For network service providers considering new approaches for transmitting various data types over a common network infrastructure, the integrated packet optical transport networks (P-OTNs) can be the answer. Built upon the ITU-T’s optical transport network (OTN) standards and supporting the reconfigurable optical add/drop multiplexers (ROADMs) functionality, P-OTNs efficiently and cost-effectively provision, transport and manage legacy TDM and data-packet services over the same infrastructure.

OTN is an industry standard—also known as the “digital wrapper”—and is based on the ITU-T G.709 standard. OTN addresses the growing migration of packet-based services such as Ethernet and Fibre Channel onto optical transport with defined operations, administration, and maintenance (OA&M) procedures. OTN also provides a standardized forward error correction (FEC) mechanism, making it possible to extend the distance of fiber transmission or reduce the power required to reach an equivalent distance. Therefore, using FEC results in more accommodated dense wavelength-division multiplexing (DWDM) wavelengths, improved optical channel performance and better deployment economics.

This application note provides an overview of the main tests that should be conducted to ensure the optimum performance of P-OTNs.

### Interfaces and Payload Testing

ITU-T G.709 defines standard OTN line rates based on the existing SONET/SDH rates and with the OTN overhead and FEC information taken into account. Typically, the resulting OTN interfaces operate at line rates roughly 7% higher than the corresponding SONET/SDH rates. Additional line rates have been introduced as over-clocked OTN to address 10 Gigabit Ethernet LAN services transported over OTN specifically.

The following table lists both the standard and over-clocked OTN rates covered by EXFO’s FTB-8120NGE/8130NGE Power Blazer and FTB-8140 Transport Blazer (these test modules support in-depth OTN, FEC and multiservice testing capabilities for qualifying P-OTNs during the verification stage as well as during installation, commissioning and troubleshooting).

<table>
<thead>
<tr>
<th>G-709 Interface</th>
<th>Line Rate (Gbit/s)</th>
<th>Corresponding SONET/SDH and Ethernet Rate</th>
<th>Line Rate (Gbit/s)</th>
<th>FTB-8120xx</th>
<th>FTB-8130xx</th>
<th>FTB-8140</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTU-1</td>
<td>2.666</td>
<td>STM-16/OC-48</td>
<td>2.488</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>OTU-2</td>
<td>10.709</td>
<td>STM-64/OC-192</td>
<td>9.953</td>
<td>x</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>OTU-1e</td>
<td>11.0491</td>
<td>10GigE LAN</td>
<td>10.3125</td>
<td>x</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>OTU-2e</td>
<td>11.0957</td>
<td>10GigE LAN</td>
<td>10.3125</td>
<td>x</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>OTU-3</td>
<td>43.018</td>
<td>STM-256/OC-768</td>
<td>39.813</td>
<td>x</td>
<td>x</td>
<td>✓</td>
</tr>
</tbody>
</table>

*Table 1. OTN standard and over-clocked rates*
One of the most important tests on an OTN device under test (DUT) is verifying the proper frequency and the frequency offset of the OTN interface. Typically, OTU1/OTU2/OTU3 interfaces run at 2.7 G/10.7 G/43 G ± 20 ppm, respectively, and OTU1e/OTU2e interfaces run at 11.0491 G/11.0957 G ± 100 ppm. These values can be verified using the Frequency Analysis functionality of the FTB-8120NGE/8130NGE Power Blazer and the FTB-8140 Transport Blazer test modules—allowing the user to monitor the received frequency from the device under test (DUT) as well as the frequency offset, maximum negative offset and maximum positive offset in ppm or bit/s unit.

Testing the OTN payload itself is typically conducted through the end-to-end, bit error rate (BER) test across the network. BER testing is an industry standard procedure allowing the user to send a pseudo-random bit sequence (PRBS) pattern in the OTN frame across the network and measure the ratio of the error bits compared to the number of sent bits. The FTB-8120NGE/8130NGE Power Blazer and the FTB-8140’s BER testing functionality offers different PRBS test patterns and up to 10 user-configurable patterns. The FTB-8130NGE specifically, also supports the mapping of SONET/SDH and 10 Gigabit Ethernet LAN signals into OTN payload and measures bit errors in seconds, count and rate. A BER test is typically executed over an extended period of time (24 to 72 hours), and once it has been launched, it is recommended to check the test results periodically—either locally on the unit or remotely using the remote management capability—to ensure that the test is running error-free.

