SIEMENS

Description of the measurement• 10/2018

Help and Explanation about – “S7-1500/CP443 OPC UA Transfer Time Measurement”

OPC ID34

Table of Contents

1 Scope of Measurement

1.1 Objective

Automation projects often require intensive data exchange between SIMATIC S7 controllers and PC systems. In this case, the usual method today is via OPC UA.

The focus here is the measurement of the transmission time of the data from the OPC UA server in the S7 1500 station to the OPC test client on a PC.

Important questions

The planner's primary interest is how long the system needs to log the change of a large to very large number of variables (OPC items).

Using the use cases, a user wants to retrieve the following information from the system:

- **Update time of n OPC nodes (monitoring variables)**
  Use case: Process values must always be present in the client
  - In a S7 CPU, all variables change simultaneously in the worst case.
  - How long is the response time until all changes of the observed variables have been registered by the OPC client?
- **Read time of n nodes (reading variables)**
  Use case: how long does it take to request the data from the OPC UA client?
  - n bytes (OPC items) are read from 1 S7 CPU
  - How long is the read time until all values exist in the OPC client?
- **Operating time of OPC items (writing variables)**
  Use case: Update time from OPC UA client to S7 CPU
  - N bytes are written into an S7 CPU from the OPC client
  - How long does it take until the changes of the variables have been registered in all receive CPUs (end time)?
- **OB1 cycle time**
  - How strongly do the OB1 cycle times in the S7 CPU differ during active communication with the OPC server?
- **Distribution of the nodes**
  Use case: How does the distribution of variables (nodes) in the PLC's DBs affect the transfer rate and what is the influence of optimized DBs versus standard DBs?

To answer these questions, Siemens Industry Online Support regularly performs extensive measurements with typical OPC UA systems. To conveniently access the measurement results, you can set up your desired configuration using the interactive user interface.

Which S7 components are best suited for the planned automation project?

- Which transfer times can be expected for typical configurations?
- Which statistical fluctuations can occur in the process?
- Which effects can be expected?

1.2 Performance data provided

The following performance data or measured variables are available to you in this measurement:

Table 1-1

Measured variable	Definition
Transfer time – monitoring variables (monitoring)	How long is the average update time of n variables (nodes) for an S7 station if all configured items (variables) have changed virtually synchronously in all S7 stations?
Transfer time – Asynchronous read (UA registered Read)	How long is the average read time of n variables (nodes) from a S7 station in the OPC UA client?
Transfer time – Asynchronous write (UA registered Write)	How long is the average write time of n variables to a S7 station from an OPC UA client?
Cycle time in the S7 controller	This is the interval between two process image updates in the S7 controller.

Note For a detailed description of the method of measurement, please refer to chapter 3 Performing the Measurements

1.3 Parameters of the measurement

This measurement has been performed with the following parameters:

Table 1-2

Component	Parameter	Explanation
S7 station	CPU	Selection of the S7 CPU type
	Load due to program	Setting the load realized in the S7 station by means of an additional STEP 7 program.
	Communication path	Selection of the interface via which communication takes place (integrated interface of the CPU or via Ethernet CP/CM).
	User data length	Setting of the data volume (number of bytes per S7 station).
	Number of S7 stations	Here always 1
	Distribution of variables (nodes)	Continuous array of bytes (one subscription for one node) Distributed variables (n subscriptions for n nodes)
OPC server/client	OPC server sampling rate	Polling cycle of the OPC UA server (= publishing rate of the OPC UA server to client)
	OPC server publishing rate	Minimum possible time allowed for CPU configuration.
	OPC service method	Setting of the access method to the nodes (monitoring variables, cpu subscription, variables, UA read, UA write).
	Security settings	Encryption of data

Note The value ranges that can be set for the individual parameters may vary depending on the configuration. Please note the respective displays in the user interface.

1.4 Scope of validity and technical data

Scope of validity

The measurement covers a typical range of components. The selection is based on the latest and most frequently used products as of “mid-2018".

The measured values apply provided that the network has been configured correctly. Due to system-internal error control, an incorrect or incomplete configuration causes significantly deviating times.

Boundary conditions of the measurement

All measured values were acquired under specific boundary conditions (configuration and parameterization).

All settings essential for the measurement are listed in the following table. STEP 7 default values are used for all settings that are not listed.

Parameter	Range of values	Comment
Implementation of OPC UA Client	C#/.NET stack on OPC UA interface via UA TCP	.NET Framework V4 UA stack version 1.02
Ethernet interface	Standard IE interface	
Security features	OPC UA - None - Basic256SHA-Sign&Encrypt	
Queue size	The queue size of an item remains at 1 for this measurement.	
DB type	All variables are stored in optimized DBs by default.	Exception: S7-400
Network load	No other network loads (PGs, HMI devices, VPN tunnels, etc.) are connected to the test object.	
S7 communication load	S7-1500: 20%	TIA Portal default values
Distributions of OPC items/nodes	Continuously in an array (one symbol)	Access to distribution with gaps is not used for 100000 bytes.
	With gaps (approx. 30% memory gaps) with n symbols	

Components used

The following table contains all components that were used in this measurement.

Table 1-3

Component		Type	Article no.	Version
	S7-1500	CPU 1510 SP	6ES7510-1DJ01-0AB0	V2.5
		CPU-1511-1PN	6ES7511-1AK01-0AB0	V2.5
		CPU-1516-3PN/DP	6ES7516-3AN01-0AB0	V2.5
		CPU-1518-4PN/DP	6ES7518-4AP00-0AB0	V2.5
	Software Controller	ET 200SP Open Controller CPU 1515SP PC	6ES7677-2AA41-0FB0	V2.5 4GB RAM, WES7 P 64; 8GB CFast
		CPU1507S	6ES7672-7AC00-0YA0	V2.5
		IPC 427D & CPU1507S	6AG4140-3BL05-3HA0	Core i3 1.6 GHz, 8GB NVRAM, Win7 Embedded 64, CFAST 8GB, 80GB SSD
OPC UA Client Station	IPC	IPC 547E		Core i7, 500GB HDD, 8GB SDRAM
SIMATIC S7 configuration software				TIA Portal V15

2 Operating the User Interface

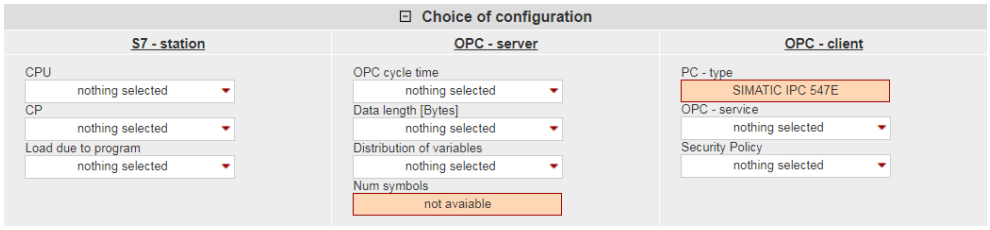
The following chapters provide you with information on how to operate the measurement via the path user interface.

2.1 Overview of the user interface

The user interface is basically divided into four areas: selection area, performance requirements, chosen topology and performance data table. All areas, except the performance data table, can be collapsed and expanded.

Selection area

Figure 2-1



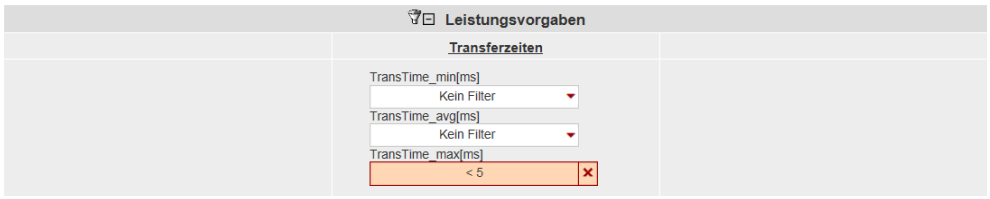
In this area, you can enter your desired configuration using the appropriate operator controls. The system supports you through various automatic functions.

Table 2-1

Icon	Explanation
	The "filter icon" indicates that at least one filter is active in the selection area.
	+: Expand input area -: Collapse input area
	These controls allow you to select components or values.
	A selection has been made by you and can be undone by clicking “X”.
	Due to the selection of another control, the system has made an automatic selection for you.

