A facility and a web application for real-time monitoring of the TTC backbone status

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Abstract

The Timing Trigger and Control (TTC) system distributes timing signals from the LHC Radio Frequency (RF) source to the four experiments (ATLAS, ALICE, CMS and LHCb). A copy of these signals is also transmitted to a monitoring system, installed in the CERN Control Centre, which provides continuous measurement of selected parameters. A web application has been designed to ensure real time remote monitoring and post-mortem analysis of these data. The implemented system is aimed at providing a tool for a fast detection of TTC signal abnormality and unavailability which results in reliability improvement of the whole TTC dependent infrastructure.

The paper discusses the architecture of the monitoring system including measurement setup as well as various concerns of data acquisition, storage and visualization.

I. LHC TIMING

The timing and synchronization of the LHC experiments is directly extracted from the timing signals used by the Radio Frequency (RF) system to capture and control the beams circulating in the accelerator. The TTC system, in charge of the distribution of these signals, is thus a key element for a successful operation of the experiments, from front-end modules to data acquisition. [1,2]

A. *TTC backbone*

The main source of the timing signal is strictly related to the location of the (RF) equipment. As for the LHC, the superconductive RF cavities have been located at one place only (POINT4 – Echenevex)[3], the signals do not get distributed across the tunnel. Instead, they are transmitted through optical fibre backbone presented on the figure 1. [4]

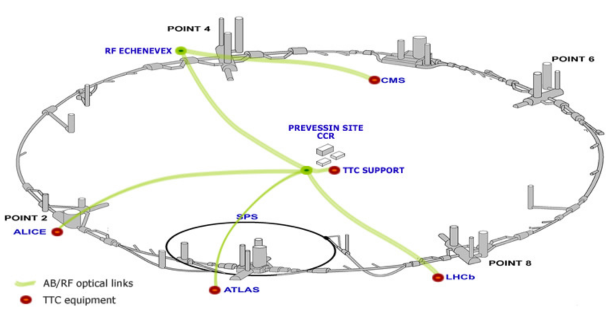

Figure 1: TTC backbone

Once generated at POINT4, the signals are transmitted to the CERN Control Centre (CCC) at the Prevessin site and from there to the experiments (ALICE, ATLAS and LHCb). The only one exception is CMS. As it is very close to POINT4, it receives the signals directly through the tunnel.

B. *TTC signals*

The TTC timing signals consist of three bunch clocks (BC1, BC2 and BCREF) and two orbit signals (ORB1 and ORB2).

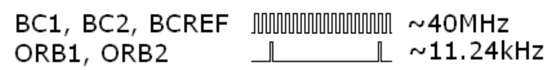

Figure 2: RF-TTC signals

For each ring the Bunch Clock is a square wave at the RF frequency divided by 10. Its rising edge has a fixed delay with respect to bunch passage. This delay is reproducible from run to run. Each BC is always locked to its related beam.

For each ring the Orbit is a sequence of 5 ns long pulses at the Revolution Frequency. The delay of each Orbit versus its corresponding Bunch Clock is also reproducible from run to run. The Orbit signal is always locked to the revolution frequency of its related beam [5].

The parameters monitored by the system that we have implemented are extracted from these five timing signals.

II. TTCPAGE1 – MAIN OBJECTIVES

As the reliability of the distribution of the LHC timing signals to the experiments is of great importance, there has been a need for a global monitoring system with an accurate real time and post-mortem analysis facility. The designed system is called TTCpage1 and gathers qualitative data describing the status of the timing signals all over the accelerator and makes them available anytime to the TTC support team and the experiments.

It also allows us to ensure that the hardware responsible for the transmission of these signals is behaving as expected.

III. MONITORED PARAMETERS

To ensure a proper operation of the TTC system it is important that the signals are monitored all their way from the place where they get generated down to all of the experiments. The status of each receiver and transmitter has to be taken into account in order to present a complete backbone picture.

