Is your cable network in synch?

VoIP, digital video require synchronization

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Convergence has become the buzzword of the new millennium, with companies like AT&T leading the way in the cable telephony sector. Divergent networks using differing technologies to transport voice, video and data are migrating into a single protocol and transport technology. AT&T's recent acquisitions of TCI and MediaOne have given cable modem and hybrid fiber/coax network solutions a huge boost and a new sense of credibility. Cable modems, which utilize Internet Protocol (IP) to carry voice and data on traditional analog video coaxial cables, are the way of the future.

Telephony over cable

Is it deja vu all over again? Yes, in many ways, it is. Years ago, television was transmitted over the airwaves and phone service was provided via cable. Since the early 1980s, wired telephony has evolved into wireless, and wireless (broadcast) television has become wired via cable TV.

Now, some of the new competitive local exchange carriers (CLECs), like AT&T's Broadband & Internet Services Group, will offer all services via cable TV's broadband facilities. This just happened in Pleasanton, Calif., where AT&T is challenging incumbent local exchange carrier (ILEC) Pacific Bell for local telephone lines ($11 a month for the first line and $5 a month for each additional line) along with cable TV, high-speed Internet access, and, in some markets, mobile phone service.

As cable TV companies begin to offer local phone services, however, they face many challenges. One of these is proper synchronization of the new multi-service networks.

What is synchronization?

Properly synchronized networks allow transmitted information to be recovered and read out at the same or similar rates (timing or frequency stability) as they were transmitted. The most rudimentary purpose of properly synchronizing networks is to prevent or control "slips" that result in loss of data.

Implementation of synchronization systems is performed by deploying clocks throughout the network, allowing the local clock to have the same frequency as the clock where the transmission initiated.

Typically, synchronization networks are designed using expensive atomic clocks in major switching centers. These clocks are Primary Reference Sources (PRS) utilizing Stratum 1 clocks such as cesium or redundant Rubidium clocks with a timing reference from the Global Positioning Satellite (GPS) system. Networks are built with different levels, or stratums, of clocks. The American National Standards Institute sets standards for stratum clocks, which are as follows in Figure 1:

Stratum	Free-run accuracy	Holdover
1	+/- 1 x 10^{-11}	–N/A–
2	+/- 1.6 x 10^{-8}	+/- 1 x 10^{-10}/day
3E	+/- 4.6 x 10^{-6}	+/- 1 x 10^{-8}/day
3	+/- 4.6 x 10^{-6}	+/- 3.7 x 10^{-7}/day
4/4E	+/- 32 x 10^{-6}	–N/A–

Figure 1

Free-run accuracy refers to the clock, or oscillator, performance without any external references (e.g., T-1/E-1 span lines or GPS). Holdover is the performance of a clock, which has been disciplined via an external reference for a specified period of time, after the external timing reference is lost. Telecommunications networks are designed with a combination of high-performance clocks (stratum 1 or 2/2E) that provide traceable reference to lower performing clocks (stratum 3/3E/4) located at the edge of the network.

Why is synchronization needed?

Today's cable TV network that delivers analog video service doesn't need network synchronization. Video channels are transported via radio frequency technology over wide bandwidth coaxial or lightwave cables and tuned to the appropriate TV channel, or frequency, by a set-top convertor. But when digital technology is introduced–be it digital video or data utilizing Internet Protocol (IP)–the need for synchronization develops.

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Digital technology is sensitive to transmission impairments such as jitter, wander and phase transients. Simply put, digital information in the Public Switched Telephone Network (PSTN) must be transmitted and received at similar rates. Jitter refers to phase error, or higher frequency variations, caused by intervening network elements, which are regenerating or reconfiguring traffic. Wander, which is lower frequency deviations, develops for other reasons, such as temperature variations of cables, phase quantization

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of slave clocks containing narrowband filters and waiting time effects of asynchronous multiplexers. Jitter and wander accumulate as traffic payloads proceed through the network. The PSTN has developed techniques for mitigating the impact of jitter, wander and phase errors through implementation of Building Integrated Timing Supply (BITS) concepts. BITS nominates one and only one clock to be the synchronization source within a central office, major transport node, or network edge equipment locations. The BITS clock is the only clock that is permitted to receive a timing signal from outside of the office. BITS concepts, working in conjunction with stratum level planning, are what keep today's PSTN synchronized.

