Synchronising the Backhaul Network

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Introduction

This short document provides a brief background on the restructuring of the analogue Inter-Exchange Network (IEN) into a purely digital IEN that is now known as the Backhaul Network (BN) or in some instances a Core Network (CN).

Historical Changes

The problem that surfaced in the Backhaul Network followed the changeover from analogue transmission equipment into digital transmission equipment from about 1980 onwards to about 1994. The lack of synchronisation problem manifested itself in many ways causing the digital components of the Backhaul Network to occasionally drop out for short periods if and when the digital buffers could no longer manage the tolerance differences due to the lack of clock synchronisation.

With analogue equipment, the prime frequencies were set with (usually) quartz crystal oscillators but very rarely were these oscillators locked with one another between transmission systems because the modulation was essentially single sideband suppressed carrier (SSBSC) and virtually all telecommunications was for telephony, where a few Hz difference made virtually no discernable issue for voice telephony. In any case, the analogue switching was physical contacts, and lack of transmission synchronism frequency was simply not an analogue switching issue.

Digital transmission systems inevitably demodulated back to analogue Voiceband (200 Hz to 3400 Hz) for 2-wire (Local and District) switching or 4-wire (Regional and National) switching, but with the change to digital switching (which is all 4-wire switching), the base streams were 64 kb/s, and even then data streams could not always be faithfully transported without losing clocking synchronisation.

Early Digital Switching

The first digital switches cross-connected digital streams that had analogue to digital interfaces, so the analogue transmission equipment could connect directly to the line interface cards.

These switches quickly found their place in analogue subscriber telephony line switching as the associated Subscriber Line Interface Cards (as part of these switches) typically held four analogue subscriber telephony lines on one card. Later versions of these switches had bigger cards and connected with 16 analogue subscriber telephony lines per card.

The digital switches were comparatively tiny compared to the earlier analogue equivalents, and the “Group” of subscribers was then digital in an 8 Mb/s pair of digital streams, or four by 2 Mb/s streams in IDSN terms. In a similar fashion, the ISDN customer connection came from the Group Switching Stage in multiples of 2 Mb/s as pairs of directional digital connections to Customer Premises Equipment (CPE), via digital transmission through the Customer Access Network (CAN).

The Emerging PDH Network

The early “legs” of the digital Backhaul Network consisted of multiples of 2 Mb/s streams of nominally 30 customer / subscriber connections at a time (plus one stream for signalling and another stream for network synchronisation using “bit stuffing” to cater for differential clocking drift), totalling 32, 64 kb/s streams.

Group switches broke these 2 Mb/s streams back to their 64 kb/s streams and cross connected with “Time – Space” switching, with no moving parts, just a few milliseconds delay per switching stage. The standard connection for the Group Switching Stages was an 8 Mb/s stream (pair), of which several could be connected in an Add Drop Multiplexer (ADM) that had 140 Mb/s PDH on its other side.

Unfortunately, most telecomms infrastructure providers worldwide had Transmission and Switch Engineering working in total isolation of each other. This isolation was because these two Engineering fields were seen as entirely different disciplines, as also was the Customer Access Network (CAN) engineering.

With the advent of digital switches being clocked, even then it took some decades before long-established engineering / management hierarchies were gradually broken down into one homogeneous engineering structure.

The saving grace was that the transmission systems in the switching part of the Backhaul Network worked with what is called Plesiosynchronous Digital Hierarchy (PDH), where each stage of the digital transmission has a digital buffer to account for differences in system clocks, even if they are the same frequency but are drifting around slightly.

Becoming Digital From Analogue

Frequency Division Multiplex (FDM) systems used in analogue Backhaul Networks were commonly structured with 12 channels per “Group”, forming a 48 kHz wide band, and two groups, making 24 channel analogue carrier systems were common.

These systems commonly ran on two pairs in quad copper cable, with amplifying repeaters located about 4 km apart. The Voiceband channels were limited to 3.4 kHz and had channel associated out of band signalling at 3.825 kHz to “talk” with the Local or District analogue switch interfacing.

The decision to use 8 kHz as the Voiceband clocking rate was a foregone conclusion, because the Nyquist criterion set the maximum Voiceband frequency at 4 kHz and a practical limit of 3.4 kHz made logical sense, and this matched the earlier analogue systems.

