Submicrosecond filtering of packet delay variation in video stream over IP metropolitan area network

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***Abstract*—Broadcasting of digital video signals uses large spectral area. In order to reduce the cost, broadcasters are optimizing their radio network. They build Single Frequency Network (SFN). To maintain efficient Quality of Service (QoS) to the end user, accurate time synchronization and frequency syntonization is needed between transmitter sites. This function is now fulfilled with local GPS slaved clocks. In order to secure this key service, lower the cost and enable extension in GPS shaded area, an alternate source of synchronization is requested.**

Version 2 of IEEE 1588 protocol is promising. The application of this protocol on mixed digital voice and data Metropolitan Area Network (MAN) infrastructure for mobile services has already proof reliability in operational backhaul network.

The deployment of new services for Digital Video Broadcast (DVB) is demanding for synchronization services that can be implemented on existing dedicated video over IP transmission network. The request is for ppb frequency accuracy and micro second time accuracy transfer. This level shall be maintained with video digitally coded stream on the same media.

The variable size of DVB-TS[1] video stream and the buffering scheme inside network switches generates milliseconds Packet Delay Variation (PDV) that destroy the transfer performances of IEEE 1588 dedicated messages.

We introduce proper end-user slave clock filtering. This filtering is applied to raw data delay measured in real broadcasting network. The results show a very efficient improvement that exceeds relative frequency accuracy level up to 1.5×10^{-10} and sub-micro second phase wander. Different stress conditions are tested and the filtering is optimized for minimum slave clock frequency source stability to optimize cost.

The results are fitting broadcasting network requirements with some implementation constraint. This alternative synchronization source can secure critical synchronization service.

[1] Digital Video Broadcast – Transport Stream.

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I. Introduction

Broadcast for the 21st Century (B21C) project is dedicated to ease introduction of new technologies in the broadcasting infrastructures. B21C propose new standards, standards improvements and standard proof through trials. It addresses all current DVB areas:

- DVB-T2 for enhancement of ground fixed terminals for high definition video;
- DVB-SH for handheld terminals with satellites transmitters;
- DVB-H for handheld terminals with terrestrial only transmitters.

The deployment of each of these standards will commit operators to upgrade the DVB broadcast network to deliver high quality of service requested by end users. Synchronization is one of the services that are request to be improved in order to minimize cost of ownership.

II. Synchronization requirement for SFN broadcast network

A. *Synchronization at the air inteface*

DVB network air interface is increasingly switching to Single Frequency Network (SFN). In opposite to multiple frequency network, SFN enable bandwidth optimization and efficient use of frequency spectrum all over a large geographic area. It also simplifies the transmitter cells roaming for mobile terminals.

Video data are transmitted over radio on burst mode. The data burst in headed with a data synchronization scheme following a guard interval. All transmitters on the same SFN area shall transmit the synchronization scheme at the same time. The comparison of the time of arrival of mixed radio transmission in the terminal enables it to choose the first incident data (Figure 1). This function minimizes decision complexity for terminal handover.

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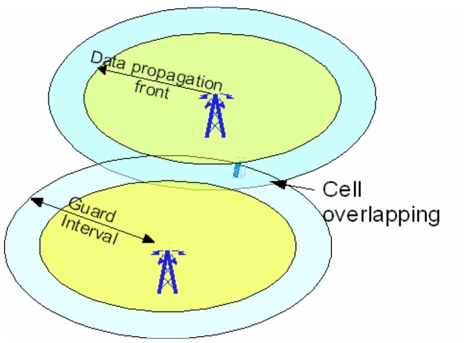

Figure 1. DVB transmission scheme in SFN network.

The guard interval duration is directly limiting the synchronization error budget in the air transmission network. Different modulation scheme are supported by the DVB. For example, Table I gives some common values in SFN 8K network.

TABLE I. GUARD INTERVAL DURATION VERSUS MODULATION SCHEME

GI Duration	Modulation
224 µs	8K 1/2
112 µs	8K 1/4
56 µs	8K 1/8
28 µs	8K 1/32

In order to avoid time varying interference between adjacent cells signals, the radio signal shall be syntonized over the SFN area. So transmitters shall be both synchronized to a common time scale and syntonized to a common frequency reference (Figure 2).

