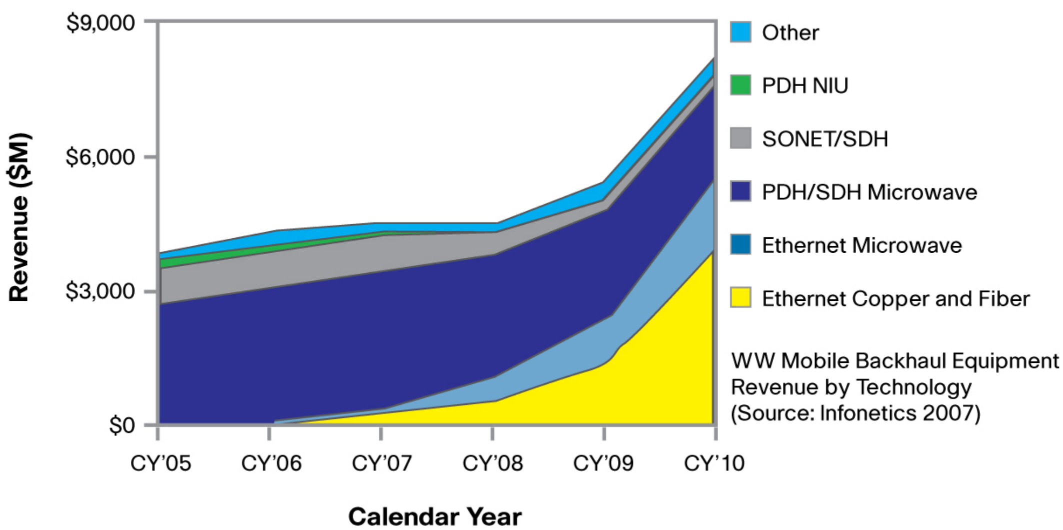
# Synchronous Ethernet: Achieving High-Quality Frequency Distribution in Ethernet NGNs

## Introduction

### Ethernet and Network Evolution

The world is changing—the more it changes, however, the more the fundamental requirements solidify. In the business world these requirements translate to the customer demands of more bandwidth, more choices, better service, faster speeds, more reliability, and lower prices. Often, but not always, these requirements conflict with the shareholder requirements of higher profitability and thus a lower total cost of ownership (TCO). The direct effect of such an environment on the networking world is a rapid migration to next-generation IP/Multi Protocol Label Switching (MPLS)-based networks (NGNs) with Ethernet as the medium of choice (refer to Figure 1 for an example of Ethernet's emergence as the transport medium of choice). That said, there is still a widely deployed and extremely lucrative services infrastructure based on the so-called "legacy" technologies of time-division multiplexing (TDM), SONET/SDH, and ATM.

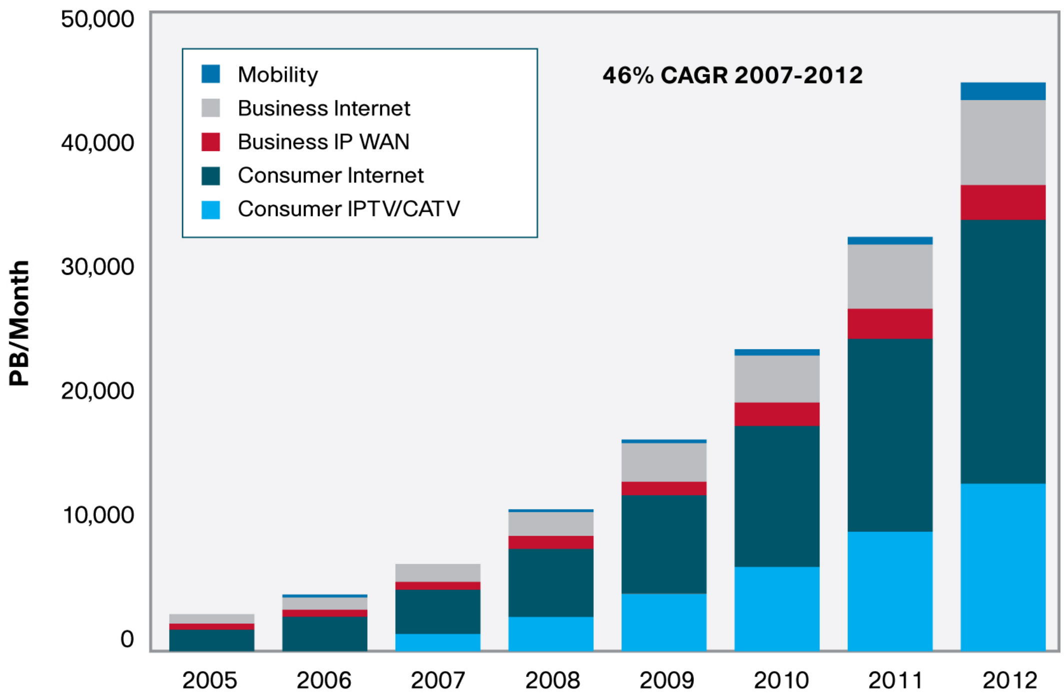
**Figure 1.** Ethernet: Technology of Choice for Mobile Backhaul