The decision of 8 bits per sample was a bit harder because this meant 64 kb/s and with a linear analogue/digital conversion, the maximum signal to sampling noise level would be only 128:1, which is only 42 dB. Considering that the typical voice level varies about 12 dB and the main peaks are 12 dB above that, this leaves about 18 dB low-level speech to sampling noise, but the minimum requirement is 24 dB.

A non-linear / logarithmic encoding / decoding method (G.711[1]) was utilised that makes the 8 bit appear like the equivalent of 14 bit and have a maximum signal to sampling noise of about 78 dB, so the quantisation noise margin is typically about 30 dB below the average speech level.

Digitally, 32 channels per stream is a perfect fit as 32 is a direct multiple power of 2, whereas 24 channels is not, but 24 channels links as a direct replacement of a 24 channel analogue system is a direct fit for previous analogue carrier equipment.

[1] http://en.wikipedia.org/wiki/G.711

Internationally, differences in digital modulation plans stemmed from an earlier split in standards, where the USA with Japan in tow, opted for 24 channels of 64 kb/s streams and one 8 kb/s Signalling/Synch channel in their Primary Rate ISDN "Megalink" of 1.544 Mb/s, and the ITU with the rest of the world opted for 32 channels of 64 kb/s streams in a "Megalink" of 2.048 Mb/s.

The ITU standard for PDH[2] then follows a simple "times 4" digital modulation scheme for each order above, 8.448 Mb/s, 34.368 Mb/s, 139.264 Mb/s, 564.992 Mb/s. The USA digital modulation scheme was considerably more complex: 6.312 Mb/s, 44.736 Mb/s, 139.992 Mb/s, 564.992 Mb/s. The Japanese PDH was different again!

As PDH replaced analogue transmission systems, transmission network synchronisation followed through, particularly from the highest order PDH systems, which was 565 Mb/s.

This overall transmission Backhaul Network system worked for most of the time without major problems for some years.

Increasing PDH Problems

PDH frequently ran into timing problems at 565 Mb/s; which was four streams of 140 Mb/s, the base major Container for PDH structures. PDH also has an internationally inconsistent digital modulation plan. Compounding that problem was that Optical Fibre[3] could operate far faster than the 565 Mb/s limit, and networks were demanding the much higher bandwidths.

Even with each digital transmission level having a degree of redundant bit buffering / stuffing, the drift between systems clocking usually resulted in a slow but reasonably inconsistent network "slip" where buffers at various transmission levels would run off the end of their range and reset themselves in their middle range.

Synchronising the Digital Switches

Generally it took several years before the telephony-based Switching Engineers realised that their digital switches were causing problems by "free-wheeling". It then took some years after that before general strategies were worked out to synchronise the telephony-based digital switches to the most stable clocking source, which was not necessarily a clock in a switch, but a clock in a transmission system.

One driving force was the rapid deployment of Fax machines in the late 1980s and early 1990s. Fax machines were effectively data modems with inbuilt scanners and printers. These data modems relied on voice channels that had a minimum of slip in the end-to-end switched transmission connection. Dial-up IP was a growing issue.

The synchronising problem generally came down to whom had the most stable clocking source, the switches or the transmission systems. What became relatively clearly established was that a digital switch could synchronise all the "child" digital transmission links, and a parent transmission link could synchronise a "child" digital switch, so a structure of network synchronisation was established with no clear head.

The hidden problem was that digital switch manufacturers did not see themselves as part of the digital transmission engineers. Consequently, the process of external clocking arrangements was not easily included, generally not utilised and the

[2] http://www.jdsu.com/ProductLiterature/sdh_pg_opt_tm_ae.pdf
[3] http://www4.ncsu.edu/~hp/Chapter7.pdf

“not-synchronised” alarming was usually masked. Even if a digital exchange were not synchronised there would be no alarm to say so until the alarm was unmasked.

Synchronising with Atomic Clocks

As the problem of slippage continued to be a major issue, a far more stable clocking source became readily available in the form of atomic clocks, using caesium as the resonant atoms.

These clocks[4] have an astoundingly stable frequency output, and with the network hierarchy now structured so that the clocking was largely synchronised from the top of the Backhaul Network hierarchy down, this added level of stability provided the breathing space necessary for better PDH stability.

PDH was an excellent (transmission) stepping stone from analogue transmission and switching to digital transmission and switching, but the perennial problem is one of extended bandwidth, and the atomic clocks provided the stability in clocking that paved the way for a rapidly increased bandwidth capability, meaning a vastly increased transmission rate – but not using PDH as the prime transmission structure.

