OSCILLOQUARTZ
An ADVA Optical Networking Company

The Synchronization of 3G UMTS Networks

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ABSTRACT

This Application Note presents a discussion of the synchronization issues in UMTS networks, and provides practical solutions for several UMTS network configurations. The paper addresses all variants of UMTS, i.e. UMTS-FDD and UMTS-TDD. In UMTS networks all network elements need some form of synchronization. The required synchronization accuracy and stability depend on the network element type. Most network elements must be synchronized in frequency. Base stations in the TDD variant of UMTS also require an external phase-alignment signal. The way to solve the synchronization question in UMTS networks depends very much on the transport network used to interconnect all the UMTS network elements. This Application Note details a number of practical solutions applicable to different transport network configurations. These solutions can be used for developing a synchronization design for any given real UMTS network.

ABBREVIATIONS

3G	3rd generation mobile system
3GPP	3rd Generation Partnership Project
ADM	Add-Drop Multiplexer
AMPS	Advances Mobile Phone System
ATM	Asynchronous Transfer Mode
BITS	Building Integrated Timing Supply
CDMA	Code Division Multiple Access
CN	Core Network
FDD	Frequency Division Duplexing
GERAN	GSM/EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GMSC	Gateway MSC
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
IMT-2000	International Mobile Telecommunications 2000
IP	Internet Protocol
ITU	International Telecommunications Union
Mcps	Mega chip per second
MGW	Media Gateway
MS	Mobile Station
MSC	Mobile Switching Center
PRS	Primary Reference Source
PRC	Primary Reference Clock
QoE	Quality of Experience
QoS	Quality of Service
SGSN	Serving GPRS Support Node
SSU	Synchronization Supply Unit
TDD	Time Division Duplexing
TD-CDMA	Time Division CDMA
TDM	Time Division Multiplexing
TD-SCDMA	Time Division Synchronous CDMA
TSG	Timing Supply Generator
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
W-CDMA	Wideband CDMA

1 What is UMTS?

UMTS stands for Universal Mobile Telecommunications System and designates a family of mobile systems of the 3rd generation. There is a number of so-called "3rd generation" or "3G" system standards. Strictly speaking the term "3G" applies to all mobile system standards which are officially backed by the ITU under the IMT-2000 program (International Mobile Telecommunications 2000). Under this program, the ITU adopted a limited number of mobile system standards proposed by standardization bodies from all over the world.

The UMTS standards were initially proposed by the European Telecommunications Standards Institute (ETSI), but now the standardization activity around UMTS is headed by a new standardization body called the "3rd Generation Partnership Project" or "3GPP" (www.3gpp.org).

Currently there are three different UMTS standards for terrestrial mobile communications (UMTS also encompasses satellite systems for personal communications, but these are outside the scope of this Applications Note). Table 1 gives a brief overview of the main characteristics of the three terrestrial UMTS systems[1]. The three standards differ in the technical solutions adopted for the radio interface between the base station and the user equipment. The differences concern the way up- and down-link communications are separated (duplexing), and the particular CDMA coding techniques used for separating multiple users (multiplexing). But more importantly it is the targeted application environments that are different.

UMTS-FDD and UMTS-TDD 1.28 Mcps are for general environments, whereas UMTS-TDD 3.84 Mcps was specifically designed for indoor pico-cells and outdoor micro-cells in densely populated areas. UMTS-TDD 1.28 Mcps was introduced only very recently as a result of a Chinese initiative.

3G mobile systems in general are being deployed in order to match growing customer demands. 3G systems provide much higher data rates than 2nd generation (2G) systems such as GSM, AMPS, and cdmaOne. 3G systems also provide single platforms for both voice-centric and data-centric services (in this document the term "voice-centric" is used to designate real-time services such as voice and also video, as opposed to non-real-time "data-centric" services). The latest enhancements of some 2G systems (e.g. with GSM/GPRS) already provide such unified platforms. But with 3G systems the combination of voice- and data-centric services comes with improved data rates: 144 to 384 kbit/s for vehicular outdoor environments, and up to 2 Mbit/s for stationary indoor and city outdoor environments.

Within the family of 3G systems, UMTS is the one that is closest to the 2nd generation GSM system. As a matter of fact, UMTS was developed with smooth GSM-to-UMTS migration in mind. During the migration UMTS radio access networks and some later evolutions of GSM radio access networks (e.g. GERAN) will coexist and connect to a single UMTS Core Network, thus providing similar services for both GSM and UMTS handsets (though with very different data rates).

[1] In fact thre are three Radio Access Network types called UTRAN-FDD, UTRAN-TDD 3.84 Mcps and UTRAN TDD 1.28 Mcps and one single UMTS Core Network type.

Table 1: Terrestrial UMTS systems

UMTS system	Intended Application	Multiple Access[1]	Duplexing[2]
UMTS-FDD	All environments, especially areas with medium population density; suited for symmetric traffic	W-CDMA[3] (3.84 Mcps chip rate[8], 2 x 5 MHz channel bandwidth[9])	FDD[6]
UMTS-TDD 3.84 Mcps	Indoor pico-cells and outdoor micro-cells in densely populated urban areas; suited for both symmetric and asymmetric traffic	TD-CDMA[4] (3.84 Mcps chip rate, 1 x 5 MHz channel bandwidth)	TDD[7]
UMTS-TDD 1.28 Mcps	All environments (expected to be deployed in China first)	TD-SCDMA[5] (1.28 Mcps chip rate, 1 x 1.6 MHz channel bandwidth)	TDD

Notes:

1: The way multiple users share the available radio spectrum within a cell

2: The way a user shares the available radio spectrum for both communications directions

3: Wideband CDMA, actually a form of Direct Sequence CDMA

4: Time Division CDMA

5: Time Division Synchronous CDMA

6: Frequency Division Duplexing

7: Time Division Duplexing

8: CDMA code moments (chips) per second

9: Radio spectrum bandwidth per user channel

2 UMTS Network Architecture

In order to understand the synchronization issues of UMTS networks, it is necessary to have a look at the general architecture of a UMTS network.

Figure 1 shows a rather detailed view of the overall network architecture. The figure depicts the constitutive functional entities and the interfaces between them.

UMTS entities are grouped into three domains, the Core Network (CN) domain, the UMTS Terrestrial Radio Access Network (UTRAN) domain, and the User Equipment (UE) domain. The Core Network is itself divided into the Serving Network and the Home Network. The Serving Network "serves" that UTRAN where the calling user resides at the moment of the call or session. The Home Network on the other hand is the network to which the user is linked by his subscription contract. From a functional point of view, the Home Network contains a database hosting the subscription information; this database is called the Home Subscriber Server or HSS (formerly Home Location Register or HLR).

The Service Network is subdivided into a Circuit Switched (CS) domain and a Packet Switched (PS) domain. This partitioning reflects the fact that UMTS mobile networks are designed for the delivery of both voice-centric and data-centric services. The two types of services are supported in the Core Network by switching nodes adapted to the circuit or packet switched nature of the traffic.

In the PS domain the switching nodes are called GPRS Support Nodes. A GPRS Support Node is nothing else than a packet switch or packet router designed for the specific packet technology used in UMTS and GSM systems (the acronym "GPRS" stands for "General Packet Radio Service"). There are two types of GPRS Support Nodes. The Serving GPRS Support Node or SGSN connects to another mobile network or to another part of the same mobile network (case where the called party is also a mobile user).