On the other hand, the TTC distribution is based on a passive fibre network hence the signals received at the CCR (Control Centre Rack Zone) are a copy of the signals received by the other experiments. Performing measurements like cycle-to-cycle jitter or skew jitter at the CCR gives a valuable

Table 1: Summary of the monitored parameters

Status of TTC backbone receivers and transmitters (published via DIP)	Jitter measurements of the signals (performed by the "jitter scope")	High precision frequency measurements	Continuous track of registers of RF2TTC and RFRx VME Modules in the TTC support rack	Signal phase shift versus temperature (performed by the "driftScope")
Transmitter optical power value at: POINT4, CCR ***Receiver average frequency value at***: CCR, ALICE, ATLAS, CMS, LHCb	***Skew jitter***: BC1 VS BCREF, BC2 VS BCREF, BC1 VS ORB1, BCREF VS ORB1 ***Period jitter:*** ORB1 ***Cycle to cycle jitter***: BC1, BC2, BCREF	***Frequency value***: BC1, BC2, BCREF absolute precision up to 1Hz, all synchronized with 10 MHz GPS(GMT)	***Locking status of QPLLs*** from RF2TTC, ***Beam mode*** from BST ***Frequency average*** at the RFRx receiver ***ORB2 period in BC counts***	***ORB1 roundtrip delay*** from CCR to ATLAS versus ***outside temperature value*** (sensor values from the DIP)

indication to the experiments on the quality of the signals at other reception points.

The table 1 presents a summary of the monitored parameters together with related measurement device. They will be presented with more details in the following subsections.

A. *TTC backbone global status - receivers and transmitters*

Two pairs of transmitters and six pairs of receivers installed along the TTC backbone are being monitored. The monitoring of these modules has been simplified to general status verification.

Table 2: TTC backbone transmitters

Transmitter name	**Location**
SR4TX	POINT4 – Echenevex, main source
RFCCRTX	CCR (Prevessin), outgoing signal (to ALICE, ATLAS, LHCb and TTC support crate in CCR)

Table 3: TTC backbone receivers

Receiver name	**Location**
RFCCRRX	CCR, incoming signal from POINT4
CCR	Signal received by TTC support crate – monitoring system
ALICERX	ALICE experiment
ATLASRX	ATLAS experiment
CMSRX	CMS experiment
LHCBRX	LHCb experiment

A pair of receivers consists of two RF_RX_D VME modules [6]. The status of each of the input channels is determined by an internal frequency counting register. The values being readout are not very accurate, however they are very useful for indicating if the signal frequency belongs to an accepted range. The ranges have been defined as 40.056 – 40.114 MHz for the bunch clocks and 11.245 – 11.246 kHz for the orbits.

Three frequency meters, described with more details in the next sections, perform the task of tracking the frequencies with higher precision.

The RF-TTC backbone transmitters being used (RF_TX_D)[7] in comparison to the receiver modules provide different structure of internal registers. In this case frequency values of transmitted signals are not calculated. However, the optical power being emitted by each channel is stored in registers and monitored. As in the previous case the values are very useful for general status validation, not for qualitative measurements.

The values of parameters extracted from the registers described above are being read out every 10 seconds and stored in a database.

It has to be mentioned that for the receivers the internal registers are updated with some delay with respect to the events occurring on monitored signals. This behaviour is caused by the frequency counting method based on statistics. The delay can be up to around 2 seconds for the Bunch Clock frequency and to 30 seconds for the orbits.

A full picture of the state of all these transmitters and receivers is very useful to get a first overview of the status of the full distribution network. It is however not providing any qualitative information about the received signals. This task is performed by accurate frequency meters and RF2TTC module housed in the TTC support rack in the CCR and will be described in the following sections.

B. *TTC support rack in the CCR*

In addition to the global TTC status monitoring described in the previous subsection the great majority of measurements is being performed by devices connected to the TTC support crate in the CCR (figure3).

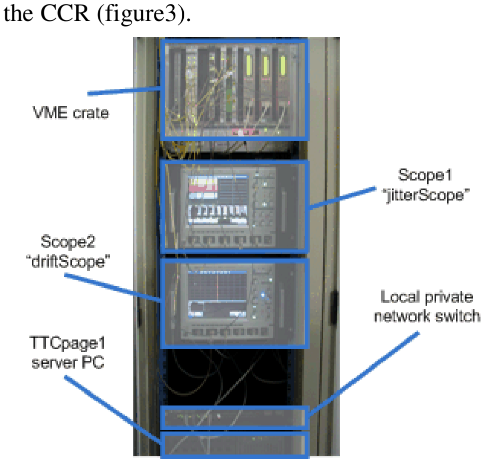

Figure 3: Measurement equipment (VME crate with frequency meters, VMEbus controller and slave modules, two oscilloscopes, local network switch and Server PC)

1) Jitter measurements – "jitterScope"

A high-end oscilloscope has been installed to provide continuous measurement of TTC signals jitters. Eight parameters listed in the table 4 have been chosen for continuous monitoring.