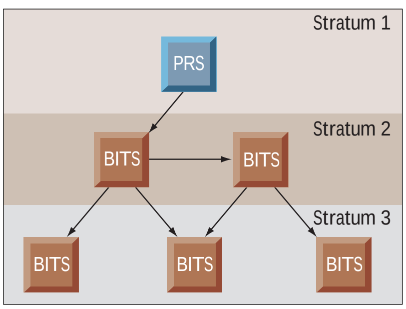

Figure 2

Elements of success

Buffering–the ability to store and forward information on a short-term basis–is a mechanism used to deal with jitter and wander accumulation. A slip buffer, as illustrated below in Figure 3, accommodates slight variations in frequency or phase by buffering the data before it is read out.

In the PSTN, a 125-microsecond buffer is used, which equals one DS-1

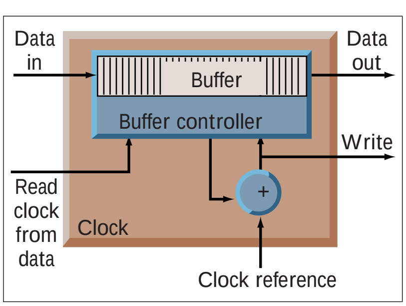

Figure 3

frame. VoIP networks use much larger buffers, typically larger than the four millisecond type which is used in ATM. Slight phase variations between the read and write clocks are absorbed by the buffer, with no degradation to the output signal. However, phase variations greater than the size of the buffer and frequency offsets result in an overflow or underflow, or "slip," of the buffer. A complete frame of data is deleted or repeated when a slip occurs. Frequency of slips within the PSTN is as follows in Figure 4:

Clock condition	Fractional frequency offset (ANSI T1.101-199)	Duration between slips (Buffer = 125 microseconds)
2 PRSs	2×10^{-11}	72 days
ST2 1st day of holdover	1×10^{-10}	14 days
ST2 free run	1.6×10^{-8}	2.1 hours
ST3E 1st day of holdover	1.2×10^{-8}	2.8 hours
ST3E free run	4.6×10^{-6}	27 seconds
SMC 1st day of holdover	4.6×10^{-6}	27 seconds
SMC free run	2×10^{-5}	6.25 seconds
ST4 free run	3.2×10^{-5}	3.9 seconds

Figure 4

The impact of a slip depends on the type of traffic being carried. For voice traffic, a slip may be unnoticeable or cause only a clicking sound. Digital data requires retransmission if a slip occurs. For analog data, slips have a more serious impact. For example, a slip during a fax transmission would typically result in a missing line at the receiver. Or for analog data transmitted with a modem, a slip could cause a modem problem that would take several seconds from which to recover.

The impact from synchronization problems in the PSTN is summarized in Figure 5.

Two drivers for synchronization in cable TV networks are:

- Digital video transport
- Voice-over-IP (VoIP).

The digital video transport initially addresses the need to expand network coverage from expensive headend equipment to satellite neighborhoods or cities. Economics now strongly favor digital video transport, which results in new synchronization requirements at locations where video is switched and/or video payloads are reconfigured.

VoIP is the mantra in today's press. The reality is that it's not here today, but will be in the near future (field trials during the year 2000 and implementation beginning in 2001). Data transported via IP has no synchronization requirements. Voice, however, and other legacy applications such as analog modem and fax, has little to no tolerance for packet discards resulting from network congestion or bad synchronization. Consequently, voice and other constant bit rate services transported via IP networks have stringent synchronization requirements.

Technical challenges

The major challenge for cable TV service providers who are planning to offer high-speed data services and telephony is how to migrate a broadband, broadcast-oriented television distribution network to a full duplex network

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capable of delivering high-speed Internet plus voice connections. Additionally, quality of service (QoS) requirements will mirror what the ILECs have historically delivered.

