

## Sync University Curriculum – An Executive Summary

What is the notion of network synchronization and timing in a telecommunications environment? How do we measure it? How do we specify it? How do we implement it? These and other questions are addressed, from a technical standpoint, in the Sync University curriculum. In this executive summary we provide a rationale for synchronization, an aspect that is not always emphasized in technical courses.

The comedian Rodney Dangerfield has built his career with self-deprecating humor characterized by the tag line “I don’t get no respect!” Synchronization (or sync, for short) can empathize with Mr. Dangerfield. As technologies go, it does not have the glitter of gigabit fiber optic transmission systems, the panache of Internet Protocol (IP) or the sizzle of soft-switches. It is less understood, less appreciated and given less importance than most other entities in the telecommunications network; however, it is the heartbeat of the network. In conjunction with other unsung heroes such as power and ground, Synchronization makes the network work or work more efficiently.

One possible explanation for the low status of synchronization is that it is not directly correlated with revenue, although it certainly enables many network elements that are essential economic engines. By and of itself, it does not generate any revenue for a telecommunications service provider. Synchronization is not sold as a service, though it probably could be. On the other hand, a Class 5 Switch, for example, can be viewed as revenue generating equipment. Each trunk can generate \$X/hour in toll revenue; each subscriber line can generate \$Y/month by providing basic POTS (plain old telephone service) with additional revenue from enhanced services and so on. No such concise model is associated with synchronization even though the switch relies on a timing input in order to operate correctly.

In the United States the Federal Communications Commission (FCC) serves a watchdog role, overseeing the various telecommunications service providers to ensure that the general consumer receives high-quality, fair-priced telecommunications services. Now, every telecommunications executive is familiar with the phrase “FCC-reportable outage.” Any service outage that affects more than 30,000 subscribers must be reported to the FCC and the general process is involved, costly and an onerous drain on resources - economic and human. In an industry report available at <http://www.atis.org/pub/nrsc/jrunyonpresentation.pdf>, a blue-ribbon panel ascertained that fully **9.4% of all FCC-reportable outages were related to timing** during 2000-2001. Analysis of the report and its findings and recommendations indicates that if just a little more attention were given to synchronization, most of these timing related outages could have been prevented. Two shop-worn clichés come to mind: *An ounce of prevention is worth a pound of cure*, and *A stitch in time saves nine* - or, in the case at hand, nine-point-four.

The need for synchronization arose primarily because of the transformation of the network from analog to digital. The original telecommunication network was geared to handle telephone traffic and was achieved by establishing analog paths between end-

point station sets (telephones). Sync was not a major consideration, the focus being on minimization of additive noise and maintaining signal-to-noise ratio (SNR). In the modern telecommunication network voice signals are digitized and, once in digital form, are transported as bits (or octets) and the notion of additive noise is replaced by the notions of bit-error-rate (BER) and slips. Bit-error-rate is related to the ability of transmission systems to deliver information (bits) over a transmission medium (copper, fiber or radio); a slip is a phenomenon related to sync and timing. Modern equipment can provide excellent BER performance, a feature rendered moot if the associated sync is inadequate.

The concept of a slip is quite straightforward once we recognize that the frequency of clocks, albeit notionally equal, can be different. If a bit source generates traffic using a clock of frequency  $f_1$  and the recipient expects traffic at a clock rate  $f_2$ , there is clearly a problem if  $f_1 \neq f_2$ . If a buffering arrangement is employed, the buffer will either overflow or underflow. This is the notion of a slip. If the transmit clock is high then data is lost; if the receive clock is high then data must be inserted, usually by repeating the last block or an equivalent strategy. This situation is not uncommon and can in fact occur in every network element involved in the delivery of the bit-stream between the end-points.

The rate at which slips occur is determined by the frequency difference,  $Df$ . It is conventional to express this difference in fractional units, i.e.,  $(Df/f)$ , which are dimensionless. For example, in the case of speech digitization at 8 kHz, the telephony standard, if the analog-to-digital (A/D) and digital-to-analog (D/A) clocks differ by 125 parts-per-million (ppm), also written as  $125 \times 10^{-6}$ , then in every one-second interval one of the clocks will have gone through one additional cycle, or period, nominally 125  $\mu$ sec. That is, there will be one slip every second. If the (fractional) frequency difference is  $1 \times 10^{-11}$ , then a slip will occur every  $1.25 \times 10^7$  seconds (about 144 days) which, for all practical purposes, is never. The damaging impact of slips is of course dependent on the type of traffic and a brief summary is provided in the following table.