Table 4: "jitterScope" measurement parameters

Group	Parameter
P1	BC1 cycle to cycle jitter
P2	BC2 cycle to cycle jitter
P3	BCREF cycle to cycle jitter
P4	BC2 vs BCREF skew jitter
P5	BC1 vs BCREF skew jitter
P6	BC1 vs ORB1 skew jitter
P7	BCREF vs ORB1 skew jitter
P8	ORB1 period jitter

The figure 4 presents measurement algorithm being used.

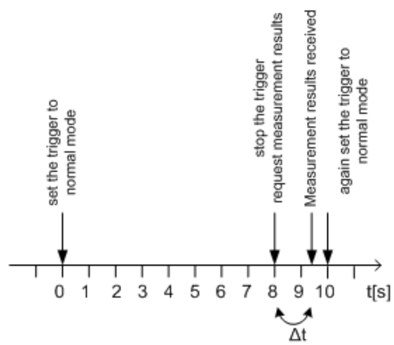

Figure 4: "jitterScope" measurement method.

Every 10 seconds a new measurement starts and data is being collected for 8 seconds. Once 8 seconds passes the statistical values such as average, peak-to-peak and standard deviation are collected and sent to the database. The statistics are cleared and next measurement starts at t=10s.

2) RF2TTC module parameters

The RF2TTC VME modules which have been installed in every LHC - TTC receiving crate act as an interface between RF optical receiver (RF_RX_D) and experiment electronics [7]. As a part of their functions they also decode messages delivered through the Beam Synchronous Timing (BST) system [8]. The TTCpage1 provides monitoring of some of the internal registers of the module. The table below presents the most important of them.

Table 5: RF2TTC converter monitored parameters

Parameter	Description
BC1 QPLL, BC2 QPLL, BCREF QPLL, BCMAIN QPLL	Status (locked/unlocked) of internal QPLLs
BST status	Status of BST message reception
BST beam mode	LHC beam mode extracted from the BST
ORB1 and ORB2 period in BC counts	Number of related bunch clock pulses per orbit period

The values of the registers listed above are read out every 10 seconds and stored in the database. To avoid any events being missed, the values of the registers are always latched when a particular condition occurs and cleared later only after reading.

There are only two exceptions from the 10 second interval. The first one is beam mode monitoring where any change of mode is being logged.

The second one is Orbit period in BC counts measurement. This task is performed with 89µS resolution (the value of period is being saved in the modules' FIFO for every orbit pulse, which for 11.24 kHz gives one measurement every 89µS). It is thus important to mention that any single Orbit signal with a period different from 3564 BC counts will be registered and displayed.

3) Frequency meters

Three high precision frequency meters based on XILINX Spartan-3 evaluation kit [10] have been developed at CERN [11] to provide high accurate frequency tracking of the bunch clocks (precision up to 1 Hz, BC ~ 40 MHz)(figure 5). These modules have a 2-slots VME form factor, and have been installed in the VME crate which provides them the required power. The modules are read out via RS232 interface. Additionally the meters have been equipped with external reference clock input. The 10MHz signal from LHC Global Machine Timing (GMT) has been used for this purpose.

A measurement is being performed every 10 seconds and results are sent to the database.

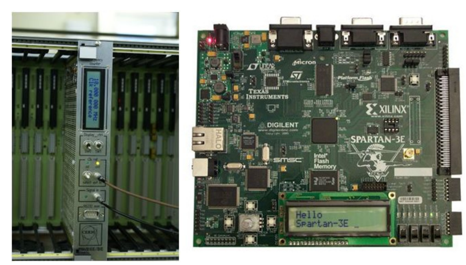

Figure 5: Frequency meter

4) Fibre transmission delay drift versus temperature variations

A spare set of fibres between CCR and ATLAS is being used for signal round trip delay measurements. These are being performed by an oscilloscope installed in the rack ("driftScope"). The results are being complemented with temperature values of the sensors provided by CERN Radiation Monitoring System for the Environment and Safety (RAMSES) metrological station.

IV. System Architecture and Data Flow

The heart of the system responsible for gathering measurement data consists of a rack mount PC (TTCpage1 server). The server has been equipped with two network adapters, one connected to the CERN Technical Network (TN) and the other one to the local TTCpage1 private network (PN).

With regard to data collecting, the TTCpage1 also provides a boot server service for the diskless VMEbus controller connected to the PN. The controller is being used for control of the RF_RX_D and RF2TTC modules.