The Gateway GPRS Support Node or GGSN is used in cases where the called party is to be reached over a fixed public data network such as the Internet or a public X.25 network.

The situation is similar in the CS domain of the Core Network. There are again two types of switching nodes called Mobile Switching Center (MSC) and Gateway Mobile Switching Center (GMSC). The term MSC can be misleading, since one could be led to believe, that this MSC is a TDM switch (TDM: Time Division Multiplexing), just like the MSC of a GSM network. This is not the case. MSC and GMSC are actually hybrids between TDM switches and packet routers (such a hybrid is usually called a Media Gateway). This is so because the MSC's and the GMSC's interfaces towards the transit network (PSTN interfaces in Figure 1) convey TDM signals (e.g. E1) with a 125 µs frame structure, whereas the (G)MSC's interfaces towards the UTRAN (IuCS interface in Figure 1) convey packets or cells. This is entirely different from the GSM case, where everything is based on TDM.

Finally there is the VLR (Visitor Location Register). It is a database serving both the CS and the PS domain; it keeps track of information concerning a visiting user (roaming).

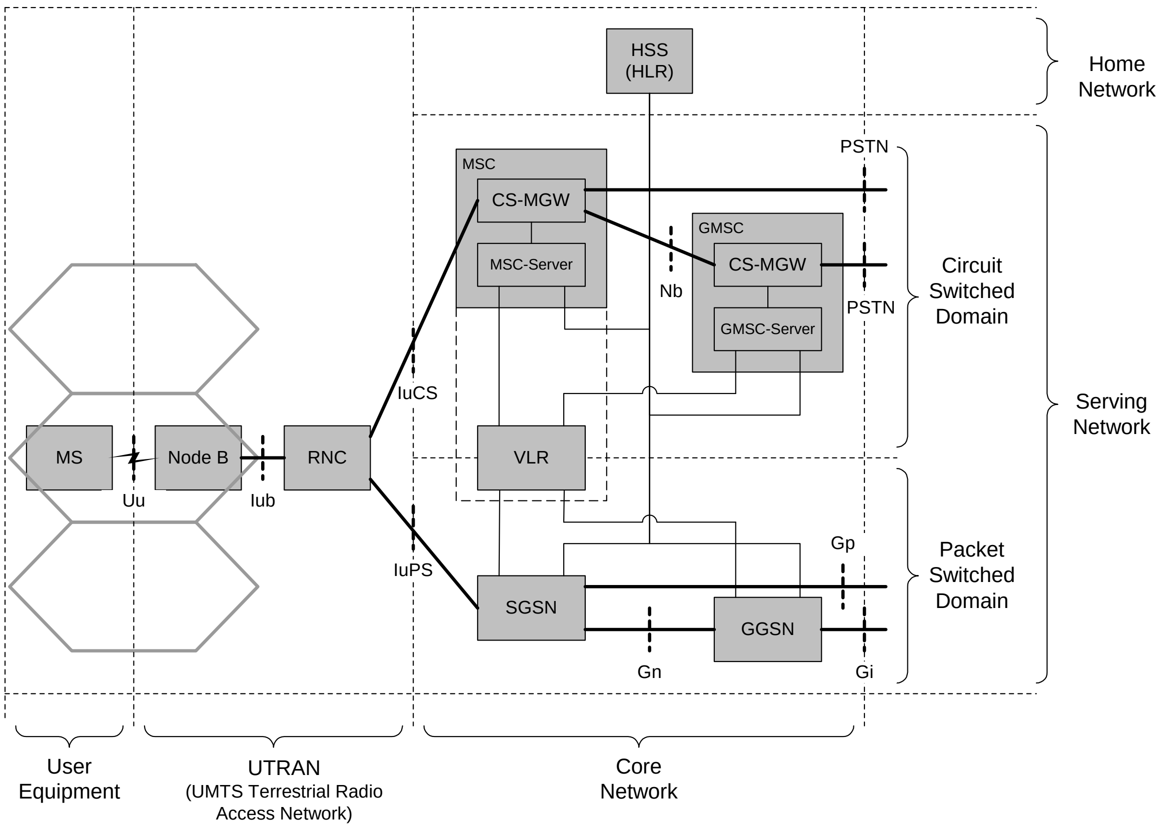

Figure 1: Architecture: entities and interfaces

In UMTS, the entire UTRAN is a packet or cell switched network. The actual structure of the UTRAN resembles the structure of the GSM Radio Access Network. Base stations called "Node B" in UMTS parlance are the transceivers serving a radio cell. A number of Nodes B is controlled by a so-called Radio Network Controller or RNC (similar to the Base Station Controller or BSC in GSM networks). The RNC handles control functions such as the allocations of radio channels to a requested call, execution of handovers and many more. Both voice-centric and data-centric traffic traverses the UTRAN either as IP packets or as ATM cells. IP and ATM are the two fundamental variants, which equipment manufacturers can choose from. It is generally expected that the first generation UTRAN equipment will be predominantly based on ATM. Many operators seem to have higher confidence in ATM when it comes to guaranteeing real-time Quality of Service (QoS) parameters such as packet/cell delay and packet/cell delay variation (jitter). Being able to maintain these parameters within acceptable limits is crucial for the Quality of Service and the subjective Quality of Experience (QoE) of real-time services such as voice or video conferencing.

In the protocol stacks admitted by the UMTS standards, ATM or IP can run over a variety of Layer 1 or L1 protocols (physical layer). The standards allows equipment manufacturers to choose from a rather long list of possible L1 protocols or signals. Table 2 shows the complete list. It is taken from the 3GPP Technical Specification TS 25.411. Although the list basically applies to all interface types, the higher data rate signals are likely to be found in the Core Network and on the IuCS and IuPS interfaces (between Core Network nodes and RNC), while the lower data rate signals are for the Iub interfaces (between RNC and Node B). In the current release of the UMTS standard (Release 6), all permitted L1 signals are synchronous signals. This has important consequences for the synchronization of UMTS networks, as will be discussed in sections 4 and 5.

3 Synchronization Issues

In UMTS networks, just as in most other network types, interconnected network elements interwork correctly only if the signals they exchange comply with given synchronization quality requirements. The synchronization quality of the signals is determined by the network elements' equipment clocks. Equipment clocks control some of the important signal processing functions within the network element (e.g. multiplexing, switching), as well as the data rate (accuracy, stability) of outgoing traffic signals. There are different clock frequency accuracy and stability requirements for different network element types. In most cases frequency accuracy specifications are much tighter than what the equipment clock could deliver if it were free running. This means that most equipment clocks need to be synchronized or "locked" to an external and possibly remote high accuracy frequency reference clock. Furthermore there are cases where accurate frequency is not enough, where all equipment clocks of a given type are required to tick in phase throughout the network. The issue of clock synchronization is how to distribute a common frequency reference and possibly a common phase reference of appropriate quality to all clocks in the network.

Network operators must design an appropriate synchronization network which guarantees that all equipment clocks operate within the relevant frequency (and possibly phase) accuracy and stability specifications. Before discussing how synchronization (frequency and possibly phase) is distributed to the equipment clocks, it is necessary to understand the synchronization performance requirements. This is the subject of the next section.