Service	Observed effect
PCM voice	No noticeable degradation for moderate slip rates
Voice-band data	Serious degradation with some modems needing up to 6 seconds to recover from a slip
Group III fax	Each slip can wipe out 0.08 inches of vertical space
Encrypted voice	Serious degradation requiring retransmission of the encryption key
Compressed video	Serious degradation resulting in freeze frames or missing lines
Digital data	Loss of messages resulting in requests for retransmission & degraded throughput

Figure 5

Emerging industry standards such as IEEE 802 and the Data-Over-Cable Service Interface Specification (DOCSIS 1.0, Radio Frequency Interface Specification SP-RFI-IO4-980724) will define how these services will ultimately be delivered. DOCSIS 1.0 appropriately addresses high-speed Internet connectivity. Future releases, including DOCSIS 1.1, will address additional methods of using the 5 MHz to 42 MHz bandwidth on the coaxial cable plant to augment a high-speed downstream network with acceptable upstream bandwidth. DOCSIS 1.1 is focused on QoS with the goal of providing a standard for cable modem termination systems (CMTS) and cable modems for delivery of VoIP as well as high-speed Internet connectivity.

As depicted in Figure 6, the new multi-service cable TV network will allow transport of two-way voice and data, analog video and digital video. Connectivity to the home or small office/home office location will be via traditional drop cables and new DOCSIS 1.1 cable modems. At the house/SOHO, the broadband signal will be split, allowing a TV interface while the cable modem provides telephone and computer interfaces.

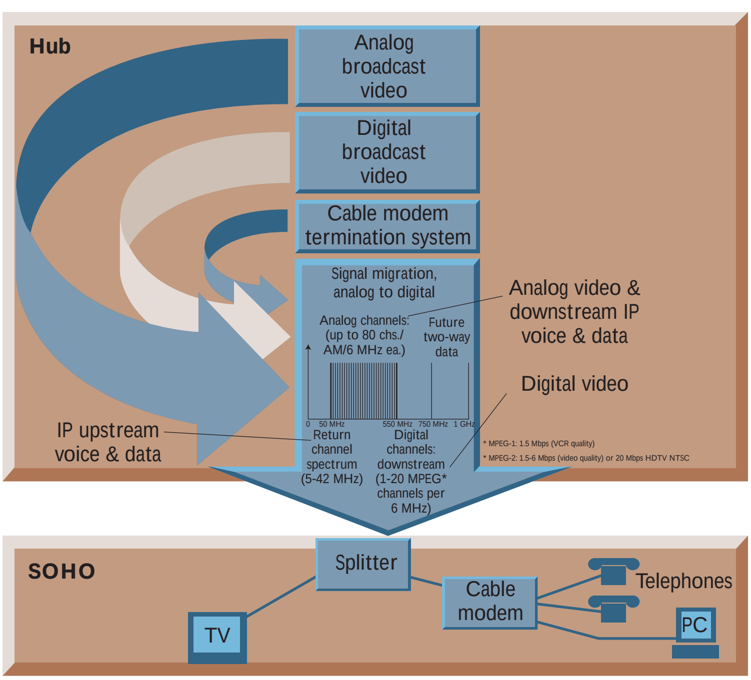

Figure 6

Synchronization requirements

Synchronization is like power and ground; a digital network will simply not work if not properly synchronized. Video services, transported digitally, should ideally be packed synchronously into a virtual circuit (VC), as opposed to being packetized. This allows for the lowest latency transport with low jitter and highest quality of service. The smoothing of jitter in packetized video is difficult, requiring large buffers in the receiving node, and results in overall higher costs for implementation.

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Today, video is migrating to digital transport, typically Sonet, coexisting with packetized voice and data, via different virtual circuits or lightwaves. To ensure video quality, service providers are deploying synchronization equipment, in the form of Primary Reference Source GPS clocks, in all headends and hubs where video is switched, passed through, added or dropped.

