WHITE PAPER

“GPS-free synchronization of Digital Terrestrial TV and Mobile TV distribution networks”

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ABSTRACT

Today's society is becoming increasingly dependent on GPS timing for many critical everyday services, such as digital TV and radio distribution systems and mobile networks. The problem is that it is very easy to jam the reception of the Coordinated Universal Time (UTC) signal via the GPS. The GPS is also military controlled, which could be a concern to some countries.

This paper describes a new solution for delivery of UTC time which is independent of the GPS. The solution enables distribution of real time information over the same infrastructure that is used for transport of video, voice and data services. This solution is secure, cost-effective and can be built resiliently. Moreover it provides the accuracy needed (~1 µs) for synchronizing e.g. digital TV and radio systems or mobile networks, which has previously not been possible with traditional time transfer methods. The paper describes the new two-way time and frequency transfer method in some detail, showing how a stable and robust time representation across the network is achieved including automatic corrections for intrinsic delays and diurnal wander. Typical applications such as integrated distribution of time and video services in Single Frequency Networks for Digital Terrestrial TV and mobile TV are also described.

Introduction

Distribution of Digital Terrestrial Television (DTT) and Mobile Digital Television (MDTV) often requires a Single Frequency Network (SFN). In an SFN several transmitters simultaneously send the same signal over the same frequency channel. The aim of SFNs is efficient utilization of the radio spectrum, allowing a higher number of radio and TV programs in comparison to traditional Multi Frequency Network (MFN) transmission. An SFN may also increase the coverage area and decrease the outage probability in comparison to an MFN, since the total received signal strength may increase to positions midway between the transmitters.

In a single frequency network the transmitter stations must be synchronized to send their signals at exactly the same time to avoid interference at the receiving antennas. Today this is achieved by installing Global Positioning System (GPS) receivers at all transmitter sites. However, GPS receivers may easily be jammed, as reported e.g. by Volpe (1), and represent an additional cost in the network. The GPS is also military controlled, which could be a concern to some countries. Previously there was no alternative solution that could deliver UTC time in a large public optical network with the accuracy needed for these digital communication systems. It was also not economically feasible to build dedicated synchronization networks.

Methods for synchronization of SFN networks

GPS based synchronization

The main components of a distribution network for SFN transmission are shown in figure 1. At the headend site the MPEG multiplexer combines the program streams from various input channels into one or more MPEG transport streams in DVB-ASI format. The SFN adapter forms a mega-frame as defined by ETSI (2) for DVB-T and DVB-H, and inserts timing information in the Synchronization Time Stamp (STS). The STS contains the time difference between the latest pulse of the 'one-pulse-per-second' reference, derived from GPS, and the start of the mega-frame.

The transport equipment adapts the transport streams to the transmission network consisting e.g. of fibre or microwave links, and provides multicast connections from the headend site to all transmitter sites.

At the transmitter site the Sync subsystem will provide propagation time compensation by comparing the inserted Synchronization Time Stamp with the local time reference from the GPS receiver and calculate the extra delay needed for SFN synchronization. The GPS receivers provide both a 10 MHz frequency reference and a 1 pulse per second (1 PPS) time reference. The 1 PPS time reference is divided into 100 ns steps provided by the cycles of the 10 MHz clock. The 10 MHz system clock is assumed to be available at all nodes in the network.

The functional blocks SFN adapter and Sync system are additional elements for SFN use, and not necessary in MFN applications.