In the early 1990s, most of the telecommunications industry worldwide went through a clock synchronisation project the Backhaul was indirectly synchronised to parent the (switch or transmission) systems’ atomic clock(s).

The general approach was to have an atomic clock in each main capital city, and have all major network switches slave clocked to this standard (through a dedicated transmission link). The transmission systems that hung off these switches were then considered be the next level of stability as these were clocked from the master clock. All atomic clocks are then phase locked to a master clock.

The “child” end of the transmission systems were synchronised to that parent switch, and that switch was synchronised to its’ prime transmission system. This strategy was carried out all the way down to the Customer Premises Equipment (CPE).

Synchronising Customer Equipment

In most cases the transmission timing problems could be dramatically minimised by synchronising the child transmission systems to the parent transmission systems.

For example, if a 2 Mb/s (MegaLink/ISDN) transmission link were connecting to a PABX in a business premises, then the 2 Mb/s clock in the PABX would be synchronised to the incoming 2 Mb/s stream as the first choice clock and the second choice clock would then be the local PABX 2 Mb/s clock.

The 2 Mb/s transmission link would (of course) be synchronised to the Backhaul Transmission Network, but the digital exchange typically would run on its own 8 Mb/s clock, accurate, but not synchronised with the transmission clocking!

Introducing Synchronous Digital Hierarchy

The advancing strategy was to remove the synchronisation padding and directly clock the receiving end with a synchronised clock – forming a Synchronous Digital Hierarchy (SDH) transmission path; and include management overhead so that the performance of the transmission links can be remotely monitored and altered as necessary; usually through a somewhat separate Service Control Network (SCN).

[4] http://leapsecond.com/hpclocks/

As usual, the USA came out with its own digital modulation plan of Synchronous Optical (Fibre) Network (SONET) while the rest of the developed world followed the ITU discussions and stabilised on SDH[5] as the accepted international standard.

The beauty about the SONET / SDH structure is they include a further degree of management overhead that allows almost instant dynamic network restructuring if an SDH ring is broken and the current status / performance of the equipment to be relayed back to management control points, and external configuration programming!

The lowest standard hierarchical link connection in the Backhaul Network is 155 Mb/s (0.155 Gb/s), optically known as a Virtual Container – 4 (VC-4), or electrically as a Synchronous Transport Module – 1 (STM-1).

The PDH Level 4 stream (140 Mb/s) can sit within an SDH STM-1, as an STM-1 has 63 streams of 2.048 Mb/s and PDH level 4 has 64 streams of 2.048 Mb/s, where some of these streams are used for synchronisation.

As it turns out, the (STM-1) is part of the Synchronous Digital Hierarchy (SDH) platform and this works perfectly well with Optical Fibre, which is extremely reliable, can connect distances of 90 km without extra equipment and has an extremely wide bandwidth[6], making it the perfect transmission medium for Backhaul connectivity.

Synchronising ATM

With these changes to use Atomic Clocks and parent connect the child switch and transmission systems, network “Slip” was virtually eliminated and timing errors were minimised. This network synchronisation work set the foundation for a range of physical connectivity protocols with a very low error rate.

As digital transmission requirements increased[7], so too did the need for different packet sizes for different transmission purposes. The committee result[8] was a 53 Byte data packet containing a 48 Byte Payload and a 5 Byte Header.

ATM was a major depart from PDH, as ATM[9] includes a header that manages and directs the data in the payload, and PDH has absolutely none of this intelligence included. ATM[10] simply sits in as a 155 Mb/s container within the SDH structure.

ATM readily connects X.25[11], [12], Frame Relay[13], HDLC[14], and ISDN Megalinks (2.048 Mb/s), and the clocking could be controlled from the ATM transmission equipment, keeping the synchronisation in order.

Because ATM included a header that included signalling data, ATM[15] could establish virtual connections through Routers (data switches) to provide route flexibility.

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5 http://www4.ncsu.edu/~hp/Chapter2.pdf
6 http://www4.ncsu.edu/~hp/Chapter9.pdf
7 http://www4.ncsu.edu/~hp/Chapter1.pdf
8 http://ccs-cabling.com/pdf/atm.pdf
9 http://www4.ncsu.edu/~hp/Chapter3.pdf
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