The purpose of using PN is to ensure stability of data transmission between the server and the measurement devices (oscilloscopes, VMEbus crate controller and frequency meters).

The location of the server within TN is imposed by a need for Data Interchange Protocol accessibility, which is unachievable within the CERN General Public Network (GPN). The security has been also enhanced by configuring firewall with restrictive policies.

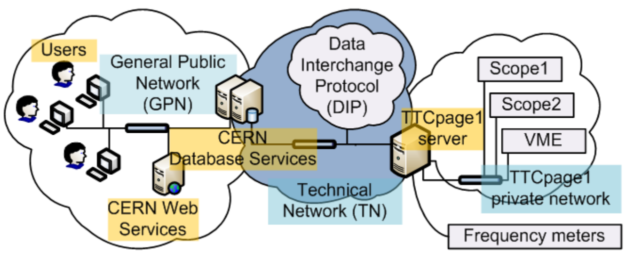

Figure 6: System architecture

Once all the measurement data is gathered it is sent to a database provided by CERN database services. While this database is used for data storage it also acts as a “gateway” between the TN and GPN. An “emergency” copy of data is also saved on local TTCpage1 hard disk array. The array has been based on RAID level 1 controller which provides simultaneous data write on two hard disk drives.

The system is mostly based on 10 second interval which is equivalent to ~1GB data volume a year. The provided database service enables the system to store all the data during the whole LHC lifetime without the need for data reduction.

A web server provided by CERN Web Services is being used for data visualization. All of the webpage logic responsible for data reception from the database and graph plotting has been implemented in PHP and JpGraph library. The user interface has been based on AJAX technology provided by GWT (Google Web Toolkit) engine.

The webpage provides data visualization of the full range of monitored parameters and additionally supports the maintenance of the service itself, by analyzing e.g. sampling intervals, error flags and other.

V. DATA GATHERING APPLICATIONS

A set of applications written in C/C++ has been developed for collecting the data.

As a part of their functions the applications provide a remote control of two oscilloscopes accessed via TCP/IP connections and Versatile Instrument Control Protocol (VICP). They make use of a General Public License (GPL) based library for controlling VICP devices.

As the Data Interchange Protocol (DIP) is used as a source of some of the monitored signals (statuses of TTC receivers, Beam mode and temperature value), the applications have been extended with DIP libraries and some interface classes providing the ability to act as both dip-publisher and dip-subscriber.

Emphasis has been put on ensuring reliability and security of the system. This includes an implementation of data buffering mechanisms in case of database connection problems, local data storage and automatic remote restart of the VMEbus controller through custom design RS232 based interface.

Email and SMS notification procedures have been added to provide fast detection of undesirable conditions and possible system failures.

VI. TTCPAGE1 – DATA VISUALISATION

The figure 7 shows the web application which has been developed. The main window area has been divided into five parts. Each part consists of a plotting area and two drop down menus for parameter and time resolution selection (e.g. last 1h, last 24h etc.) The webpage is being continuously refreshed every 10s (while working in real-time monitoring mode).

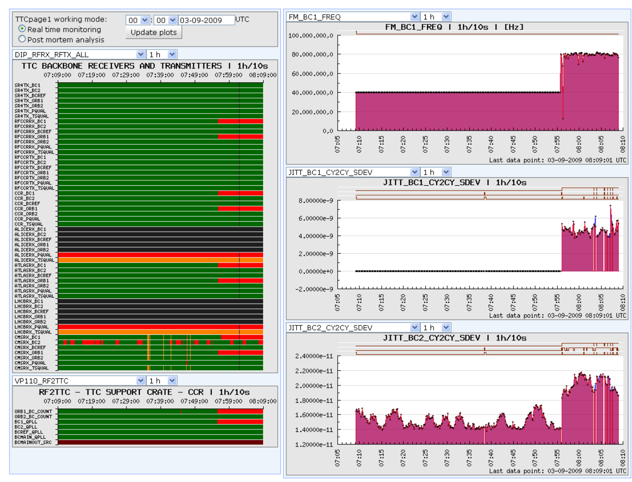

Figure 7: TTCpage1 – web application
http://cern.ch/ttcpage1 - CERN NICE user authentication required

The historical data can be analyzed at any time. A user who wants to see the status of the system at any given point in the past, can specify a desired date and after one click on “Update plots” data will appear on the screen.