Service Providers (SPs) want to continue servicing existing customers on these "legacy" networks, even as they enhance their access and core networks to handle the huge surge in traffic and the change in traffic patterns (refer to Figure 2). This situation translates to increased importance of applications such as TDM circuit emulation and mobile backhaul as well as interworking between the next-generation IP networks and the existing TDM/SONET/SDH-based infrastructure.

**Figure 2.** Technology Drivers for the "Zetabyte" Era




Source: Cisco, 2008

This paper evaluates one of the implications of this business requirement on Ethernet—the need for frequency distribution (usually for synchronization purposes) and the solution(s) that have been devised to address that need (including their advantages, disadvantages, and potential uses).

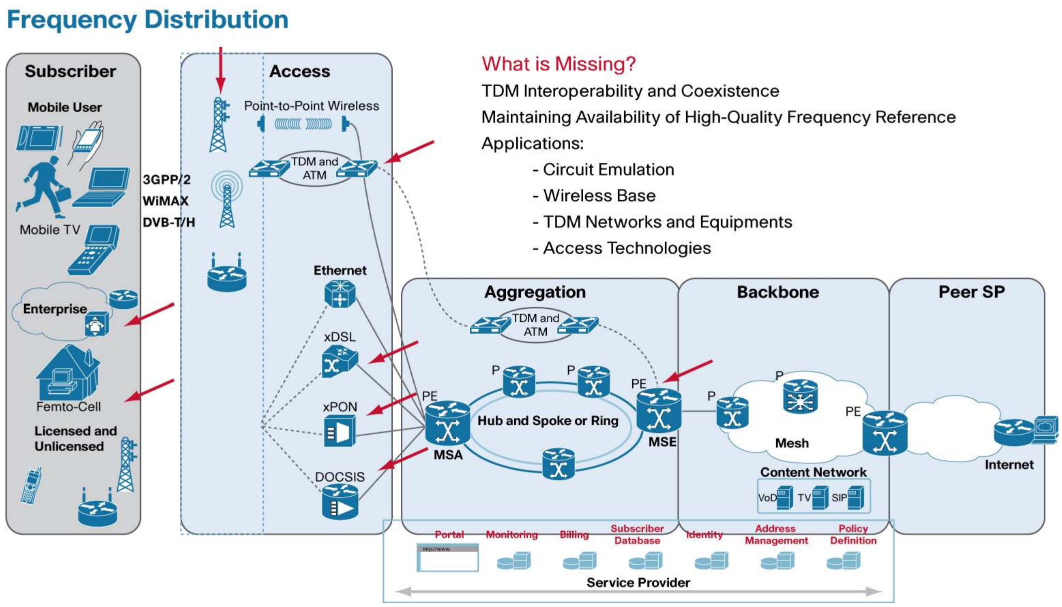
**Note:** A distinction must be made between "time" and "frequency" synchronization. Highly accurate time synchronization requires frequency synchronization (syntonization), but the opposite is not true. In this paper "timing" refers to frequency synchronization only—"time" synchronization is referred to explicitly.