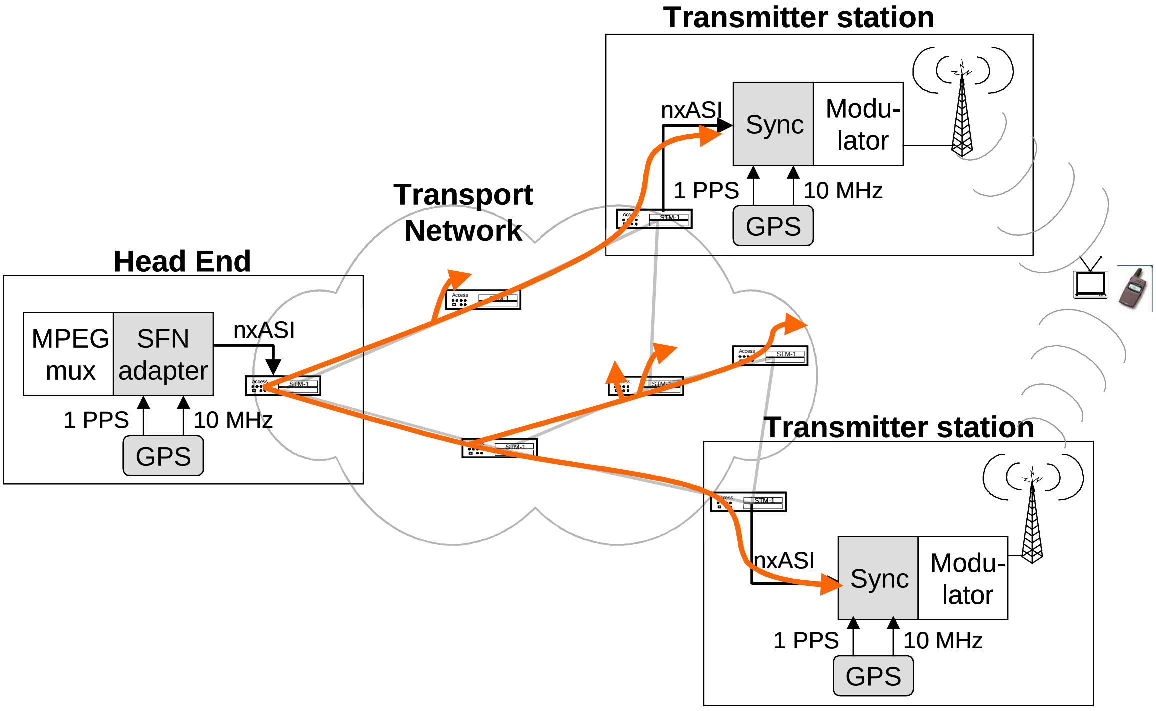

Figure 1 – Distribution network for SFN transmission using GPS synchronization.

Alternative solutions

The European Union has for a long time considered launching its own ‘GPS’ satellite system, a project called Galileo. Launching and maintaining several tens of satellites is a major project, which becomes quite expensive, a reason why the project has been continuously delayed. However, such a solution would still be sensitive to jamming and spoofing like the GPS system. The signal transmitted from a satellite can be compared to light from a light bulb seen from the other side of the Atlantic, i.e. it is a very weak signal.

Over IP networks and in the Internet, a protocol called NTP (Network Time Protocol) is used to synchronize different clocks. NTP uses time stamps sent in data messages for time synchronization. In non-dedicated networks it is difficult to reach accuracies better than 10 milliseconds using NTP, which is too low for handling synchronization of TV antennas and mobile phone systems.

An attractive solution would be to be able to distribute the real time information over an optical or microwave network that could also be used to distribute the actual user data. By distributing the UTC over a redundant optical network, jamming is not possible. Additionally, the same infrastructure could be used for data, voice and video communication. Such a solution would be cost-effective and could be built resiliently. However, traditionally time transfer over communication networks has not provided the reliability and accuracy needed (~1 µs) for synchronizing e.g. digital TV and radio systems or mobile networks.

Integrated time transfer solution

The Time Transfer option of the Nimbra™ transport platform allows highly accurate distribution of real time over the same network that carries the video signals. At the headend site the transport equipment will receive the same reference signals (1PPS and 10MHz) as the SFN adapter, see figure 2. These synchronization signals could be provided by any high-precision clock source e.g. an atomic clock or a GPS receiver backed up by an atomic clock. The time and frequency synchronization is distributed through the transport network and at the transmitter site the transport equipment will deliver the same synchronization interfaces to the Sync subsystem that was previously delivered by a GPS receiver.