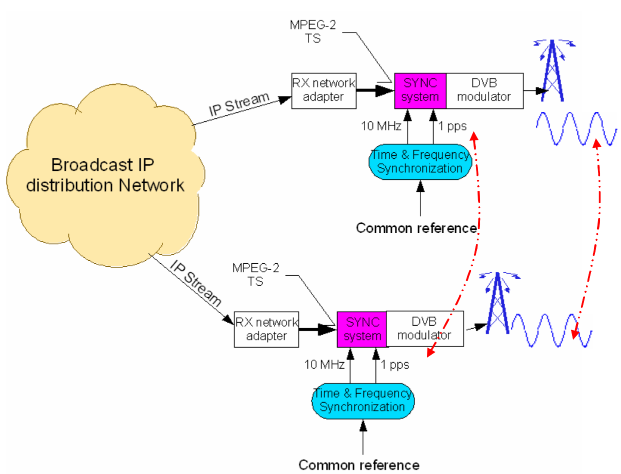

Figure 2. DVB transmitters synchronization and syntonization.

Common best practice in network architecture is to set a 10% synchronization reference error budget relative to guard interval duration. This results on a 3µs maximum error between 2 transmitters on the same SFN area. So local time references shall be maintained with 1µs maximum error. On the frequency alignment side, experiments result in maximum differential frequency error of 1×10^{-9}.

B. Synchronization through video transport network

Video and sound is digitized at content creation level. MPEG[2] format is used. Then it is delivered in real time or on demand through a fully IP network. MPEG format is then encapsulated in the transfer stream multiplex. The packet sequence are then concentrated for transmission through wide area heterogeneous network. The multi-support routing and network switching can disrupt chronology of the packet stream. It must then be rebuilt at the distribution network ends, near the transmitters before air modulation is performed (figure 3).

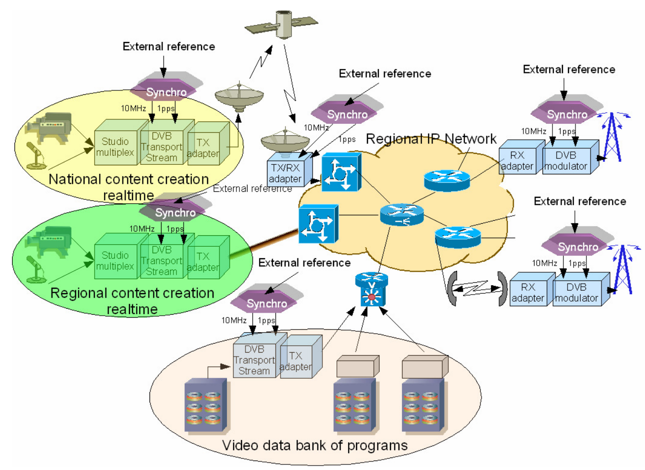

Figure 3. Packet encapsulation and transport to Transmitter stations.

This highlights the synchronization requirement all over the transmission chain, from the content creation to the air delivery.

III. SYNCHRONIZATION SERVICE OPTIMIZATION

Already installed network are using Global Positioning System (GPS) remaining on satellites signals for both time and frequency alignment on each Transmitter.

As long as network are augmenting, the operators are looking for lower cost of ownership, improved quality of service, increased availability and reliability and third party independence. They seek for redundancy in synchronization source to minimize vulnerability of the network. The Synchronization issue task force of B21C helps to identify alternative source and set relevant study to recommend their implementation.

[2] Moving Picture Experts Group.