### Need for Frequency Distribution

Many existing networks have a strong requirement of frequency synchronization across the entire network—accurate multiplexing and demultiplexing of data depends on that capability. TDM network technologies (for example, SONET/SDH and Plesiochronous Digital Hierarchy [PDH]) have native capability to carry a timing reference at the physical layer. Unless the two ends of a circuit are synchronized, the target device cannot decode the data encoded by the source device. Next-generation mobile deployments, Circuit Emulation Service (CES), accurate time-of-day dissemination, and precise latency measurement applications can also benefit from highly accurate distribution of frequency, that is, frequency synchronization. Unlike the SONET/SDH networks, however, frequency synchronization is not mandatory for Ethernet-based packet networks because packet network nodes do not need timing synchronization to work. They have been optimized for performance and cost efficiency using statistical techniques. Although Ethernet has been embraced by enterprise, residential, and now the service provider market as the technology of choice to build the next generation of packet networks, it was not designed for the transport of this "synchronization". The demand to distribute synchronization (frequency and time) over NGN comes from multiple applications and many locations in the network: core, edge, aggregation, access, operator, and customers depicted in Figure 3.

**Figure 3.** Why Is Frequency Distribution Required and Where?




As all of these networks rapidly migrate to Ethernet, a methodology was needed to overcome the inherent limitations of the technology with respect to synchronization transfer. Without this capability there would be “network timing holes” that would make the evolution from older networks to NGNs costly, slow, and potentially quite painful. Synchronous Ethernet (SyncE) was thus born

**Note:** SyncE is a standard for distribution of frequency over Ethernet links. Other standards [IEEE Std. 1588 Precision Time Protocol (PTP), IETF Network Time Protocol (NTP), etc.] have been and are being developed or enhanced for high-quality time distribution and Adaptive Clock Recovery (ACR) requirements.

### Synchronous Ethernet

Synchronous Ethernet is the ability to provide PHY-level frequency distribution through an Ethernet port. It can be considered one of the critical building blocks of the NGN. Previously, SDH and SONET gear were used in conjunction with external timing technology (primary reference clock [PRC] or primary reference source [PRS] using Cesium oscillators and / or global positioning system [GPS] as the clock source) to provide accurate and stable frequency reference. Using similar external references as a source, SyncE, natively supported on the Cisco® ASR 9000 Series routers, aims to achieve the same function.

### Synchronization Applications

Table 1 gives a range of possible deployment scenarios in which the technology (SyncE) can play a direct (frequency) or indirect (syntonization for time or phase) role. It is a critical enabler that can help Ethernet progress toward a widely deployable carrier-class WAN technology.

**Table 1.** Synchronization Applications

| Synchronization Type | Application | Required or Targeted Quality |
|---|---|---|
| **Frequency** | TDM support (ex.: Circuit Emulation over Packet [CEoP] or Circuit Emulation Service [CES]) | PRC traceability (that is, reference signal from Stratum 1 or G.811 in normal situation) |
| | Third-Generation Partnership Project (3GPP2) base stations (including Long Term Evolution [LTE]) | Frequency assignment shall be better than ±5 x $10^{-8}$ (± 0.05 ppm) or ±10 x $10^{-8}$ (± 0.1 ppm) for frequency division duplex (FDD) micro to femtocells ±10 x $10^{-8}$ (± 0.25 ppm). |
| | IEEE 802.16 (WiMAX) | Unsynchronized Orthogonal Frequency Division Multiple Access (OFDMA): Frequency accuracy shall be better than ±2 x 10–6 (±2 ppm).<br>Frequency-synchronized OFDMA: Frequency accuracy varies with, for example, Fast Fourier Transform (FFT) size and channel bandwidth (±1% sub-carrier spacing in synchronized network). |
| | Digital Video Broadcasting Terrestrial / Handheld (DVB-T/H) | Frequency accuracy depends on radio frequency, down to a few ppb. |
| **Time**<br>• Phase (relative time)<br>• Time-of-day (ToD; “wall-clock”, absolute time) | 3GPP2 Code Division Multiple Access (CDMA) | Time alignment error should be less than 3 microseconds and shall be less than 10 microseconds. |
| | 3GPP Universal Multiple Telecommunications Service (UMTS) Time-Division Duplex (TDD) | Inter-cell synchronization accuracy must be better than ±2.5 microseconds between base stations (or < ±1.25 microseconds from common source). |
| | DVB-T/H single-frequency network (SFN) | All transmitters within a single-frequency network must broadcast an identical signal to within 1-microsecond accuracy. |
| | 3GPP LTE Multi-Media Broadcast over a Single Frequency Network (MBSFN) | Cell synchronization accuracy should be better than or equal to 3 microseconds for SFN support (TBC). |
| | 802.16D/e TDD | Requirements depends on: mode, modulation, application, implementation, and option used; it likely would have to be better than 5 microseconds (TBC) ; ≤±1/16 x Cyclic prefix. |
| | IP service-level agreement (SLA) or performance measurement<br>Correlation of logs | Examples of this applications: ITU-T Y.1731 or new Y.ETHPerf, IETF RFC-2455, Metro Ethernet Forum Service Operation And Management (SOAM) for one-way delay measurement<br>The short-term goal is to improve precision to < 1 ms (within 10-ms class today). The target is a few orders of magnitude below average delay (i.e. ~ 10–100 microseconds).<br>For correlation, the finer the time-stamping, the faster the correlation (for example, for security). |

