LTE Stretches Synchronization to New Limits

This paper uses the term "syntonization" to refer to frequency alignment of network clocks. This functionality is also commonly called "timing synchronization" and "frequency synchronization." When discussing phase and time-of-day alignment of clocks, this paper uses the common industry terms "phase synchronization" and "time-of-day synchronization."

Introduction

Mobile subscribers are demanding more and more bandwidth to support high-speed data and multimedia applications. To satisfy that demand, reduce costs and improve operating efficiencies, mobile operators around the world are evolving their networks from circuit-switched to packet-switched technologies.

As operators replace their TDM equipment with IP/Ethernet/MPLS platforms, they face a major challenge: how to provide the precise frequency reference or "syntonization" for base-station clocks and do so in a cost-effective way.

Actually, operators confront a broader, two-part challenge. First, they must replace their TDM-based clock function with a suitable packet clock. Secondly, as they deploy advanced LTE technologies, they eventually must expand that packet-clock capability so that it can distribute not just the frequency reference but also phase and time-of-day synchronization.

Finding an operationally efficient and cost-effective way to distribute syntonization and synchronization functions across the packet network is the major hurdle. Frequency division duplex (FDD) base stations require only a frequency reference, because the air interface uses different frequencies for the uplink and downlink. In most FDD deployments, operators have used the legacy TDM network to distribute syntonization.

However, because TDM-based distribution obviously is not available with asynchronous packet-based backhaul networks, many operators retain a T1/E1 link at the cell site solely to distribute the frequency reference. Unfortunately, that strategy is expensive and significantly reduces the operational efficiencies packet technologies are designed to deliver.

Consequently, operators need an alternative, carrier-grade solution that paves a smooth network-migration path to various 4G technologies and, in the process, overcomes the syntonization and synchronization issues.

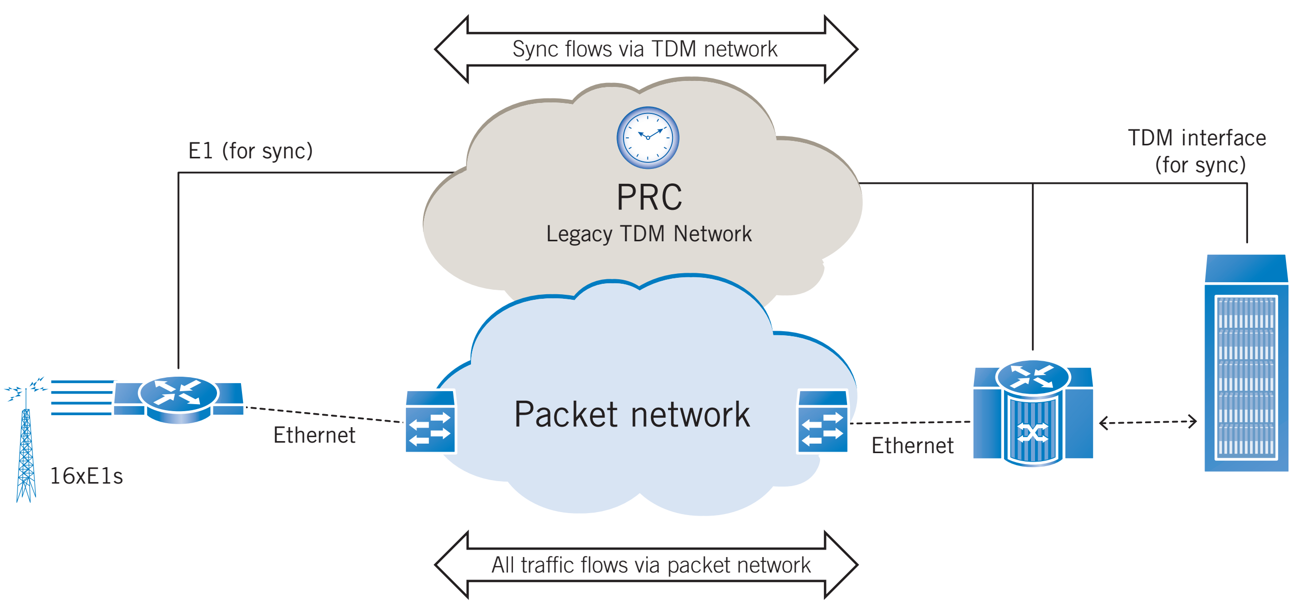

Figure 1: Typical Ethernet backhaul - E1 links deployed only to distribute frequency reference

Functions of Syntonization and Synchronization

Mobile networks already have evolved a long way from 2G technology. Today, fiber and packet-microwave links connect more and more base stations, often feeding into a converged, multiservice aggregation network. Operators are replacing their TDM or hybrid backhaul segments with packet technologies, such as IP, Ethernet and/or MPLS.

