Understanding the Challenges of, and Planning, Access Layer Synchronisation in SDH Networks

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Introduction

National telecom networks have evolved or are in the process of evolving from state controlled monopolies into a plethora of independent networks. The original and hence largest of the networks continue to provide the serious bandwidth at the core of the network. The business model for many of the newer arrivals is to provide access technology to business and personal users and sometimes stitch together their local access networks with their own national transmission infrastructure. Overlaid on these networks are the wireless networks, both existing GSM (Global System for Mobile Communications) the newer TETRA (Terrestrial Trunked Radio Access) and LMDS (Local Multipoint Distribution Service) and the future e.g. UMTS (Universal Mobile Telecom System). Dipping in and out of the national environment is the new breed of global operators together with the remote switches of major national carriers from other countries. Last but not least there are the specialist companies e.g., electronic information providers, Internet Service Providers (ISP’s), undersea cable operators, satellite ground station operators, hosting companies etc, etc.

All these carriers interwork in one way or another. They mainly exchange traffic, often the smaller or “tenant” network takes synchronisation from the larger or parent network. These interworking networks exhibit the classical signs of symbiosis, normally encountered as a biological definition – “A close association between two different organisms, from which both derive benefit”

This symbiotic relationship is being disrupted by the rollout of SDH technology and the migration to a packet based transport environment of ATM over SDH. The traditional PDH time slot zero route to the network synchronisation reference master clock is no longer viable and is being jeopardised by the adoption of ATM and SDH technology. Wireless networks are particularly at risk and considering the current and future investment in 3G UMTS services, this should be cause for concern with both manufacturers and carriers/network operators.

How is Synchronisation Passed Through a Telecom Network?

The classical mechanism for passing sync through a telecom network is to use time slot zero. Here the sync is carried within time slot zero of the E1 signal and is effectively recovered by the tenant application from the incoming traffic link with the parent network.

Strategic equipment design was straightforward. Network equipment is primarily designed to deal with telecom traffic, therefore, all equipment was designed to recover the clock from timeslot zero and use it to flywheel a local oscillator and provide sync for the application.

This was the situation in the PDH environment. However the dramatic increase in the requirement for transmission bandwidth instigated considerable development effort in the field of transmission technology and media. SDH technology in Europe and SONET technology in the USA together with fibre rather than copper as the transmission medium were developed to increase available bandwidth along each telecom route. In order to overcome slip problems in the older PDH networks, SDH and SONET employed a “container” structure to move the traffic through the network. This had the benefit of considerably reducing the impact of poor synchronisation on the efficiency of the transmission network and correspondingly improving the throughput of applications. Perversely, this improvement in transmission throughput was done at the expense of the TS0 synchronisation channel. In other words, as the virtual containers realigned
themselves within the transmission layer, they injected phase hits onto the synchronisation layer. Tenant applications, which rely on the parent E1 to deliver sync, would now be at risk.

Although industry recognised alternative ways of implementing synchronisation. The relevant Standards bodies did not implement these fixes. The net result was that TS0 in an E1 delivered over an SDH or SONET network would be susceptible to phase hits if the network were to become badly behaved and experience pointer adjustments. Any applications dependent on a clean, stable wander-free TS0 would now be potentially at risk.

What is the Nature of the Problem?

The problem exists in two distinct forms being non-systematic, i.e. spontaneous and unpredictable and systematic, i.e. regular and continuous. The process of delivering timing across a SDH or SONET network using ATM technology causes both non-systematic and systematic effects.

The problem is also application dependent and time varying, which means that you may not be affected and if you are, the problem may only be evident from time to time. This also causes the classic Murphy’s Law scenario relating to engineer call-outs that the problem does not materialise whilst the engineer is there, but as soon as he goes it comes back!

This paper will now examine both systematic and non-systematic problems.

Non-Systematic Noise

From a non-systematic perspective in the SDH or SONET environment, as the virtual container is moved around to accommodate anomalies in transmission, TS0 experiences either VC-4 or VC-12 phase hits. VC-4 pointers occur if the virtual container is in the higher level and VC-12 pointers occur if the virtual container is in the lower level. VC-4 pointer adjustments have less of an impact than VC-12, being 160nsec rather than 3.57 µsec.

Chronos has conducted susceptibility tests on network infrastructure equipment particularly wireless base stations and shown that often, the clock recovery circuit (usually a phase locked loop) can behave in an unpredictable manner and in some cases lose lock when impacted with a pointer adjustment. Effects not only include loss of lock but also wander amplification. In other words, since the downstream application PLL design has not been optimised to suppress pointer hits, the follow-on effect is often worse than the hit itself.