### SyncE Standards

SyncE specifications and requirements are bounded by four primary standards:

- ITU-T G.8261: Timing and synchronization aspects in packet network
- ITU-T G.8262: Timing characteristics of Synchronous Ethernet equipment slave clock
- ITU-T G.8264: Distribution of timing through packet networks
- ITU-T G.781: Synchronization layer functions

These standards specify the jitter and wander tolerances, supported frequencies, clock specifications (Synchronous Ethernet Equipment Clocks [EECs] are defined to ensure compatibility with SONET/SDH clocks detailed in ITU-T G.813 and G.812 or Telcordia GR-1244-CORE), clock selection logic, possible clock quality levels, error responses, noise tolerances, noise generation and transfer limits, holdover performance, deployment scenarios, interworking requirements, clock selection process, Synchronization Status Message (SSM) support, as well as a new Ethernet Synchronization Messaging Channel (ESMC) that allows interworking with existing SONET/SDH infrastructure by allowing the SyncE links to convey the SSM quality level as defined in ITU-T G.707, G.781, Telcordia GR-253-CORE, and ANSI T1.101.

**Note:** To maintain the timing chain in SONET/SDH, operators often use SSM. Information provided by SSM Quality Levels (SSM-QL) helps a node derive timing from the most reliable source and prevent timing loops. Because Ethernet networks are not required to be synchronous on all links or in all locations, a specific channel, the ESMC channel defined in G.8264, provides this service. ESMC is composed of the standard Ethernet header for an organization-specific slow protocol, the ITU-T OUI; a specific ITU-T subtype; an ESMC-specific header; a flag field; and a type, length, value (TLV) structure -- the use of flags and TLVs aimed at improving the management of Synchronous Ethernet links and the associated timing change.

The main idea behind the exacting standards is to ensure Primary Reference Clock (PRC) traceability—as defined in ITU G.811—of the SyncE input and output. This stringent approach translates to a long-term accuracy of ± 10 parts per trillion—10 million times better than the “standard” Ethernet input free-running reference clock accuracy of ± 100 parts per million as specified by IEEE 802.3. Such a high degree of accuracy is required to ensure sanity of the clock recovery and propagation processes over multi-hop paths.

### Alternatives

In general, for any kind of frequency, phase or time synchronization requirements there are three kinds of solutions available:

- Physical layer (Layer 1):SONET/SDH, Synchronous Ethernet, G.SHDSL, and Gigabit Passive Optical Network (GPON)
- Radio or satellite navigation systems: Global Positioning System (GPS), Global Navigations Satellite System (GLONASS), Indian Regional Navigation Satellite System (IRNSS), Long Range Aid to Navigation (LORAN), and Galileo
- Packet-based (Layer 2 and Layer 3) distribution: Adaptive Clock Recovery methods using IEEE 1588-2008 PTP, IETF NTP, Circuit Emulation Services (CES) encapsulation or possible future ngTP from ITU-T or IETF

The matrix in Table 2 summarizes the various available alternatives ranked by ease of “deployablility” and reliability of operation.

