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APPLICATION WHITE PAPER

Timing Excellence for Packet-Based Mobile Backhaul

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The wide-scale adoption of Carrier Ethernet in mobile backhaul has resulted in base stations being isolated from traditional TDM synchronization references. While many mobile operators have started early to deploy short-term fixes to benefit from Carrier Ethernet economics in their backhaul networks, differentiating long-term solutions can be challenging and need to prove efficiency and technological maturity. Synchronous Ethernet and IEEE 1588v2 are recognized as long-term timing distribution solutions but the economic viability of a timing platform is not based upon just the distribution technology. Assuring the accuracy of the delivered timing information and the capability to offer timing as a service to mobile operators are equally important. The advantages of a unified and fully managed synchronization solution embedded into the Carrier Ethernet backhaul platform outweigh independent systems focusing only on distribution. Ultimately, an integrated synchronization solution built on standards-based implementation and including a comprehensive management platform for assuring the quality of the timing information delivered removes deployment risk and saves money.

Introduction

Mobile subscribers are demanding more and more bandwidth to support high-speed data and multimedia applications. Text messaging no longer satisfies the subscriber needs and unlike voice services, mobile broadband is always-on and considered to be always available. To satisfy that demand, reduce costs and improve operating efficiencies, mobile operators around the world are evolving their backhaul networks from circuit-switched to packet-switched technologies. Carrier Ethernet is considered a practical solution for mobile backhaul and therefore the inevitable choice.

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As operators replace their TDM-based backhaul with Carrier Ethernet, they face a major challenge: how to provide precise timing reference or synchronization for base station clocks and do so in a cost-effective way. Mobile services are dependent on timing and base stations need a stable frequency reference to support mobility. Actually, operators are confronted with a broader, two-part challenge. Firstly, they must replace their TDM-based clock function with a suitable packet clock. Secondly, as they deploy advanced LTE or CDMA technologies, they must eventually expand that packet-clock capability so that it distributes not just the frequency reference but also phase and time-of-day information.

The timing requirement for different air interface standards is summarized in Table 1. Frequency Division Duplex (FDD) base stations require a frequency reference only, because the air interface uses different frequency bands for the up and downlink. The alignment of clock frequency enables base stations to stay within the allocated spectrum, avoid interfering with other base stations and provide proper hand-off between them. While the frequency requirement is ever present, Time Division Duplex (TDD) base stations additionally require phase and time-of-day alignment of all clocks to switch between uplink and downlink transmission at the same instant. Phase synchronization is also required for coordinated multi-point transmission as in the case of LTE Multimedia Broadcast Multicast Service (MBMS).

Air Interface	Frequency	Time/Phase
CDMA2000	50 ppb	< 3 µs to < 10 µs
GSM	50 ppb	-
WCDMA	50 ppb	-
TD-SCDMA	50 ppb	3 µs
LTE (FDD)	50 ppb	-
LTE (TDD)	50 ppb	3 µs
LTE MBMS	50 ppb	5 µs

Table 1: Air interface stability needs

Fiber links connect more and more base stations due to the rapidly increasing bandwidth demand, often feeding into a converged, multi-service backhaul and aggregation network. Regardless of the type of mobile technology deployed today, backhaul network operators need transport solutions that can distribute robust and assured frequency and time-of-day synchronization efficiently and resiliently.

Synchronization over Packet Networks

Two practical mechanisms for providing synchronization via packet-based networks have emerged: Synchronous Ethernet (SyncE) and IEEE 1588v2.

Both Carrier Ethernet system vendors and the timing community worked on methods to deliver synchronization information over packet networks. The obvious goals were to keep it simple, cost-effective, predictable and reliable. Two practical mechanisms for providing synchronization via packet-based networks have emerged: Synchronous Ethernet (SyncE) and IEEE 1588v2. Both standards are the result of efforts by international standards bodies, notably the International Telecommunication Standardization Sector (ITU-T) and the Institute of Electrical and Electronics Engineers (IEEE).