Four candidate technologies have been evaluated regarding their time and frequency transfer capabilities:

- GNSS: Global Navigation Satellite Systems, including legacy GPS, are (or will) all providing accurate time to all point in view of the sky over the Earth. The derivation of successive time transfer or direct carrier signal measurement provide frequency accuracy that over perform the requirement.
    - Pro: GNSS systems availability is good and is increasing. They are in replenishment, upgrade or development like GPS, GLONASS, Galileo and COMPASS. Time information is very accurate. Coverage extends all over the Earth. Systems are mature.
    - Con: Accessibility is limited to open sky view. Reliability is not under control. The systems are vulnerable to failure or local jamming. Total life cost of ownership is not as cheap as desired because of environment vulnerability and antenna installation costs.
- Synchronous Ethernet: This technology is standardized under ITU-T G.8261. The core network transmission clocks are synthonized from end to end.
    - Pro: Provides very accurate frequency alignment with long term stability.
    - Con: Does not provide time transfer. The implementation requires the renewal of all the network elements to support updated hardware.
- NTP: Network Time Protocol has been standardized for decade with IETF RFC 1305. It enables time transfer from end to end at UDP/IP layer over Internet network. This is a very widely used service over open Internet.
    - Pro: Time stamping distribution is performed with very low impact on the other services. Syntonization is calculated from successive time transfer. It is a very mature technology. It is a very low cost technology.
    - Con: Syntonization performances are limited to long term regarding to jitter data path delay mitigation post processing capability. Synchronization performances through large area network are limited to 1 to 10ms due to lack of network delay compensation.
- IEEE 1588v2: This protocol has been standardized in July 2008. It is also known as PTP: Precise Time Protocol. This is a packet based technology like NTP, but the time stamp distribution is done with unitary delay path compensation (Figure 4).
    - Pro: Network elements unitary delay can be removed or compatible elements. Time transfer performances up to 100ns with renewed compatible network elements. Syntonization capabilities commensurate with integration time. Delay path instabilities over time shall be limited with topologies and network services.
    - Con: Propagation asymmetry variations over time are not compensated.

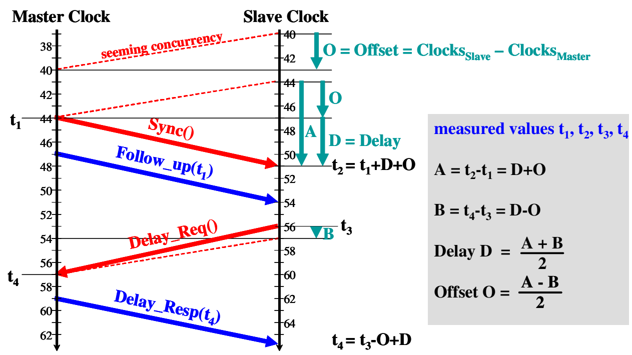

Figure 4. IEEE 1588v2 unitary delay path compensation.

The result of the comparison is that the IEEE 1588v2 protocol has been chosen for study and analysis.

IV. Tests on IEEE 1588 v2

A. *Tests definition*

In order to master the implementation impact on the broadcast network, we target to validate performances over both conventional network and IEEE 1588v2 compatible network.

Some tests have been performed earlier over general purpose IP IEEE 1588v2 compatible network. Though it was small extension network, they confirmed the performances expected from the standard. Further tests will be done in more extended network later.

Tools for demonstration of end to end synchronization and syntonisation transfer performances have been built. This is a tests platform. The architecture is shown in figure 5. It is defined to measure the capabilities of PTP clocks demonstrators. PTP clocks demonstrators are fully IEEE 1588v2 compliant hardware and software platforms. They can be set as master or slaved clock.

The test platform is versatile enough to experiment Master to Slave synchronization with parametric tests on:

- Introduction of a variable load MPEG video traffic using UDP multicast encapsulation;
- Test different path delay variation and switching;

- Test different priority services like VPLS[3] that an upper layer to MPLS[4] adapted for multipoint connectivity adapted to video network characteristics.

The target is to get a clear overview of the behavior of PTP according to the different network features: architecture, events, settings, concurrent traffic.