**Table 2.** Possible Central Office Synchronization Solutions

| | Intra-CO | Inter-CO |
|---|---|---|
| **Timing (Frequency)** | • **Synchronous Ethernet**<br>• From ITFS thru external timing interface (For example DTI/J.211 or from BITS, SSU…)<br>• SDH/SONET | • **Synchronous Ethernet**<br>• SDH/SONET<br>• CES ACR<br>• IEEE1588-2008 PTP<br>• IETF NTPv4<br>• GPS/GLONASS/LORAN/Galileo/… |

| | | |
|---|---|---|
| **Time (Relative and Absolute)** | • From ITFS thru external timing interface (For example J.211, IRIG-B, PPS…)<br>• Combination of L1 (SyncE, SONET/SDH) and L2/L3 (IEEE 1588 PTP, IETF NTPv4) | • CES ACR<br>• IEEE1588-2008 PTP<br>• IETF NTPv4<br>• GPS/GLONASS/LORAN?Galileo/… |

**Note:** Not an exhaustive list; green color represents "existing" solutions, ITFS: Integrated Time and Frequency System

The choice of which mechanism to use depends on a variety of considerations, starting with whether the requirement spans multiple central offices or is restricted to intra-central office deployments. In the latter case it is expected that service providers will leverage existing Building Integrated Timing Supply (BITS) and Synchronization Supply Unit (SSU) systems, eliminating the need for evolution to newer technologies such as SyncE. For the inter-central office applications, however, the choice of the medium will depend on a multitude of factors, such as SP network and operation design, service goals, and synchronization parameters, which eventually contribute to the TCO and the overall revenue opportunity. These factors include (but are not limited to): Consumer requirements (for example, performance, regional preferences, and sensitivities)

- Equipment software and hardware (some upgrades may be necessary)
- Network radius (from reference source or sources to consumer)
- Network links (type, speed, number, etc.)
- Traffic behavior (for example, what services does the network support?)
- Scalability (for example, traffic generated by packet-based solution, number of sessions per server, etc.)
- Reliability and redundancy (solution should be at least as robust as the strongest network elements)
- Security (any packet-based solutions are subject to attacks)
- Management (network synchronization quality evaluation, ease of measurement, etc.)
- Transition, coexistence, backward compatibility (for example, what solution would ease network evolution?)
- Availability of tools and metrics (to characterize, measure, and test timing distribution)

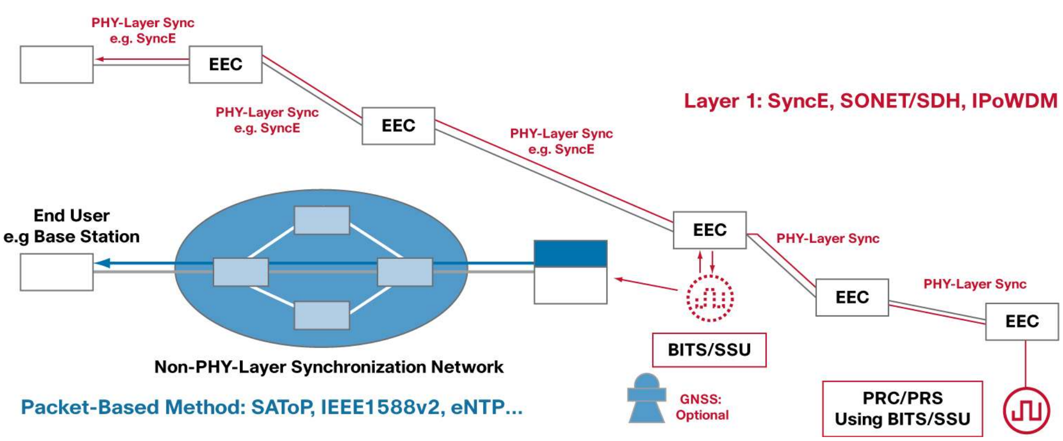
Synchronous Ethernet, natively supported on the Cisco® ASR 9000 Series routers, ranks highly with respect to all these parameters, unlike the other two methods of synchronization. For example, Global Navigation Satellite Systems (GNSSs) have vulnerabilities based on geographical (unobstructed sky view), regional concerns (standards are country-specific, hence not universally accepted), and technical (natural interference, for example, aurora borealis; and jamming and spoofing concerns) factors. Some, but not all, of these factors can be overcome—but at an increased cost of specialized solutions. Radio navigation systems such as LORAN are more resistant to some technical problems but require dedicated, geography-limited infrastructure expenditure to deploy and maintain.