SyncE uses the Ethernet physical layer to synchronize neighboring nodes. It is attractive to many network operators because it closely resembles the familiar SONET/SDH model and its timing quality is completely independent of the network load. However, SyncE only provides frequency synchronization and requires that each node in the hierarchy supports it. If a single network element in the chain does not support SyncE, all nodes lower in the hierarchy do not receive accurate timing information.

IEEE 1588v2, in contrast, specifies a master-slave exchange of packets that carry time stamps for recovering frequency, phase and time-of-day information. Operators can use IEEE 1588v2 to provide synchronization directly across any packet network. However, operators must ensure that the synchronization flow is not distorted by packet loss, delay or delay variation beyond the filtering capabilities of the slave clock. For high accuracy network phase synchronization, all nodes in the network must support IEEE 1588v2 boundary or transparent clock functionality. Both mechanisms provide additional information about the delay conditions in the network and therefore support increased clock accuracy. Table 2 summarizes the key differences.

Attribute	SyncE	IEEE 1588v2
Capability	Frequency	Frequency, Time, Phase
Layer	Physical	Ethernet, UDP
Distribution	Physical Layer	In-Band Packets
Topology	Point-to-Point	Point-to-Multipoint
Sensitivity	Asynchronous Switches	Delay, Jitter, Loss

Table 2: SyncE/IEEE 1588v2 comparison

SyncE and IEEE 1588v2 are complementary technologies that can co-exist in the network and can be used on the same path. Both technologies have distinct advantages and disadvantages over each other. SyncE is deterministic and the performance is independent of the network load. IEEE 1588v2 can function over asynchronous switches and additionally distributes phase and time-of-day information. Slaves that support both can converge on accurate timing information quickly by using the SyncE frequency to control the local oscillator. SyncE in conjunction with IEEE 1588v2 also provides an alternative holdover capability in case of failure at the packet layer. A combined implementation promises to deliver the best overall performance.

Although not a packet technology and not linked to the backhaul network, the use of Global Positioning System (GPS) is also considered. It has traditionally been used for synchronizing CDMA radio access networks. While GPS might be used for initial LTE installations, wide-scale adoption is not feasible due to technical and economic reasons. One obstacle to broader GPS adoption is service availability in metropolitan and indoor installations resulting from weak and reflected signals. A large portion of LTE cells are expected to be located in metropolitan areas as a consequence of deploying small cells for increased broadband capacity. GPS is also sensitive to weather conditions and is susceptible to jamming, preventing it from achieving telecom grade 99.999% availability. Furthermore, deployment and maintenance of GPS can be costly, particularly in urban areas.

Infrastructure Challenges – Delivery and Assurance

The architecture of packet-based mobile backhaul networks is not consistent for all network operators. There are topological and operational differences depending on whether the backhaul network is operated by the mobile service provider or leased from a fixed network operator. While a single-operator environment provides advantages in terms of simplicity and efficiency, the multi-operator environment illustrated in Figure 1 is the typical case. Mobile backhaul services are often provided by a third-party operator or a separate organization within the same company. In a multi-operator environment, mobile backhaul services are typically provided over a converged, multi-service backhaul and aggregation infrastructure. Network resources are then shared with other services such as DSL backhaul and business Ethernet for enterprises.

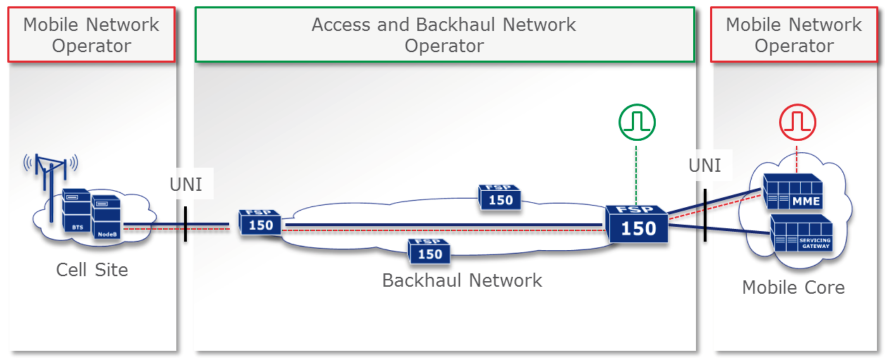

Figure 1: Multi-operator mobile backhaul environment

These different scenarios result in three different implementations when it comes to delivering synchronization information to the radio access network.

