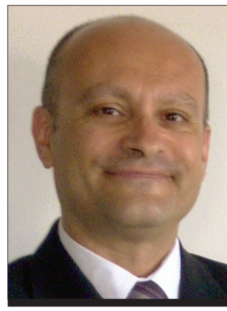
SYNCHRONIZATION OVER ETHERNET AND IP IN NEXT-GENERATION NETWORKS



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Network synchronization deals with the distribution of time and frequency over a network of clocks, including clocks spread over a wide area. The goal is to align the time and frequency scales of all the clocks by using the communications capacity of links between nodes.

A synchronization network is the facility that implements network synchronization. The basic elements of a synchronization network are nodes (autonomous and slave clocks) and communication links interconnecting them. Since the 1970s and '80s, most telecommunications operators have set up synchronization networks to synchronize their switching and transmission equipment.

Over this time, network synchronization has been gaining increasing importance in telecommunications. As a matter of fact, the quality of many services offered by network operators to their customers depends on network synchronization performance.

Since the introduction of early digital switching systems, network synchronization was needed to avoid slips in circuit-switched voice and data networks. The deployment synchronous digital hierarchy/synchronous optical network (SDH/SONET) networks imposed new and more complex requirements on the quality of synchronization systems. To study those new problems, international standard bodies established specific work groups, which culminated in the '90s with the release of a new series of International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) Recommendations on synchronization of digital networks (G.810, G.811, G.812, and G.813), as well as their counterparts released by the Alliance for Telecommunications Industry Solutions (ATIS) and Telcordia (e.g., GR-1244) in the United States and by the European Telecommunications Standards Institute (ETSI) in Europe.

More recently, it has been recognized that the importance of network synchronization goes even further: asynchronous transfer mode (ATM) and cellular mobile telephone networks (Global System for Mobility [GSM], Global Packet Radio Services [GPRS], Universal Mobile Telecommunications Services [UMTS]) are two striking examples where the availability of network synchronization references has been proven to significantly affect the quality of service.

Traditionally, synchronization has been distributed to telecommunications network nodes using circuit-switched links in time-division multiplexing (TDM). In particular, E1 and DS1 circuits have been most commonly used over European and North American standard plesiochronous digital hierarchy (PDH) systems, respectively.

The recent migration of network operators to the packet-switched next-generation network (NGN) once again poses newer and even more difficult problems for network synchronization. Today, as fixed and mobile operators migrate to NGN infrastructures based on IP packet switching, Ethernet transport is becoming increasingly common. This trend is driven by the prospect of lower operation costs and the convergence of fixed and mobile services. However, migrating trunk lines to IP/Ethernet transport poses significant technical challenges, especially for circuit emulation and synchronization of network elements.

Therefore, the network evolution toward IP packet switching has led to increased interest on the part of communications engineers in synchronization distribution using packet-based methods. After a few years of declining research, considerable new investigation activity on network synchronization has restarted in both industry and academia.

International standard bodies have also resumed significant levels of activity on this subject. Since 2004 the ITU-T has been developing a new set of Recommendations, specifically for synchronization on packet-switched networks, beginning with ITU-T Recommendation G.8261/Y.1361, "Timing and Synchronization Aspects in Packet Networks." In 2002 IEEE released a new "Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems" (IEEE 1588, revised in 2008).

At this point, it is worth pointing out that the traditional model, in which synchronization distribution is engineered carefully for optimal performance and survivability, may give way to scenarios in which there is greater expectation of automatic, self-configured operation while still maintaining adequate synchronization quality. This model is similar to that of Ethernet "plug and play," in which Ethernet equipment may be connected into a network without significant, or any, a priori configuration, yet expected to come up and work satisfactorily. As NGN synchronization is transported increasingly via packet networks, there are indications that such an expectation will arise for synchronization as well.

This consideration widens the scope of interest in synchronization beyond specialists, reaching the wider audience of telecommunications engineers in general. An example is the distribution of synchronization to next-generation wireless base stations, which are connected to the core network only via packet-switched networks, but still require highly accurate synchronization to meet standard quality of service expectations.