Packet-based synchronization methods, such as IEEE Std 1588-2008 PTP (IEEE1588v2), offer the flexibility of being able to provide time and frequency synchronization. They are also potentially able to work over existing infrastructure without requiring specialized equipment, unlike what would be required in the case of a SyncE deployment (because each device in the path would need to be SyncE-capable). In theory, then, these methods sound like perfect synchronization solutions, but they do have limitations, especially in the case of time distribution, which requires two-way time transfer (TWTT) solutions. Some of the concerns of service providers follow:

- Effect on network behavior: Packet delay variations [PDV], performance guarantees, and compatibility concerns etc.
- Scalability: Increased protocol traffic and timing packet generation and distribution etc.
- Efficiency: Packet rate vs. timing quality, payload size vs. packet-rate trade-off, etc.
- Need for specialize network design: Dependence of deployment design on server, master, client, slave, network traffic, protocol configuration, and network efficiency—factors that are obviously different from deployment to deployment etc.
- Lack of quantifiable data: Some protocols require specialized hardware for time-stamping as a means of improving performance but there is little proof that this helps in telecom environment, and there are concerns over multi-hop performance and deployment as well.
- Variation of results due to slave implementation (e.g. timing recovery algorithm used, oscillator used etc.)

Because SyncE is a dedicated PHY-level synchronization mechanism with crisply defined standards, it does not suffer from these limitations. In addition, SyncE can work as a powerful enabler for a packet-based solution, providing the requisite reliability in a hybrid system that aims to balance the strengths of both methods to reduce TCO. Figure 4 provides an evolution scenario for such a “hybrid” system.

**Figure 4.** Evolution of Aggregation and Access with Insertion of Synchronization Services



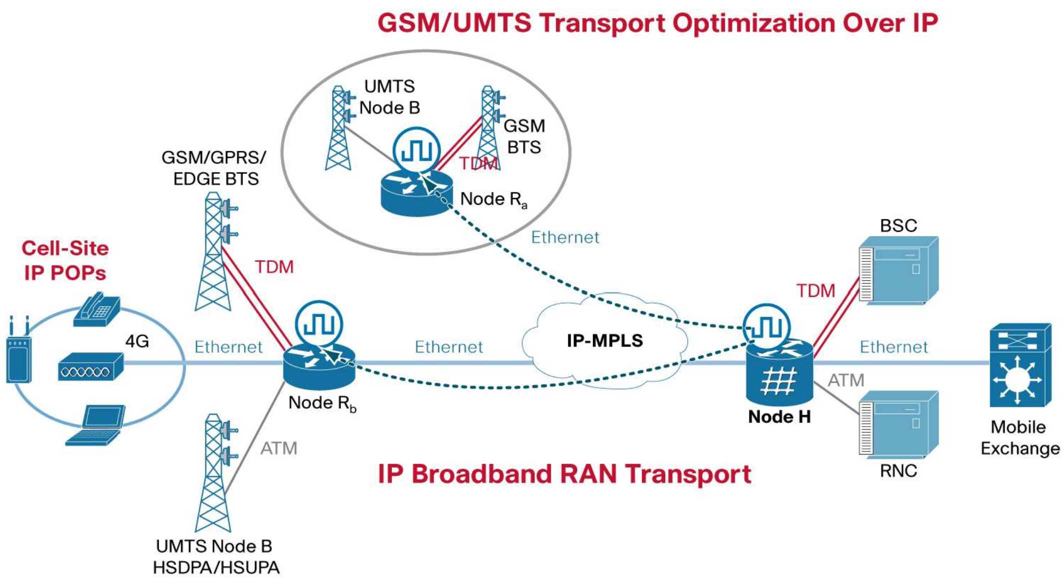

## SyncE Deployment Scenarios

Although business opportunities for SyncE use abound, Mobile and Metro-Ethernet networks provide the two biggest markets for its deployment. The carrier-class Cisco® ASR 9000 Series of routers with their superior scalability, high-availability architecture, power and thermal efficiency and native Synchronous Ethernet support are the ideal choices to power these NGN build-outs and expansions.

### Synchronous Ethernet for Mobile Networks

SyncE frequency distribution within a generalized mobile network is depicted in Figure 5. In most of the new mobile network build-outs, Ethernet is the only connection from hub (marked Node H) to remote nodes (marked Node Ra and Node Rb), so it must provide a means to distribute frequency to these remote sites (from the Cisco® ASR 9000 Series perspective, the deployment is agnostic to the last-mile implementations) for the base-stations to be synchronized. This synchronization allows efficient use of the radio spectrum, thus improving usage and utilization, enhancing customer experience, and reducing costs.