Figure 1 below, shows a VC12 pointer when viewed on an E1 trib. The corresponding MTIE signature is shown in figure 2 and is well outside any of the ETSI/ITU PDH or SDH masks for MTIE.
Systematic Noise

Systematic phase transients are created within the various equipment elements in a telecom network by either the phase locked loop behaviour of the clock recovery circuit or the effects of buffer correction activity. Recent developments in test equipment capability over the last few years have enabled us to "see" these systematic effects and quantify their impact on network performance from a practical perspective.

For example, Figure 3 below, shows the phase or TIE behaviour of a Primary Rate ISDN link connecting a business user's digital PBX into a telecom network. Data was collected over just under three and a half days. The reference used was a Caesium Standard. Phase transients with amplitudes well in excess of 2 µsec are seen regularly and in the longer term much larger phase variations are evident.

![Figure 3. Primary Rate ISDN TIE Plot](image)

In the long term, it can be seen that the ISDN link is synchronised to the carrier's primary reference clock. In the short and medium term, the relative wander is extreme. Another way of looking at this data is to examine the MTIE signature. This is shown in Figure 4 below.

![Figure 4. MTIE Signature of Primary Rate ISDN](image)

The MTIE will eventually cut through the ETSI PRC mask somewhere on the $1 \times 10^{-11}$ slope, indicating PRC traceability of the ISDN link.
As the phase varies, so does the frequency. Closer examination of a small part of the frequency plot shows in detail the extent of the frequency variations. Figure 5 and Figure 6 show 11 hours of data from the test carried out in Figure 3 and an expanded section to illustrate how the frequency behaves in the short term.

A GSM system requires .05 ppm stability, i.e. $5 \times 10^{-8}$. It can be seen that regular frequency switching phenomena are occurring which considerable exceed this figure. The new third generation services are looking at $2 \times 10^{-8}$.

**Figure 5.** Approximately 11 hours of data.

**Figure 6.** Blocked area from Figure 5 showing extent of frequency deviation.

**What is Causing This Switching Phenomenon?**

In legacy PDH networks long term frequency drift or very long wander build up within a network must be compensated for at the access point. If not, it will cause problems by filling up the buffer and creating a slip.

Network equipment is designed to mitigate these effects by using the relative position of data within a buffer. Data will be allowed to move within the buffer between two limits, sometimes referred to as watermarks - the high watermark and the low watermark.
As the data approaches the high watermark, it triggers a change in the rate at which it is clocked out of the buffer, i.e. it is clocked out faster until it approaches the low watermark, when another change is triggered; now it will be clocked out more slowly. There are two main benefits of this technique, one is cost, the other is regular symmetrical data which ensures that there are no slips, however this causes the observed switching phenomena or systematic wander. This can be a major problem for frequency sensitive applications connected to that network tributary. Figure 3 to Figure 6 above illustrate PDH systematic noise.

In the newer packetised world "Delay" is the enemy. The ATM CES is compensating for "Delay". Delay within the ATM network includes Packetisation Delay and Buffering Delay.

Packetisation delay is the delay caused by the necessity to fill a packet before it is transmitted and is particularly evident with compressed voice calls associated with GSM traffic. Buffering delay results from the need to maintain a real time delivery of voice traffic across the network. The traffic must be broken down into packets in order to be transmitted. These packets must then be reassembled in order to reproduce (emulate) the original voice call. This delay can often be considerable and if it is not carefully controlled can cause problems with CBR traffic such as voice over ATM. However the control mechanism, i.e. the buffer imposes its own effect on the E1, experienced as the frequency switching.

Figure 7 and Figure 8 show an E1 circuit emulation service (CES) from an ATM switch. Note the switching similarity between the PDH and ATM examples, both in terms of frequency magnitude and duration.

Closer examination of Figure 8 below reveals that the areas above and below the zero offset line are approximately equal. As the network wander pushes the data in the buffer towards the high watermark so the need for the extent and magnitude of the frequency correction changes.
Are These Systematic and Non-Systematic Effects a Problem?

Both types of noise will be a problem where the connected application is expecting to see good quality synchronisation on the E1.

As SDH technology replaces PDH for the transmission layer, the risk of non-systematic VC12 pointer activity increases. Therefore the possibility of detrimental effects in connected networks running different applications increases.

In the days of PDH-only networks, analysis of synchronisation problems was limited to frequency offsets and time for a buffer to fill and cause a slip; then the effect of that slip on the type of traffic. This was a kind of one-dimensional problem - a simple cause and effect. Now we are faced with wander which is not constant and therefore not predictable and which may or may not cause a problem depending on the application. In order to understand the effect on the application, that application needs to be well understood. But since new applications are being developed all the time, how can a core-network architect predict what these effects will be?