Toward this end, this special issue aims to introduce readers to some notable changes in network synchronization technology, which have recently arisen from the evolution to NGN. Two articles (Ferrant *et al.* and Garner *et al.*) review the current state of standardization activity in the ITU-T and IEEE. Two articles (Cosart and Shenoi) deal with aspects of characterization and measurement of synchronization performance in packet networks. Finally, one article (Ouellette *et al.*) describes the use of IEEE 1588 for time synchronization.

In further detail, the article by J.-L. Ferrant and S. Ruffini summarizes the work done by ITU-T Q13/15 over the last six years to standardize the transport of timing over packet networks, including a summary of the relevant documents published by the ITU-T. It also provides insight into the future work in ITU-T Q13/15 on the transport of timing in packet networks.

The article by G. M. Garner and H. Ryu presents the Audio/Video Bridging (AVB) project in the IEEE 802.1 working group, focused on the transport of time-sensitive traffic over IEEE 802 bridged networks. The IEEE 802.1AS is the AVB standard that will specify requirements to allow for transport of precise timing and synchronization in AVB networks. This article provides a tutorial on IEEE 802.1AS and also new simulation results for timing performance.

The article by L. Cosart describes techniques for performance data measurement and analysis of NGN packet network synchronization. It introduces some of the new metrics that are used for performance evaluation of packet timing.

The article by K. Shenoi presents metrics and analytical methods suitable for specifying timing requirements in NGN packet networks. It provides a brief overview of timing fundamentals, followed by an explanation of how packet-based methods transfer timing. Two groups of metrics, the TDEV and MTIE families, are discussed.

Finally, the article by M. Ouellette, K. Ji, S. Liu, and H. Li describes the use of IEEE 1588 and boundary clocks for time distribution in telecommunications networks. This technology is primarily used to serve the radio interface synchronization requirements of mobile systems such as WiMAX and LTE, and to avoid the dependence on GPS systems deployed in base stations. It also presents some preliminary field trial results, which indicate that it is possible to transfer accurate phase/time across a telecom network for meeting the requirements of mobile systems.

This issue does not include an update on the topic of synchronous Ethernet. Recent activity in the standards bodies has recognized that no single method is likely to achieve acceptable results for both time and frequency distribution, and a combination of methods will be required. Research activity is now focused on using synchronous Ethernet to transfer frequency, and then using a different protocol as an overlay to distribute time. (IEEE 1588 is one example of a protocol that may be used in combination with synchronous Ethernet, although this has yet to be proven to work well enough). Ferrant *et al.* (*IEEE Communications Magazine*, 2008) recently provided a review of synchronous Ethernet. Another article will be published in a forthcoming issue of *IEEE Communications Magazine* providing a further update on this topic, including aspects of how synchronous Ethernet may be used together with other protocols for time distribution.

BIOGRAPHIES

STEFANO BREGNI [M'93, SM'99] (bregni@elet.polimi.it) is an associate professor at Politecnico di Milano, where he teaches telecommunications networks and transmission networks. In 1990 he graduated in telecommunications engineering at Politecnico di Milano. Beginning in 1991, he worked on SDH and network synchronization issues, with special regard to clock stability measurement, first with SIRTI S.p.A (1991–1993) and then with CEFRIEL (1994–1999). In 1999 he joined Politecnico di Milano as a tenured assistant professor. Since 2004 he has been a Distinguished Lecturer of the IEEE Communications Society, where he holds or has held the following official positions: Member at Large on the Board of Governors (2010–2012), Director of Education (2008–2011), Chair of the Transmission, Access and Optical Systems (TAOS) Technical Committee (2008–2010; Vice-Chair 2002–2003, 2006–2007; Secretary 2004–2005) and Member at Large of the GLOBECOM/ICC Technical Content (GITC) Committee (2007–2010). He is or has been Technical Program Vice-Chair of IEEE GLOBECOM 2012, Symposia Chair of GLOBECOM 2009, and Symposium Chair for eight other ICC and GLOBECOM conferences. He is Editor of the IEEE ComSoc *Global Communications Newsletter* and Associate Editor of *IEEE Communications Surveys and Tutorials*. He was tutorial lecturer for four IEEE ICC and GLOBECOM conferences. He has served on ETSI and ITU-T committees on digital network synchronization. He is an author of about 80 papers, mostly in IEEE conferences and journals, and of the book *Synchronization of Digital Telecommunications Networks* (Wiley, 2002). His current research interests focus mainly on traffic modeling and optical networks.

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