Regardless of whether the underlying technology is 2G, 3G, 4G or a combination thereof, syntonization and synchronization are essential for all mobile networks. Syntonization, or the alignment of clock frequency, enables base stations to stay within allocated spectrum and thereby avoid interfering with other cells. Syntonization also is necessary to support the call-handover mechanisms between base stations.

Phase synchronization, or the alignment of all clocks in phase, is critical for mobile networks that use single-frequency techniques, such as time-division duplexing (TDD); these require all the base stations to switch between uplink and downlink transmissions at the same instant. Phase synchronization also is required for coordinated multipoint transmissions, in which several base stations transmit concurrently to a single handset. Because of the need to increase the network's data throughput and the fact that available air-interface radio frequencies are largely allocated, operators increasingly use these techniques to squeeze more data bandwidth from their existing spectrum allocations.

In addition, at least one type of service – location – requires phase synchronization because the accuracy with which a handset can be located depends directly on time-of-day synchronization among the base stations. This is a critical feature for emergency services. Both coordinated multipoint and location services are part of the evolving LTE-advanced specifications.

Operators have different requirements for Ethernet backhaul – those still maintaining legacy TDM links solely for syntonization want to eliminate that costly equipment from their networks, while those that focus on TDD-LTE or LTE-advanced see the impending need for distributing phase-synchronization. The latter also want to avoid having to install GPS technology at every cell site. Even CDMA operators who traditionally have relied on GPS now want solutions that are not as vulnerable to jamming.

Regardless of the types of mobile technologies they deploy today, all operators need transport solutions that can distribute syntonization and synchronization, efficiently and with resilience, to address packet loss, jitter and variable latency.

Evolving Standards Help Tackle the Challenge

Two practical mechanisms for providing syntonization via the transport network have emerged: Synchronous Ethernet (SyncE), which uses the Ethernet physical layer to syntonize neighboring nodes and IEEE 1588v2, which specifies a master-slave exchange of packets that carry time stamps. Operators can use IEEE 1588v2 to provide syntonization directly across a packet network; for high-accuracy network phase synchronization, the nodes in the network must support IEEE 1588v2. Many operators already deploy a combination of SyncE and IEEE 1588v2, and they likely will continue to do so for the foreseeable future.

Both standards are the result of efforts by international standards bodies, notably the 3rd Generation Partnership Project (3GPP), the International Telecommunication Standardization Sector (ITU-T) and the Institute of Electrical and Electronics Engineers (IEEE).

SyncE - Operators first proposed SyncE to ITU-T in 2005 as a way to use the Ethernet physical layer to carry syntonization. The ITU-T two years later defined in its G.8262 recommendation the "timing characteristics of synchronous Ethernet equipment slave clock." In 2004, Tellabs already had implemented a pre-standard version of "Ethernet timing" in its multiservice access platform.

Then in 2008, the ITU-T defined in G.8264 the Ethernet Synchronization Messaging Channel or ESMC. This not only allows clock Quality-Level information to be carried over synchronous Ethernet but also enables a downstream node to select the reference from the best available source. The ESMC provides 100-percent compatibility with the Synchronization Status Messages of SDH. In fact, from the synchronization point of view, design requirements mandate that SyncE and SDH be completely interoperable.

IEEE 1588v2 - The IEEE 1588-2002 standard defines the Precision Time Protocol (PTP) protocol suite, including the concept of boundary clocks (BC), for synchronizing distributed clocks over Ethernet networks. Revisions in 2008 specified transparent clocks (TC), along with even greater precision and accuracy, and provided an IP encapsulation option as well. The standard offers distinct advantages in that operators can deploy IEEE 1588v2-compliant equipment and thereby avoid the cost and potential jamming issues that come with deploying GPS receivers at every base station.

By using BC or TC functions in the nodes between the master and slave clocks, IEEE 1588v2 significantly reduces the effects of latency and other network delays. The standard specifies that master and slave exchange packets containing short messages that measure and eliminate latency caused by residence delay variations.