4 Synchronization Performance Requirements

4.1 Overview

The method to be used for distributing synchronization obviously depends on the targeted synchronization performance. The performance requirements differ from one network element type to another. The traditional way of specifying synchronization performance in a network is to state frequency accuracy and jitter & wander limits for certain types of interfaces. Table 3 summarizes the synchronization requirements for the important interfaces of a UMTS network (see Figure 1 for the location of the interfaces). The way things are specified in the standards pre-suppose or assume that synchronization distribution flows from the Core Network to the RNC, from the RNC to the Node B, and finally from the Node B to the Mobile Station (see Table 3, column 2). The last column of the table indicates the 3GPP Technical Specification where requirements are taken from.

4.2 Requirements for CN Nodes and RNC

The important network elements of the Core Network, i.e. MSC, GMSC, SGSN and GGSN, are called Core Network nodes or simply CN nodes. As mentioned earlier, the protocol stacks running over the interfaces between CN nodes and RNC are either cell- or packet-switched protocols. Switching and forwarding cells and packets are asynchronous operations. One could therefore be led to believe, that CN nodes and RNC would not require any synchronization. However this is not the case at all. In cell- and packet-switched networks, synchronization requirements are driven by the needs of the Layer 1 (L1) protocols. As mentioned earlier, there is a variety of possible L1 protocols (see Table 2). In the current release of the UMTS standard (Release 6), all permitted L1 signals are required to be synchronous signals.

Table 2: Layer 1 signal types

Designation	Data rate [Mbit/s]	Electrical specification and frame structure	Network Limit for wander	Network Limit for jitter
STM-4	622	I.432.2	G.825, § 5.2 or G.823, § 6.2.3	G.825, § 5.1
STM-1	155	I.432.2		
STM-0	51	ETSI/TTC		
STS-3c	622	T1.105		
STS-12c	155	T1.105		
E3	34	G.751[1]	G.823, § 6.2.4	G.823, § 6.1, Table 1, "PDH synchronization interface"
E2	8	G.703/704[2]		
E1	2	G.703/704		
T3	45	G.703/704	G.824, § 6.2.2, Tables 5 and 6	G.824, § 6.1
T1	1.5	G.703/704		
J2	6.3	JT-G.703/704		
J1	1.5	JT-G.703/704		

Notes:

1: G.751 specifies the mapping of four E2 into one E3; this means that it is not ATM cell to E3 mapping according to G.804 (otherwise TS 25.411 would state "G.832" which specifies the E3 frame structure for G.804 mapping).

2: The mapping of ATM cells into E2 is not defined yet in G.804 (where it is expected to be specified).

Table 3: Synchronization performance requirements

Interface	Direction of synchronization distribution	Requirements	References
IuCS, IuPS	CN node to RNC	$\lvert y \rvert \leq$ 1E-11 N.L.:G.823/824/825[4]	TS 25.411, § 4
Iub	RNC to Node B	$\lvert y \rvert \leq$ 1E-11 N.L.:G.823/824/825[4]	TS 25.431, § 4
Node B Synch. Input Port[2, 3]	External source To Node B	$\lvert y \rvert \leq$ 5E-8 $\lvert x \rvert \leq$ 1.25 μs[2, 3]	TS 25.402, § 6.1.2[2, 3]
Uu	Node B to MS	$\lvert y \rvert \leq$ 5E-8 $\lvert x \rvert \leq$ 1.5 μs[2, 3]	TS 25.104, § 6.3[1] TS 25.105,§ 6.3[2, 3] TR 25.836, § 6[2] TR 25.868, § 6[3]

Notes:

x: Phase-time

y: Fractional frequency

N.L.: Network Limit

1: FDD

2: 3.84 Mcps TDD

3: 1.28 Mcps TDD

4: Depending on layer 1 signal type, see Table 2

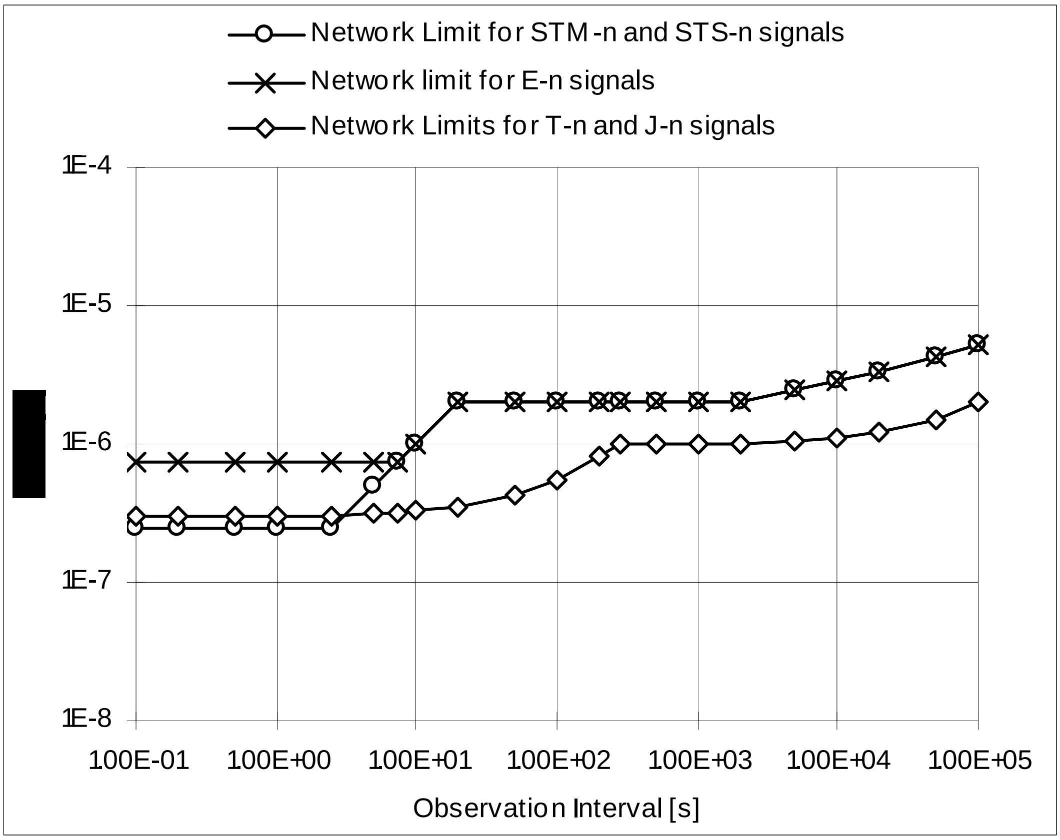

Figure 2: MTIE Network Limits for Iub, IuCs and IuPS interfaces

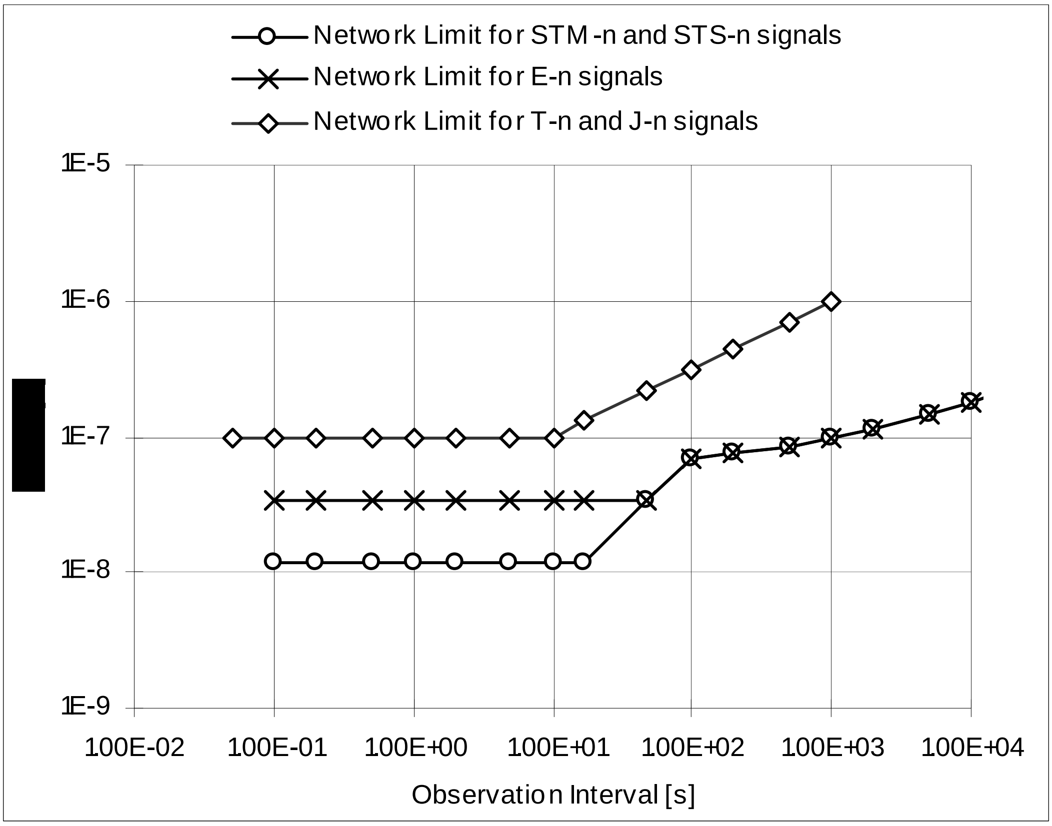

Figure 3: TDEV Network Limits for Iub, IuCs and IuPS interfaces

For all these signal types the required accuracy of the data rate is

$$|y| \leq 1E\text{-}11 \,,$$

where y is the fractional (or relative) frequency deviation. This accuracy figure is the same as the one specified in ITU-T Rec. G.811 for a Primary Reference Clock[1] (PRC). This means that CN nodes and RNC must be synchronized directly or indirectly to a PRC, their equipment clocks must be "traceable to a PRC".

The jitter and wander present on the IuCS, IuPS and Iub interfaces are required to be within the so-called Network Limits specified in ITU-T Rec. G.823, G.824 and G.825. The last two columns of Table 2 give the exact bibliographic references for these important Network Limits. G.823 and G.824 contain several Network Limits specifications for different network configuration cases. Because IuCS, IuPS and Iub interfaces are used to carry synchronization from CN node to RNC and from RNC to Node B respectively[1], it is the so-called "Network Limits for Synchronization Interfaces" which apply.

Figures 2 and 3 show the Network Limits for wander expressed as MTIE and TDEV thresholds. The curves shown in the two figures are taken from the ITUT Recommendations mentioned in Table 2.

4.3 Requirements for Node B

Because synchronization flows from the Node B to the Mobile Station (user equipment), the standards specify synchronization performance at the Node B's radio interface Uu (the transmitting antenna). For UMTS-FDD there is only a frequency accuracy specification:

$$|y| \leq 5E\text{-}8 \;.$$

The specification basically means that the Node B's transmitter must deliver a radio signal whose carrier frequency and carried data rate exhibits this accuracy. Visibly this specification is less stringent than the one for the CN nodes and the RNC. Normally the Node B in UTRAN-FDD derives frequency synchronization from a traffic signal traversing the Iub interface. For that purpose, the traffic signal carrying synchronization to the Node B must comply with the Network Limits indicated in Table 2.

The 5E-8 frequency accuracy is needed for a number of reasons. First, accurate synchronization of all Nodes B is required for successful handover processing. Degraded synchronization has a direct and measurable impact on the number of user calls or sessions lost during the handover. Secondly, accurate radio carrier frequencies at the transmitter outputs (antennas) guarantee that radio channels of neighboring cells do not overlap in the spectrum domain. Spectral channel overlap causes channel cross-interference, which in turn causes a noticeable and at times very annoying degradation of voice quality (signal-to-noise ratio). Thirdly, accurate synchronization is a pre-requisite for all the frame synchronization processes that take place over the various interfaces. Signal frame structures are aligned by special protocol procedures 1) between CN nodes and RNC, 2) between RNC and Nodes B, and 3) between Node B and Mobile Station. These frame synchronization processes optimize handover times, user signal delay and user signal jitter. Although frame synchronization is achieved by software-driven protocol procedures, they function only if the accuracy of the physical synchronization is within the mentioned 5E-8 frequency accuracy specification. In the two UMTS-TDD systems, the Node B and the Mobile Station not only need frequency synchronization, but also phase synchronization. In other words: the equipment clocks of all Nodes B and all Mobile Stations are required to deliver clocking signals which are phase-aligned against each other. There is a phase accuracy specification for the Node B's radio interface. The specification is the same for both UMTS-TDD systems (3.84 Mcps and 1.28 Mcps):

$$|x| \leq 1.5\ \mu s \;.$$

Phase synchronization is needed in order to assure that frames transmitted by neighboring cells are aligned in time. This is called Inter Node B Synchronization. With the TD-CDMA and TD-SCDMA techniques used in UMTS-TDD, degradation or loss of Inter Node B Synchronization results in high cross-interference between use channels. In the UTRAN-TDD, it is not possible for the Node B to get a phase reference from the distant RNC. Instead the Node B must be supplied with an external phase synchronization signal over its so-called Synchronization Input Port. The electrical characteristics of the port (RS-422) and the format of the reference signal are specified in TS 25.402. The signal is essentially a 100 Hz pulse train (0.5 to 1 ms pulse-width) with additional frame markers every 2.56 s (2 to 3 ms pulse-width) and every 40.96 s (4 to 5 ms pulse-width). The three superposed periodic signals are used to align the "frames", the "multi-frames" and the "SFN periods" of the radio signals (SFN stands for Single Frequency Network). The phase reference signal must have an accuracy of

$$|x| \leq 1.25\ \mu s \;.$$

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[1] called Primary Reference Source (PRS) in North America

[2] See 3GPP Technical Specification TS 25.411, § 4.2.1

The only practical way to supply such a signal is to generate it locally with a GPS-receiver. GPS-receivers are able to deliver frequency, phase and even time signals with very high accuracy. These signals are indirectly (i.e. via the GPS satellites) derived from the ground master clock of the GPS system.

5 Synchronization Solutions

5.1 Reference Solutions

Said simply, the task at hand is to distribute …

- frequency with an accuracy of 1E-11 to all CN nodes (MSC, GMSC, SGSN, GGSN) and all RNC,
- frequency with an accuracy of 5E-8 to all Nodes B, and
- phase with an accuracy of 1.25 µs to all Nodes B (in the UMTS-TDD case), …

… and make sure that the distributed synchronization signals also comply with the relevant Network Limits for jitter & wander.

