Executive Summary

Alcatel-Lucent engaged Iometrix to test and validate the ability of the Alcatel-Lucent IP/MPLS based 7705 SAR, 7450 ESS and 7750 SR products, acting as Synchronous Ethernet Nodes, to maintain accurate timing in a hybrid Ethernet/SONET/SDH environment. In addition, Iometrix analyzed a set of test results performed for Banverket Swedish Rail to verify the ability of the Alcatel-Lucent devices to distribute accurate timing (1) in a G.803 reference chain of 20 Sync-E nodes, (2) during synchronization reference failover events, (3) in a hybrid environment, (4) in extreme thermal stress conditions and (5) pushing the limits in a chain of 24 Sync-E nodes.

To the best of our knowledge this series of tests is the first and most comprehensive publicly available examination of Sync-E timing distribution.

Tests were performed using the JDSU ANT-20 Wander Analyzer and the TTC Fireberd Communications Analyzer to measure TIE*, MTIE*, TDEV* and bit error rate. The key findings of this series of tests performed on the Alcatel-Lucent 7705 SAR, 7450 ESS and 7750 SR acting as Synchronous Ethernet Nodes are:

- The MTIE and TDEV results are well within the industry standard objectives for a 20-Node network defined in G.803
- The MTIE and TDEV results are well within the industry standard objectives during primary to secondary reference clock failover events on a 20-node network defined in G.803
- The MTIE and TDEV results are well within the industry standard objectives when Sync-E network elements participated in a hybrid environment defined in G.803
- The MTIE and TDEV results are well within the industry standard objectives while Sync-E network elements were operating in extreme thermal stress conditions
- The MTIE and TDEV results for a 24-node chain are still within the industry standard objectives defined in G.803 for a 20-node chain

This series of tests assesses the ability of packet-based networks to support accurate and stable frequency distribution. The results provide conclusive evidence that Ethernet and IP/MPLS networks can distribute synchronization of the same quality as SONET and SDH networks in environmentally challenging multi-hop configurations.

These test results directly address the concerns that large organizations have when they are confronted with the challenge of transitioning from legacy to fully converged packet networks. In the particular case of Banverket where highly accurate timing is critical to several of its rail applications, the level of Sync-E testing and test results achieved on Alcatel-Lucent 7705 SAR, 7450 ESS and 7750 SR as detailed in this test report exceeded their stated objectives and allowed them to initiate the transition.

* TIE, MTIE and TDEV metrics are described in section “Metrics and Measurements” on page 2 of this test report.
Synchronization
Metrics & Measurements

A large number of applications delivered on packet networks require traceability to a Primary Reference Clock (PRC).

Synchronous Ethernet has specifically been designed to provide this traceability making use of the Ethernet physical layer similarly to SONET and SDH.

Even though all nodes in a network are traceable to one PRC, their frequency references may drift due to jitter and wander, inducing a number of errors, losses and overflows.

Whereas wander is defined as the phase error with frequency components between 0 and 10Hz of the spectrum, jitter is phase error with frequencies higher than 10Hz.

Excessive amounts of jitter and wander can adversely affect network quality. The effects of these impairments vary with the service being transported as well as with the terminating systems.

Consequently, it is necessary to set limits on the amount of jitter and wander allowed in a network to guarantee consistent quality of service. These limits are defined in ITU-T Recommendations G.823 and G.824.

The technique used to measure timing stability and accuracy is to compare the phase of a clock signal under test to a PRC. The measurement is called Time Interval Error or TIE.

TIE measurements are the basis for the calculations of the Maximum Time Interval Error (MTIE) and Time Deviation (TDEV), the industry-standard synchronization metrics used in this test report.

In simple terms, MTIE is the maximum time interval error (peak-to-peak) of the clock signal under test that occurs within a specified period of time compared to a PRC.

MTIE is used for detecting important and very common clock signal frequency offsets.

TDEV is a statistical value calculated from the measured TIE samples. Complementary to MTIE, it provides information about the frequency drift rate or the oscillator noise.

