicating TDM, the regional differences include the need to support DS1, E1, and J1.

FSAN interoperability testing events that focus on services are planned for G-PON. For the next test events, vendors are invited to "choose their partners," which have implement-

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ed the support of services in the same way. Subsequently, vendors need to integrate the same implementation of VoIP, multicast, and TDM along with their configuration method, because the G-PON Recommendations allow for options and alternatives that provide the "hooks" for the higher-layer support of the services.

With future test events, the results of test cases associated with the alternative types of vendor implementations could be compared for performance and quality. As the implementation options narrow over time, the test events could involve more stringent adherence to a base set of test cases that are derived from select alternatives in the G.984 series and common technical specifications for the higher layers.

Depending on the service to be supported, FSAN relies on other standards groups for higher-layer protocols and other specifications to which G-PON is linked to the higher layers. FSAN's Interoperability TG takes this a step further with its interoperability demonstrations by putting into practice the integration of implementations referencing other standards that are supported over G-PON, such as those of the IETF, IEEE, MEF, and DSL Forum, in addition to the ITU-T.

Reaching interoperability can be very challenging if only a subset of services are supported in a common manner amongst the vendors' G-PON products. When verifying interoperability between an OLT and ONT, vendors must resolve these issues.

Continuing Challenges

FSAN has taken on the challenge of interoperability through its development of test cases and demonstrations. Although significant traction has been gained over the last couple of years, efforts continue to build toward assuring seamless GPON interoperability. Additional steps are being taken to further facilitate collaboration toward interoperability, including the development of test plans consisting of compendiums of approved test cases. Through consensus, common test plans are derived from technical requirements to clarify different interpretations of the technical requirements in the ITU G.984 series of Recommendations. Agreement among the many members also contributes to building confidence in the utility of the test cases and their applicability to a large number of products. Furthermore, the FSAN members' regular review and demonstration of G-PON capabilities help fulfill demand for broadband service offerings.

As FSAN member companies continue to participate in interoperability test-plan development and test events, implementation variations are identified and addressed. To overcome the challenges of interoperability, vendors proceed to align their designs to ensure "plug and play" of G-PON products, as operators continue to advocate the "mix and match" of interoperable OLTs and ONTs.

Conclusions

The FSAN Interoperability Program is set to further reduce operation costs by transforming the implementation of OLTs and ONTs, so that they interoperate and work across various serving areas of operator networks. With the teamwork arranged by the Interoperability TG, the industry's convergence on common requirements for interoperability is a major step forward towards the goal of making G-PON easier to deploy. Standards-based implementations combined with the interoperability testing process by test laboratories are expected to make OLTs and ONTs easier to install and to give operators an assurance that these NEs will interwork. At the same time, the vendors are given some assurance that they are designing and developing G-PON products that will be accepted in the marketplace.

Acknowledments

The authors extend their appreciation to the members of FSAN for helping advance the work of interoperability. Thanks to Yoichi Maeda, Kent McCammon, and the reviewers for their guidance and editing.

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Biographies

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Keith Bennington has served as the interoperability test plan editor since 2005. For the past 30 years he has worked with corporations such as ITT and Alcatel in the design and development of central office switching. His experience spans from the step-by-step systems to the current softswitch hardware. He has a B.S. from Capitol College and an M.S. in system engineering and management from George Washington University.

Rob Bond is a senior system engineer in the Telecom Services business unit of Telcordia. His career, spanning 20+ years, has focused on access system technology, system requirements, and technical analysis of access system products. He is the lead author on a number of well-known Telcordia Generic Requirement documents, including GR-303 (IDLC systems) and GR-909 (Fiber-in the-Loop systems). He currently represents Telcordia in the FSAN group, supporting the group's activities related to G.983 (B-PON)/G.984 (G-PON) interoperability.

Jeremy Maselko is the system engineering manager for Entrisphere. He joined Entrisphere in 2000. His 10-year career has included work on ATM systems, Class 5 switches, DSL systems and PON systems. He is a member of Entrisphere's FSAN representation team and editor of the Interoperability Test Plan Living List. He received a B.S. in physics from Susquehanna University.