**Figure 5.** SyncE Application in Mobile Networks

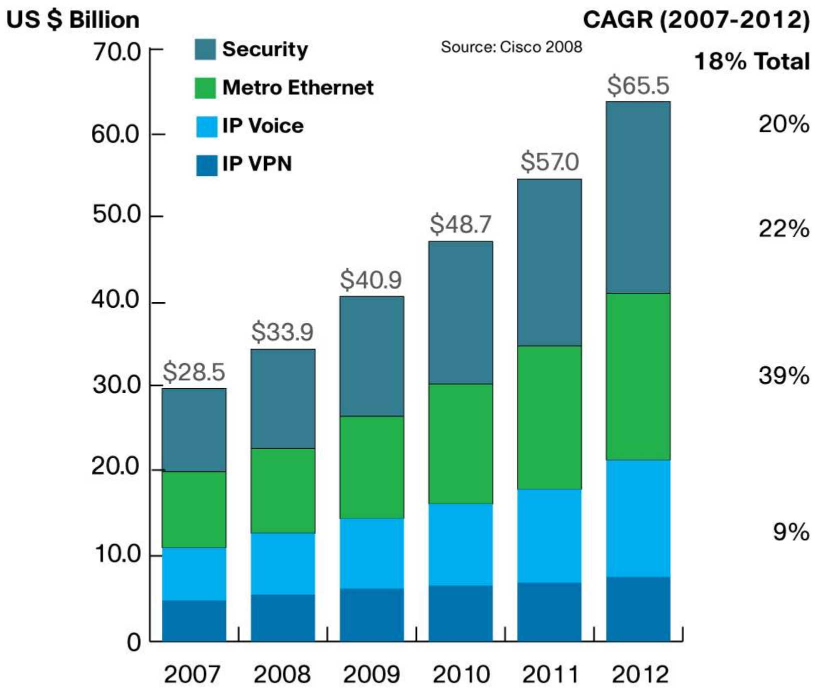



It is generally proposed that physical layer timing transport is required to guarantee frequency distribution to the extent necessary for encapsulated signals to meet network performance requirements. Although it is acknowledged that other methods such as IEEE Std 1588-2008 PTP or other ACR methods may be used for this purpose, because it is impervious to the effects of traffic load, physical layer Synchronous Ethernet provides the best technical option for guaranteed frequency accuracy and stability. For the backhaul requirements where the Ethernet network interfaces with the traditional TDM networks, SyncE can provide the necessary clocking input required for TDM links at the endpoints (in the previous example those endpoints could be the Base Transceiver Stations (BTSs) at two cell-sites with T1/E1 inputs) as well as for new-generation Ethernet-based base stations.

Although it is also possible to place reliable Primary Reference Source (PRS) capability at each node, hub, and remote site, the purpose of Synchronous Ethernet is to eliminate this need and reduce the network capital requirements and maintenance costs. SyncE may even be used as a backup to such primary references, if those references are deemed the primary choice, thereby providing a high-quality synchronization redundancy option.

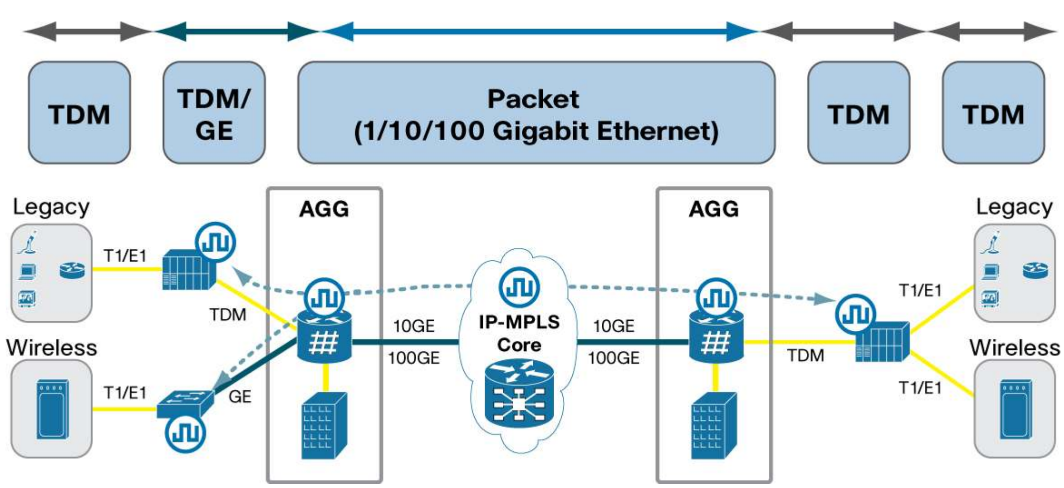
**Figure 6.** SP Retail Revenue Break-down




