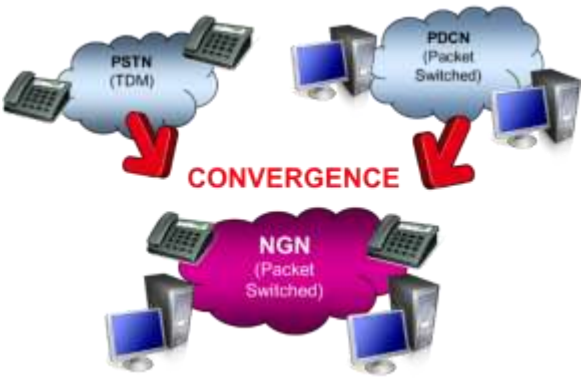
Timing requirements in core telecom networks

and mobile telephony

The last two three decades have seen drastic evolution of our personal environment. Telecom migrates form the well organized and well-structured PDH/SDH world after the first era of analog, to the more chaotic IP world. Then, all the timing resources embedded in SDH and available every where in the SDH network vanished, and timing signal became no longer available for free. Time is no longer network time but service time, and became a commodity that user must take care of.. Various network timing and various timing over network were introduced, based on protocols (NTP, and PTP), or on SDH event timing, or dedicated interfaces over network. Aside the availability and accuracy, traceability (at least common source) became an issue. Wireless telephony timing requirement evolved also a lot during the last decades. From 2G, FDD (Frequency Division Duplex) to the last TS-SCDMA (the most complex, mixing frequency, time and code duplex technologies), 4G and next to come 5G, issues like frequency aggregation at Radio Access Network, exhibit timing requirements from some microsecond down to +/- 130 or even +/- 65 ns (nanosecond : 1.10^{-9} second…).

The first strong evolution was the IP & SDH convergence, paving the way to packet switching, migrating from switch circuits to packet switching, for voice and data traffic.



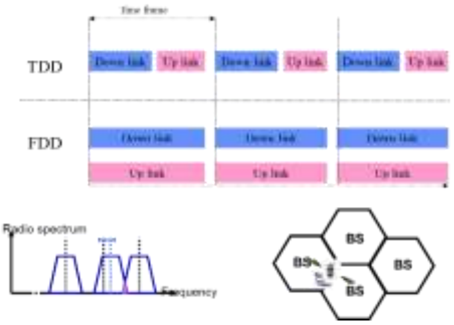
The cost per Mbit was then drastically reduced, and the evolution towards mobile capabilities was anticipated.
Telecom technologies (fix lines) evolves from SDH to IP, providing the expected cost reduction, with the consequence of lost of SDH synchronization. Synchronization in Telecom Networks became "service based" rather than "network based".

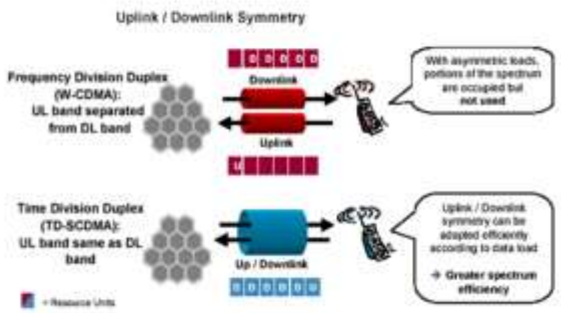
Then service provider had to take care of their system (service) synchronization, using various technologies GNSS of wire-based signals

In wireless telephony, the main fight was "mobility versus bandwidth". In the beginning of the decade, the band width, ie the capacity of heavy data exchange, was more in favor to fix-line network, and mobility more on the wireless side. Fix network attempt to expand their mobility (accessibility), while mobile operators tried to expand their bandwidth and their transport capabilities.

Fix network try to enhance its "mobile access", main attempt was the WIFI, WIMAX, providing mobility to fix line, and wireless designers have introduced capacity growing band width to mobile telephony, through different release and evolution, such as 2.5G, CDMA, EDGE, HPSA, 3G , now 4G and soon 5G. With wider bandwidth, the flow rate was drastically improved. Recently, we have also observed introduction of multi wavelength data traffic, allowing to improve the effective bandwidth by using multiple carrier, introducing timing requirement at aggregation level.

The original FDD / TDD scheme, was using symmetrical capability once link was established, leaving one way (usually the upstream) quite unused. A significant improvement was driven while taking into account the asymmetrical traffic, and introducing more complex ways for channel occupancy





Then the time and frequency requirements evolve with the deployment of telecom technologies, 2G asking a frequency tolerance (channel selection) of 5*10^{-8} and using channel spacing of # 200 kHz, with a traditional frequency conversion scheme. The first base station were using 45 MHz filters, then 71 MHz filters then 211 MHz filters, 200 KHz bandwidth, originally bulk acoustic waves (quartz) high frequency fundamental, with high rejection to adjacent channels. Later on, filtering migrates towards SAW filters, thanks to huge progress towards low insertion losses. Direct conversion to base band was introduced beginning of years 2000's. The time accuracy target was # 10ms. Base station syntonisation was done using SDH frame (E1 or T1 frame) or GNSS signals. Once migrating the transport network from SDH to IP, SDH syntonisation was no longer available, some manufacturer tried to use NTP protocol (enhanced, over clocked,..) to syntonise local oscillators (1 ms is equivalent to the impact of frequency offset by 1.10^{-8} after 1 day…, so expecting 1 ms through NTP protocol might allow to manage frequency within the 2G tolerance target, but getting 1ms out of NTP was not an easy task…), and most of the synchronization was done using GNSS receivers, under the form of "GNNS receivers modules", ie a low end oscillator driven by GNSS. Migrating towards TDD 3G (TDD LTE, UMTS..) asked for timing requirement around 3 µs, and hen decreasing down to 1.5 and even 1 microsecond, pushed by services that mobile operators were willing to implement (MBMS,…).