Voice-over-IP is the wave of the future because its benefits include optimization of bandwidth utilization based upon voice compression (e.g., G.729A 8 kbps voice versus 64 kbps PCM), packet transport (allows statistical multiplexing), and silence suppression to deal with packet congestion and associated discards. The result is a new requirement for synchronization to deliver high-quality services as well as monitoring QoS for implementation of service level agreements (SLAs).

Synchronization requirements for VoIP include:

• Vocoders, the devices that convert analog voice to digital and compress to 8 kbps or less, are the major source of degraded voice quality. In today's network, voice passes through a minimum of two vocoders (one on each end), and sometimes many more. Vocoders depend on proper synchronization. Network references are no longer sufficient because services traverse multiple networks each with their own master clock. Selected carriers are taking the position that vocoders must be synchronized to a national clock. As a result, GPS clocks will typically be co-located with CMTS equipment. Performance improvements are expected to include the elimination of the clips that accompany silence suppression in congested networks.

• Legacy applications such as analog modem and fax, like voice, have zero tolerance to slips or packet discard. These applications are often transported through IP networks using circuit emulation. Precise frequency synchronization will allow transport of these legacy applications via the new IP networks without degraded quality of service.

• As mentioned previously, IP transport does not require traceable synchronization for proper operation when traffic is solely data. IP therefore has no mechanism for providing a synchronization reference. Once access lines become IP-based, the synchronization reference currently available on circuit oriented T-1 and E-1 transport will no longer be available. Many times, IP access will be used in locations where legacy equipment such as PBX and T-1/E-1 multiplexers exists. Synchronization will have to be deployed at these locations to allow continued operation of legacy equipment.

• As cable telephony service becomes accepted, large corporations will migrate to these new networks. Service level agreements (SLAs) based upon certain quality of service parameters such as latency, packet discard, delay variation, and guaranteed bandwidth availability will become the norm. Recent VoIP field trials have experienced latencies in hundreds of milliseconds, which is problematic because latency in excess of 200-300 milliseconds becomes distracting to the telephone user. A goal of the VoIP networks is to keep one-way latency below 125 milliseconds. To meet deployment guidelines, QoS measurements will require a precise time stamp, typically with 50-100 microsecond resolution, to reliably measure and report performance requirements meeting terms of SLAs. Implementation of these QoS services will be via time of day stamps traceable to absolute time reference provided by the GPS system.

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Cable telephony synchronization deployment guidelines

Synchronization equipment has dramatically changed with the maturation of the GPS systems and associated clock technology. Today, integrated clock and GPS technologies that use whatever reference is available allow deployment of affordable, primary reference sources (PRSs) everywhere. GPS traditionally has required full view of the sky so that four or more satellites can be tracked and integrated into the timing solution. Products introduced over the last year allow synchronization solutions where only one GPS satellite is in view 40 percent of the time, or, where CDMA cellular/PCS signals can be received. This means that antennas–for the reception of GPS reference–can now be mounted on the roof, in the window or within the building.

Some simple rules will help emerging cable telephony solutions to meet and exceed PSTN voice quality. These include:

• Implement BITS concept (Cable BITS) throughout the network.

• Place PRSs with holdover clocks and digital clock distribution systems in all master and mini-headends.

• Synchronization requirements at the cable modem end locations will be served by the cable modem termination systems located just upstream from the cable modems. All CMTS sites should be synchronized to a national GPS clock to provide the proper synchronization for digital video and VoIP services.

• All Sonet transport nodes should either be synchronized to a PRS or a traceable source such as a derived DS-1 from Sonet transport with sync status messaging (SSM) implemented.

• Deploying PRS at all CMTS is a sensible guideline and prevents any problems from poor synchronization. Short of that, deployment of PRS at every other, or every third CMTS along a Sonet ring with SSM may meet requirements at a lower cost.

The bottom line is that synchronization is required in emerging VoIP cable telephony and digital video networks. GPS PRS clocks are readily available at economical costs. New technologies offer reduced cost, improved performance and simple installations anywhere. Synchronization planning, implementation and management are a must for cable telephony and multiservice networks to meet the QoS standards that have been set for decades by the PSTN. ■

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