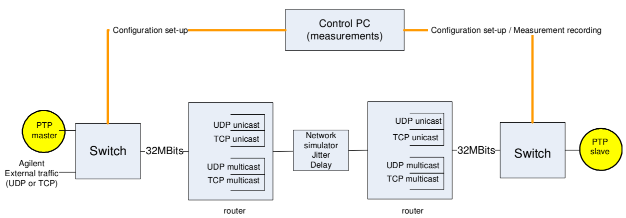

Figure 5. IEEE 1588v2 test platform.

The Table II details the different settings that are tested on the platform.

TABLE II. NETWORK SETTINGS FOR TESTS

Traffic management Traffic management	VPLS UDP		VPLS TCP		VPLS MPEG TS +TCP	
Primary/secondary Sequence	No	Yes	No	Yes	No	Yes
Interruption / network failure (impact on buffer)	0 50ms 300ms 1 s 3 s	0 300ms 3 s	0 50ms 300ms 1 s 3 s	0 300ms 3 s	0 300ms 3 s	300m 3
Jitter	0 1 ms 10 ms	0 1ms 10 ms	0 1 ms 10 ms	0 1ms 10 ms	0 1 ms 10 ms	1m 10 m
Test duration (1 p/sec shift to 100 p/sec)	15 min/test	30 min/test	15 min/test	30 min/test	15 min/test	30 min/test
Total duration (min)	120	150	120	150	120	150
Total duration (hours)						**13,**

B. *Tests on IEEE 1588 v2 non-modified network*

In order to optimize performances over a conventional network, we collect the data from each PTP measurement on the platform in slave clock. The data are then post processed in a tree step mode:

- Pre-filtering for inconsistent path delay measurement rejection;
- Filtering for smoothing and averaging the time transfer data;
- Oscillator smoothing in order to regenerate short term frequency stable signal and wipe out any erratic network behavior.

Six different types of oscillators regarding their drift and temperature sensitivities are used for post processing. Details are given in Table III.

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[3] Virtual Private LAN Service.

[4] Mulprotocol Label Switching.

TABLE III. OSCILLATORS CHARACTERISTICS

Quartz	Aging: Frequency stability per day	stability function of temperature
XO	5,00E-07	1,00E-04
VCXO	5,00E-08	3,00E-05
TCXO	5,00E-08	2,00E-06
MCXO	1,00E-09	1,00E-08
OCXO	2,00E-10	1,00E-09
DOCXO	1,00E-10	4,00E-10

Figure 6 shows collected and post processed data for a no network delay variation added and data stream of 3Mbits. The network collected data are at 21.4% inside the 500ns interval to the average path delay. Table IV summarizes results. The last 4 columns listed performances of synchronization signals post processed at the output of the slaved clock.

TABLE IV. POST PROCESSED RESULTS, DELAY = 0MS, JITTER = 0MS, TRAFFIC = 3MBITS/S

Oscillator	Data aquisition : % < 500ns	TDEV :	MTIE:	Sync error : % < 500ns:	Frequency error : % < 10^-9
XO	21,40533507	9,24338E-06	0,00021169	1,538976246	100
VCXO	21,40533507	2,77291E-06	6,35127E-05	1,973904316	100
TCXO	21,40533507	1,84837E-07	4,24605E-06	18,60153898	100
MCXO	21,40533507	1,89618E-09	2,82982E-07	**100**	**100**
OCXO	21,40533507	1,69008E-09	2,73377E-07	**100**	**100**
DOCXO	21,40533507	1,69007E-09	2,72737E-07	**100**	**100**

Figure 7 shows collected and post processed data for a 5ms network delay, 1ms range network delay added variation and data stream of 3Mbits. The network collected data are at 0% inside the 500ns interval to the average path delay. Table V summarizes results. The last 4 columns again listed performances of synchronization signals post processed at the output of the slaved clock.