**Synchronous Ethernet Within Carrier and Metro Ethernet Networks**

An analysis of service provider retail revenue highlights IP voice and Metro Ethernet as the two strongest areas for potential growth. The implications of that statement are self-evident, if surprising—more Metro Ethernet build-outs, more traffic transferred to Metro Ethernet networks, with voice continuing to remain an important factor affecting revenue. The world will quickly move toward voice over IP (VoIP), but existing termination points that are on TDM networks cannot be ignored because they are an integral part of this “voice” world—the fastest-growing of all four segments. With the need to continue to support TDM infrastructure through CES and allow for a smooth traditional-to-NGN migration comes the need for frequency distribution similar to the one within mobile networks. Frequency distribution applications for Metro Ethernet wire-line networks are depicted in Figure 7.

**Figure 7.** SyncE Application in Metro Ethernet and Carrier Ethernet Networks



In this example, core and aggregation network nodes (for example, the Cisco® ASR 9000 Series routers) are required to interface to primary reference source and distribute frequency to downstream nodes (but not necessarily on all links). Aggregation nodes are required to be able to recover the reference frequency from links connected to core nodes as well as optionally be able to interface to BITS and SSU timing equipment, which are part of the synchronization hierarchy (Cisco® ASR 9000 Series has both of these capabilities). Remote nodes are almost always line-timed, so they need to recover timing from links connected to aggregation and core nodes whenever a Synchronous Ethernet service is desired. It is noted that Synchronous Ethernet implementations are required to provide the same clock accuracy, stability, and traceability provided by SONET and SDH networks. Jitter requirements for Synchronous Ethernet remain compliant to IEEE definition (ITU-T G.8261), the wander being relevant to the Ethernet Equipment Clock recommendation (ITU-T G.8262). SONET and SDH jitter requirements are defined to ensure accurate and precise transport for TDM signals. Networks based on Ethernet and required to transport TDM will use Circuit Emulation-over-Packet (CEoP) technology, so more rigorous Ethernet jitter specification is unnecessary. It is the emulated signal that is required to be jitter-compliant, and this compliancy is enabled by Synchronous Ethernet clock distribution. ITU-T G.8264 enables continued clock traceability over SyncE links and synchronization trails.

## Conclusion

With the world rapidly transitioning to IP/MPLS-based NGNs with Ethernet as the transport medium of choice, there is an increasing need to enhance services and capabilities while still leveraging existing infrastructure, thereby easing the transition while continuing to increase revenue and reduce the TCO. In areas such as mobile backhaul, TDM CES etc., these requirements create a need for SONET/SDH-like frequency synchronization capability in the inherently asynchronous Ethernet network. Synchronous Ethernet, natively supported on the Cisco® ASR 9000 Series routers, is an ITU-T standardized PHY-level way of transmitting frequency synchronization across Ethernet packet networks that fulfills that need in a reliable, secure, scalable, efficient, and cost-effective manner. It allows Service Providers to keep existing revenue streams alive and create new ones while simplifying the network design and reducing TCO.

### For More Information

For more information, refer to:


- ITU-T Rec. G.8261, Timing and Synchronization Aspects in Packet Networks, Feb. 2008
- ITU-T Rec. G.8262, Timing Characteristics of Synchronous Ethernet Equipment Slave Clock (EEC), Aug. 2007
- ITU-T Rec. G.8264, Distribution of Timing Through Packet Networks, Feb. 2008
- ITU-T Rec. G.781, Synchronization Layer Functions, Feb. 2008
- ITU-T Rec. G.803, Architecture of Transport Networks Based on the Synchronous Digital Hierarchy (SDH)
- ITU-T Rec. G.707, Network Node Interface for the Synchronous Digital Hierarchy (SDH)
- ITU-T G.810, Definitions and Terminology for Synchronization Networks
- IEEE Communications Magazine, “Synchronous Ethernet: A Method to Transport Synchronization”, Sept. 2008

- IEEE 1588-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, July 2008



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