The Need for Testing Synchronization Distribution Quality

Service providers are eager to migrate their residential, business and wireless services from legacy networks to more cost effective packet networks. Mission critical industry networks, including transportation and energy are trying to rationalize many separate application-specific networks to a single converged network to reduce OPEX and CAPEX, provide higher safety and quality services delivery and meet the demanding expansion of bandwidth requirements. One of the key challenges however, is to deliver time sensitive services such as TDM circuit emulation and mobile backhaul and to support specific transportation and utilities applications that require accurate and stable frequency synchronization.

Unlike SONET and SDH networks that have inherent capabilities for carrying a timing reference at the physical layer, packet networks that do not need synchronization to transport customer data were not initially designed for carrying accurate frequency.

Synchronous Ethernet overcomes the inherent timing limitations of packet networks by providing the ability to distribute frequency at the PHY-layer via an Ethernet interface. Just like SONET and SDH network elements, Synchronous Ethernet nodes require a stable and accurate reference source such as a cesium oscillator or GPS to provide high quality timing distribution.

Synchronization accuracy and stability have traditionally been measured on SONET and SDH networks using metrics defined by the ITU-T. Recommendations like G.803 and G.781 that were developed for SONET and SDH deployments are being updated to include Synchronous Ethernet in the architecture of transport networks and in the synchronization layer functions. Other recommendations such as G.8261, G.8262 and G.8264 are specifically being developed for packet network timing.

It is imperative that Synchronous Ethernet networks interwork with existing SONET and SDH networks. ITU-T G.803 envisages the replacement of a chain of 20 SDH network elements by (1) a chain of 20 Synchronous Ethernet nodes, (2) by a mix of SDH and Sync-E nodes or (3) by a mix of nodes that support both Sync-E and STM-N ports meeting the same performance criteria. The 20-Node chain, 24-Node chain and the hybrid networks are three test cases that are detailed further in this report.

The capability to support multiple timing references and the ability to switch from a degraded synchronization reference to an alternate one in a timely manner are features that must be implemented on both hybrid and Sync-E nodes. This subject is analyzed in the second test case.

Another extremely important requirement of hybrid and Sync-E nodes is the ability to sustain a wide range of temperature variations or thermal noise. In test case 4, thermal chambers were used to introduce temperature variations at multiple points along the 20-Node Synchronous Ethernet chain.
Three scenarios were defined to perform these extensive benchmarking tests.

Banverket, the Swedish Railway Authority, defined the first scenario based on the mission critical applications supported on its Global System for mobile Communications-Railway (GSM-R) infrastructure.

Alcatel-Lucent defined the second scenario to push the limits of the 7705 SAR, 7450 ESS and 7750 SR acting as Synchronous Ethernet nodes.

Iometrix defined the third scenario to verify the interoperability and performance of Sync-E nodes deployed in a hybrid environment.

Banverket’s test scenario consisted of MPLS-based Ethernet infrastructures using Synchronous Ethernet to distribute timing and to provide the accuracy required by their mission critical applications and communications running over GSM-R.

The second test scenario defined by Alcatel-Lucent was meant to stress the boundaries of their products from a protocol and from a temperature standpoint. This scenario involved several lab setups including the use of thermal chambers.

The third scenario was defined by ourselves, Iometrix, to ensure that the performance of hybrid networks built of Sync-E and SONET/SDH network elements still meet the industry standards objective for MTIE and TDEV defined in ITU-T Recommendations G.823/G.824.

These three scenarios form a complete and comprehensive set of test cases that an organization like Banverket can trust and rely on when the time comes to deploy a converged infrastructure supported by Synchronous Ethernet.

First Scenario: Supporting Mission Critical Applications

The first scenario was designed by Banverket to simulate a number of their network topologies and time sensitive applications.

Banverket defined six comprehensive performance tests and Alcatel-Lucent added six more to cover all of the requirements of Banverket’s GSM-R infrastructure. In addition to Synchronous Ethernet performance testing, features such as MPLS Fast Reroute in response to link failures, Pseudowire redundancy and OSPF routing were all tested in parallel.