Using a primary reference time clock as a source, a 1588v2 boundary clock syntonizes to the master clock and then functions as a master clock to all other "downstream" clocks across the network, thereby providing accurate time transfer.

Transparent clocks, as defined by 1588v2, compensate for switching delays by updating a correction field within the PTP messages, i.e., with the actual residence time.

Two ITU-T Service Profiles for IEEE 1588v2

The IEEE specified 1588v2's protocol suite, including the boundary and transparent clocks, and provided a profiling mechanism for adapting to the specific requirements of different industries and applications. For telecommunications applications, the ITU-T has defined two distinct IEEE 1588v2 profiles:

The *frequency profile* uses IP/UDP encapsulation to transfer a frequency reference across existing data networks. G.8265.1, which the ITU-T completed in 2010, specifies an end-to-end model in which the intermediate nodes do not play an active role in the syntonization network. The latest standards from the ITU-T, particularly G.8260, G.8261.1 and G.8263, go a long way to address operator concerns about performance guarantees. Many operators are adopting IEEE1588v2 for network syntonization, especially in cases where SyncE support is not available.

The *phase profile* responds to the new mobile requirements for tight (<1µs) phase alignment between base stations. The ITU-T goal is to develop support for phase and time-of-day synchronization distribution in new transport networks. Still in their early stages, these efforts center on the development of a telecommunications boundary clock model that will allow the combination of SyncE and IEEE 1588v2. Currently, G.8271 specifies the requirements and architecture for synchronization in telecommunications networks and paves the way for transferring phase, hop by hop, with every node supporting the boundary clock function.

Different Applications Have Different Requirements

The various applications which use syntonization/synchronization services require different levels of accuracy. Traditional syntonization provides a reference to guarantee that base stations can satisfy frequency-accuracy requirements of +/-50ppb at the air interface.

G.8261.1 specifies the network limits applicable to packet-based methods; these limits basically establish an acceptable range of "noise" which the network is allowed to produce and which the packet clock must be able to tolerate. Allocating a budget of 16ppb (of the 50ppb air interface budget) for the transport network providing the syntonization flow, G.8261.1 is a welcome step in the right direction.

When the transport network provides phase and time-of-day synchronization, there again are several applications with varying levels of required accuracy. The following are the main applications that need phase/time-of-day synchronization, along with their respective range of accuracy requirements:

- billing, alarms - 1µs -500µs
- IP delay monitoring - 5µs - 100µs
- LTE-TDD (large cell) - 1.5µs - 5µs
- WiMAX TDD (some configurations) - 1.5µs -5µs
- UTRA-TDD - 1µs - 1.5µs
- LTE-TDD (small cell) - 1µs -1.5µs
- WiMAX TDD (some configurations) </= 1µs
- Some LTE-A features - <= 500 nanoseconds (still under study)

Although standards bodies continue to discuss the requirements for phase accuracy of less than 1µs, the generally-agreed-on requirement is 1µs. Unlike CDMA, LTE can use any arbitrary time scale, meaning, LTE requirements are not tied to Universal Time Coordinated (UTC); however, the industry likely will use UTC.

Technology Considerations for Implementing Syntonization and Synchronization

Whether the required syntonization/synchronization service is a 16ppb (50ppb) frequency reference or a 1µs phase reference, operators have four implementation alternatives.

1. SyncE - Although the SyncE standards are now mature, much of the deployed base of Ethernet equipment does not support it. If a single Ethernet switch in the chain does not support SyncE, all nodes lower in the hierarchy do not receive the timing service. The addition of SyncE support to an existing network typically requires the operator to replace line cards or do a forklift upgrade of nodes.

Nevertheless, SyncE is attractive to many operators because it closely resembles the familiar SONET/SDH model, that is, each node in the hierarchy contains an Ethernet Equipment Clock that syntonizes frequency from the node above. Hop-by-hop processing, in which every node in the data path is an active participant in the syntonization network, distributes the reference provided by the master clock.

Operators also like SyncE because its timing quality is completely independent of network loading.