- **Single-operator environment**
  The complete network infrastructure including radio access, backhaul and mobile core network is controlled by one organization. The synchronization network can therefore be designed and optimized across all three domains. Service Level Agreements (SLA) for synchronization services are typically not defined at intermediate nodes.

- **Multi-operator environment – independent synchronization service**
  The backhaul network operator provides an independent synchronization service in addition to and integrated with the data service connecting the radio access network with the mobile core. Frequency and phase information is handed over to the mobile operator at the User Network Interface (UNI) with quality of service defined by a separate SLA.

- **Multi-operator environment – integrated synchronization service**
  The mobile operator owns both endpoints of the synchronization service and utilizes the backhaul network for transporting timing information. Based on the SLA of the backhaul service leased from the fixed network operator, the mobile operator is responsible for recovering accurate timing information.

The first and the second scenario are likely to be found in real-world deployments, with the second one, which is shown in Figure 1, expected to be typical. The complete timing domain resides with one operator, therefore clearly defining the responsibility for recovering an accurate timing signal. Interworking between radio access, backhaul and mobile core network is straightforward. The third scenario is rather complex when it comes to utilizing SyncE and IEEE 1588v2 with boundary and transparent clock functionality. It would result in sharing the operation of the synchronization architecture between two operators. Both technologies are not designed for shared operation. Efficient wide-scale deployment with distinct SLA assurance therefore requires a very specific design. Potential solutions are currently being investigated by the ITU-T.

Ultimately, deploying a complete and standards-based synchronization solution for next generation mobile networks is elementary for investment protection, as well as meeting long-term requirements. A universal synchronization platform integrated with the Carrier Ethernet backhaul solution is most cost-

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effective, more robust and plays a large part in the optimization of the network. An advanced solution also features a variety of tools for managing and monitoring the end-to-end performance of the synchronization infrastructure. Delivering the timing information is not enough for enabling stable operation of radio access networks. Assured delivery with guaranteed quality of service metrics is a must. In the following sections, the important aspects of deployment flexibility, cost efficiency and timing quality assurance are examined in more detail.

Deployment Flexibility

Mobile networks are growing. In many countries, radio access network installations have evolved from 2G to 3G and are now evolving to 4G while maintaining a large portion of the legacy radio equipment. The diversity of radio equipment installed at cell sites poses a challenge especially to independent backhaul network operators. They often provide backhaul services to multiple mobile network operators sharing the same cell towers, potentially having different requirements on the timing service delivered.

