AN EVENT DRIVEN COMMUNICATION PROTOCOL FOR PROCESS CONTROL: PERFORMANCE EVALUATION AND REDUNDANT CAPABILITIES

J. Ortolá Vidal, E. Blanco Viñuela, M. Boccioli, T. Nunes da Rocha
CERN, Geneva, Switzerland

Abstract

The CERN **UN**ified **I**ndustrial **CO**ntrol **S**ystem framework (UNICOS) with its Continuous Control Package (UNICOS CPC) is the CERN standard solution for the design and implementation of continuous industrial process control applications. The in-house designed communication mechanism, based on the Time Stamp Push Protocol (TSPP) provides event driven high performance data communication between the control and supervision layers of a UNICOS-CPC application. In its recent implementation of full redundant capabilities for both control and supervision layers, the TSPP protocol has reached maturity. This paper presents the design of the redundancy, the architecture, the current implementation as well as a comprehensive evaluation of its performance for SIEMENS PLCs in different test scenarios.

INTRODUCTION

UNICOS is a CERN framework to develop control applications as UNICOS-CPC is the framework package devoted to industrial process control. It provides developers with means to design and develop full control applications and operators with ways to interact with all items of the process from the most simple to the high level objects. In addition UNICOS offers tools to diagnose the process and the control system [1].

The method to develop process control applications proposed by UNICOS-CPC is based on a decomposition of the process in a hierarchy of objects. The principles are the same as the ISA-88 standard for controlling batch processes. These objects are classified according their functionality (i.e. Input/Output, Interface, Field and Control Objects) and are used as a common language by process engineers and programmers to define the functional analysis of the process.

In addition to the method, tools have been produced to automate the instantiation of the objects in the supervision and process control layers and generate skeletons of the Programmable Logic Controller (PLC) programs.

The UNICOS-CPC package can be deployed to different platforms. For the control layer, Siemens and Schneider PLCs are supported (Codesys is currently being validated), WinCC OA as SCADA at the supervision layer and it also includes a full library for local operation based on Siemens Touch Panels.

The communication between the control and supervision layer is an in-house development based on an event driven mechanism [2].

This paper focuses on two aspects of the communication between Siemens PLCs and WinCC OA: the performance and the development of a mechanism to allow redundancy in UNICOS.

Time Stamp Push Protocol (TSPP)

The Time Stamp Push Protocol is an event driven communication protocol for process control. TSPP was created for both, data transfer optimisation from the PLC to the data server and time-stamped data at source.

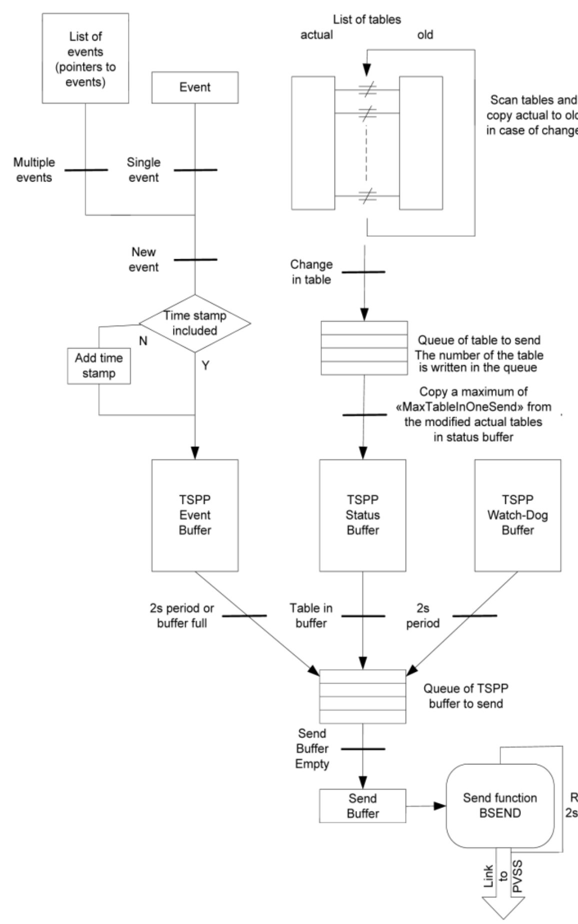

Figure 1: TSPP organization diagram.