Connectivity Testing

OTN supports multiple trace messages including the optical channel data unit (ODU), path monitoring (PM), trail trace identifier (TTI), optical channel transport unit (OTU), section monitoring (SM) TTI and six tandem connection monitoring (TCMi) TTI trace messages. When commissioning a new OTN link, trace messages are typically used to monitor the integrity of the connection routing between termination points during the connection setup process. Furthermore, TTI messages are needed to ensure that connectivity is maintained while the connection is active. The OTN TTI messages contain network-related information in the form of source and destination access point identifiers (SAPI and DAPI). Typically, a trace identifier mismatch (TIM) alarm is raised when the received SAPI and/or DAPI values found in the TTI do not match the expected, pre-provisioned values. Using the test module’s TTI testing capability, the user can provision SAPI, DAPI and operator-specific information fields in the SM, PM or TCMs TTI and verify that they are properly delivered across the network. The modules can also be used to monitor the TTI messages provisioned through the network-management system.
Performance Testing

Qualifying the performance of the OTN network elements and their proper response to errors and alarms is essential. The performance test is typically conducted in carriers’ labs as part of the product acceptance testing; the test equipment is used to generate alarms and errors and to verify the proper response of the DUT. A single OTN stimulus may result in several simultaneous responses. Figure 3 highlights the major OTN stimuli that can be triggered using the FTB-8120NGE/8130NGE Power Blazer and the FTB-8140 Transport Blazer test modules and the expected response of the OTN DUT in both upstream and downstream directions. For example, the user can trigger an AIS-P and verify that the DUT sends an OTU-BDI alarm upstream and OTU-AIS downstream.

Proper FEC Behavior

As a key element of OTN, FEC needs to be validated as part of the G.709 testing. FEC testing is typically conducted as part of the system manufacturers’ validation procedure and as part of the operator’s acceptance testing and field commissioning testing. In order to determine the appropriate FEC behavior of the DUT, the user can start with generating FEC correctable errors. As the name suggests, FEC correctable errors should be detected and corrected by the OTN DUT, and the test equipment should then receive an error-free signal in response. The second test is to generate FEC uncorrectable errors to determine the maximum number of errors that can be detected and corrected by the OTN DUT. In the case of uncorrectable errors, the DUT should report the proper alarm in the network management system. Finally, the user can conduct the FEC stress test shown in Figure 4; this test generates random errors over the entire OTU frame. The DUT should still be able to correct all the errors and send back an error-free OTN signal.
Proper Mapping of Client Signals

The OTN standard has been designed to transport a range of synchronous and asynchronous payloads. Using the Decoupled mode capability of the FTB-8120NGE/8130NGE Power Blazer and the FTB-8140 Transport Blazer test modules, shown in Figure 5, the user can generate a SONET/SDH client signal in the transmit direction and verify the received OTN signal with mapped SONET/SDH client signals. This test confirms that the optical interface supporting the G.709 functionality is adding the proper OTN overhead and FEC portions as part of the mapping process. The de-mapping process of the client signal can also be verified using Decoupled mode, in which the test unit generate an OTN signal with mapped SONET/SDH within and verify the received SONET/SDH after removing the OTN overhead and FEC by the DUT.

10 Gigabit Ethernet LAN Services over OTN

Over-clocked OTN technology enables the transportation of 10 Gigabit Ethernet LAN services over OTNs using 11.0491Gbit/s (OTU1e) and 11.0957 Gbit/s (OTU2e) line rates. When commissioning and turning up over-clocked OTN links with 10 Gigabit Ethernet services, it is essential to verify the transport layer of the network as well as the service itself, end-to-end (as shown in Figure 6).