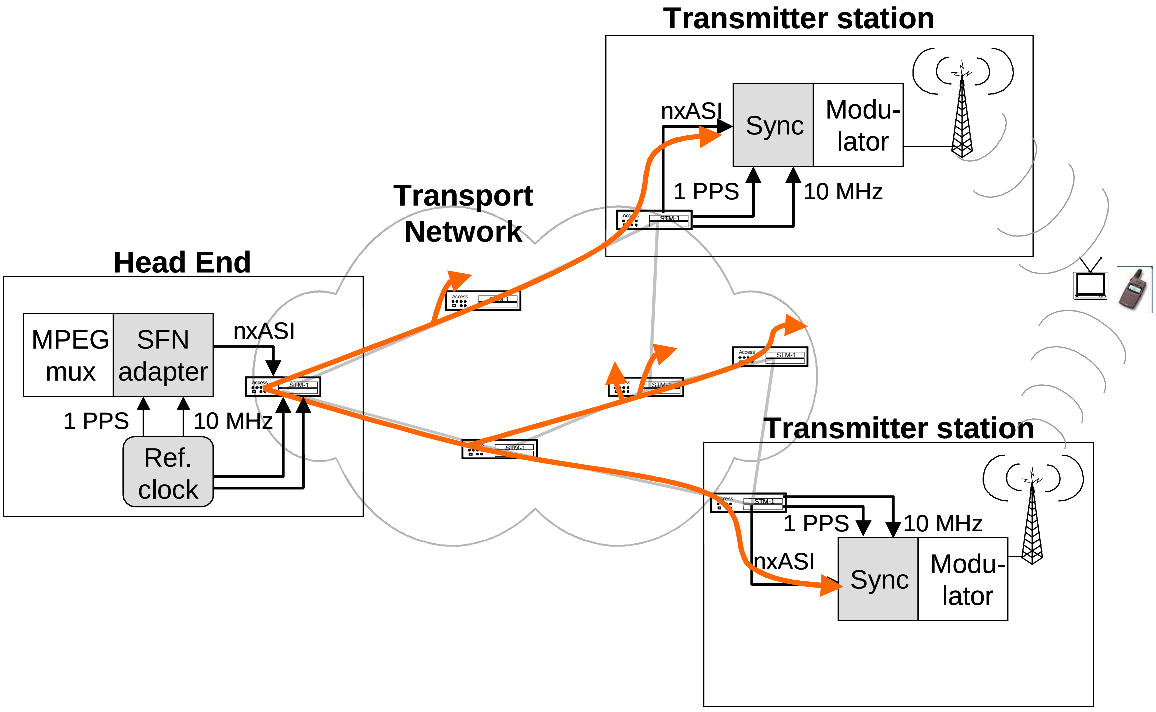

Figure 2 - Distribution network for SFN transmission using integrated time transfer

Initially, such a solution could be used as a complement to GPS in order to enhance the robustness and resilience of the UTC distribution. However, with a redundant network architecture and redundant synchronization interfaces it would be possible to fully rely on the integrated time transfer functionality, since the data signals would anyway not reach the receivers if the network would go down.

DTM Technology

Net Insight’s integrated time transfer solution is enabled by the Dynamic Synchronous Transfer Mode (DTM) technology standardized by ETSI (3). DTM is designed to provide a guaranteed Quality of Service e.g. for streaming video and audio, but can be used for packet-based services as well. Comparing it to other technologies, the transport mechanism of DTM is based on time division multiplexing and in this sense is similar to SDH/SONET, albeit more flexible and adapted to other types of traffic and applications. The signalling system on the other hand could be compared to what is available in packet-based technologies such as ATM and IP. The corresponding features in DTM however were designed to minimize manual configuration and provide simplicity in operation.

In DTM transport the link capacity is divided into fixed-size frames of 125 microseconds. The frames are further divided into a number of 64-bit time slots. As each slot is repeated 8000 times per second, the transport capacity of a slot is

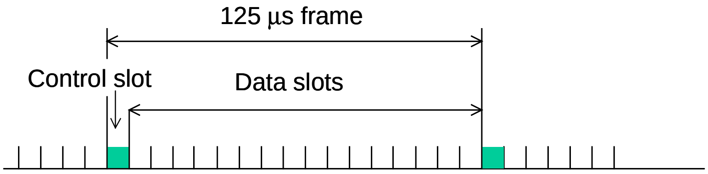

Figure 3 – Main principles of DTM frame

512 kbps. The number of time slots per frame is dependent on the bit rate. Using a bit rate of 155 Mbps the number of time slots within each frame totals 288. Slots can be used either for network-internal signalling (control slots) or for user traffic (data slots). User traffic such as MPEG transport streams may hence be carried with a granularity of 512 kbps.