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The protocol implements a mechanism to detect new data, encapsulate it, associate the time stamp and then send it in a single telegram. The time stamp allows better diagnostic capabilities than classic polled data.

TSPP is designed to send three distinct types of time stamped data: the *Events* (Boolean changes in the state of the UNICOS-CPC objects), the *Status* (analogue changes of the objects) and the *Watchdog* (connection alive message). The three types of TSPP data buffers are managed in parallel but only one send-channel is used. To manage this mechanism, a first in – first out (FIFO) queue has been created.

The *Events* are individually time stamped, buffered and then sent to the data server. This allows a comprehensive event analysis in case of failure. By contrary, the *Status* are time-stamped in blocks and sent to the data server without buffering, therefore only current status values are ensured.

On Siemens PLCs the protocol is developed using a standard S7 communication function, *BSEND*, which sends large amounts of data to a remote partner (WinCC OA).

Fig. 1 represents the TSPP UNICOS Manager function that performs two basic tasks: create and send buffers.

TSPP PLC REDUNDANCY IMPLEMENTATION

Fault-tolerant automation systems in SIMATIC (S7-400H PLC) consist of two redundantly configured subsystems that are synchronized via optical fiber cables.

The user programs in both S7-400H CPUs are identical and executed synchronously. Synchronization is performed automatically by the PLC operating system and has no impact on the user program. The PLC application is created in the same way as for standard S7-400 CPUs.

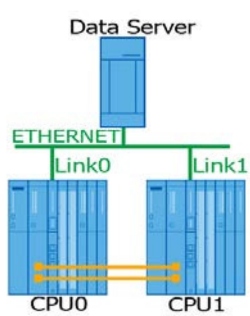

Figure 2: Redundant PLC architecture.

In a typical redundant architecture, both CPUs are connected through Ethernet to a data server (Fig. 2). An active link is established between the master (active) CPU and the data server. When an error occurs in the master CPU, the slave CPU (back-up) takes control of the process and then, the TSPP manager detects that change and switches over the active link.

Implementation

To develop UNICOS-CPC applications in systems needing higher availability, the TSPP manager had to be adapted to deal with redundant PLCs: S7-400H PLC.

The TSPP manager administers the two links in a redundant PLC architecture: one to the CPU0 and the other to the CPU1. In a non-redundant implementation the TSPP manager checks every cycle that the communication link is established and sends the data. In case of a connection problem (e.g. broken link), the manager makes several attempts before flagging the error. In a redundant architecture, the TSPP manager has been designed to check the status of both connections and select the one used to send data.

When the program is initialized both connections are established, *Link0* is taken as default to send data to the data server. If a connection error occurs (once it is detected), the manager will switch over the stand-by connection (*Link1*) at the next PLC cycle.

The switchover mechanism does not occur instantaneously due to the problem of detection timeouts. In order to make sure that all the values will be updated when the connection is re-established, a flag is set on the manager to trigger a new transmission of all status tables.

When both connections are active, the *Watchdog* is sent through both connections in order to maintain both connections active.

Validation

A full battery of tests has been performed to measure the switchover time between the connections. Ideally, every time a connection problem occurs the data should be sent through the stand-by connection, but that is not possible due to the time necessary to detect that a problem occurred and the time to re-establish a new connection.

This mechanism was optimized tuning the parameters of WinCC OA S7 driver and the TSPP manager.

A test procedure was created to make sure that all the connection problems were covered. The test bench consisted in a redundant PLC S7-400H (CPU 414-5H PN/DP) with a CP443-1 advanced card connected to WinCC OA 3.11 SP1 software running in a Windows 7 (i7-3770 CPU@3.40Ghz) machine.

Problematic situations that require switching the connection (e.g. CPU goes to STOP mode, broken link) were identified and checked and the switching time was measured. In all the test scenarios the switch-over mechanism took between 10 a 12s.

These tests proved that the switching time between connections is around 10s and never higher than 15s. These are the values that will be taken as reference in the UNICOS applications using S7-400H PLCs.

TSPP IMPLEMENTATION FOR TWO DATA SERVERS

In a non-redundant architecture, if any problem occurs with the data server connected to the PLC, the control layer is not accessible and it is not possible to operate or

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monitor the control system anymore. To overcome this kind of situations and ensure high availability of the supervision layer, it is also possible to implement redundant connection to two data servers. In this case, the PLC application sends the data to all the data servers, therefore the monitor and control of the system can be made through any of them.