The way this is achieved depends essentially on the type of transport network used for interconnecting the UMTS network elements. This section presents six reference solutions, three for UMTS-FDD and three for UMTS-TDD. For each of the two cases there are three solutions corresponding to three different transport network configurations:

1. Trusted SDH or SONET transport network
2. Trusted PDH transport network
3. Leased lines

For the clock synchronization issue it makes a difference, whether the transport network is itself synchronous or not, and whether the transport network is able to transport synchronization signals transparently or not. The three transport network scenarios listed above reflect these differences. In the first scenario the transport network (SDH or SONET) is itself synchronous. This means that all transport network elements are synchronized to a PRC, and synchronization derived from the transport network elements can be used to synchronize other equipment. In the second scenario, the transport network (PDH) is transparent for the timing of the transported traffic signals (tributaries). This means that the transported traffic signals can be used to carry synchronization from one place to another. The case where the transport network elements are not synchronous and the transport network is not transparent for timing defines the third scenario.

The synchronous nature of SDH/SONET networks and the timing transparency of the PDH networks can only be exploited for synchronization, if these properties can be relied upon. The synchronization delivered by an SDH/SONET network element can be used only if the required synchronization quality is there with a high availability. A PDH tributary can be used for the transport of synchronization only if the timing transparency does not get degraded by failure conditions or other disruptive events that are not under the control of the UMTS operator. This kind of "trust" pre-supposes either that the UMTS operator controls the transport network, or that there is a contract between UMTS operator and transport service provider concerning synchronization. With traditional leased lines this is precisely not the case.

Here the transport network is owned by the leased line provider, and the standard leased line service definitions do not describe synchronization aspects in an appropriate manner. So leased lines provide neither trustworthy synchronization nor trustworthy timing transparency.

5.1.1 UMTS-FDD, Trusted SDH/SONET Transport Network

Refer to Figures 4 and 5. SDH and SONET networks are synchronous networks. They possess their own synchronization distribution system which guarantees that all SDH/SONET network elements are synchronized to a PRC under normal operating conditions (no failures). A well-designed SDH/SONET synchronization distribution network also guarantees that the synchronization performance complies with the relevant Network Limits, again under normal operating conditions. Provided that the SDH/SONET transport network's own synchronization distribution can be trusted, synchronization reference signals for the UMTS network elements are simply taken from co-located SDH/SONET network elements. This is always possible, since all SDH/SONET network elements have so-called External Timing Output ports delivering a non-traffic-carrying synchronization signal (usually 2.048 MHz, 2.048 Mbit/s or 1.544 Mbit/s). All it takes is to connect the SDH/SONET network element's External Timing Output to the UMTS network element's External Timing Input. Since PRC-traceability can get disrupted under certain failure conditions occurring inside the SDH/SONET network, it is highly recommended to add an SSU[1] (Synchronization Supply Unit) in each site containing a CN node (MSC, GMSC, SGSN, GGSN) or an RNC. In case the traceability to the PRC gets lost because of some failure condition, the SSU enters an operation mode called holdover. In holdover mode the SSU becomes an autonomous frequency generator. The frequency accuracy in holdover mode, though slowly degrading with time, is sufficient for operating the connected UMTS equipment for a period of 1 day to over a week, depending on the SSU model and the temperature conditions. SSU deployment is important for all CN nodes and all RNC, because a disruption of synchronization supply at these places would affect a large number of user calls and sessions, and have very negative impact on customer satisfaction.

Nodes B which are co-located with an SDH or SONET network element take synchronization directly from the SDH/SONET network element. The situation is somewhat different when there is no SDH or SONET network element co-located with the Node B. In this case the traffic is carried from the egress SDH/SONET Add-Drop-Multiplexer (ADM) to the Node B over a lower order tributary signal such as E1, E2, E3, T1, T3, J1 or J2 (see Table 2). These signals are generated by an RNC which is normally traceable to a PRC (or to an SSU in holdover mode). The lower order tributaries traverse the SDH/SONET network from the RNC site to the egress ADM closest to the Node B. Whether these tributaries are suitable or not for carrying synchronization to the Node B depends on the timing transparency of the SDH/SONET transport network. The timing transparency must be good enough to keep the jitter & wander of the transported tributary within the relevant Network Limits (refer to Figures 2 and 3). This is the case in most real situations. The condition is that the SDH/SONET transport network is well synchronized, so that pointer adjustments do not occur too frequently. There can be situations, however, where these conditions are difficult to fulfill at all times. In sparsely meshed SDH/SONET networks the probability of synchronization failures can be too high (availability issue). This may lead to increased pointer activity, which in turn can degrade the wander on dropped E1, T1 and J1 signals well beyond the specified Network Limits. In such cases the solution is to re-time the E1, T1 and J1 tributaries in the site where they leave the SDH/SONET network. As shown in Figure 5, the Re-timing function imprints the synchronization derived from the egress ADM's External Timing Output port onto the dropped tributary. More about this subject can be found in the Oscilloquartz Application Note "Re-timing: Cost-effective Synchronization via Re-timed E1 and DS1 Signals".

[1] called TSG (Timing Supply Unit) or BITS Clock (Building Integrated Timing Supply) in North America)

5.1.2 UMTS-FDD, Trusted PDH Transport Network

Refer to Figure 6. The network elements of a PDH network are not synchronous. The higher order tributaries are not synchronized to a PRC; instead their data rate is derived from the free running equipment clocks contained in the network elements (PDH multiplexer). The frequency accuracies of these oscillators are in the range of 15E-6 to 50E-6 (fractional frequency). This mode of operation is called plesiochronous mode. Given these frequency accuracies, signals generated by the PDH equipment clocks cannot be used for synchronizing UMTS equipment. On the other hand, PDH transport networks are perfectly transparent for the timing of the transported traffic signals (tributaries). This property is exploited in order to build synchronization distribution networks. In Figure 6 a CN node (e.g. an MSC) is synchronized by the co-located PRC. Traffic signals generated by this CN node are therefore synchronous. In the figure, one of these traffic signals is used for carrying synchronization from the CN node to the RNC over the PDH network. In the RNC site, synchronization is extracted from the traffic signal and fed to an SSU. The SSU's output signal is then connected to the RNC's External Timing Input port. This principle is applied to all RNC and also to all other CN nodes (those which are not co-located with the PRC). The SSU plays the same role as in the previous scenario: it provides holdover protection in case traceability to the PRC gets lost because of some failure condition. The distribution of synchronization from the RNC to the Node B is done in the same way (except that there is no SSU associated with the Node B): a synchronous traffic signal transports synchronization and user data from the RNC to the Nodes B over the PDH network. The compelling simplicity of this solution is a consequence of the nearly perfect timing transparency of PDH networks.

5.1.3 UMTS-FDD, LEASED LINES

Refer to Figure 7. This section presents a reference solution for the case where the transport network is not sufficiently transparent for the timing of the transported traffic signals, and where the transport network cannot deliver valid synchronization signals derived from its own synchronization distribution system. In this case there is only one solution: each site containing a UMTS network element must be equipped with a GPS-receiver. As shown in Figure 7, the GPS-receivers deliver synchronization signals which are connected to the External Timing Input ports of the UMTS network elements. Frequency accuracy as well as jitter & wander levels of synchronization-grade GPS-receivers comply easily with PRC[1] standards; hence these GPS-receivers are suitable for the synchronization of all UMTS network elements.