What we can say with a high degree of certainty is that since SDH networks are proliferating with increasing rapidity, problems associated with rollout are increasing and are unlikely to go away by themselves. Also, with the need to remove transmission effects, we are seeing an increasing amount of switching wander on E1’s delivered over SDH networks and out of ATM switches.

Before moving on to examine a real application, examination of the MTIE and TDEV performance of the noise examples in Figure 9 and Figure 10 reveals signatures well outside the ETSI quality metrics.
What Applications Are Most at Risk?

Many applications have been around for a long time and are well understood with regard to classical frequency offset issues, e.g. slips causing freeze frames on video conferencing, or missing sections from faxes, etc.

The reality now is that we don't send faxes anymore, we send attachments to emails. Video conferencing uses digital camera technology not analogue. Wireless communications is about communications on the move, data messaging, linking your PC to a suitable ISP for email collection and internet access. We now digitise and compress voice and send it over packetised networks - voice over IP and voice over frame relay. Comparatively large amounts of data are moving around networks utilising ever greater amounts of bandwidth and over many different technologies. A clear prescription for disaster if the interworking of all these networks is not planned very carefully.
The human eyes and ears are the most critical quality assessors that exist. The ability of new core and access networks to interwork with new digital packetised transport technologies and applications must ensure that these human analogue receptors continue to deliver the right messages to the brain. If they do not the standard “human” interface will reject the service!

Qos and The Standards

“Quality of Service” requirements are now being talked about in terms of access technologies and Service Level Agreements with customers. Voice and video type traffic are the most critical with a Real Time tag followed by Video on Demand with a Near Real Time label. In the Best Effort category there is business data for example ATM and Frame Relay, which should be prioritised over Internet access.

Synchronisation does not have formal QoS labels. However the Standards give us MTIE and TDEV which help considerably and these are sufficiently well defined in EN 300 462-1 for the inter operator boundaries and EN 300 462-7-1 for local node SSU’s.

The main ITU synchronisation recommendations are:-

G.803 - (06/97) Architecture: Specifies Number of SECs and SSUs (SASEs) in SDH Tributaries
G.810 - (08/96) Definitions
G.811 - (09/97) PRC Stability, Jitter/Wander & Reliability
G.812 - (06/98) Level II/III Holdover Stability, Jitter/Wander, Clock Types I to VI
G.813 - (08/86 was G.81S) SDH Equipment Clock SEC’s Option 1 and 2
G.822 - Controlled slip rate objectives on an international digital connection
G.823 - (03/93) Jitter and wander in networks based on the 2048 kbit/s hierarchy
G.824 - (03/93) As G.823 but for 1544kbit/s
G.825 - (03/93) SDH Network Limits for jitter and wander

These are the main ones, other relevant ITU recommendations include: -

G.703 - (04/91) Physical/electrical characteristics of hierarchical digital interfaces.
G.704 - (07/95) Synchronous frame structures used at 1544, 6312, 2048, 8488 and 44,736 kbit/s hierarchical levels
G.783 - (01/94) Characteristics of SDH equipment functional blocks
O.172 - (03/99) Jitter and wander measuring equipment for digital systems based on SDH

These are all available on line from www.itu.org

The main ETSI Standards are the “Generic Requirements for Synchronisation Networks” Family

EN 300 462-1-1 V1.1.1 (98-05) - Definitions and Terminology
EN 300 462-2-1 V1.2.1 (90-10) - Synchronisation Network Architecture
EN 300 462-3-1 V1.1.1 (98-05) - Control of jitter & wander within sync networks
EN 300 462-4-1 V1.1.1 (98-05) - Timing characteristics of SASE type slave clocks suitable for sync supply to SDH & PDH equipment
EN 300 462-5-1 V1.1.2 (98-05) - Timing characteristics of SEC type slave clocks for operation in SDH equipment
EN 300 462-6-1 V1.1.1 (98-05) - Timing characteristics of primary reference clocks
EN 300 462-7-1 V1.1.1 (00-10) - Timing characteristics of slave clocks suitable for synchronisation supply to local node applications

The last one is very new and overcomes some contradictions from the earlier members of the family.