Performance requirements

Figure 2-2

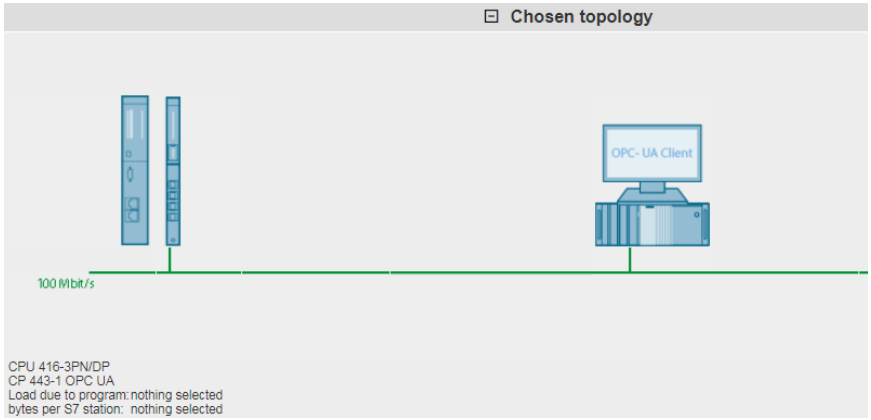


In this area, numerical filter conditions that appear when clicking on the appropriate control allow you to additionally restrict the measured values of the results table.

In this example, the minimum transfer time must be under 5 ms. In addition to the filters of the selection area, this filter will now be used for the results table.

Configuration selected

Figure 2-3



In the "Chosen topology" area, the system displays the graphical structure of your configuration. If nothing has been entered for one or more controls in the selection area, this is indicated by a question mark or “---” in the specific area.

Performance data table

Figure 2-4

Ergebnisse: 4 von 7272 Ergebnisse herunterladen (*.csv) Spalten anzeigen

Prg-Load	CP	Num S7-stations	Num Items	OPC-ClientLoc	OPC-Service	TransTime_min[ms]	TransTime_avg[ms]	TransTime_max[ms]
5 ms	---	4	100	Remote (LAN)	Write	2,1	2,4	4,2
5 ms	---	1	100	Local	Read	2,3	3,3	4,8
5 ms	---	1	100	Local	Read	2,4	3,3	4,9
10 ms	---	1	100	Local	Read	2,5	3,3	4,9

1

This area displays the measured performance data with all the filters you have selected. Further columns can be shown or hidden using a dialog box by clicking on "Show columns". Clicking "Download results (*.csv)" allows you to export the displayed selection as an Excel csv spreadsheet. This enables you to make more sorts for your applications.

2.2 How to operate the user interface

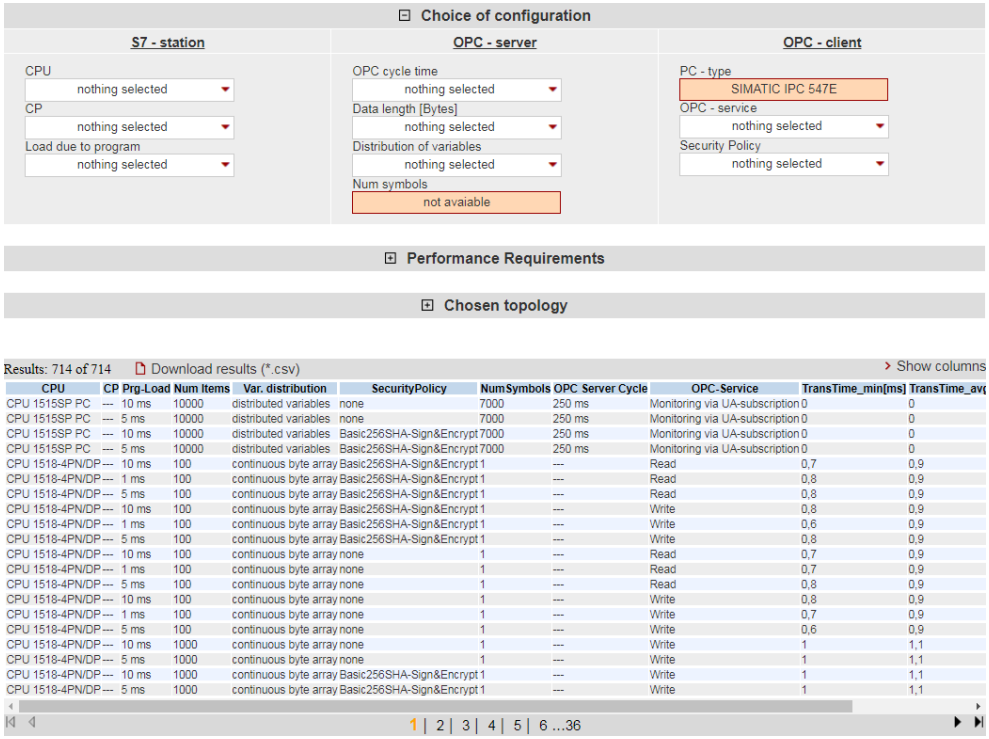
The following chapters provide you with information on how to operate the user interface:

2.2.1 Initial situation when starting the application

When calling the web application for the first time, the status of the application is as follows:

User interface

Figure 2-5



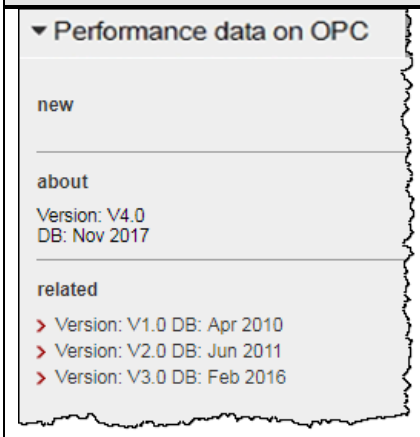
The selection area and the performance data table are always visible. The “Performance Requirements” and “Chosen topology” areas are hidden.

Description of the menu items

The following section explains the items of the application menu bar.

Figure 2-6

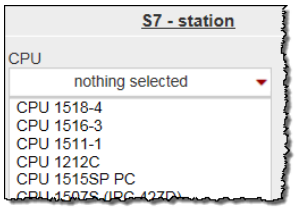
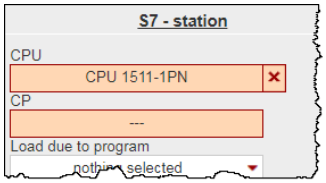
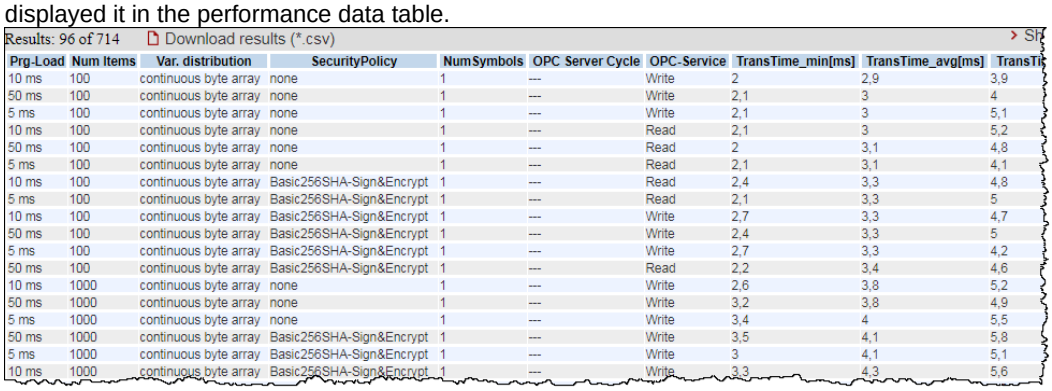
Table 2-2

Menu item	Description
	Clicking the **Performance data for the OPC** opens a dialog where you can • restore the user interface to its initial state by clicking on the **new** menu item. • in the **about** area, the version of the measurement and the database can be looked up. • the **related** area allows you to directly switch to other versions of this measurement type.
Language	The user interface is implemented in German and English.
Contact	Links to Online Support
Help	Calling these help pages

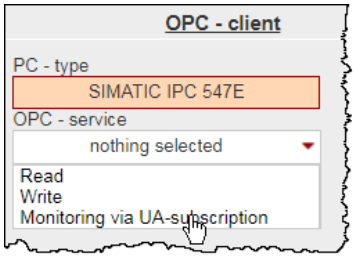
2.2.2 Entering the desired configuration

In the "Selecting configuration" area, you can specify the desired hardware configuration.

Table 2-3

<table>
<tr><th>No.</th><th>Operator action</th><th>System response</th></tr>
<tr><td>1.</td><td>Select a configuration by clicking on the various parameter controls and selecting a component.
Example:
Select a CPU in the S7 station area
 
</td><td>The system has applied your desired CPU (here, CPU 1511-1 PN) and at the same time, where applicable, automatically made the follow-up selection of the CP for you.
 