TRANSMISSION TYPE	IMPACT
VOICE	AUDIBLE CLICKS
FAX	MISSING LINES / DISTORTION
VOICE BAND DATA	CARRIER DROPOUT
VIDEO	PICTURE FREEZE / "BLUE" SCREEN
DIGITAL DATA	REDUCED THROUGHPUT
ENCRYPTED DATA	RETRANSMISSION
CELLULAR TRANSMISSION	DROPPED CALLS / POOR HANDOVER

The objective of synchronization in telecommunications networks is to enable operators to transport digital information intact between network elements and across network and national boundaries. In order to accomplish this goal, all network elements that comprise the global switching and transport network infrastructure must be synchronized (or in some cases phase or time-aligned). Ideally, they'd be synchronized to the same reference, but having a single reference applicable across the globe is clearly impractical. As a "compromise" a certain level of performance has been determined and any frequency source that meets these accuracy and stability requirements is considered a Primary Reference Source (PRS). The output frequency of a PRS is within  $1 \times 10^{-11}$  of perfection. Consequently, the frequency offset between any two PRS devices is less than  $2 \times 10^{-11}$ .

Distribution of accurate and stable synchronization in telecommunication networks is performed at two levels:

- *Inter-office*: Distribution of synchronization between offices. If an office does not have a local PRS, it can accept signals derived from traffic carrying transmission systems connected to a second office as a timing reference. Ideally, this second office has a PRS or, sub-optimally, has derived its timing reference from a PRS-traceable source linked to a third office.
- *Intra-office*: Distribution of synchronization within an office. Equipment that achieves this may be called a BITS (Building Integrated Timing Supply) clock, a TSG (Timing Signal Generator) or an SSU (Synchronization Supply Unit).

Network elements that perform the switching and transport functions in the network have internal frequency sources or oscillators that are not inherently as accurate as the frequency provided by a Primary Reference Source. In order to synchronize the flow of traffic between all these elements, the internal frequency sources or oscillators in the network elements must be locked (traceable) to the accuracy level of the distributed frequency provided by a PRS. The network elements are designed to phase or frequency-lock the internal frequency sources or oscillators to that of the external signal applied which, if the sync network is properly designed, will be traceable to a PRS. A synchronization failure occurs when the network element loses phase or frequency-lock to the externally applied signal or when traceability back to a PRS is interrupted so the network element is performing at the accuracy level of its internal frequency source or oscillator, an event referred to as "holdover". Such a failure is not immediately catastrophic since the holdover performance of the oscillator may keep the quality of sync reasonably good for a period of time to allow for craft intervention. Message switches typically have reasonable holdover mechanisms. However, terminal equipment like D4 Channel Banks and some SS7 link terminating equipment do not.

The performance of clocks is categorized in "strata". At the highest level is stratum 1, which corresponds to a PRS. The only stand-alone equipment that qualifies as a stratum 1 source is a cesium atomic clock. The next level down is stratum 2, typically a rubidium atomic clock. Stratum 3E and Stratum 3 clocks are predominantly built with ovenized crystal oscillators (OCXOs). Stratum 4 represents relatively inexpensive

crystal oscillators used in terminal equipment. The following table summarizes the key aspects of the various stratum levels. The long-term accuracy is representative of the inherent accuracy of the oscillator. In the absence of a PRS-traceable reference, a stratum 2 clock, for example, will provide a 1.544 MHz output that is accurate to better than 0.025 Hz. If a stratum 2 clock loses its PRS-traceable reference, it will provide a 1.544 MHz output that will drift less than 0.000154 Hz per day.