A few comments on leased lines are in order at this place. There are two categories of leased lines in use: structured and unstructured leased lines. Unstructured leased lines do not require the transported client signal to comply with any particular frame structure, as long as the data rate is within the specified range (e.g. $\pm$ 50 ppm for 2048 kbit/s unstructured leased lines). Unstructured leased lines are only semi-transparent for the timing of the transported client signal: they preserve the long-term average data rate, but they inject jitter & wander. However, service definitions usually do not include any guaranteed limits on the injected jitter & wander. Real world experience shows that the wander levels at the leased line egress points can be very high and often violate the Network Limits of Figures 2 and 3. Structured leased lines, on the other hand, require the transported client signals to have a standard frame structure (e.g. according to ITU-T Rec. G.704, etc.). Structured leased lines come with several timing options. The common ones are called "User Timing", "Network Timing" and "Loop Timing".

[1] ITU-T Rec. G.811, ANSI T1.101, Telcordia GR-2830, ETSI EN 300 462-2

A full discussion of the synchronization properties of these timing modes is outside the scope of this document. It is important, however, to summarize the main points: 1) none of the three options provides adequate timing transparency, and 2) none of the three options can deliver good synchronization signals derived from the transport network itself (with the "Network Timing" option the data rates of the client signals are in fact imposed by the transport network timing, but service definitions usually do not include any guaranteed limits on frequency accuracy, jitter and wander). From the above it follows that leased lines are neither good synchronization carriers nor good synchronization sources, hence they should never be trusted for synchronization.

5.1.4 UMTS-TDD Scenarios

Refer to Figures 8 to 10. With UMTS-TDD, Nodes B require accurate phase synchronization. The only practical way to make available a phase reference is the GPS. In Figures 8 to 10 Nodes B are equipped with synchronization-grade GPS-receivers.

They deliver a synchronization signal acting both as a frequency reference and as a phase reference. The 3GPP Technical Specification TS 25.402 proposes a standard signal format consisting of a 100 Hz pulse train with special markers every 2.56 s and every 40.96 s. Due to the GPS, the markers of all Nodes B in the network are phase-aligned with sub-microsecond accuracy. The way the CN nodes and the RNC are synchronized is exactly the same as in the three UMTS-FDD scenarios.

In the UMTS-TDD cases based on PDH or SDH/SONET transport, there is the possibility of using a (synchronous) traffic signal going from the RNC to the Node B as a 2nd priority frequency reference. The idea is to have some protection against GPS-receiver problems: if the output signal of the GPS-receiver fails (e.g. because of a hardware failure or bad radio reception), then the Node B uses the traffic signal coming from the RNC as a frequency reference. This back-up solution pre-supposes that the Node B's internal clock is capable of maintaining phase alignment while being steered by the frequency (data rate) of the traffic signal; this is the case with all known implementations. Provided that the 2nd priority frequency reference is accurate and stable, the accuracy of the phase-alignment in this operation mode will be slightly degraded, but still good enough for acceptable performance.

5.2 Real World Solutions

In the reference solutions presented here, one and the same transport network type (SDH/SONET or PDH or leased lines) is used in the entire Core Network and for the interconnections of all RNC. In reality there is often a mix of several transport network types. In such cases a synchronization distribution concept must be worked out by combining the techniques from the six reference solutions.