</td></tr>
<tr><td></td><td colspan="2">The system has immediately sent a query with the currently active filter to the database and displayed it in the performance data table.
 

Prg-Load	Num Items	Var. distribution	SecurityPolicy	NumSymbols	OPC Server Cycle	OPC-Service	TransTime_min[ms]	TransTime_avg[ms]	TransTi
10 ms	100	continuous byte array	none	1	---	Write	2	2,9	3,9
50 ms	100	continuous byte array	none	1	---	Write	2,1	3	4
5 ms	100	continuous byte array	none	1	---	Write	2,1	3	5,1
10 ms	100	continuous byte array	none	1	---	Read	2,1	3	5,2
50 ms	100	continuous byte array	none	1	---	Read	2	3,1	4,8
5 ms	100	continuous byte array	none	1	---	Read	2,1	3,1	4,1
10 ms	100	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Read	2,4	3,3	4,8
5 ms	100	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Read	2,1	3,3	5
10 ms	100	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Write	2,7	3,3	4,7
50 ms	100	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Write	2,4	3,3	5
5 ms	100	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Write	2,7	3,3	4,2
50 ms	100	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Read	2,2	3,4	4,6
10 ms	1000	continuous byte array	none	1	---	Write	2,6	3,8	5,2
50 ms	1000	continuous byte array	none	1	---	Write	3,2	3,8	4,9
5 ms	1000	continuous byte array	none	1	---	Write	3,4	4	5,5
50 ms	1000	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Write	3,5	4,1	5,8
5 ms	1000	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Write	3	4,1	5,1
10 ms	1000	continuous byte array	Basic256SHA-Sign&Encrypt	1	---	Write	3,3	4,3	5,6

In this example, 96 out of a total of 714 measured values measured with this exact CPU are available. As the S7 CPU has now been permanently assigned, this column has been removed from the results table.</td></tr>
<tr><td>2.</td><td>Proceed in the same way to enter the parameters of your choice for the “OPC client” area.
Example:
Selection of the “Monitoring via UA subscription” OPC service
 
</td><td>The system has applied your desired entries.</td></tr>
</table>

No.	Operator action	System response
	As in 1, the system has made another database query with the advanced filter settings and has therefore further restricted the number of relevant measured values.	

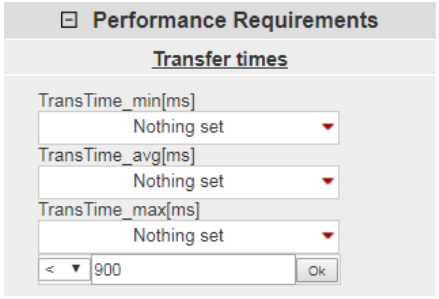
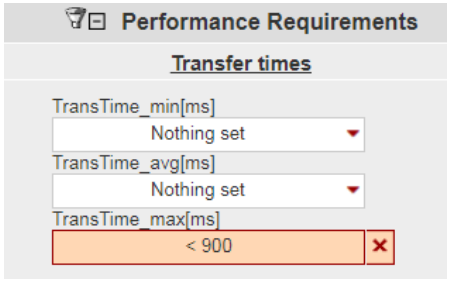
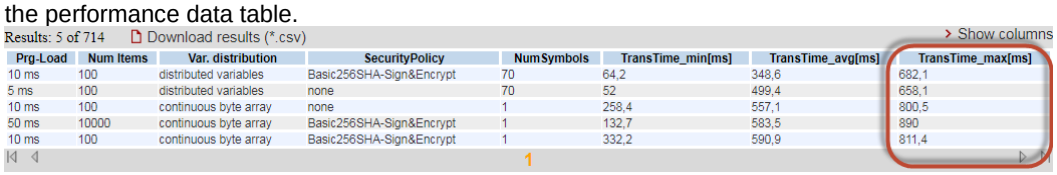
Results: 32 of 714 Download results (*.csv) › Sh

Prg-Load	Num Items	Var. distribution	SecurityPolicy	NumSymbols	TransTime_min[ms]	TransTime_avg[ms]	TransTim
10 ms	100	distributed variables	Basic256SHA-Sign&Encrypt	70	64,2	348,6	682,1
50 ms	100	distributed variables	Basic256SHA-Sign&Encrypt	70	53	426,9	963,9
50 ms	100	distributed variables	none	70	35	483	962,2
5 ms	100	distributed variables	none	70	52	499,4	658,1
10 ms	10000	continuous byte array	Basic256SHA-Sign&Encrypt	1	139,3	501,7	911,1
10 ms	100	distributed variables	none	70	109,5	503,9	979,6
5 ms	1000	continuous byte array	none	1	24,9	507,6	968,9
50 ms	1000	continuous byte array	Basic256SHA-Sign&Encrypt	1	33,9	513	938,3
10 ms	1000	continuous byte array	Basic256SHA-Sign&Encrypt	1	54,1	517,8	962,8
50 ms	1000	continuous byte array	none	1	50,3	519,9	976
5 ms	100	distributed variables	Basic256SHA-Sign&Encrypt	70	20	520,7	978,3
10 ms	1000	continuous byte array	none	1	69,2	522,2	930,1
10 ms	10000	continuous byte array	none	1	200,8	523,7	952,9
5 ms	1000	continuous byte array	Basic256SHA-Sign&Encrypt	1	45,5	534,2	967,8
10 ms	1000	distributed variables	Basic256SHA-Sign&Encrypt	700	182,7	551,8	1027,4
10 ms	100	continuous byte array	none	1	258,4	557,1	800,5
50 ms	10000	continuous byte array			58,9	558,8	890

2.2.3 Entering the performance requirements

In addition to specifying the hardware components, you can restrict the range of tolerable message runtimes in the "Performance Requirements" filter area.

Table 2-4

No.	Operator action	System response
1.	Enter the minimum, average or maximum values required for your system. For a description of the different measured values, please refer to chapter 1.2, a brief explanation is available via a tooltip directly on the control. Example: You want the maximum tolerable transmission time of the system to be less than 900 ms.  Confirm your entry by clicking on the OK button.	The system has applied your desired entry. 
	The system has sent a query with the now active filters to the database and displayed results in the performance data table.  With the selected sample filter settings, the system has found only 5 data record that meets all default criteria.	

Results: 5 of 714 Download results (*.csv) › Show columns

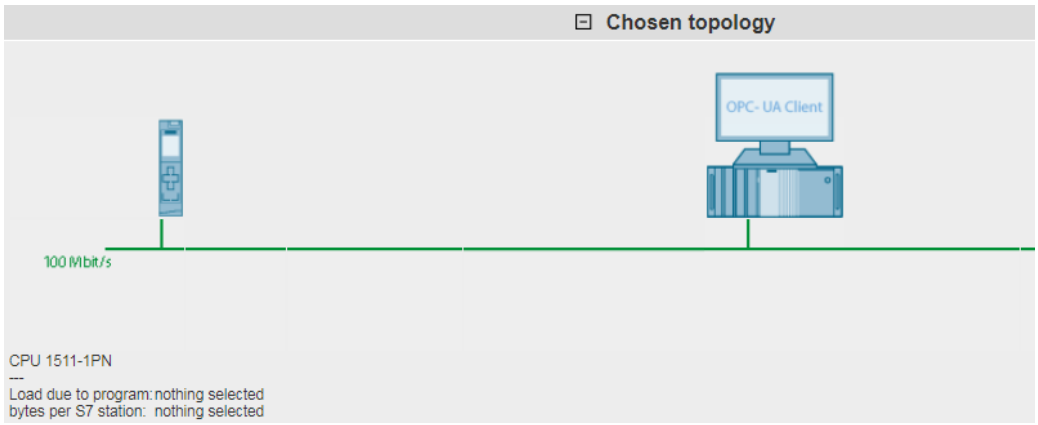
Prg-Load	Num Items	Var. distribution	SecurityPolicy	NumSymbols	TransTime_min[ms]	TransTime_avg[ms]	TransTime_max[ms]
10 ms	100	distributed variables	Basic256SHA-Sign&Encrypt	70	64,2	348,6	682,1
5 ms	100	distributed variables	none	70	52	499,4	658,1
10 ms	100	continuous byte array	none	1	258,4	557,1	800,5
50 ms	10000	continuous byte array	Basic256SHA-Sign&Encrypt	1	132,7	583,5	890
10 ms	100	continuous byte array	Basic256SHA-Sign&Encrypt	1	332,2	590,9	811,4

1

2.2.4 View of the selected configuration

You can view the hardware configuration diagram for this configuration by expanding the "Chosen topology" area.