The following two test cases were defined as part of the first scenario and are analyzed in detail in this report:

- Test Case 1: 20-Node Sync-E Network
- Test Case 2: Sync Reference Failover

Second Scenario: Pushing the Systems to the Limit

The second scenario was designed by Alcatel-Lucent to fully stress the 7705 SAR, 7450 ESS and 7750 SR to show that Synchronous Ethernet is capable of offering stable and predictable performance even under extreme conditions.

From a protocol perspective, the Alcatel-Lucent scenario included a 24-node chain of Synchronous Ethernet network elements used to distribute timing to a 7705 handing off an emulated E1 TDM circuit requiring very high timing accuracy. Next, to simulate performance in the field under extreme temperatures, thermal chambers were used to create a harsh environment inducing temperature variations along a chain of 20 Synchronous Ethernet nodes.

These two test cases, part of the second scenario, are also analyzed later in this report:

- Test Case 3: 24-Node Sync-E Network
- Test Case 4: Thermal Stress Conditions

Third Scenario: Interoperability with Existing SONET/SDH Networks

The interoperability of Synchronous Ethernet with existing SONET/SDH networks is essential. The third and final test scenario was defined by Iometrix to focus on the performance of hybrid networks as described in ITU-T Recommendation G.803.

Whereas timing distribution has been traditionally implemented on SONET/SDH networks, the introduction of Ethernet and IP/MPLS networks in the timing chain presents significant challenges and must still earn the trust of network operators.

The third scenario addresses these concerns directly by simulating a hybrid network combining both SONET and Sync-E nodes.

To conclude this test report, we analyzed the performance of such a hybrid network:

- Test Case 5: Hybrid Network
Wander analysis was performed during a 17-hour period of time using the JDSU ANT-20 Wander Analyzer. The ANT-20 was referenced to a PRC and measured the clock stability at the egress of the 20th 7705 SAR Sync-E node. In parallel, the TTC Fireberd Communications Analyzer referenced to Sync-E Node #20 generated and analyzed an E1 circuit carried over the MPLS network as shown in figure 1. The TTC results proved that the quality of timing distributed using Sync-E across a 20-node chain was high enough to support the emulation of TDM circuits without any bit errors.

The measured Time Interval Error (TIE) is represented below, on graph 1. MTIE and TDEV metrics were computed to verify the synchronization stability at the 20th Sync-E node and are displayed on the next page on graph 2 and graph 3.
Graph 2: MTIE graph showing the 20-Node Sync-E network performance meeting the industry standards objectives defined in ITU-T Recommendation G.823 for traffic interface, PDH synchronization interface and for PRC.

Graph 3: TDEV graph showing the 20-Node Sync-E network performance meeting the industry standards defined in IUT-T Recommendation G.823 for PDH synchronization interface and for PRC.
Wander analysis was performed during a 30-minute period of time around the failover event using the JDSU ANT-20 Wander Analyzer during which a synchronization reference failover happened. The ANT-20 was referenced to a PRC and measured the clock stability at the egress of the 20th Sync-E node. In parallel, the TTC Firebird Communications Analyzer referenced to Sync-E Node #20 generated and analyzed an E1 circuit carried over the MPLS network as shown in figure 2. The TTC results proved that even when experiencing a Sync reference failover, the Sync-E timing distribution was accurate enough to support the E1 emulated circuit without any bit errors.

The measured Time Interval Error (TIE) is represented below, on graph 4. MTIE and TDEV metrics were computed to verify the synchronization stability at the 20th Sync-E node and are displayed on the next page on graph 5 and graph 6.

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**Graph 4:** TIE graph showing the phase difference between the signal measured at the 20th Sync-E node and the Primary Reference Clock. MTIE and TDEV results displayed on the next page are based on these TIE results.
Sync Reference Failover
Test Case #2

MTIE Test Results
Performance of the Sync-E Network Experiencing a Sync Reference Failover

Graph 5: MTIE graph showing the 20-Node Sync-E network experiencing a sync reference failover performance meeting the industry standards objectives defined in ITU-T Recommendation G.823 for traffic interface, PDH synchronization interface and for PRC.