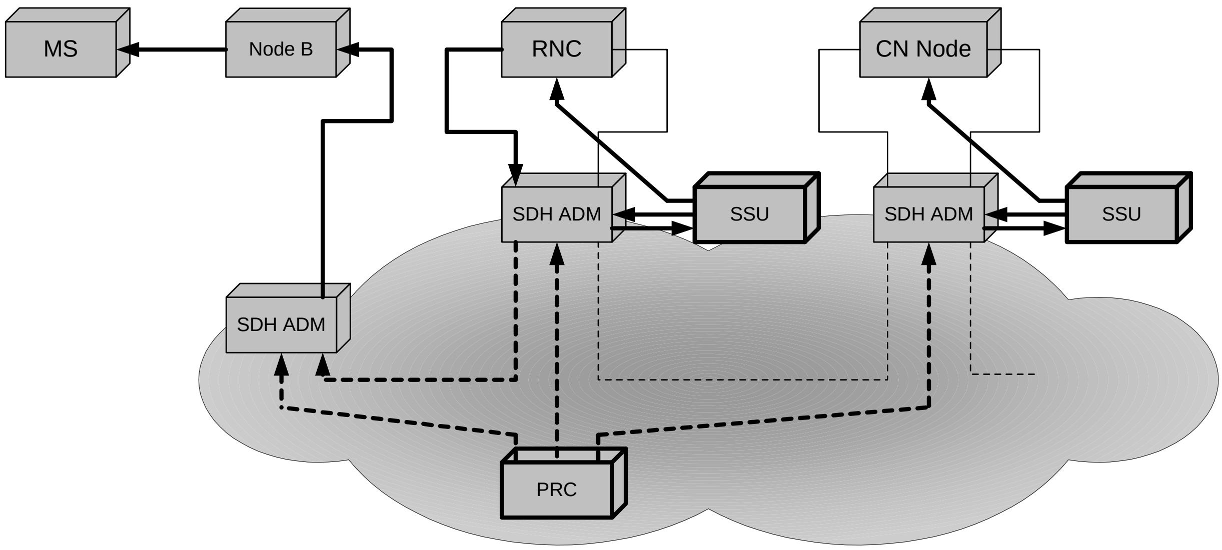

Figure 4: UMTS-FDD, trusted SDH / SONET transport network, without re-timing

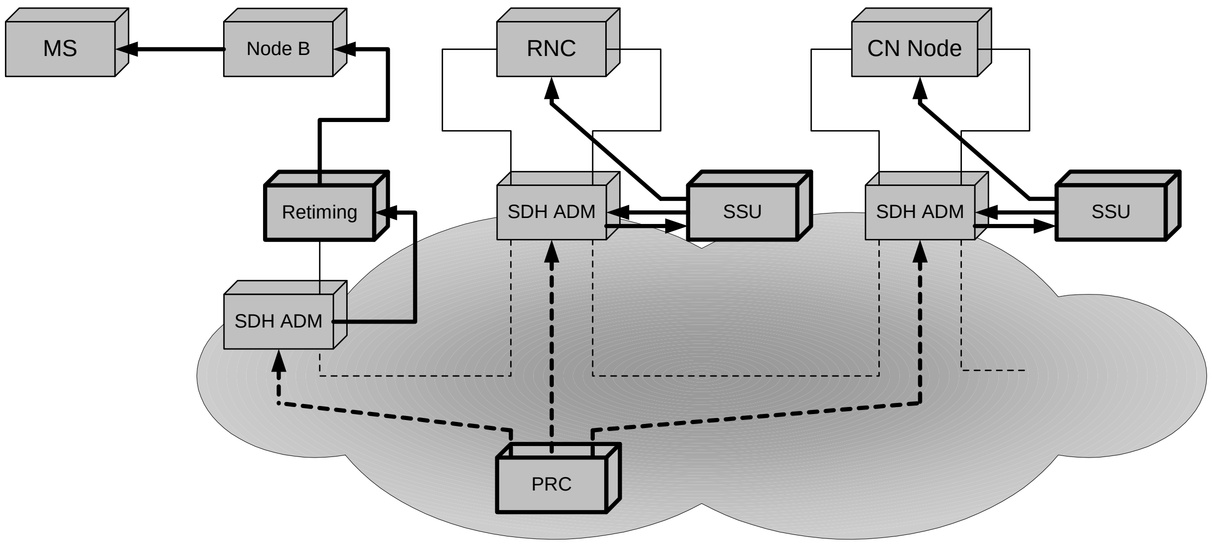

Figure 5: UMTS-FDD, trusted SDH / SONET transport network, with re-timing

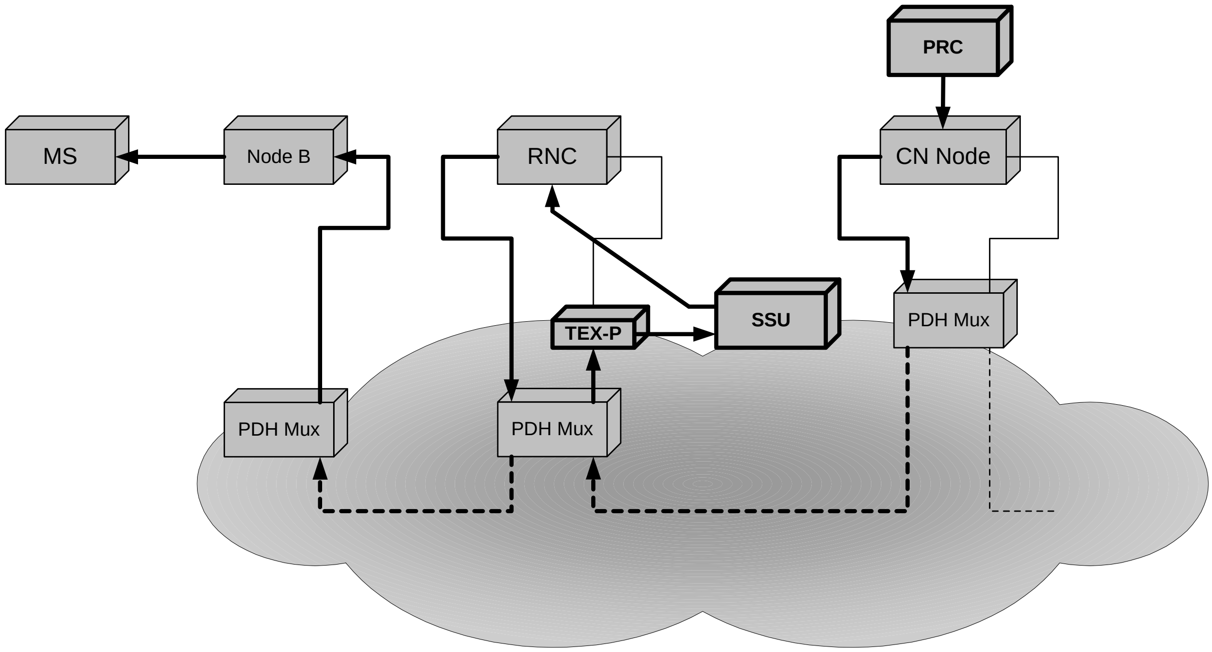

Figure 6: UMTS-FDD, trusted PDH transport network

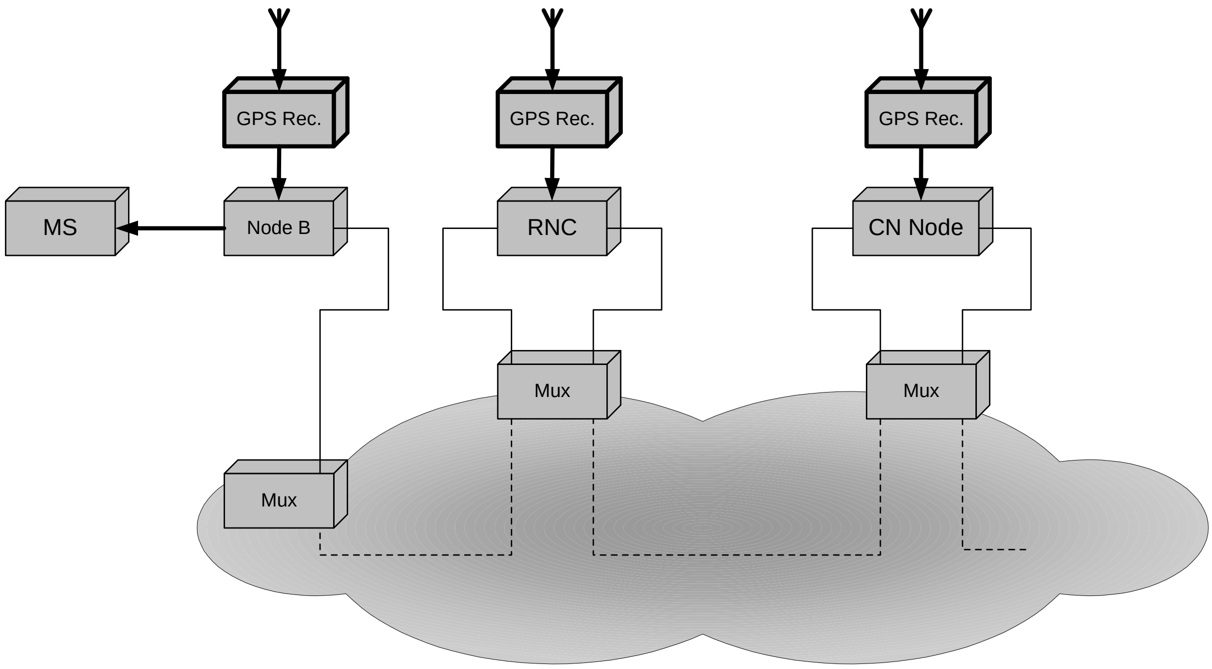