Figure 2-7



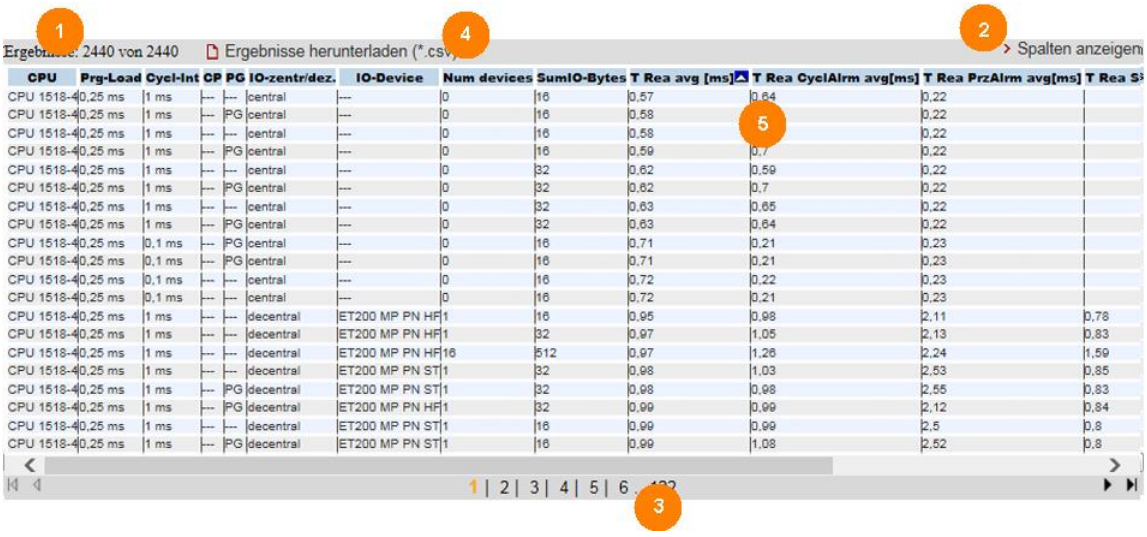
Components that have not been selected are indicated by a question mark icon  in the graphic and "nothing selected" or "---" in the text.

2.2.5 Table of performance data

The performance data table shows the database contents of the respective measurement restricted by the previous filters. This area is permanently visible. By default, the table displays only a selection of the columns available in the database for this measurement. A dialog box allows you to select or deselect individual columns.

Control elements of the table

Figure 2-8



Explanation of the control elements

The following table describes the control elements shown in figure 1-8.

Table 2-5

No.	Explanation
1	The table control displays • the number of results • the maximum number of data records of this measurement
2	By clicking on the "> Show columns" control element, you can open a dialog box where you can select or deselect individual columns.
3	Provided that there are multiple results pages, the control bar elements of the table control allow you to select the individual results pages and go to the next, previous, last or first page.
4	When you click on "Download results (*.csv)", the web server uploads all contents of the results table to the client browser as a csv file. Depending on the browser and the installed Excel version, the data is immediately displayed in an Excel spreadsheet.
5	Clicking on the column header of the measured values (in this example - TransTime_avg) triggers a sorting of the table according to this criterion. Each further click on the respective column header changes the sorting status of the column accordingly. TransTime_min[ms] Values unsorted TransTime_min[ms] Values sorted in ascending order TransTime_min[ms] Values sorted in descending order **Note:** You can only sort one column at a time!

Meaning of the columns

Tooltips provide more detailed information on all column headers.

Table 2-6

Column name	Explanation
CPU	CPU type
CPUFW	CPU firmware version
CP	CP type
CPFW	Firmware version CP
Prg-Load	Load due to program in OB1
Num Items	Number of bytes per S7 station
Var. distribution	Distribution of OPC variables
Server PC	OPC server PC type (not changeable)
OPC-Server Cycle	OPC server cycle time
OPC service	OPC service
Security Policy	Security level
TransTime_min[ms]	Minimum transfer time [ms]
TransTime_Q25[ms]	25% quartile of transfer time [ms]
TransTime_avg[ms]	Average transmission time [ms]

Column name	Explanation
TransTime_Q75[ms]	75% quartile of transfer time [ms]
TransTime_max[ms]	maximum transfer time [ms]
Cycle time min[ms]	Minimum OB1 cycle time [ms]
Cycle time avg[ms]	average OB1 cycle time [ms]
Cycle time max[ms]	Maximum OB1 cycle time [ms]

3 Performing the Measurements

The following chapters provide information on how to perform the measurements.

3.1 Method of measurement and measurement setup/sequence

Measuring sequence

The basic measurement sequence is as follows:

1. Configuring a configuration, including the download to all stations involved.
2. Measuring all measured variables (each measurement is repeated several times).
3. Evaluating the measurements and determining the statistical position parameters.

Measuring method for the performance data

- **Transmission time:**
  - In the "Monitoring via cpusubscription":

    how long does the average update time of n variables at an S7 station take, if all configured variables have changed virtually synchronously?

  - "UA Read" variant:

    how long is the average read time of n variables from a S7 station for a synchronous trigger in the OPC client?

  - "UA Write" variant:

    how long is the average write time of n variables to a S7 station for a synchronous trigger in the OPC client?

- **Cycle times:**

  The cycle time is the interval between two process image updates of the IO controller in OB1. This value is measured with system-internal functions.
  The cycle time is measured during operation: The S7 controller communicates with the distributed stations or its central modules.

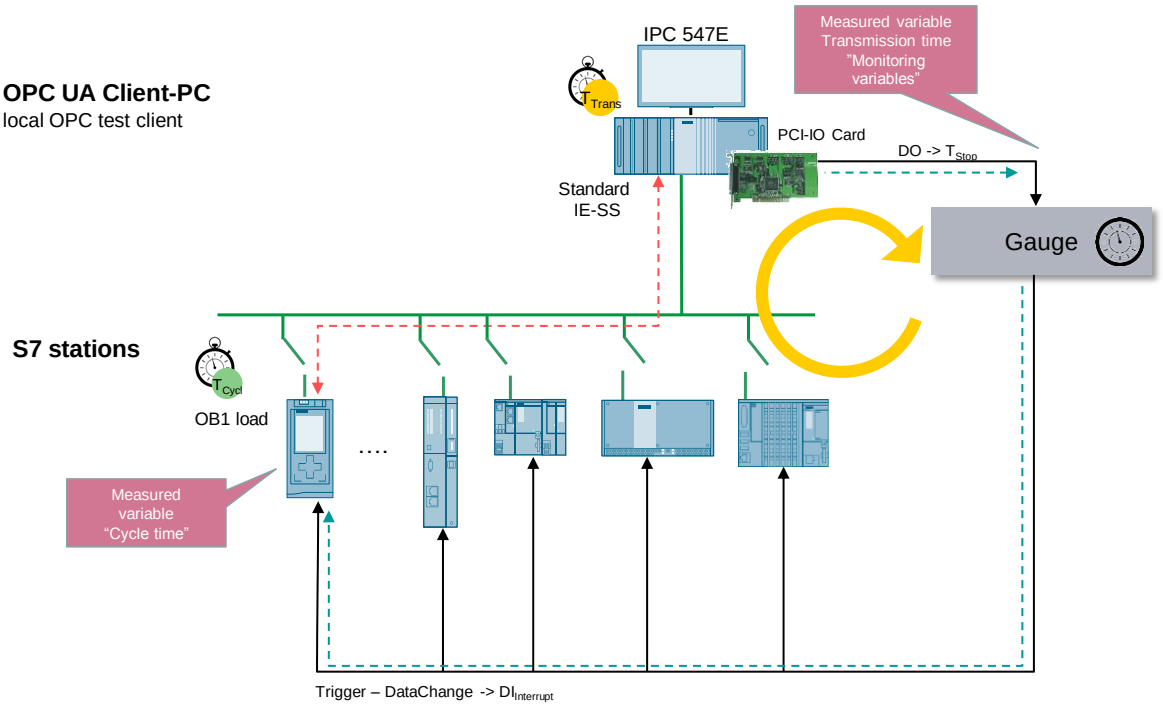
3.2 Measurement setup

The figure below shows the basic measurement setup for the different OPC UA methods of measurement. It does not show components and signals for the gauges (e.g., ready signals) used only to perform the measurement.

The measurement takes place under the following boundary conditions:

- The communication program in the S7 stations (if necessary) is called cyclically in OB1 of the S7 controller.
- Source/destination of the data in the S7 station are in the respective data blocks.
- Source/destination of the data in the OPC TestClient are in the respective data structures in the memory of the PC.
- The connection between the Test OPC client and the gauge occur via an interrupt-capable PCI-IO PC card.