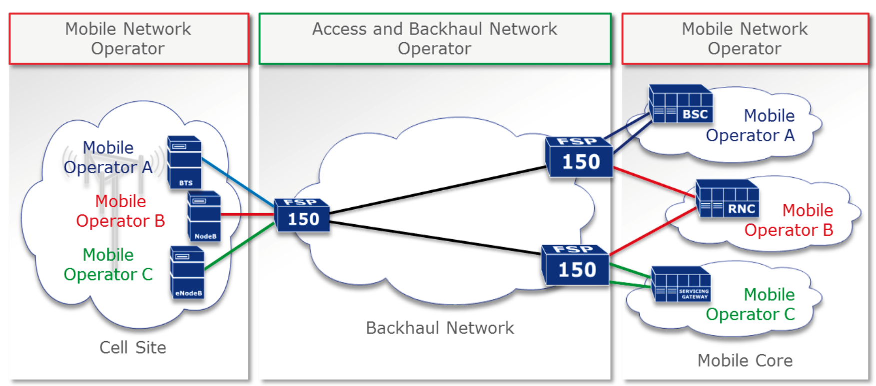

Figure 2: Generic mobile backhaul application

Consequently, a synchronization solution is required to deal with these challenges. What's more, it needs to be flexible enough to deliver accurate timing services over a generic multi-hop backhaul infrastructure. Distance and number of aggregation points between the individual cell tower locations and the mobile core differ vastly in rural and metropolitan areas. Also the architecture of the mobile core including number of core sites and their location is different for each mobile network operator. A high-performance implementation of boundary clock and transparent clock functionality across the entire backhaul network becomes essential for enabling accurate recovery of phase and time-of-day information in case of IEEE 1588v2. Furthermore, the slave clock has to be based on a strong clock recovery algorithm delivering solid performance independent of the actual network load. Variable load conditions are expected in particular when sharing the backhaul network with other services.

Last but not least, the requirements on how to deliver timing information at the UNI can be different. Over time, the industry has defined a number of timing interfaces applicable to mobile backhaul. These include in-band and out-of-band variants including SyncE, Building Integrated Timing Supply (BITS), Pulse per Second (PPS) and Time of Day (ToD) amongst others. Dependent on the radio equipment deployed and the requirement for frequency and time-of-day synchronization, different interfaces need to be supported.

Cost and Efficiency

Backhaul costs are a critical cost driver for all mobile network operators. In fact, the architecture of the future backhaul network is a major pain point for all mobile operators today. Only the migration from TDM to packet switching in both the radio access and the backhaul network enabled managing the ever increasing bandwidth demand in a cost-efficient way. Backhaul service providers are now facing new challenges with highly accurate frequency, phase and time-of-day synchronization becoming an additional requirement. They need solutions that are reliable and cost-effective to deploy, operate and maintain. Building a separate synchronization network infrastructure on top of the Carrier Ethernet backhaul solution is not an option to be considered for the long-term.

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A synchronization solution fully integrated with the Carrier Ethernet backhaul equipment is ultimately the best solution. Supporting both SyncE and IEEE 1588v2 in demarcation devices and aggregation switches is easy to operate and therefore saves time and money. It provides reliable distribution of accurate timing information and is highly compact. Space available for installing telecom equipment is one of the most valuable assets at many cell tower locations.

Despite this being the ideal situation, backhaul networks for mobile services are commonly not greenfield solutions. Independent fixed network operators often add mobile backhaul services on top of their existing Carrier Ethernet infrastructure, which initially was built for the aggregation of voice and data traffic origination from DSL subscribers and enterprise customers. However, most of the aggregation switches deployed during the early roll-out phase of Carrier Ethernet do not support timing distribution or cannot provide the functionality to recover a sufficiently accurate clock signal at the cell site location.

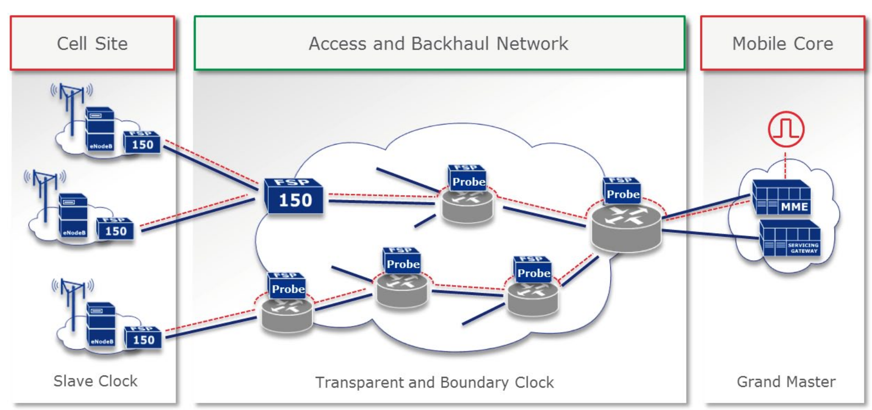

Figure 3: Enabling existing infrastructure with probe devices

The capability of efficiently enabling existing infrastructure to participate in a full end-to-end synchronization architecture therefore plays an important role. Accurate timing distribution and seamless interworking with master and slave devices already supporting an advanced implementation of IEEE 1588v2 can be achieved by introducing intelligent probe devices.