Fig. 3 shows a typical architecture based on two data servers.

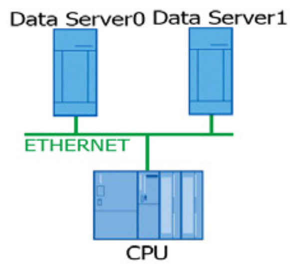

Figure 3: Two data servers architecture.

Implementation

In double-data server architecture, the PLC establishes connection with the two data servers and the data is sent through all the links. The TSPP manager checks if the message is correctly sent and received in the supervision layer. The next message is only sent when the previous one is received by all the servers.

Whenever a connection problem occurs in one of the links, the data will be sent through the active connections. The TSPP manager checks the broken connection every cycle, and re-establishes the data flow in that connection as soon as the link is available. A flag is set in the TSPP manager when a connection is re-established in order to send all the *Status* tables to recover all data that has not been sent during the communication disturbances.

Validation

Several tests were done with two data servers (redundancy architecture) to check the performance of the switchover mechanism.

A S7-319-3 PN/DP Siemens PLC was connected with two WinCC OA 3.11 SP1 data servers, hosted in a Windows 7 (i7-3770 CPU@3.40Ghz) machine and in a virtual Windows 7 (2CPUs, 4Gb RAM) machine. The time that the communication takes to be recovered after a disconnection has been measured.

The connection recovered in less than one second, unless both connections were inactive. In this specific case, the connection needed less than 5 seconds to recover. This time is also the time necessary for a connection to recover in non-redundant mode.

At the supervision, the operator commands could be sent through both data servers. The changes made in one data server were shown on the other server instantaneously.

PERFORMANCE TESTS

In order to be able to optimise the data transfer between the PLC and WinCC OA data servers, a full battery of performance test has been designed using different parameters on WinCC OA S7 driver and on the PLC TSPP manager.

The important parameters that have been measured to determine the performance of the communication are the corrupted and lost values during the data transfer, the connection problems (e.g. due to overflow) and the number of PLC cycles necessary to send a message. With those parameters, it is possible to check if the message arrives correctly to the data server, calculate the transfer rate and evaluate the stability of the driver and the performance of the TSPP mechanism.

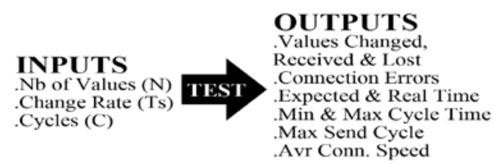

Figure 4: Test inputs and outputs.

Therefore, a standard UNICOS-CPC application with bunches of 100 analog values (5000 in total) that change their value according to a desired change rate, was created. Each analog value is equivalent to 8 bytes of data sent. The values change their values between 0 and 100, as many times as defined by the user. Fig. 4 represents the test inputs and outputs.

The test routine in the PLC program changes the values of the selected bunches of values with the defined change rate. The TSPP manager detects that the *Status* tables of those AIs have changed and packs them in the TSPP buffer until they are sent to the data server where it is processed by the WinCC OA S7 driver and stored in the machine archives.

To make sure that all the tests are performed under the same conditions, an automatic test script and a dedicated user interface in WinCC OA were created

In the WinCC OA user interface the user can define a range for each of the tests inputs. The script runs the test with all the possibilities and saves the results.

The script analyses the data in the archives, checks if all the data was correctly received, calculates the expected time and the real time of the data transfer and the connection speed during the data transfer.

This automatic test application is now considered an important improvement of the permanent test bench used to test and validate future versions of the TSPP and WinCC OA S7 Driver as well as checking the communications performance of different PLCs.

Performance Test Results

Two main architectures have been tested: single data server and double data server.

In a classic PLC redundant architecture (S7-400H) only one link is sending data between the PLC and the data server therefore the overall performance is not affected

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and, as a consequence, TSPP performance tests are focused in architecture with a single PLC.

The test bench is composed by a S7-319-3 PN/DP Siemens PLC connected to a WinCC OA 3.8 SP2 data server, hosted in a Windows 7 (i7-3770 CPU@3.40Ghz) machine and additionally with second data server.