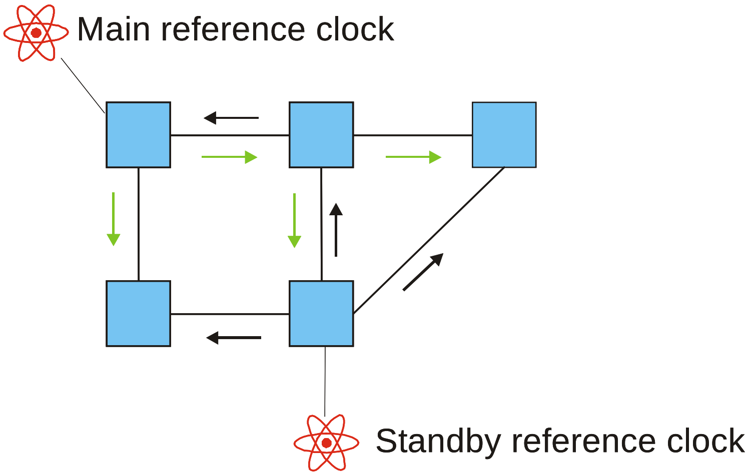

Figure 4 – A signalling protocol enables automatic network synchronization

Already in basic transport mode without Time Transfer functionality, all nodes of a DTM network are fully synchronized. The DTM based solution inherently preserves both frequency and relative phase in the network. The DTM Synchronization Protocol (DSYP) automatically determines the network synchronization topology to ensure optimum distribution of the synchronization reference clock from a master node to all other nodes in the network (figure 4). In case of failure of a synchronization path, DSYP will recalculate the synchronization tree enabling automatic synchronization restoration and avoiding synchronization loops in the network.

Two-way time and frequency transfer

With the introduction of Time Transfer functionality, every DTM node will be synchronized to maintain also the same *absolute* phase. This is obtained using a method called “two-way time and frequency transfer”. The two-way time transfer functionality works such that the source node transfers its time to the neighbouring nodes in the network, these nodes return their time and compensate so that the neighbouring nodes work with the same time as the source node. This repeats itself until all nodes in the network operate on the same time.

In basic operation the DTM Equipment Clock (DEC) tracks the 8 kHz synchronization timing received on one of the incoming line interfaces, as selected through DSYP signalling. For Time Transfer, the DEC establishes a local time scale using International Atomic Time (TAI) and maintains that time scale based on two-way time and frequency measurements in the network. The normal phase measurement of the DEC PLL now needs to include the time of the local and remote node in order to resolve the integer 125 µs ambiguity between nodes. This turns the functionality of the DEC into a Time Locked Loop (TLL).

The Time Transfer functionality is able to measure round-trip delays, compensate for intrinsic, static and dynamic delays and to synchronize TAI and UTC time between nodes. It is able to distinguish uncalibrated links and nodes from calibrated and to achieve traceable time. In order to execute the round-trip measurements and calculate the time scale errors, the measured time error of one node needs to be relayed back to the remote node. In order to provide for this information flow a 1-slot (512 kbps) channel is set up in each direction for all interfaces involved in time transfer. This is the Time Transfer Channel. Within this channel the Time

Transfer Channel Protocol transports time stamps, time difference measurements, correction factors and various statistics between nodes involved in time transfer. The protocol operates synchronously with the DTM framing.

The main principle of the two-way time transfer is illustrated in figure 5. Time is to be distributed from node A, which has received traceable time from an external clock source, to all other nodes in the network. Through the DSYP protocol node B has received the information that it is going to receive its timing reference from node A. In this example, when the local time in node A (T_{A1}) is 10:00 it inserts this time stamp in the time transfer channel and sends it to node B. The transfer of the time stamp is subject to a delay (d_{AB}) and reaches node B when the local clock in node B is 10:20 ($T_{B, Rec}$). The local clock in node A is then T_{A2}. In the same way Node B will send a time stamp to node A. In this example node B sends a time stamp when its local clock (T_{B1}) is 10:10. The transfer to node A is subject to a delay (d_{BA}) and reaches node A when the local clock in node A is 10:06 ($T_{A, Rec}$). The local clock in node B is then T_{B2}.