TABLE V. POST PROCESSED RESULTS, DELAY = 5MS, JITTER = 1MS, TRAFFIC = 3MBITS/S

Oscillator	Data aquisition : % < 500ns	TDEV :	MTIE:	Sync error : % < 500ns:	Frequency error : % < 10^-9
XO	0	8,45647E-06	0,000213811	0,498726655	100
VCXO	0	2,5404E-06	7,10601E-05	0,997453311	100
TCXO	0	2,33302E-07	4,11935E-05	10,97198642	100
MCXO	0	1,62502E-07	3,90705E-05	27,57852292	100
OCXO	0	1,62508E-07	3,90609E-05	27,57852292	100
DOCXO	0	1,62508E-07	3,90603E-05	27,57852292	100

Results are fitting with target performances frequency syntonization accuracy for high jitter in the delay path, but time transfer precision is not fitting in this poor network conditions. The stability of the oscillator in slave clock does not improve time accuracy enough for network path inconsistency mitigation.

V. CONCLUSION

As tests results are not fitting the target performances on all conditions, we propose to mitigate conclusion regarding the network components and services.

For conventional legacy network, slaved clock must include a high performance oscillator, and path delay variation must be limited to low levels or compensated through filtering. Path delay can be lowered by factor >300. VPLS service is recommended to be used for a non dedicated synchronization distribution network. Thus it minimizes the impact of other traffic by insuring a quality of service (minimum jitter, minimum delay). Complementary test shall be performed for validation on a real DVB network (path delay variation, filtering and network configuration).

For a next generation network with IEEE1588-V2 compatible network elements all along the path, all synchronization and synthonization broadcast requirements are fulfilled. This is the preferred approach to ensure the highest availability.

ACKNOWLEDGMENT

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VI. ANNEXE: FIGURES OF DETAILED NETWORK RAW DATA AND FINAL PROCESSING STEP