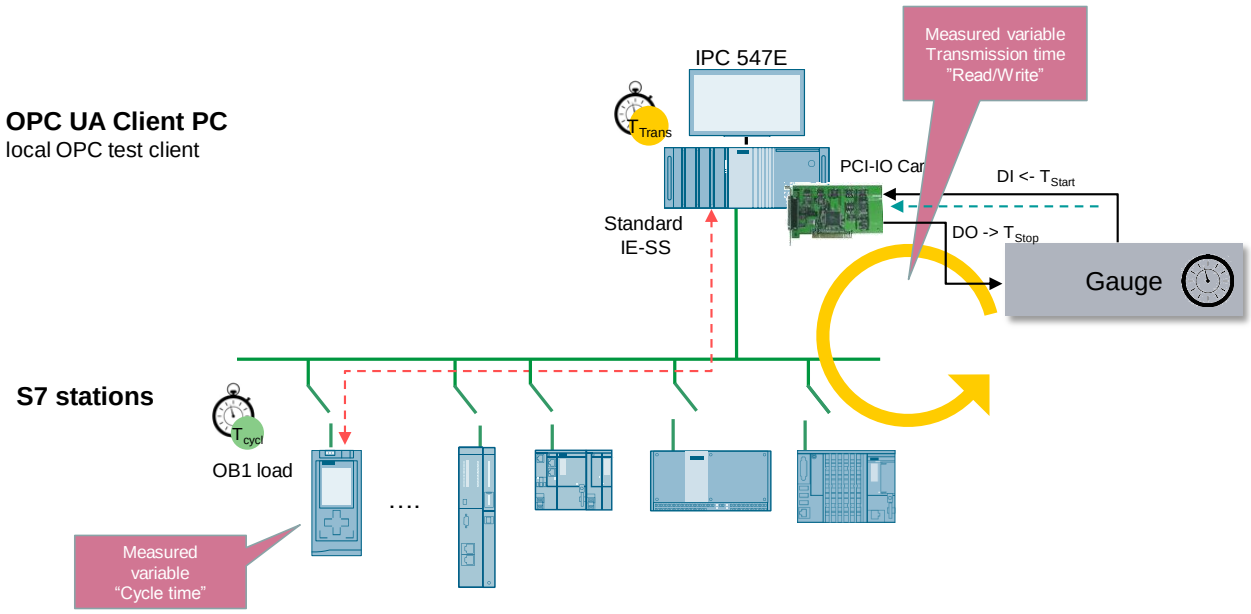
Measurement setup: “Monitoring Variables”



Note

The average absolute measuring error is approx. 0.07 ms for this measurement, due to the runtime of the trigger signal by the PCI IO card.
Explanation see chap. 3.10.

Measurement setup: “OPC UA Read/Write”



Note When the appropriate hardware interface of the S7 CPU is available, the gigabit port is always used.

3.1 Method of measurement of the “Monitoring via UA subscription/cpu subscription” transfer time

This section describes the variant “Monitoring via cpu subscription”.

Measuring principle

The transfer time in "Monitoring via cpusubscription" mode indicates how long it takes for the OPC UA server in the S7-1500, which permanently monitors a number of n variables for changes, to store this data in a data structure of the OPC UA test client.

The transmission time is acquired in a gauge:

- **Start of time measurement:**
  The measuring station triggers all S7 stations for synchronous change of their variables in the data block (OPC items);
  i.e. for the OPC server: all configured data have changed virtually simultaneously.

- **Stop of time measurement:**
  The OPC UA test client received all DataChange events of all observed variables in the S7 station from the OPC UA server.

The ready signal (T3) indicates that the changed data (here always the maximum number of configured variables) has been filed completely in a data structure in the OPC UA TestClient and is available for possible further processing in the PC.

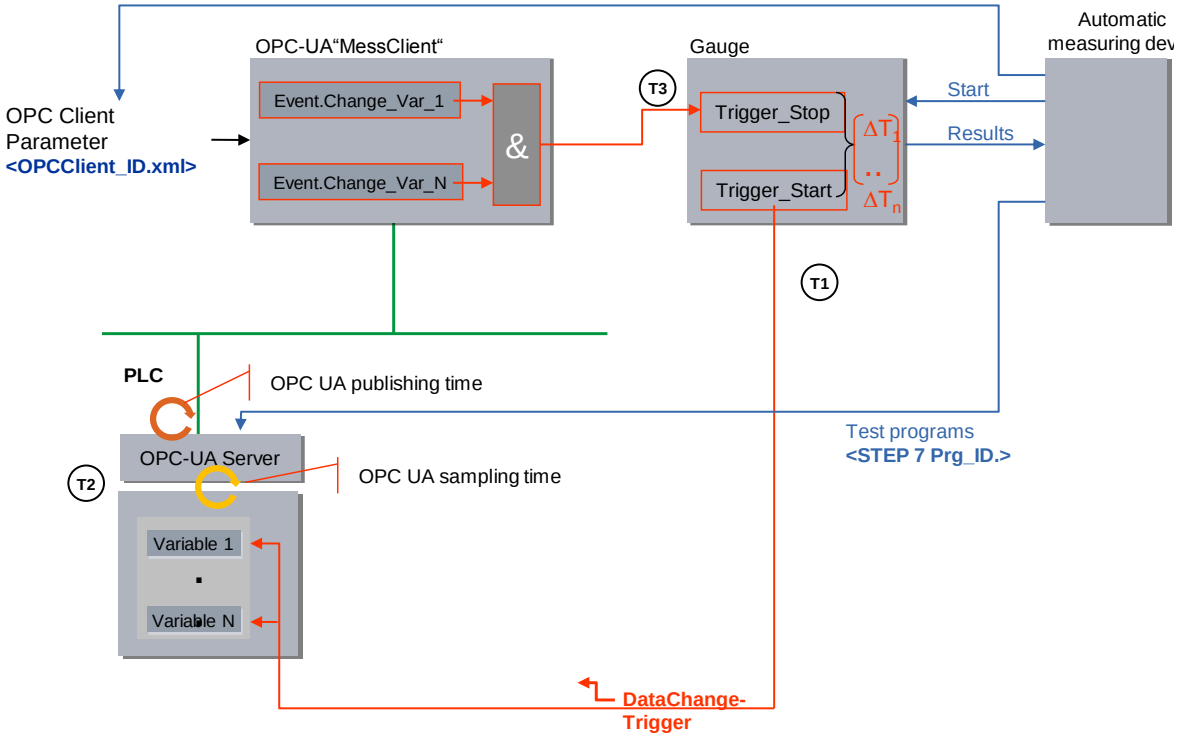
The OPC UA server always polls the variables with the maximum possible update rate, which varies depending on the CPU type (OPC UA sampling rate).

The measurement is repeated several times for each configuration (measurement setup) ($\Delta T1$. ΔTn)). The most important statistical position parameters are then determined from this data.

Functional model of the measurement

The following functional model explains the basic method of measurement:

Figure 3-1 Measuring principle “Monitoring Variables”



The following table describes the individual time intervals T_x:

Table 3-1

Time	Description	
T1	from	Gauge sets the start signal the configured S7 station.
	up to	Start signal of the S7 station acquired via **Process alarm**.
T2	from	S7 station synchronously changes the configured send data (variables)
	up to	Variables are pollled by the OPC UA server for changes (sampling rate).

Time	Description	
T3	from	The OPC Testclient registers the DataChange events of all configured variables one after the other.
	up to	**All** DataChange signals have been acquired in the OPC test client and trigger the stop signal of the gauge via a PCI-IO card.

Note The mere transfer time corresponds to the time T2. Systematic measuring errors are minimized by time-optimized programming of the OPC UA TestClient and interrupt-controlled programming of the PCI IO card.

Evaluations

From a maximum of 200 single measurements, the dial gauge calculates the statistical position parameters of the measured values. (See chap. 3.5 Measured variables and statistics)

3.2 Method of measurement of the “UA Read” transfer time

This section describes the “OPC UA Read” variant.

Measuring principle

The transfer time in "Async Read/ UA Read" mode specifies how long it takes to read a number of n variables from the user area (data block) of the active S7 station and provide them in a data structure on the OPC UA test client.

The transmission time is acquired in a gauge:

- **Start of time measurement:**
  Via an interrupt of the PCI IO card, the measuring station triggers the OPC UA test client to read **all** configured variables from the active S 7 station.
- **Stop of time measurement:**
  The OPC UA test client has received all ReadComplete events from the OPC UA server of the S7 station -> the data is available for possible further processing, if necessary.