These "node-B" requirements were mostly provided by GNSS-driven high end oscillator including some "smart" operation allowing to minimize drift and thermal effect of the oscillators for some time (1 – 2 days) after entering in holdover.

Providing GNSS time with a 1.5 μs accuracy was "technologically simple" with such GNSS-LO devices, but holdover longer than a couple of days ask for ultraprecise oscillators (high end OCXO, Rb oscillators), getting cost out of range…

The continuous improvement, migrating towards 4G / 4G+ / 5G, going from FDD to TDD, introducing stringent time requirement at Base Station level, μs level need and femto cell dissemination in closed area, (subways, car park, buildings,…) drove PTP v2 protocol development, instead of using GNSS everywhere,
Microsecond Synchronisation between neighbor Base station, was also a requirement for hand over between BS.

The timing requirements are now moving « sub micro second », for network operation, carrier operation and service operation, such as :

- ITU-T G8271: historical requirement for ~**1500ns** synchronization error in LTE-TDD and single carrier LTE-FDD systems;
- OTDOA positioning (US E911 requirement), Carrier Aggregation, dense MIMO, other LTE-A features, and 5G driving time requirements down to **100ns** and below.
- TDD: 1500ns
- OTDoA Location: 100ns
- MIMO/Tx Diversity: **32.5ns**
- LTE-A: eICIC: 1500ns / CoMP: 1500ns
- Video Broadcast: 1500ns
- CA inter-band: 130ns
- CA contiguous: **65ns**
- Multi-antenna coord: ?ns
- 5G: Expect <**50ns**

Then there are clearly two issues

- GNSS is still a widely used technology, but it is acknowledged that the vulnerability is an issue
- Most of the recent deployment are using PTP / PTP-SynE, IEEE 1588, which is hardly to come down to the micro second
- The evolution and trends are going towards tight tolerances (aggregation, ….) in the 100's ns range.
    - GNSS is no longer matching the technical requirements, not matching nor the security/availability and cyber-robustness requirements
    - PTP / PTP-SyncE is not providing the required timing performance.

In other words, the evolution of timing requirement in telecom, and mainly in the wireless domain, will ask for new synchronization technologies, providing accuracy (down to 10's ns), security, cyber robustness, and low cost.

IoT based or fiber based White Rabbit (a high performance version of PTP, using both symmetrical PTP and symmetrical SyncE)

Mobile Requirements (*3GPP TS 36.104 sec 6.5.3.1)

Application	Sync error rqmts (+/-)
Location Based Services using OTDOA (30m accuracy)	100 ns
Inter-band carrier aggregation	130 ns*
Intra-band non-continuous carrier aggregation	130 ns*
Intra-band contiguous carrier aggregation	65 ns*
MIMO or TX diversity transmissions, at each carrier frequency	32.5 ns*
More emerging LTE-A features that require multiple antenna co-operation within a cluster	Under Study < 32 ns?
5G	Under Study < 25 ns?

*Ref1: *Requirements_for_the_eCPRI-Transport_Network_d_0_1_2017_08.30.pdf, Ericsson, Huawei Technologies, NEC and Nokia, 31 August 2017, Table 2*
Ref2: Analysis of the Synchronization Requirements of 5G and Corresponding Solutions", Han Li et al, IEEE Communications Standards Magazine, March 2017

Prior to LTE (and Wimax), mobile RAN did not require phase sync across different radio sites at the radio antennas.
Whereas LTE-FDD maintained primary focus on frequency sync, LTE-TDD requires phase sync of +/- 1500 ns, measured at the transmitting antennas of radio sites.
Although a number of high-value LTE-FDD features requiring an order-of-magnitude tighter phase sync (+/-32.5 ns to +/-130 ns) have been introduced (e.g. MIMO, carrier aggregation), very limited deployment to date across different radio sites has minimized the need to address.

Thus, precise and reliable cross-site sync below the +/- 1500 ns level is the today's standard.

Cross-tower 5G requirements are expected at similar order-of-magnitude range as advanced LTE-FDD features, of +/-130ns or lower. Coupled with targeted 5G demand for much denser radio sites in support of both indoor and outdoor/metropolitan densification, sufficiently precise and reliable phase sync solution across radio sites is no longer optional, but required.

In the document "Network Assistance for Network Synchronization" 3GPP Study Item RP-151084, TR36.898, the potential technologies foreseen to match the new requirements are listed as :

- GNSS (satellite-based)
  - Performance limited, Not providing security
- 1588/PTPv2 (IP data-network based, via shared IP channels)
  - Performance limited
- Assisted Partial Timing Support, or APTS (Combination of GPS and PTPv2)
  - Performance limited, cost
- Metropolitan Beacon System (terrestrial-based GPS alternative on separate spectrum)
  - Deployment cost
- "White Rabbit" Based (terrestrial-based, via dedicated IP channels)
  - The only one "proven and commercially available" as by to day
- Other sync technologies to come in the field …?