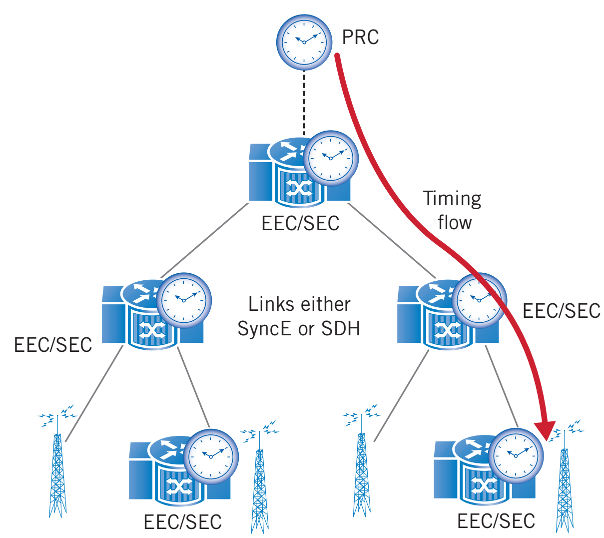

Figure 2: Synchronous Ethernet timing hierarchy is the same as for SDH/SONET

2. IEEE 1588v2 (syntonization) - IEEE 1588v2 is the main option for operators with packet backhaul networks that do not support SyncE. Slave clocks at the base stations receive frequency from master clocks deployed at appropriate network locations.

For existing networks, the IEEE 1588v2 end-to-end model is typically easier to deploy than the SyncE model because only the end points must support IEEE 1588v2. However, operators must ensure that the syntonization flow providing the frequency reference is not distorted by packet delay variation beyond the filtering capabilities of the packet slave clock.

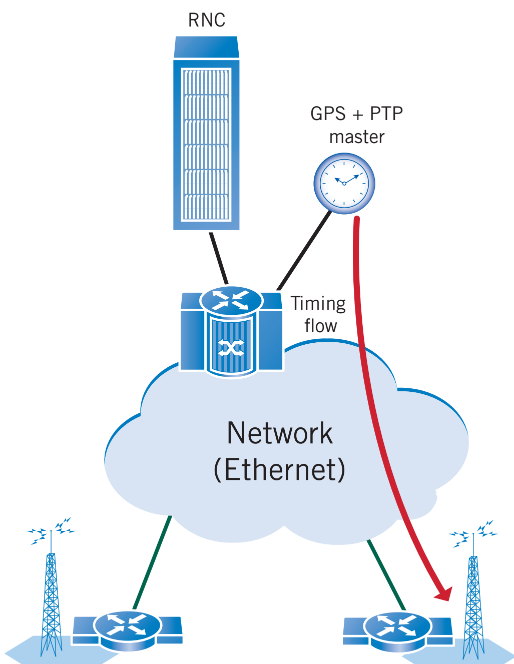

Figure 3: Synchronous Ethernet timing hierarchy is the same as for SDH/SONET

A network which complies with G.8261.1 ensures that "for any window interval of 200 seconds, at least 1 percent of transmitted timing packets will be received within a fixed cluster, starting at the observed floor delay, and having a range of 150 μs." In practice, this means that almost all Ethernet networks can meet the network limits of G.8261.1.

3. Circuit Emulation Service (CES) Timing - Operators can use the recovered clock from a TDM pseudowire to provide syntonization to a 2G base station. However, although CES as a transparent TDM service has been standardized by the Internet Engineering Task Force (IETF), there is no standard for using CES to clock a network node. There also are no standardized protection mechanisms for CES syntonization.

4. GPS and IEEE 1588v2 (synchronization) - GPS is the last resort for some operators and, for those who require phase synchronization today, it may be the only option. Certainly GPS is the only practical global reference for phase or time-of-day. Even when segments of the transport network can support IEEE 1588v2 synchronization delivery, the reference and timescale will be derived from GPS.

Given that emerging mobile technologies require phase alignment, the mobile transport network will evolve to support a synchronization service with guaranteed 1μs accuracy. Enforcing a boundary clock hop-by-hop model mitigates packet delay variation. There may be a temptation to "skip" a node or two, i.e., to carry the IEEE 1588v2 synchronization flow across a segment of the transport network that does not support the boundary clock function. The resulting impact on phase accuracy will be significant and may cause operators to exceed the 1us budget.

Other issues still to be overcome include network asymmetries resulting from differences in the fixed delays of network links, e.g., different fiber lengths will produce offsets. It is possible to measure and compensate for such asymmetries, but operators need an automated method of doing so.

Because standardization work on the phase profile is ongoing, there can be no general interoperability guarantees until the standards are complete. While the long-term goal is IEEE 1588v2 support in every node of the transport network, operators will use IEEE 1588v2 in the near term to extend the reach of GPS within network segments.