The addition of low-cost probe devices that support transparent clock and boundary clock functionality to legacy Carrier Ethernet aggregation switches provides the necessary capability. It enables operators to deploy and operate a seamless synchronization infrastructure also across legacy Carrier Ethernet equipment.

The additional benefit of deploying probe devices is the capability of end-to-end management, monitoring and testing of the synchronization network. Assured delivery of timing information is critical to the reliable operation of the radio access network and can only be achieved by an intelligent end-to-end synchronization solution. Probe devices add this capability to existing network infrastructure in a cost-effective way and interwork seamlessly with fully-integrated solutions and the synchronization control and management platform.

Quality Assurance

The ability to consistently monitor and accurately test and troubleshoot the synchronization infrastructure when delivering timing information via IEEE 1588v2 is mandatory for assuring clock accuracy and therefore the quality of the delivered timing service. Assured delivery with guaranteed quality of service metrics is a necessity not only for data services but also for timing services. As IEEE1588v2 packet flows potentially traverse different technologies and operator networks, service assurance mechanisms as implemented in Carrier Ethernet Operations, Administration and Maintenance (OAM) are required.

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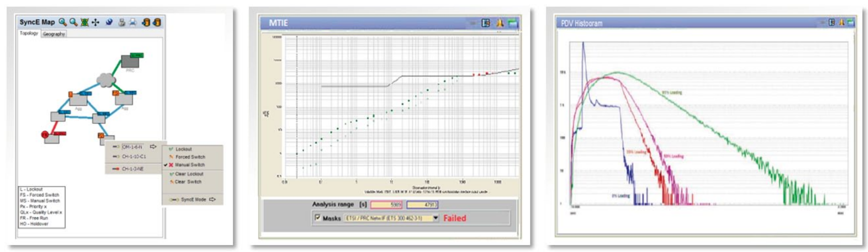
What is the distribution topology? How accurate is the slave clock performing? Are all slave clocks tracking their masters? How to localize a fault? From a service assurance perspective, this is relevant and important information for the operator of the synchronization domain. Network timing behavior is not a stationary process. It is subject to dynamic conditions and changes over the short and longer term. Appropriate tools are required for cost-effective and time-efficient end-to-end management of the synchronization domain during all phases of the network lifecycle – installation, turn-up testing, monitoring and troubleshooting. The support tools listed below are essential components:

- **Synchronization Map**
  Topological visualization of the synchronization network for SyncE and IEEE 1588v2. It monitors topology changes, displays synchronization status and distribution capabilities and is the entry point for synchronization quality testing.

- **Synchronization Quality Testing**
  A set of functions intended to monitor, test and analyze the quality of slave clocks in the network. It includes collection of Time Interval Error (TIE) measurement data and phase offset, processing and analyses of results in well-known metrics, notification of alarms and display of slave clock performance statistics.

- **Synchronization Path Analysis**
  A set of tools for collecting and displaying the end-to-end performance of communication paths in the synchronization network, including monitoring for packet delay and delay variation, frame loss and availability. Analysis of transparent clock residence time and boundary clock performance statistics.



Sync Map | Sync Quality Testing | Sync Path Analysis

Figure 4: Synchronization service assurance support tools

The quality of the recovered frequency, phase and time-of-day information heavily depends on the packet delay variation experienced on the transmission path and the robustness of the clock recovery algorithm. Recent developments have shown that no single metric is sufficient to characterize packet delay variation when it comes to timing quality assurance. Therefore, a suite of metrics becomes necessary. However, when selecting the appropriate packets and analyzing these metrics, the quality of the recovered timing signal can be correlated to the quality of service experienced on the transmission path. For this reason, an integrated implementation of packet forwarding and synchronization functionality is beneficial to the delivery and assurance of highly accurate timing information over packet networks.