For a defined number of analog values being sent through TSPP, the communication speed was measured. The TSPP manager has been designed to cope with the BSEND limitations and it can send a maximum of 32 Kb per BSEND execution. The tests were made with change rates (Ts) from 100ms to 500ms. Fig. 5 shows the calculated transfer rate for a change rate of 100 ms regarding the number of bytes transmitted. According to this plot, the best performance is achieved in the transmission of 24.2 Kbytes. This is due to the maximum amount of data that the TSPP manager can send in in one single cycle time. Above this amount of data, the TSPP manager requires an additional cycle time to send all the remaining data, duplicating the time to send the data and impacting the overall performance.

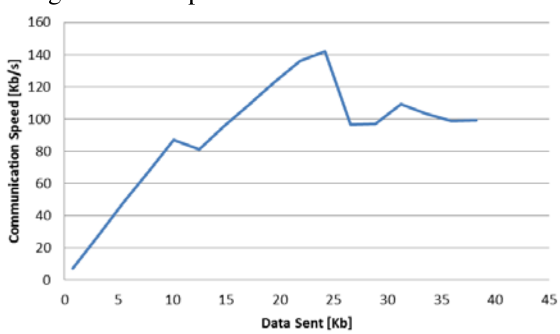

Figure 5: TSPP performance for a change rate of 100 ms.

Fig. 6 compiles the test results in a single chart taking the best performance result from each change rate test. The graph shows lower transfer rates for short change rates times close to PLC cycle times (142.1 Kb/s for Ts = 100ms), average performances from 200 kb/s to 230 Kb/s for applications requiring changes rates from 150ms to 350s and a performance slightly increasing together with the increase of the change rate to a best performance of 245.6 Kb/s for Ts = 450ms.

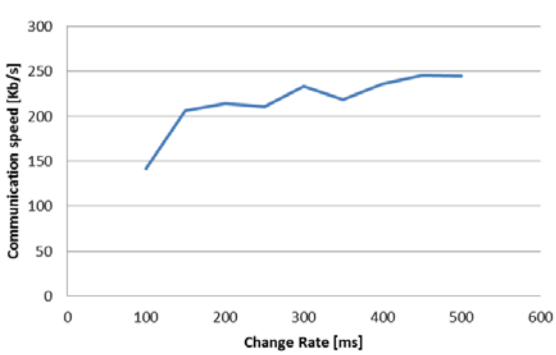

Figure 6: Optimal performance.

The PLC cycle time has a direct impact on the transmission performance as the TSPP manager is designed to build one transmission per PLC cycle execution. Applications with shorter cycle times may improve the overall TSPP performance. In order to overcome the limitation of 32 Kb per BSEND execution and increase the performance, further modifications in the TSPP mechanism for the addition of additional calls to the BSEND function in the same cycle time are foreseen.

The Fig. **7** shows the plot of the results obtained in the test of the double data server architecture, compared to the performance measured for one single data server at a change rate of 200ms. The graph shows an expected decrease of performance of the double connection.

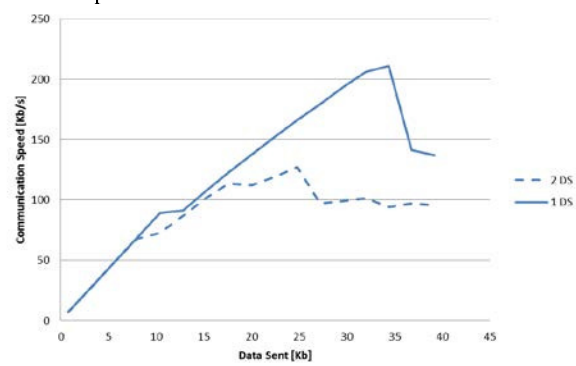

Figure 7: Comparison of the TSPP performance in a Single and Double Data Server architecture (change rate=200ms).

CONCLUSIONS

In an environment like CERN, where downtime in an application represents large expenses, the increase of the availability of the control system is crucial. The new redundant capabilities included in the UNICOS framework are an easy way to develop more robust applications and to decrease downtimes, without any extra effort for the developer.

The performance of the communication mechanism has been comprehensively tested, providing very satisfactory results especially on demanding change rates and large data transfer applications. As a result, the TSPP mechanism is considered to reach maturity in an environment clearly evolving towards fast and efficient data transfer control systems.

In addition, a full test platform has been developed constituting a stable and permanent test bench to be used in the analysis and validation of future versions of the TSPP communication mechanism as well as to assess the performance of different PLC models.

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