Clock Designation	Long Term Accuracy *	Holdover Stability (Worst Case)		Input/Output
	± HZ	± HZ	Slip Rate	Filtering
Stratum 1	±0.000015 Hz	N/A	1 in 72 days	N/A
Stratum 2	±0.025 Hz	±0.000154 Hz (per day)	1 in 14.5 days	Yes
<b>Stratum 3E</b>	±1.54 Hz	±0.0154 Hz (per day)	7 per day	Yes
<b>Stratum 3</b>	±7 Hz	±0.57 Hz (1st day)	255 1st day	No
Stratum 4	±50 Hz	Not specified	1 per 4 seconds	No

\* Frequency deviation is shown for a 1.544 MB/s signal

Now frequency is tied to the notion of “cycles-per-second” and represents one measure for oscillatory behavior. Clearly, to “measure” frequency we have to count the number of cycles over some time interval. Whereas two clocks may both exhibit the same number of cycles over a day and thus be considered to have the “same” frequency, this conclusion may be correct for an interval spanning a day but may not be representative of behavior over shorter intervals. This non-ideal behavior is classified in terms of *jitter* and *wander*.

While one normally associates the time interval of each cycle to be *uniform*, that is, equal from cycle to cycle, this may not be the case. A timing signal may start off pristine but, because of transmission, regeneration, multiplexing and de-multiplexing in network elements and for a variety of other reasons, could be corrupted. The variations from uniformity are quantified in terms of a *time interval error* (TIE), and this error, or “clock noise,” is not necessarily deterministic and is best treated as a random process. Fourier analysis is quite useful in studying this phenomenon and, primarily for convenience, components with a Fourier frequency greater than 10 Hz are considered *jitter* and those below 10 Hz *wander*. The notion of filtering then is to remove jitter and wander, to the extent possible, from a timing signal input reference to generate a smooth (uniform or stable) timing signal output.

In addition to accuracy requirements of maintaining traceability to a PRS there are stability requirements for signals used in synchronization distribution and stability requirements for the traffic at the network interfaces. Stability is determined by how noisy, from a sync viewpoint, a signal is and is not synonymous with accuracy. Filtering clocks or oscillators, such as those in BITS equipment, are necessary to remove noise or produce output signals of high stability even though the signals at the input may be highly unstable or noisy.

As noted before, distribution of accurate and stable synchronization could be inter-office and intra-office. There are rules and guidelines for both inter-office and intra-office sync distribution that must be followed to insure signal integrity and diversity are not compromised. The necessary level of sync in terms of stratum levels is further dependent of the classification of the office and/or the equipment. These rules can be briefly summarized:

The hierarchy of clocks is grouped into four stratum levels:

- ⇒ *Stratum 1 is at the top of the clock hierarchy*
  - In order to meet interface standards, all digital signals between carriers must be under the control of a clock or clocks traceable to a stratum 1 source
- ⇒ *Stratum 2 clocks must be used in the BITS at critical network sites.*
- ⇒ *Stratum 3 clocks are found in digital switches, digital cross-connect systems (DCSs) and BITS clocks at non-critical network sites.*
  - SONET requires an enhanced stratum 3E clock in the BITS
- ⇒ *Stratum 4 clocks are found in channel banks, PBXs and such terminal equipment.*

With the increased popularity of packet-switched network architectures, commonly referred to as “IP-Networks” (for Internet Protocol), there is one school of thought that synchronization is moot. The assumption is that all network elements can run asynchronously and yet provide reliable transport of data. There are numerous fallacies in this argument. While it is true that “non-real-time” services can run asynchronously, synchronization is essential for providing real-time services and near-real-time-services that are governed by service level agreements (SLAs). It is well accepted that while the bulk of traffic may well be non-real-time data transfer, the preponderance of revenue-generating services will be real-time or near-real-time in nature. It is eminently obvious that synchronization is essential at all boundaries between circuit-switched and packet-switched networks. It is also true, though not so obvious, that synchronization does indeed play a vital role in packet networks. In fact, synchronization is needed for effective bandwidth utilization in packet networks and is necessary for providing good quality of service (QoS).

In summary, there are numerous questions pertaining to telecom sync. What is the notion of synchronization in a telecommunications environment? How do we measure it? How do we specify it? How do we implement it? These and other questions are addressed, from a technical standpoint, in the Sync University curriculum. Clearly various levels of training and experience are required to fully understand the concepts,

terminology, technology and applications associated with telecom network synchronization. Sync University is a great place for becoming conversant with this body of knowledge. The website is an online learning tool and is sponsored by Symmetricom, Inc. as a public service and the intent is to have a vendor-neutral forum for the promulgation of a somewhat esoteric knowledge base for the benefit of the industry at large.

Kishan Sheno  
Dean, Sync University.