Because of their massive investments in existing mobile networks, operators understandably demand that their vendors lay out a planned migration path for any LTE-driven changes in base-station technologies and associated developments in the transport network. In the case of LTE specifically, operators must make two changes in the transport network's syntonization/synchronization capabilities:

1. packet [frequency] syntonization application for FDD, or migration away from TDM, to reduce costs in the FDD transport network
2. phase transport application, or migration toward phase capability, to boost radio bandwidth efficiency via techniques that require phase alignment without the need for GPS at every base station

The Right Packet Syntonization/Synchronization Solution

Operators have a broad range of topologies and requirements--many own microwave and/or fiber, while others lease connectivity, and still others buy a managed backhaul service from a fixed-line carrier. Those that own their transport networks will want to upgrade links to be SyncE-capable. Those that lease capacity and do not have access to SyncE should run IEEE 1588v2, end to end, between the master and the client at each cell site. These operators want IEEE 1588v2 clients that comply with the standards, especially G.8265.1 and G.8261.1.

Packet Syntonization

Advanced solutions, such as the Tellabs® Smart Routers, support a range of syntonization options. For example, an operator may own the access infrastructure but lease core connectivity where SyncE syntonization service is not available. Such a solution enables the operator to use IEEE 1588v2 across the core network and SyncE across the access network via microwave radios.

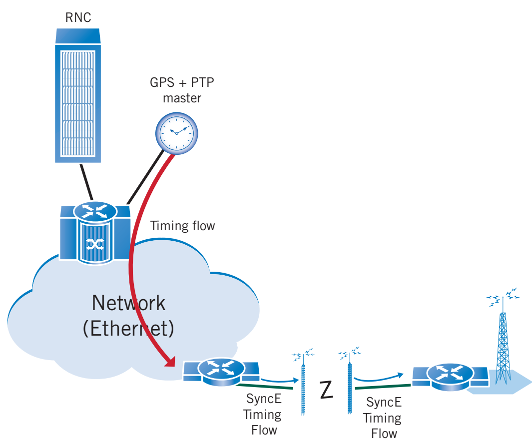

Figure 4: IEEE1588 timing service together with SyncE

By combining IEEE 1588v2 in the core with SyncE in the access, this solution effectively shortens the number and length of the IEEE 1588v2 flows and thus reduces the number of required IEEE 1588v2 masters. In addition, the solution's ability to run SyncE, rather than IEEE 1588v2, over the access wherever possible may improve end-to-end syntonization performance; delay characteristics of Ethernet/IP-MPLS switches are more predictable than those of non-Ethernet access technologies.

Packet Phase Synchronization

Using IEEE 1588v2 to extend GPS obviously reduces the number of required GPS antennas and the associated cost, and it enables operators to distribute phase synchronization to sites where GPS is difficult to deploy. Although operators who are deploying LTE-TD today may need to use GPS connections at every base station, they will be able during 2012 to take advantage of a phase-synchronization service to distribute GPS across small islands of the transport network.

Until the ITU-T completes the IEEE 1588v2 phase profile, network paths carrying phase synchronization will be short and based on pre-standard implementations. Meanwhile, operators are developing roadmaps for boundary clock and transparent clock, and they want solutions they can deploy today but upgrade remotely, once ITU-T members reach agreement on the IEEE 1588v2 phase profile. Advanced syntonization/synchronization solutions such as the Tellabs Smart Routers already feature the necessary hardware. In most cases, operators can upgrade these solutions, via software download and without installation of additional equipment, to support IEEE 1588v2 phase services.

Effective Monitoring Attests the Quality of Syntonization

An advanced syntonization solution also can use an external reference to monitor the output clock accuracy of an IEEE 1588v2 frequency slave. It enables operators to measure the quality of the syntonization accurately and thereby determine whether the IEEE 1588v2 is performing at the expected level. Essentially each node contains a "wander meter" which uses an external reference to make accurate measurements. Controlled by a next-generation network management platform, the syntonization-monitoring solution can monitor thousands of nodes – an especially useful capability during customer migration from legacy TDM to IEEE 1588v2, using the "last E1" as a reference.