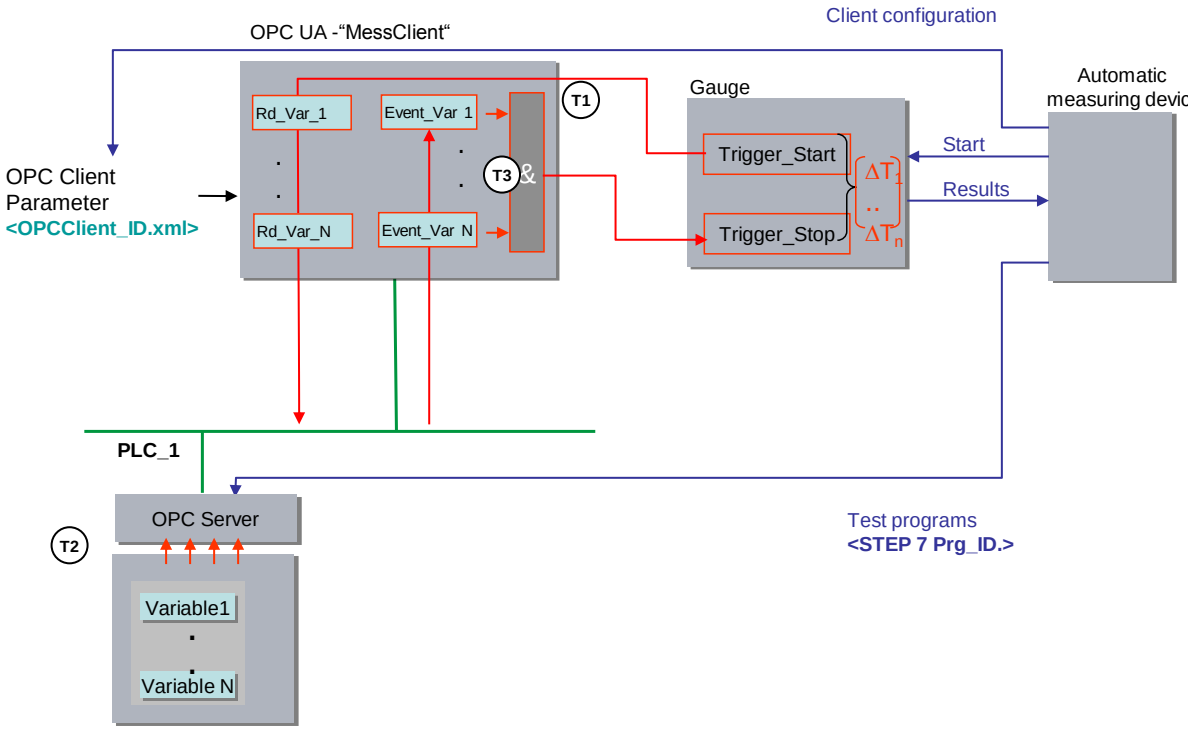
The ready signal (T3) indicates that the data (here always the maximum number of configured variables) has been filed completely in the data structure of the OPC TestClient. The S7 protocol used here ensures this with a level 7 acknowledgement to the OPC server.

The measurement is repeated several times for each configuration (measurement setup) ($\Delta T1. \Delta Tn$)). The most important statistical position parameters are then determined from this data.

Functional model of the measurement

The following functional model explains the basic method of measurement:

Figure 3-2 Principle “Variable service – Read”



The following table describes the individual time intervals T_x:

Table 3-2

Time	Description	
T1	from	Dial gauge sets the start signal to the OPCUA - test client
	up to	All asynchronous read jobs were sent from the OPC UA test client to the OPC server of the S7 station.
T2	from	The OPC server of the S7 station collects the required variables from the memory of the S7 station via quantized read jobs within the communication time slots (OB1 interrupts).
	up to	The read data is sent sequentially to the OPC UA TestClient.
T3	from	The OPC server reports each arrival of a data package to the OPC UA test client via a ReadComplete event.
	up to	If all ReadComplete events have been received by the OPC UA test client, the OPC test client triggers the stop signal of the gauge via the PCI IO card.

3.3 Method of measurement of the “UA Write” transfer time

This section describes the “OPC UA Write” variant.

Measuring principle

The transmission time in "Async Write/ UA Write" mode specifies how long it takes to write a number of n variables from a data structure in the OPC UA test client to the user area (data block) of the active S7 station. The transmission time is acquired in a gauge:

- **Start of time measurement:**
  Via an interrupt of the PCI IO card, the measuring station triggers the OPC UA test client to write **all** configured variables into the active S 7 station.
- **Stop of time measurement:**
  The OPC UA test client has received all WriteComplete events from the OPC server.

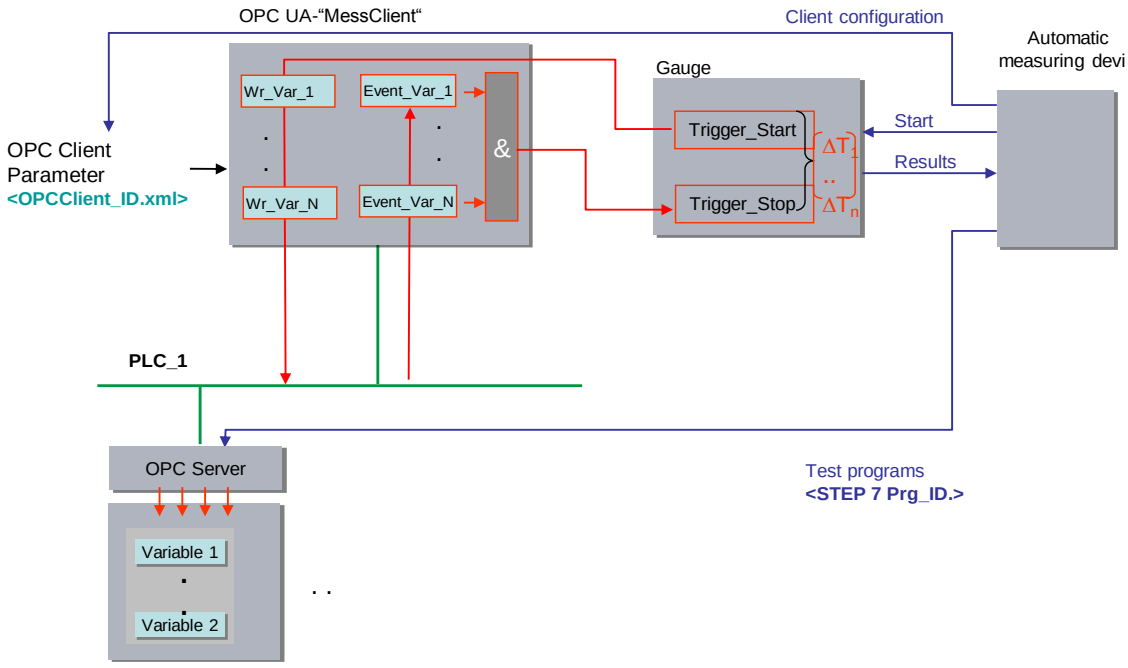
The ready signal (T3) indicates that the changed data (here always the maximum number of configured variables) has arrived completely in the data block of the configured S7 station.

The measurement is repeated several times per configuration (measuring setup) (DT1.. DTn). The most important statistical position parameters are then determined from this data.

Functional model of the measurement

The following functional model explains the basic method of measurement:

Figure 3-3 Principle “Variable service – Write”



The following table describes the individual time intervals T_x:

Table 3-3

Time	Description	
T1	from	Dial gauge sets the start signal to the OPC UA test client
	up to	All asynchronous write jobs were sent from the OPC UA test client to the OPC UA server.
T2	from	The OPC UA server forwards the write jobs in the communication time slots of the cyclic OB1 to the variables.
	up to	All data have arrived in the DBs
T3	from	The OPC server reports each arrival of a data package in the S7 station to the OPC UA test client via a WriteComplete event.
	up to	If all WriteComplete events have been received by the OPC UA test client, the OPC UA test client triggers the stop signal of the gauge via the PCI IO card.