> *… an integrated implementation of packet forwarding and synchronization functionality is beneficial to the delivery and assurance of highly accurate timing information …*

To reduce the complexity of monitoring and testing synchronization networks as well as identifying potential problems before they cause outages, an integrated and automated test and measurement system can reduce the number of different tools required. It ensures that operators have the capabilities they need to effectively operate and test their synchronization network, and address all problems. Displaying information with different levels of detail simplifies step-by-step troubleshooting. Ideally, a first level provides an overall synchronization health indication. A second level gives high level health indication of each reporting tool, while a third level delivers sufficient information for fault localization and troubleshooting. Figure 5 shows a structured and compact implementation of layer synchronization performance reporting.

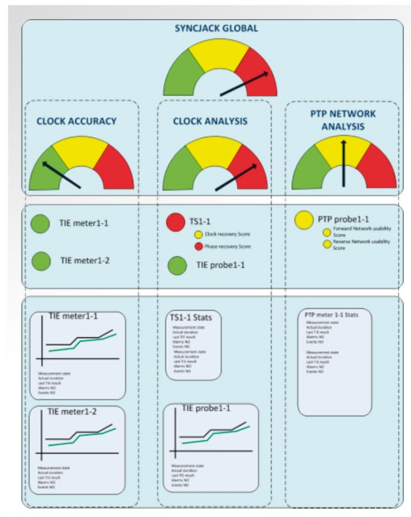


Figure 5: Layered synchronization performance reporting

The Right Solution for Packet Network Synchronization

While quickly moving away from TDM-based backhaul and short-term fixes, mobile operators no longer take synchronization capabilities of packet-based backhaul networks for granted. As they increasingly deploy 4G radio access technologies and depend on accurate delivery of frequency, phase and time-of-day synchronization, they are seeking advanced solutions that not only deliver the required timing information accurately but also assure its delivery. And they want to understand the actual performance of the timing network when leasing backhaul connectivity and timing services from independent backhaul operators. With our comprehensive Syncjack™ suite that is fully integrated into our market-leading FSP 150 Carrier Ethernet access and backhaul solution, we offer a complete synchronization solution that includes delivery and end-to-end quality assurance. The rich and robust implementation of SyncE and IEEE 1588v2 functionality guarantees highly accurate delivery of timing information across any network. Complemented by cost-effective probe devices, highly accurate frequency, phase and time-of-day information can now be delivered over any Carrier Ethernet backhaul network including legacy builds.

Our Syncjack™ suite includes a complete synchronization network management platform with strong emphasis on predictability and quality assurance. An extensive set of tools enables operators to display the synchronization network topology, continuously monitor and test the quality of the delivered timing information to predict impairments as well as analyze and troubleshoot the network in case of quality impairments. Our FSP 150 Carrier Ethernet solution with fully integrated Syncjack™ suites provides operators with the capability to evolve their mobile backhaul network without constraints.

About ADVA Optical Networking

ADVA Optical Networking is a global provider of intelligent telecommunications infrastructure solutions. With software-automated Optical+Ethernet transmission technology, the Company builds the foundation for high-speed, next-generation networks. The Company's FSP product family adds scalability and intelligence to customers' networks while removing complexity and cost. Thanks to reliable performance for more than 15 years, the Company has become a trusted partner for more than 250 carriers and 10,000 enterprises across the globe.

Product

FSP 150

ADVA Optical Networking's family of intelligent Ethernet access products provides devices for Carrier Ethernet service demarcation, extension and aggregation. It supports delivery of intelligent Ethernet services both in-region and out-of-region. Incorporating an MEF-certified UNI and the latest OAM and advanced Etherjack™ demarcation capabilities, the FSP 150 products enable delivery of SLA-based services with full end-to-end assurance. Its comprehensive Syncjack™ technology for timing distribution, monitoring and timing service assurance opens new revenue opportunities from the delivery of synchronization services.

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