TDEV Test Results
Performance of the Sync-E Network Experiencing a Sync Reference Failover

Graph 6: TDEV graph showing the 20-Node Sync-E network experiencing a sync reference failover performance meeting the industry standards objectives defined in ITU-T Recommendation G.823 for PDH synchronization interface and for PRC.
Wander analysis was performed on a 24-node network during a 30-minute period of time using the JDSU ANT-20 Wander Analyzer to verify that the stability was in a similar range to the 20-node network. The ANT-20 was referenced to a PRC and measured the clock stability at the egress of the 24th 7705 SAR Sync-E node. In parallel, the TTC Fireberd Communications Analyzer referenced to Sync-E Node #24 generated and analyzed an E1 circuit carried over the MPLS network as shown in figure 3. The TTC results proved that the quality of timing distributed using Sync-E across a 24-node chain was high enough to support the emulation of TDM circuits without any bit errors.

The measured Time Interval Error (TIE) is represented below, on graph 7. MTIE and TDEV metrics were computed to verify the synchronization stability at the 24th Sync-E node and are displayed on the next page on graph 8 and graph 9.

Graph 7: TIE graph showing the phase difference between the signal measured at the 24th Sync-E node and the Primary Reference Clock. MTIE and TDEV results displayed on the next page are based on these TIE results.
Wander analysis was performed during a time interval of 17 hours using the JDSU ANT-20 Wander Analyzer. The ANT-20 was referenced to a PRC and measured clock stability at the egress of the 7705 SONET/SDH Node 3. In parallel, the TTC Fireberd Communications Analyzer referenced to Sync-E Node 1 generated and analyzed an E1 circuit carried over the hybrid network shown in figure 1. The TTC also verified that the quality of synchronization distributed along Sync-E, hybrid and SONET/SDH nodes.

The measured Time Interval Error (TIE) is represented below, on graph 13. MTIE and TDEV metrics were computed to verify the synchronization stability of the Hybrid network and are displayed on the next page on graph 14 and graph 15.

Graph 8: MTIE graph showing the 24-Node Sync-E network performance meeting the industry standards objectives defined in ITU-T Recommendation G.823 for traffic interface and PDH synchronization interface.

Graph 9: TDEV graph showing the 24-Node Sync-E network performance meeting the industry standards objectives defined in ITU-T Recommendation G.823 for traffic interface and PDH synchronization interface.
Wander analysis was performed during a time interval of 85 hours using the JDSU ANT-20 that was referenced to a PRC. Clock stability was measured at Sync-E Node 5, 10, 15 and 20 while thermal chambers were used to introduce temperature variations along the chain of 7705 Sync-E nodes as shown on figure 4. The temperature variation profile for the 6 nodes placed in the thermal chambers was as follows:

<table>
<thead>
<tr>
<th>Temp Start</th>
<th>Temp End</th>
<th>Time Start</th>
<th>Time End</th>
</tr>
</thead>
<tbody>
<tr>
<td>+26°C</td>
<td>+26°C</td>
<td>0h</td>
<td>24h</td>
</tr>
<tr>
<td>+26°C</td>
<td>-10°C</td>
<td>24h</td>
<td>30h</td>
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<tr>
<td>-10°C</td>
<td>-10°C</td>
<td>30h</td>
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<td>-10°C</td>
<td>+56°C</td>
<td>42h</td>
<td>53h</td>
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<tr>
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<td>+56°C</td>
<td>53h</td>
<td>65h</td>
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<tr>
<td>+56°C</td>
<td>-19°C</td>
<td>65h</td>
<td>77.5h</td>
</tr>
<tr>
<td>-19°C</td>
<td>+26°C</td>
<td>77.5h</td>
<td>85h</td>
</tr>
</tbody>
</table>

The measured Time Interval Error (TIE) is represented below, on graph 10. MTIE and TDEV metrics were computed to verify the synchronization stability and are displayed on the next page on graph 11 and graph 12.