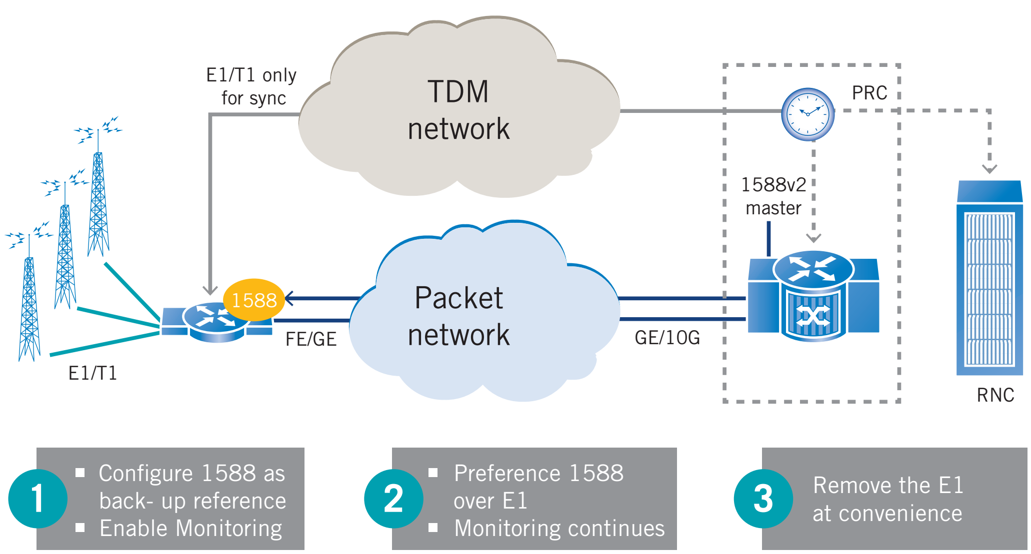

Figure 5: Monitoring of IEEE1588 output clock in migration scenario

An advanced syntonization solution also features a variety of tools for monitoring network performance during the migration from TDM, including:

- TIE measurements against external reference clock
- MTIE measurements
- Network view of alarms filtered on MTIE mask crossed alarms
- Packet-based quality metrics

Note: Because the packet-based quality metrics now specified in G.8260 and G.8261.1 are both new (approved in December 2011) and very conservative, operators likely will want to use the more familiar physical measurements for comparison. Monitoring of the physical IEEE 1588v2 clock output can be considered a long term solution for a small number of selected sites using an SDH or GPS derived reference clock.

A node can run two clocks in parallel – both the Ethernet Equipment Clock (EEC), which is the node clock, and the IEEE 1588v2 clock, which may be monitored against a selected reference source. Although the IEEE 1588v2 clock is available as a reference, the syntonization solution will select it only if it has preferred status over other candidates. This enables the IEEE 1588v2 clocks to be activated and monitored in an existing production network with no disturbance to the network.

Enabling the clock-selection process to choose between the IEEE 1588v2 clock and a physical reference clock is a convenient way to switch from legacy E1 syntonization to IEEE 1588v2 syntonization. Operators also have the flexibility to keep the IEEE 1588v2 syntonization candidate as a long-term backup option for a preferred SyncE candidate, for example, in situations in which data traverse multiple paths but SyncE is available only on unprotected links.

A Vision of Ubiquitous Syntonization and Synchronization

Operators no longer take syntonization and synchronization capabilities for granted. As they deploy increasingly advanced 4G/LTE technologies, these two functions are essential to the delivery of high-speed, high-quality and cost-effective services. Consequently, operators want comprehensive, well-integrated solutions.

Specifically, they are seeking advanced syntonization solutions with a proven track record, which can pave a controlled and simple migration path to IEEE 1588v2-based syntonization. Operators also want solutions with the built-in capability and flexibility to support phase synchronization as soon as final standards emerge.

Such solutions are available today, and operators can take advantage of them to satisfy the growing demand for bandwidth, improve operating efficiencies, reduce costs and sustain long-term profitability.

North America

Tellabs
1415 West Diehl Road
Naperville, IL 60563
U.S.A.
+1 630 798 8800
Fax: +1 630 798 2000

Asia Pacific

Tellabs
3 Anson Road
#14–01 Springleaf Tower
Singapore 079909
Republic of Singapore
+65 6215 6411
Fax: +65 6215 6422

Europe, Middle East & Africa

Tellabs
Abbey Place
24–28 Easton Street
High Wycombe, Bucks
HP11 1NT
United Kingdom
+44 871 574 7000
Fax: +44 871 574 7151

Latin America & Caribbean

Tellabs
Rua James Joule No. 92
EDIFÍCIO PLAZA I
São Paulo – SP
04576-080
Brasil
+55 11 3572 6200
Fax: +55 11 3572 6225