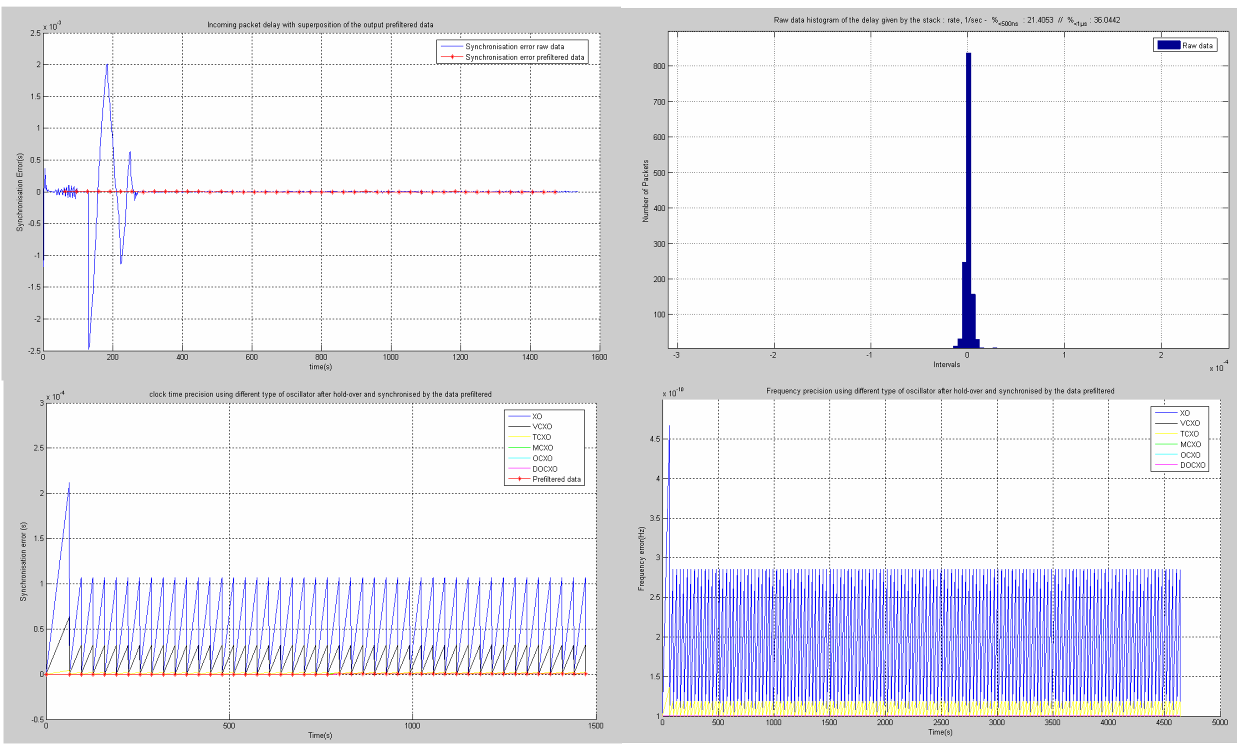

Figure 6. Test settings: DELAY = 0ms, JITTER = 0ms, Traffic = 3Mbits UDP

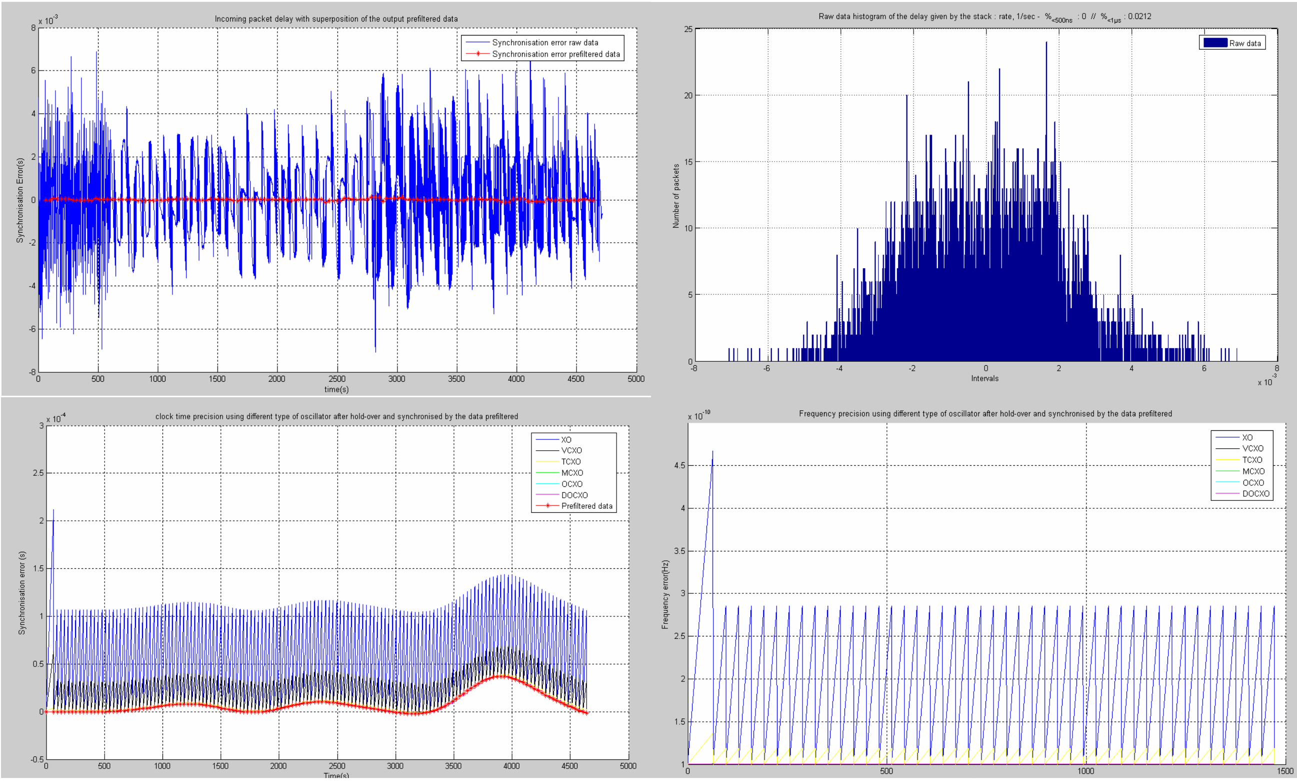

Figure 7. Test settings: DELAY = 5ms, JITTER = 1ms, Traffic = 3Mbits UDP