3.4 Measurement: Cycle time/cycle control time

Principle

The cycle time in the sending and receiving stations is determined via system functions of the S7-1500. From the repeated measurements, the S7 controller automatically determines the statistical position parameters of the cycle time

Measurement period

- From the start of the respective measuring cycle (triggering by the dial gauge)
- Up to the end of the measuring cycle with X-repeats

Evaluation

From a maximum of 500 single measurements, the dial gauge calculates the statistical position parameters of the measured values. (See chap. 3.5 Measured variables and statistics)

3.5 Measured variables and statistics

Position parameter

In order to make an assessment regarding the significance of the mean (median), the other statistical position parameters should also be considered. To this end, all measured variables are measured multiple times (up to 200 individual measurements). From the entity of the measured values the gauge calculates the following statistical values which can be selected by the user in the result table.

Table 3-4

Position parameter	Definition
TransTime_min	The smallest measured value in the series of measurements
TransTime_Q25	The first quartile (**Q25**) states that 25% of the measured values are below this number
TransTime_avg	The **median** (Q50) indicates the measured value that divides the number of sorted measured values into two halves of equal size. This position parameter is the most important one in the measured value table.
TransTime_Q75	The third quartile (**Q75**) indicates that 75% of the measured values are below this number.
TransTime_max	The largest measured value in the series of measurements

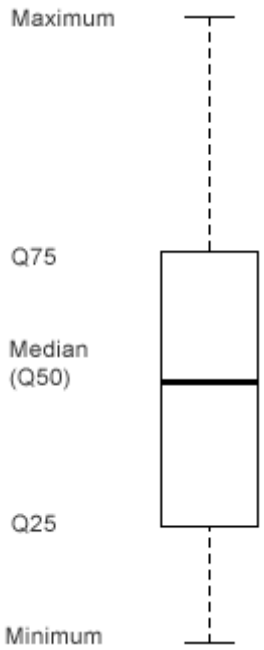
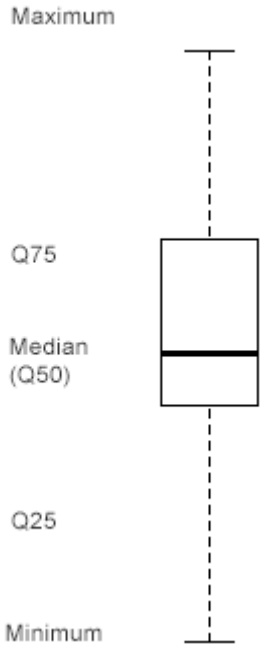
50% of all measured values are in the so-called interquartile range (IQR), i.e., the range between TransTime_Q25 and TransTime_Q75. This area enables the user to derive a statement on spread and reliability of the mean value (median).

Note In OPC UA Read/Write mode, the significance of the median is very precise for the number of single measurements selected here. In “Monitoring Variables” mode, the minimum and maximum values of the measurement require greater attention. In this case, the median strongly depends on the number of single measurements.

Interpretation of the measured values

The box plot representation standardized in statistics indicates, for example, the spread of the measured values.

Table 3-5

Box Plot	Position parameter	Interpretation
	Here, the maximum of the measured values is slightly asymmetric to the rest. 50% of all measured values are in the IQR range (Q25 to Q75). In this example, this range is relatively large compared to the second example. The median (Q50 value) lies fairly symmetrical in the IRQ range.	In this measurement, there is a slight upward deviation. 50% of all measured values are spread relatively widely, i.e., the entire IRQ range is more likely for this measurement.
	50% of all measured values are in the IQR range (Q25 to Q75). Compared to the first example, this measurement is much narrower.	50% of all measured values are spread relatively narrowly. For this configuration, the results and the value of the median are very meaningful and likely.

NOTICE	Especially for non-deterministic Windows PC systems, extreme outliers regarding the maximum value may occasionally occur. The median value has the greatest informative value for PC measurements!

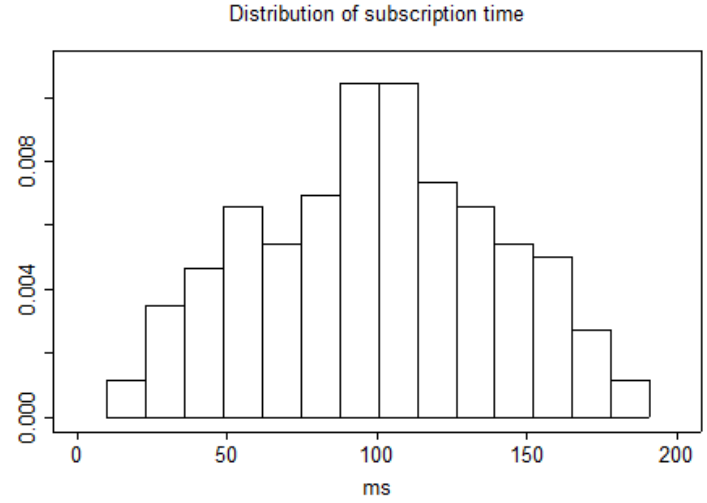
Special aspects of “Monitoring Variables” (subscriptions)

All n single measurements are collected by the gauge and then evaluated statistically.

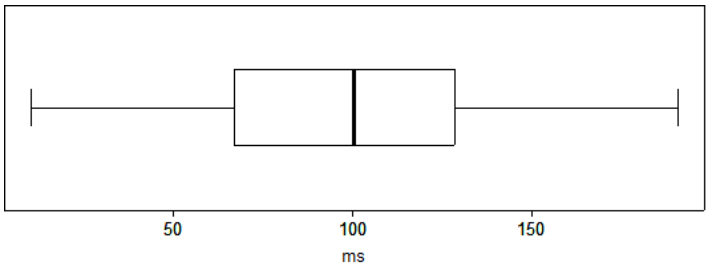
Especially in the “Monitoring Variables” mode, the shape of the distribution of the transfer times also strongly depends on the number of single measurements. For a theoretically infinitely long measurement duration, a constant sampling rate of the OPC UA server results in an ideal Gaussian bell curve. This depends on the asynchronous, cyclic systems involved in the data transfer (S7 CPU, OPC server, OPC client).

Example: “Monitoring Variables” mode for a CP 443-1 OPC UA, monitor 1000 bytes, 10ms OB1 cycle, 100ms OPC server cycle, 200 individual measurements

Figure 3-4



Corresponding box plot:



However, this ideal distribution of values can deviate to a greater or lesser extent with correspondingly fewer individual measurements, especially in the "subscription" mode, which then leads to a different median value.

Note Therefore, the median value in “Monitoring Variables” mode reflects the true (for infinite measured values) value only to a limited extent. In this case, the minimum and maximum value should rather be used for interpretation.

3.6 Explanation of the OPC UA test client

Apart from the S7 station, the test OPC client is the central measurement object in the entire sequence. In the following, we give you an overview of its properties.

Functions of the OPC UA TestClients

The OPC UA TestClient is supplied with the measured configurations by the automatic measuring device.

- It dynamically adjusts to the quantity frameworks to be received,
- Collects all callbacks from the registered OPC UA objects,
- receives the appropriate trigger signals from the gauge via a digital IO card in the PC and informs it of the ready signals for determining the runtime.

Program features of OPC UA test clients

The OPC UA client is programmed to be as runtime optimized as possible.

The communication with the PCI IO card is part of the OPC UA TestClient.

Development environment:

.NET Framework V4.0 with Microsoft Visual Studio 2014

Image of the S7 station in the OPC client

Each S7 station with its variables is mapped in the object of the OPC UA subscription class. Depending on the measurement configuration, the number of OPC subscription objects is dynamically generated by the OPC TestClient in the initialization phase.

Communication with PCI IO card

To exchange the control signals with the gauge and the automatic measuring device, the interrupt-capable PCI IO card APCI-1500 from ADDI-DATA was used.

Latency time of the measuring system:

The runtime of the trigger signal from and to the OPC test client via the PCI-IO card was detected by mirroring routine in the OPC test client. For this purpose the time of the digital input of the PCI-IO card to the test OPC client and the instant mirroring of the signal and output on a digital output of the PCI-IO card was detected. The measurement was repeated 500 times.

Results of the latency time measurement of the pure measuring system:

T latency$_{Min}$: 0.1285 ms

T latency$_{Avg}$: 0.1345 ms

T latency$_{Max}$: 0.1489 ms

This means a trigger signal from the digital input of the card to the OPC TestClient needs T latency/2 (here: on average approx. 0.067 ms)

Note These values have to be seen as an estimate and apply only to the IPC environment used. For other PC systems the values may vary.

3.7 Explanatory notes on the STEP 7 program

The STEP 7 program directly affects the measured values. The following chapters provide an overview of the STEP 7 program on which the measured values are based.