VII. DATA VISUALISATION

Two types of plots are being used for data visualisation. The figure 8 presents a graph with the status of all of the TTC backbone receivers and transmitters versus time. Eight locations (as described in section III A) have been included.

This type of the plot can only display a limited number of discrete values (colours such as green, orange, red, etc.) which in some of the cases is insufficient. The issue has been solved with tabular form of data presentation, which has been made available for any graph being selected (figure 9).

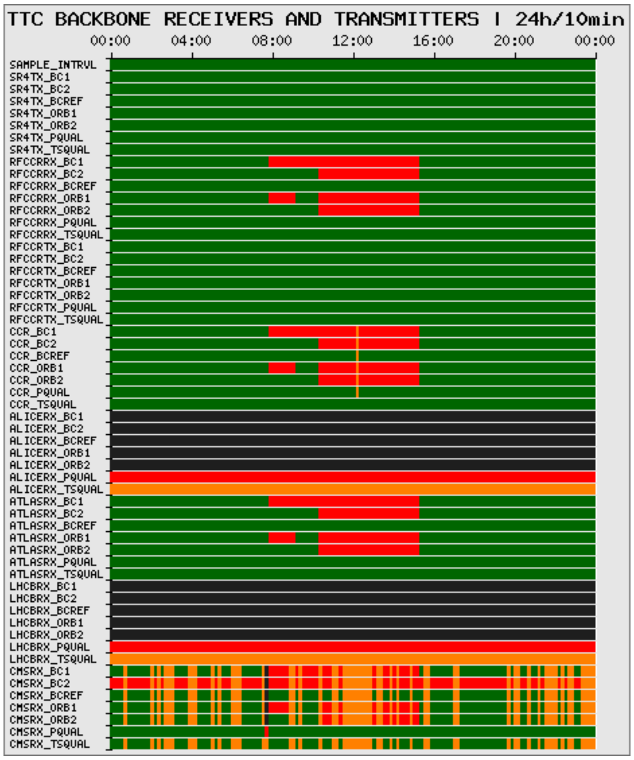

Figure 8: TTC receivers and transmitters graph

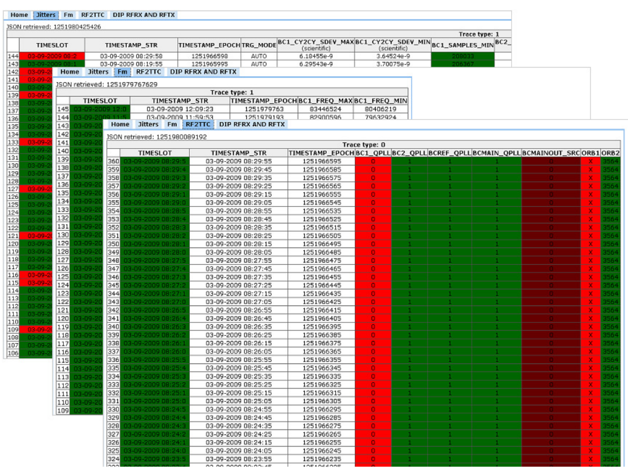

Figure 9: Tabular form of data presentation

The second kind of plots being used has been presented on the figure 10. The example shown on the figure 10 presents the BC1 frequency in Hz versus time during RF ramping tests in October 2009.

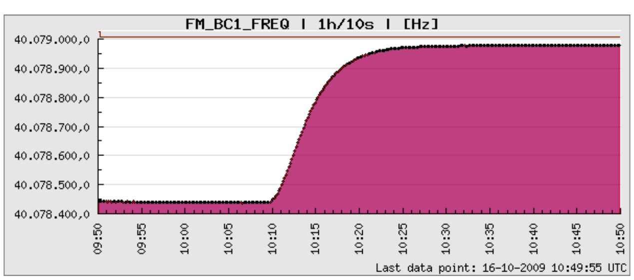

Figure 10: BC1 frequency versus time

VIII. Conclusions

A full system has been designed for RF-TTC remote status monitoring. The deployed system fully complies with existing CERN infrastructure and services such as databases, networks, etc.

A web based application will provide fast data visualization to the LHC experiments, in order to monitor the TTC status in real time. The application is available to the users and helps them to quickly detect unexpected conditions and cross correlate those with other events. All data being collected is time-stamped and stored in a database which facilitates both real time and post-mortem data analysis. The implemented facility will for sure be essential for a close and efficient monitoring of the timing signals and of the complete TTC backbone system.

IX. References

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