Figure 7: UMTS-FDD, leased lines

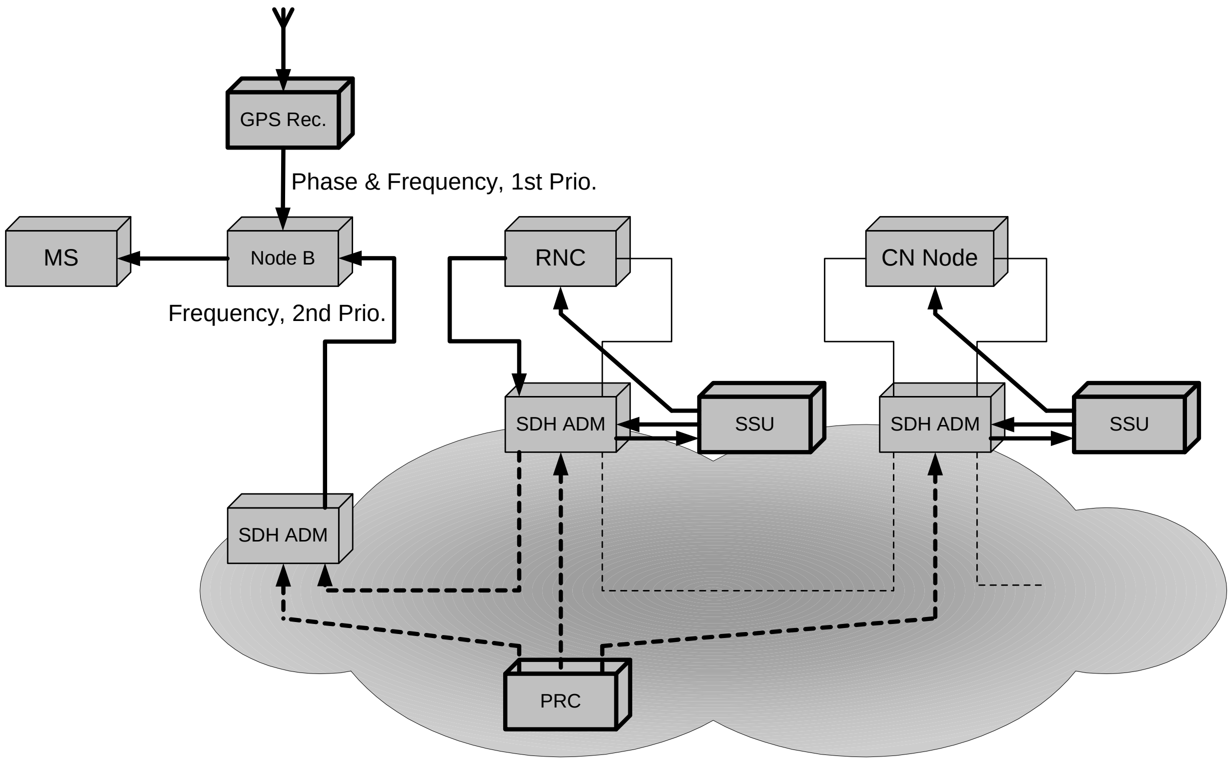

Figure 8: UMTS-TDD, trusted SDH / SONET transport network, without re-timing

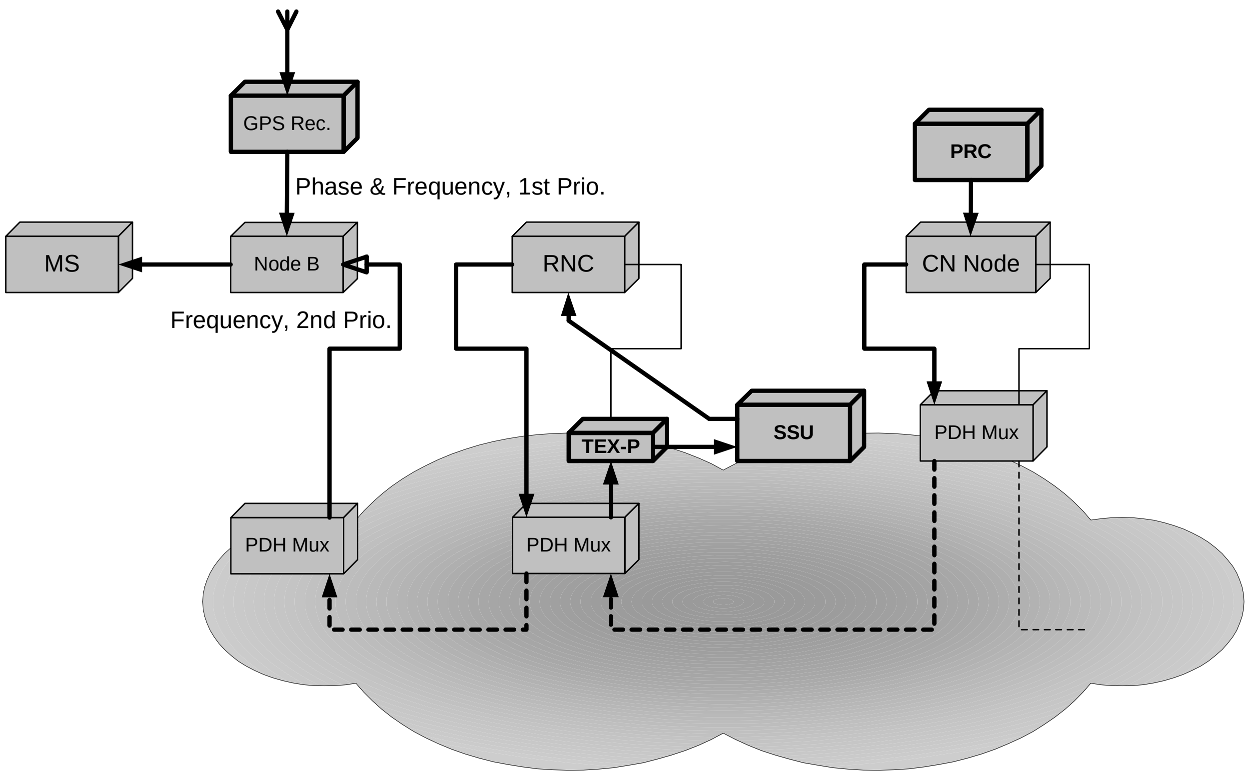

Figure 9: UMTS-TDD, trusted PDH transport network

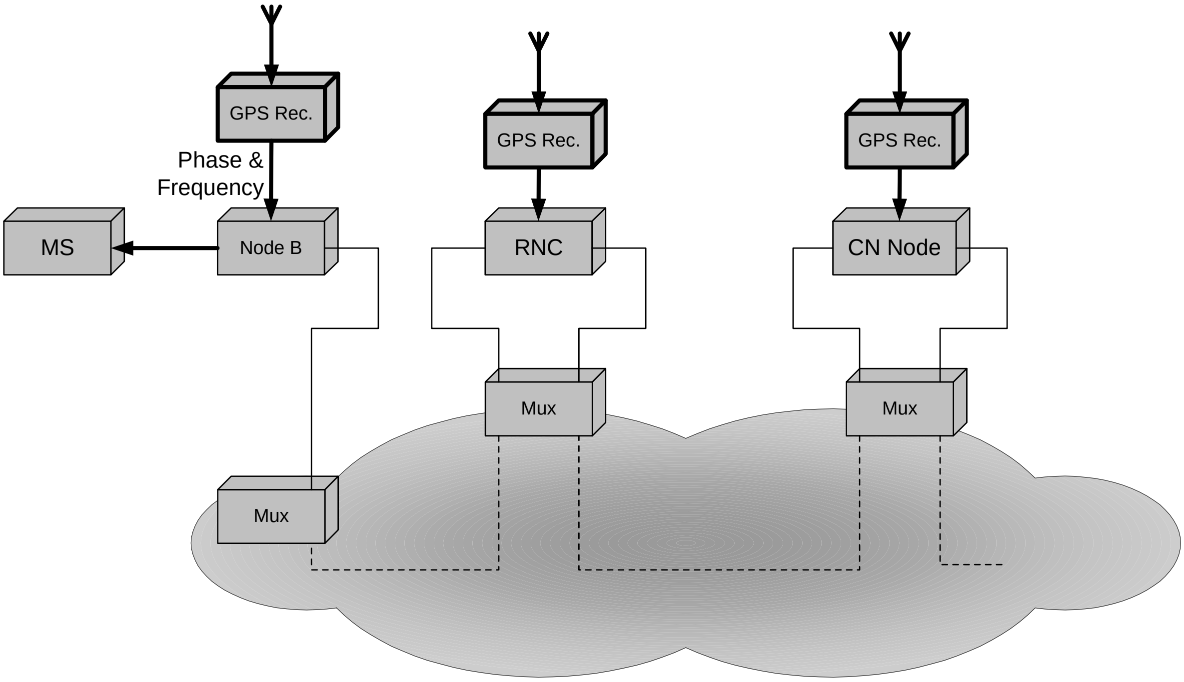

Figure 10: UMTS-TDD, leased lines

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