3.7.1 Variable structure in the S7 CPUs

The test variables in the S7 CPUs are arranged for the different variants in the following types

- Optimized data blocks
- Standard data blocks
- In a contiguous array of bytes (without gaps) (addressing as a variable (symbol))
- In a distributed structure (addressing of n variables)

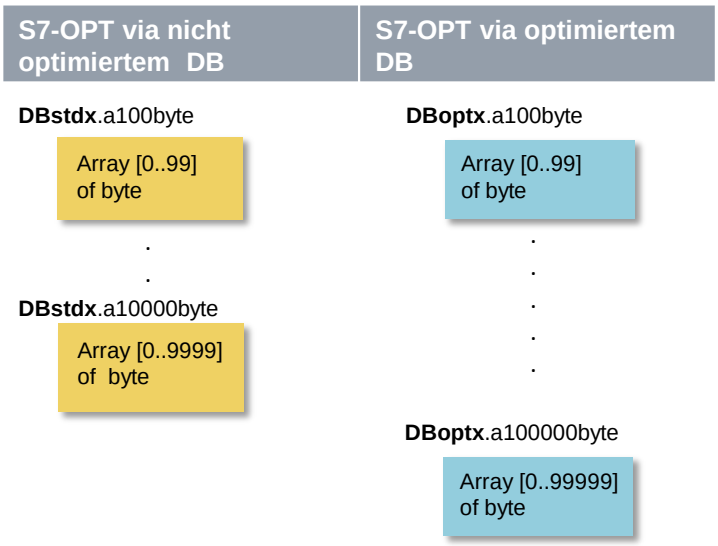
The time response of the measured values differs when accessing the different variables.

OPC UA variable structure for distribution without gaps

In the “without gaps” case, the bytes to be transferred are created in an **optimized** and **standard data block** as an **array [0..max-1] of bytes**.

Symbolic access from the OPC UA view only via the NodeIDs of the variables. In this case only **one** symbol is addressed.

Figure 3-5 DB Objects array without gaps



OPC UA variable structure for distribution with gaps and several symbols

In the “with gaps” case, the bytes to be transferred are created in an **optimized** and **standard data block** as an **array [0..max-1] of typeMix**.

The **typeMix** data type is defined so that so – due to the placement of elementary data types > 1 byte at each word boundary of non-optimized DBs – a “**gap degree**” of approx. **30%** can be used. In this case the addressing in the OPC UA Client is done via the **N - single symbols**.

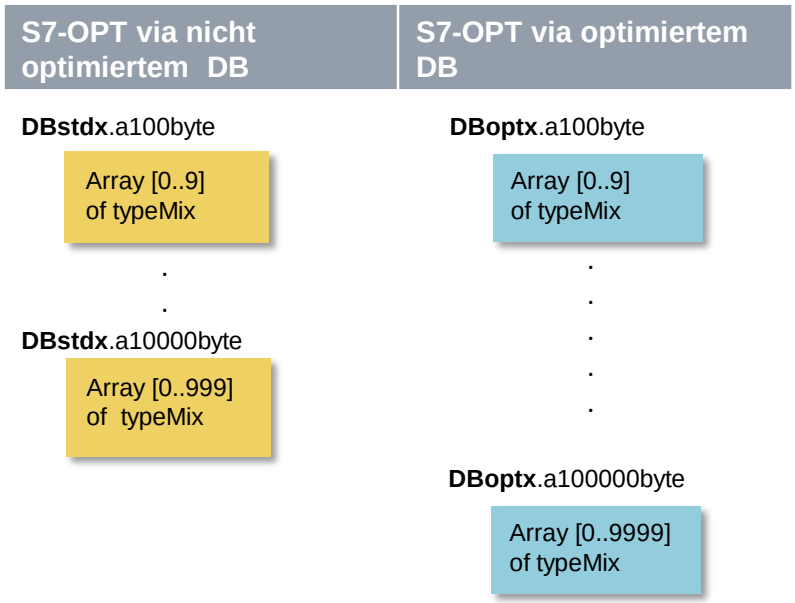
PLC-Type: typeMix

Element	Abs. Byte-Adresse	Variablen -Typ	Netto -Bytes
EL_1	0	Byte	1
	1	-	
EL_2	2	WORD	
	3		3
EL_3	4	BYTE	4
	5	-	
EL_4	6	WORD	
	7		6
EL_5	8	BYTE	7
	9	-	
EL_6	10	WORD	9
	11		
EL_7	12	BYTE	10

The **typeMix** type with its 13 bytes in an array is expanded to 14 bytes.

In the data array, **10 bytes** of **net data variables** have 14 bytes of used memory, which corresponds to a **"gap degree" of approx. 29%**.

Figure 3-6 - DB objects gaps in single symbol mapping 3-7



3.7.2 Overview of the STEP 7 - programs

The table below shows the function of the individual program components. During a measurement, all program components are loaded.

The user program contains primarily STEP 7 blocks for automating the measurement and communicating with the distributed stations.

Table 3-6

STEP 7 program component		Task in the S7 controller
Measuring program	Function program	Program parts that have nothing to do with the actual measured-value acquisition. (e.g. call of communication blocks, HMI program, etc.)
	Acquisition program	Program parts used exclusively to acquire the measured values and generate the control signals. • Acquire start/stop measurement signal • Measuring the cycle time
Load program		The load program does not perform specific tasks; the program itself has no function. It is merely used to increase the size of the STEP 7 program and thus extend the cycle time.

3.7.3 Measuring program

The following table provides an overview of the possible measuring programs:

Table 3-7 Measuring program in the S7 PLC

Measuring program		Purpose	Execution in the S7 CPU
Function program	I/O trigger program	Read/write signal via central or distributed digital I/O to change and acquire the defined time of item variables via the gauges.	A hardware interrupt OB (OB40) allows time-optimized acquisition of the gauge signals.
	Communication program	--	For the S7-1500, explicit S7 communication blocks are no longer necessary.
Acquisition program		Acquisition and evaluation of measured values.	In all series of measurements. Concerns only the **cycle time**.

I/O trigger program

Mode: Monitoring variable

The EA trigger program (measurement start action) changes **all** variables monitored by the OPC server in the S7 CPU within **one** cycle.
It is initiated by a process interrupt **triggered** by the gauge on a digital module with interrupt capability in the central rack of the S7 station.
(Exception: The microbox with the CPU 1507S requires that the trigger signal be picked up via a distributed I/O station.)

In this case, the start signal to the S7 CPUs is the time when the gauge starts measuring. For the small S7 CPUs and large data volumes that need to be changed, this process takes very long in some cases (> 100 ms). This time is nonetheless included in the transfer time as the transfer to the OPC server starts continuously already during this time interval.

Acquisition program in OB1

The acquisition program is used for acquisition and evaluation

- of the cycle time in the OB1 cycle.
- The average, minimum and maximum OB1 cycle time of the S7 CPU is determined using the RD_SINFO system block.

3.7.4 Load program

The load program is part of the STEP 7 program in the S7 controller. The size (length) of the load program is selected such that it results in a default "cycle time without communication" in the S7 controller.

Definition of "cycle time without communication"

The “cycle time without communication” is the cycle time set in the S7 controller when the S7 controller is **not subject to** influences of the communication. For the S7 controller, this means that no data is sent and no communication blocks are processed.

Defining a "cycle time without communication"

To be able to define the "cycle time without communication", a load program is downloaded to the S7 controller. This load program can be used to simulate the practice-relevant case of communication and other control tasks being simultaneously performed in the S7 controller. The load program is implemented with a simple loop which does not have any influence on the remaining program. The variation of the loops can be used to set the "cycle time without communication".

Selecting the "cycle time without communication"

For this measurement, the length of the load program has always been selected such that there is a no-load cycle time (“cycle time without communication”) of **1 ms** (low CPU load due to control tasks) or **50ms** (high CPU load due to control tasks). This implies that the length of the load program varies per S7 controller to ensure that the desired no-load cycle time is set.

Structure of the load program

The load program consists of a combination of different types of STEP 7 statements. The number of STEP 7 statements of a type is selected such that this type has a defined percentage of the total execution time of the load program.

Table 3-8

Type of STEP 7 assignment	Percentage of the execution time	e.g., in the case of a cycle time = 10 ms
Binary statements	approx. 60%	approx. 6ms
Time / counter statements	approx. 20%	approx. 2ms
Data word commands	approx. 10%	approx. 1ms
Floating-point arithmetic	approx. 10%	approx. 1ms

4 Version

Table 4-1

Version Measurement	Measurement setup	Publication	Description
V 4.0	Mid-2018	2018, October	Repeat measurement only with S7 1500 OPC UA server.
V 3.0	Early 2016	January 2017	Repeat measurement
V 2.0	Late 2012	March 2012	Repeat measurement
V 1.0	Mid-2010	October 2010	First measurement