Other Relevant ETSI Standards & Publications include:

- TR 101 685 V1.1.1 (99-08) - Timing and synchronization aspects of ATM networks
- TS 100 912 V8.4.0 (00-08) - Digital cellular telecommunications system (phase 2+); Radio subsystem synchronisation
- EN 300 417-6-1 V1.1.3 (99-05) - Generic requirements of transport functionality; Synchronisation layer functions
- M1/M-01086 (Started 00-02) - Development of an ETSI position on synchronisation aspects of Optical Transport Networks (OTN)
- EN 302 084 V1.1.1 (00-02) - The control of jitter and wander in transport networks
- EN 300 166 - Physical and electrical characteristics of hierarchical digital interfaces for equipment using 2.048 kbit/s PDH or SDH
- Draft EG 201 793 V1.1.1 (00-04) Synchronisation network engineering

All are available from www.etsi.org download free!

TR 101 685 and E.G. 201 793 are new and particularly relevant.

Application Example

The best way to illustrate the nature and extent of the problem is to examine in some detail, a particular application - GSM wireless traffic over SDH and ATM technology.

SDH E1 Traffic Interface

It has been shown that there is a significant risk of pointer justification events out of a traffic bearing E1 trib from SDH networks. Most GSM base stations are looking to the E1 for frequency synchronisation. The net result is that some base stations may lose lock and cease to function for a period of time. All calls will be dropped and under extreme conditions, the base station may be “off the air” for as much as 20 minutes. The E1 is usually the only route into the base station. So if the carrier providing back-haul bandwidth to the wireless operator is using SDH technology or decides to rip out the legacy PDH equipment, there is a high probability of regular and catastrophic failure. This migration may be entirely transparent to the GSM user since the last mile is perhaps PDH radio.

ATM E1 Circuit Emulation

The ATM Circuit Emulation Service (CES) provides the ability to map current TDM based network services over ATM Adaptation Layer 1 (AAL1) continuous bit rate (CBR) circuit services. ATM technology is now being used or specified for the transport of GSM traffic, particularly as the demand for greater bandwidth increases with more users and next generation wireless technology. The data manipulation within the buffer to compensate for upstream wander causes significant frequency switching in the downstream delivered E1’s out of an ATM network. Although generally within PDH and SDH SEC MTIE wander limits this switching, when viewed in the frequency domain is outside of the ETSI GSM standards requirement of .05 ppm. It has even been observed outside of the new relaxed pico cell requirement of .1 ppm.

Effect on the User?

The net effect is to compromise the ability of the GSM network to successfully hold calls as the user moves between cells. This is a significant issue for fast moving calls such as those made from a car or train. It is
also dependent on the ability of the phone itself to track adjacent cells that are outside of the GSM frequency limits; i.e. some mobile phones are better than others. It is also time varying, therefore very difficult if not impossible for the problem to be identified and repeatable tests to be carried out.

**The Solution**

Not only has Chronos conducted wander tests on GSM base stations and analysed the performance and synchronised GSM 900, GSM 1800 and TETRA networks, Chronos has also investigated the network performance and synchronised major carriers and enterprise networks at both core and access layers. The Sync Audit® consultancy service has enabled Chronos to “see” synchronisation problems that are normally invisible to most organisations. The Chronos Retimer solution is so effective and technology independent that carriers can now guarantee that any GSM base station may be connected to any manufacturer's SDH and ATM products, without risk of loss of traffic for reasons of synchronisation.

As with everything there is always more than one way to achieve a suitable solution. Factors to take into account include budget, resiliency, quantity of base stations to be serviced, fibre or copper to the base station and availability of a suitable local sync source at the launch point. The solution combines GPS technology with retiming functionality and specially designed fibre interface units to enable PRC quality to be transported via the traffic bearing E1 right into the base stations.

Once fitted, the GSM base station sync interface acts as a firewall to all pointer adjustments and internally generated wander form the interface network element. Trouble free operation is then guaranteed. In addition, this solution will also allow any other switching or transmission technology including DWDM and IP networks to be incorporated into the network without having a detrimental effect on the GSM traffic. It will also present a future proof philosophy and architecture for eventual 3G UMTS networks that require an even tighter RF frequency stability specification of .02ppm.

In fact the solution is so fail safe that a Service Level Agreement can be entered into and finally Operators can guarantee Quality of Service (QoS) for synchronisation for leased lines to GSM base stations.

![Figure 11. Solution for GSM Base Station Synchronisation](image-url)
The Future

The future will bring far more bandwidth hungry applications out through the access network and into a customer-facing situation. For example, we may soon be accessing m-commerce applications via third-generation wideband wireless technology or Video-on-Demand via xDSL from an unbundled local loop. The standards are calling for .02 ppm for frequency stability, but this is not available at the access layer today unless carefully planned synchronisation architecture is realised.