Figure 4: The ANT-20 interconnected to a 20-node Sync-E network built of Alcatel-Lucent 7705s submitted to a temperature variation stress profile using thermal chambers.

Graph 10: TIE graph overlaying the phase difference between the signals measured at the 5th (in blue), 10th (in red), 15th (in purple) and 20th Sync-E node (in green) and the Primary Reference Clock. MTIE and TDEV results displayed on the next page are based on these TIE results.
MTIE Test Results
Performance of the Sync-E Network Under Thermal Stress Conditions

Graph 11: MTIE measurements at the 5th (in blue), 10th (in red), 15th (in purple) and 20th Sync-E node (in green) under thermal stress conditions meeting the industry standards objectives defined in ITU-T Recommendation G.823 for traffic interface, PDH synchronization interface and for PRC.

TDEV Test Results
Performance of the Sync-E Network Under Thermal Stress Conditions

Graph 12: TDEV measurements at the 5th (in blue), 10th (in red), 15th (in purple) and 20th Sync-E node (in green) under thermal stress conditions meeting the industry standards objectives defined in ITU-T Recommendation G.823 for traffic interface, PDH synchronization interface and for PRC.
Hybrid Network Test Case #5

Wander analysis was performed during a time interval of xx seconds using the JDSU ANT-20 Wander Analyzer. The ANT-20 received its reference from a PRC and measured clock stability at the egress of the 7705 Node 3. In parallel, the TTC Fireberd Communications Analyzer referenced to Sync-E Node 1 generated and analyzed an E1 circuit carried over the hybrid network shown in figure 1 verifying that the quality of synchronization distributed along Sync-E, hybrid and SONET nodes supported TDM circuit emulation without any bit errors.

MTIE and TDEV metrics were used to verify the synchronization stability at the third node of the hybrid network. The MTIE and TDEV results displayed in figure 4 and figure 5 show results that are well within the industry standard objectives defined in G.823.

Figure 5: The ANT-20 and TTC Fireberd interconnected to a Hybrid network built of Alcatel-Lucent 7705s, and 7750 measuring frequency stability and effects of synchronization distributed over Ethernet and SONET links on a TDM circuit emulated E1 carried over the hybrid network as a C-Pipe service.

MTIE and TDEV metrics were used to verify the synchronization stability at the third node of the hybrid network. The MTIE and TDEV results displayed in figure 4 and figure 5 show results that are well within the industry standard objectives defined in G.823.

Figure 5: The ANT-20 and TTC Fireberd interconnected to a Hybrid network built of Alcatel-Lucent 7705s, and 7750 measuring frequency stability and effects of synchronization distributed over Ethernet and SONET links on a TDM circuit emulated E1 carried over the hybrid network as a C-Pipe service.

Graph 13: TIE graph showing the phase difference between the signal measured at the 3rd Hybrid node and the Primary Reference Clock. MTIE and TDEV results displayed on the next page are based on these TIE results.
Graph 14: MTIE graph showing the Hybrid network performance meeting the industry standards defined in IUT-T Recommendation G.823 for traffic interface, PDH synchronization interface and for PRC.

Graph 15: TDEV graph showing the Hybrid network performance meeting the industry standards defined in IUT-T Recommendation G.823 for PDH synchronization interface and for PRC.
Iometrix is the networking industry’s preeminent testing authority. Established in Silicon Valley in 2003, Iometrix is the successor to ENL (European Network Laboratories) the pioneering test lab Bob Mandeville founded in 1991 in Paris, France.

Iometrix provides globally recognized and trusted certification tests as the officially endorsed test lab of the Metro Ethernet Forum, the MultiService Forum and the Broadband Forum.

Iometrix is strongly committed to advancing industry testing standards and has developed test specifications for protocols and services in several standards bodies including the IETF, IEEE, MEF, MultiService Forum and Broadband Forum since 1993, developed and implemented procedures to execute testing for a broad range of networking equipment and also developed and implemented efficient test reporting processes.