The following relations exist:

$$T_{A2} = T_{A1} + d_{AB} \qquad \text{..........................(1)}$$

$$T_{B2} = T_{B1} + d_{BA} \qquad \text{..........................(2)}$$

The time error T_E between the clocks in node B and node A can be expressed as:

$$T_E = ((T_{B, Rec} - T_{A2}) + (T_{B2} - T_{A, Rec})) / 2 \qquad \text{..........................(3)}$$

Inserting (1) and (2) the time error becomes:

$$T_E = ((T_{B, Rec} - T_{A1}) + (T_{B1} - T_{A, Rec}) + d_{BA} - d_{AB}) / 2 \qquad \text{..........................(4)}$$

With the actual values in the example, and assuming a symmetric delay $d_{AB} = d_{BA}$, the time error becomes $T_E = (0{:}20+0{:}04)/2 = 0{:}12$, i.e. the clock in node B should be adjusted by –0:12 to be locked to node A. It can also be seen that the delay $d_{AB} = d_{BA} = 0{:}08$ in this hypothetical case.

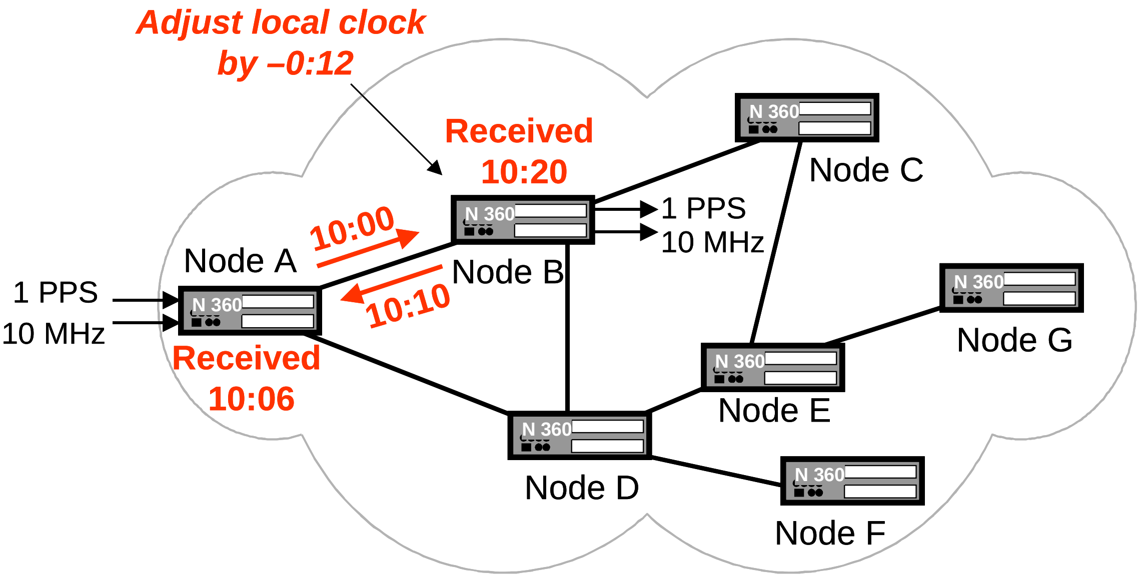

Figure 5 – Example of two-way time transfer

The time transfer function works on bi-directional point-to-point links between a pair of interfaces. In its basic mode of operation the time transfer function assumes that the delay over the link is essentially symmetric, i.e. the transmission delay from A to B is equal to the transmission delay from B to A with an accuracy of +/- 100ns. The delay over the links is allowed to vary slowly (e.g. due to changing temperatures), as long as the delay is symmetric all the time.