Wireless network operators will not be able to synchronise from the core carrier networks as they have done in the past. Even if the wander is well within the frequency stability specification, what will happen when the phase hit from a pointer adjustment meets the clock recovery PLL in the BTS? Yet will fitting GPS technology at every BTS, as they have done with CDMA base stations be the solution?

Constant Bit Rate Services such as voice over ATM, combined with the need to remove the effects of cell delay and pointer adjustments will continue to stretch the capabilities of SDH to interface to frequency dependent access services.

The only real solution is to fit network independent sync solutions and deliver that sync to edge of network elements in a failsafe manner. GPS synchronisation technology combined with the ability to retime PDH links which launch from the same location will provide carriers and their major interconnect clients with a reliable and fool proof synchronisation architecture. The real need for a true flat sync network architecture has arrived. The traditional hierarchical architecture would have used SSU’s in quantities of 10’s. The next generation sync network architecture will use access sync solutions in quantities at least ten times those traditionally deployed in the core.

Conclusion

The problems and issues outlined in this paper have always been there, but probably masked (time varying) or difficult to pinpoint. They are now exacerbated by the rollout of new technology and the need to investigate more specifically reasons for failure or degradation of the quality of service.

Figure 12, Before & After MTIE Signatures. 2 = ATM CES, 3 = PRISDN, 1 = Retimer Output
Packetised networks don’t care about sync, they are designed to move vast amounts of data irrespective of the core sync stability. In the process of achieving this transmission nirvana, they have destroyed the traditional route that the access applications have used to derive stability from the network. Whilst the core network is now less susceptible to the effects of wander, some access applications have become more susceptible to wander.

The classical hierarchical PRC sync model using Caesium must finally be laid to rest. Access sync solutions utilising GPS and Retiming technology combined with a detailed knowledge of the sync path through the network are the only way to successfully overcome interworking in and SDH environment.

A significant benefit will be that when access sync solutions are deployed, carriers can at last offer a QoS commitment to customers, something which has traditionally been impossible to deliver from the legacy core sync architecture.

Carriers will be able to interwork over core and access networks using any new technology and the symbiotic relationship between bandwidth provider and user may be maintained without degradation.

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Acknowledgements:

ETS 300 462-3-1 Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 3-1: The control of jitter and wander within synchronization networks.

EN 300 462-4-1 Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 4-1: Timing characteristics of slave clocks suitable for synchronization supply to Synchronous Digital Hierarchy (SDH) and Plesiochronous Digital Hierarchy (PDH) equipment.

EN 300 462-6-1 Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 6-1: Timing characteristics of primary reference clocks.

EN 300 912 V8.4.0 Digital Cellular telecommunications system (Phase 2+) Radio subsystem synchronization.


Definitions and Abbreviations

AAL1 - ATM Adaptation Layer 1
BSC - Base Station Controller
BTS - Base Transmitter Station, Wireless Base Station
CBR - Constant Bit Rate
CES - Circuit Emulation Service
E1 - 2.048 Mbps Bearer, Span Line or "Trib"
GPS - Global Positioning System
GSM - Global System for Mobile Communications
ISP - Internet Service Provider
LMDS - Local Multipoint Distribution Service
MSC - Master Switch Controller
MTIE - Maximum Time Interval Error, one of the key sync metrics
PDH - Plesiochronous Digital Hierarchy
PRC - Primary Reference Clock
PRISDN - Primary Rate ISDN
QoS - Quality of service
SDH - Synchronous Digital Hierarchy
SLA - Service Level Agreement
SONET - Synchronous Optical Network
SSU - Synchronisation Source Utility
STM-1 - 155 Mbps SDH
TDEV - Time Deviation, one of the key sync metrics
TETRA - Terrestrial Trunked Radio Access
TDM - Time Division Multiplexed
TSO - Time slot Zero
UMTS - Universal Mobile Telecom System, 3rd generation cellular
VC4 - AU-4 Pointer
VC12 - TU-12 Pointer
The Author

Charles Curry is Managing Director of Chronos Technology Ltd. He has a Bachelor of Engineering (Hons) degree in Electronics from Liverpool University. His career started at GEC Hirst Research Centre where he was involved with research into semiconductor physics boundary properties. He then moved to Racal Instruments where he was responsible for sales of test equipment and frequency and time products. He moved into the rental business as sales manager with MicroLease and then Managing Director of GSE Rentals in 1983. He founded Chronos Technology in 1986 and for the last ten years Chronos has been a leading system integrator of synchronisation products for the telecom industry. The Chronos Technology SyncAudit® service for the evaluation and analysis of telecom network quality is now carried out regularly on a global basis.