Using EXFO’s FTB-8130NGE Power Blazer, the user can generate over-clocked OTN signals with a mapped 10 Gigabit Ethernet LAN client signal containing configured and framed Layer 2 parameters, including frame size, transmit rate, source/destination MAC addresses and VLAN ID. This test offers network operators full visibility of the OTN transport layer, as well as its alarms, errors, trace messages and overhead bytes. Furthermore, this test also provides complete 10 Gigabit Ethernet traffic statistics, throughput (bandwidth) and line-rate utilization. Once the transport-layer testing is complete, the user can conduct the RFC 2544 test, which provides performance availability, transmission delay, link burstability and service integrity measurements. Using the RFC 2544 test results, carriers can certify that the working parameters of the delivered 10 Gigabit Ethernet LAN service comply with their service-level agreements (SLAs).
In-Service Testing

In-service testing is typically conducted by Tier-2 engineers for troubleshooting and maintenance purposes. In-service testing procedures help identify defects that can have an impact on or even degrade the performance of a live network. Different factors can affect optical link performance, including optical noise, fiber problems and network timing. Furthermore, since with ROADM's being actively deployed, network operators are challenged more than ever before to maintain the network performance and honor their SLAs with their customers.

Taking advantage of the ROADM's flexibility to add and drop any wavelength at any port, the EXFO’s FTB-8120NGE/8130NGE Power Blazer and FTB-8140 Transport Blazer can be configured in OTN Through mode, as shown in Figure 7, to monitor any selected optical channel transparently. In this process, once the optical channel is dropped, the test set checks the signal’s OTU, ODU and OPU alarms and errors before sending it out again as an added channel. For example, monitoring the bit interleaved parity (BIP-8) error detection code information within the OTU, ODU and TCM overhead bytes reflects post-FEC uncorrectable errors presented on the optical link and helps to evaluate the network performance against defined thresholds. The test modules take in-service testing a step further with their supported Intrusive Through mode testing capability, which allows the user to insert OTN alarms and errors, in the normally transported OTN signal. Intrusive Through mode is typically used for verifying the OTN network element’s fault detection, reporting and generating the proper consequential actions as well as network element’s automatic protection switching (APS) capabilities. In addition, Intrusive Through mode can be used during field commissioning and turn-up to validate the interoperability of the OTN elements.

Performance Monitoring

The OTN OTU layer supports six tandem connection monitoring (TCM) fault monitoring levels. TCM enables an operator to monitor the traffic quality when transported between different segments in the network and to trace errors and defects along the path to a particular segment. This is particularly important when the optical signal path passes through multiple networks for one or different operators. In this scenario, it is typically not possible to determine which network or operator is responsible for the bit errors that occurred. Today, the assignment of monitored connections is a manual process that involves an understanding between the different network operators as there is not a common standard that specifies how the TCM levels should be assigned.

Figure 8 illustrates TCM1 being used by the customer to monitor the connection’s end-to-end path, where TCM2 is used by network operator A, B and C independently to monitor the connection through its own sub-network. The FTB-8120NGE/8130NGE Power Blazer's and the FTB-8140 Transport Blazer’s TCM monitoring capabilities include: TCM-bit interleave parity-8 (TCM-PIB-8) and TCM-backward error indication (TCM-BEI) error monitoring as well as TCM-alarm indication signal (TCM-AIS), TCM-loss of tandem connection (TCM-LTC), TCM-open connection indication (TCM-OCI), TCM-locked (TCM-LCK), TCM-trace identifier mismatch (TCM-TIM), TCM-backward defect indication (TCM-BDI), TCM-incoming alarm error (TCM-IAE) and TCM-backward incoming alignment error (TCM-BIAE) alarms. Using TCM errors and alarms, operators can monitor the performance of their networks in detail or as an overview.
Conclusion

OTN is becoming the optical transport layer of the future with P-OTNs, providing protocol, bit rate and timing transparency and extending SONET/SDH-like OAM capabilities to data protocols like Ethernet and Fibre Channel. This is in addition to its FEC capability, which provides a significant gain for the overall optical power budget of the link. EXFO’s OTN test offering supports up to 43G in its portable FTB-500 Platform giving service providers all they need for testing an OTN network from commissioning to in-service monitoring. For more information on testing your next-generation network, go to www.unlimited.EXFO.com or visit the FTB-8120NGE/8130NGE Power Blazer and the FTB-8140 Transport Blazer product pages.