However, the time transfer protocol is also able to handle asymmetric delays and to divide the link into multiple segments from delay point of view:

$$d_{AB} = d_{A,\,tx} + d_{AB,\,link} + d_{B,\,rx} \qquad \text{..........................(5)}$$

where the total delay d_{AB} from A to B is the sum of the the output delay of the transmitter in node A ($d_{A,\,tx}$), the delay of the transmission link ($d_{AB,\,link}$), and the input delay of the receiver in node B ($d_{B,\,rx}$). The transmitter and receiver delays are typically known in advance and may be entered manually. If the link delays $d_{AB,\,link}$ and $d_{BA,\,link}$ are known to be asymmetric, this may also be entered manually following a calibration at the time of installation.

The DTM-based time transfer solution provides a transfer accuracy of better than +/-1.5µs over 10 hops in the transport network. To maintain this high accuracy, SDH/SONET systems that do pointer adjustments cannot be used as underlying links. It is also not possible to run Time Transfer on links that use an intermediate system with automatic protection switching, since this can introduce a sudden change in the transmission delay.

Resilience

In case of link failure, the DSYP protocol will automatically reroute the time transfer signals using an alternative path through the network. In the example in figure 5 node B normally receives its time reference from node A. If the link between nodes A and B fails, DSYP will change the time distribution path to A-D-B, i.e. node B will now receive its time reference from node D.

Several sources such as atomic clocks, located far apart from each other, may be used to create a system with full redundancy. The interfaces used at the ingress and egress nodes (1 PPS and 10 MHz) may also be duplicated for redundancy purposes.

Since the time transfer is fully integrated with the data transfer, there will always be a path through the network for the time transfer signals if there is a path for the data signals. This means that it is possible to fully rely on the integrated time transfer functionality, since the data signals would anyway not reach the receivers if the network would go down.

Implementation

Figure 6 – Nimbra 360

The time transfer functionality has been implemented in Net Insight's Nimbra platform, which is a multiservice transport solution optimized for demanding video applications. In DTT and DVB-H applications, native DVB-ASI signals are inserted directly into the Nimbra products at the headend and are multicast across the network to the transmitter sites, without the need for network to ASI adapters. To maximize utilization, only the payload of the ASI signals is sent over the network. The platform accepts ASI signals from 2 to 212 Mbps. Adding E1 cards and the unique E1 multicast makes it easy to distribute digital radio and DMB signals. IP video, data, AES/EBU audio contribution services, and voice traffic may be transported over the same network used for DVB distribution, which significantly reduces total infrastructure cost. Time transfer is supported regardless of the traffic signals carried.

Figure 6 shows the Nimbra 360 multiservice access switch where dual pairs of time transfer interfaces (1PPS and 10MHz) have been integrated on the chassis. The time transfer ports are configurable to support either input or output signals. The chassis also comes with integrated Gigabit Ethernet and multirate SDH/SONET ports. Two slots are available for plug-in modules for other services or trunk interfaces. Figure 6 shows the product equipped with two 8-port ASI cards, allowing for up to 16 ASI transport streams to be carried e.g. over an STM-1 interface together with the time and frequency synchronization signals.

Conclusions

This paper has described a novel, integrated solution for high-accuracy distribution and synchronization of real time. The solution has the following main advantages:

- **GPS independence**
  The time and frequency transfer solution may replace or complement the GPS for TV distribution in SFN networks. GPS has high accuracy but has the disadvantages of being military controlled and that it is possible to externally jam the signals. Previously there was no alternative solution that could deliver UTC time in a large public transport network with the accuracy needed.
- **Integration of time and traffic distribution**
  The solution enables timing information to be sent over the same infrastructure that provides distribution of video and audio signals to the transmitter sites. The integrated time transfer solution introduces a more secure and less costly way of achieving the necessary SFN synchronization.
- **Fault tolerance**
  The synchronization protocol (DSYP) automatically determines the network synchronization topology to ensure optimum distribution of the synchronization reference clock from a master node to all other nodes. In case of failure of a synchronization path, DSYP will recalculate the synchronization tree enabling automatic synchronization restoration and avoiding synchronization loops in the network. DSYP also supports standby reference clocks at geographically separated locations.

References

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