4.1 Control Loop Basic Model

4.1.1 Control loop operation

Industrial network applications are based on three main types of building blocks which may be combined in one device, or provided as separate devices interconnected through a suitable communication network.

These basic building blocks are;

- Sensor applications which provide input measurements indicating the state of a parameter being monitored or controlled,
- Controller applications which operate on combinations of measurements and external demand settings to develop output requests,
- Actuator applications which implement output requests as physical changes to the process or machine under control, such as a level in a storage tank, the speed of a printing press, or movement of a robot.

A control loop is formed when the process or machine responds to the actuator output and produces a new measured value at the sensor.

The complete loop is shown in Fig 1 where the application devices are connected as end stations of a TSN.

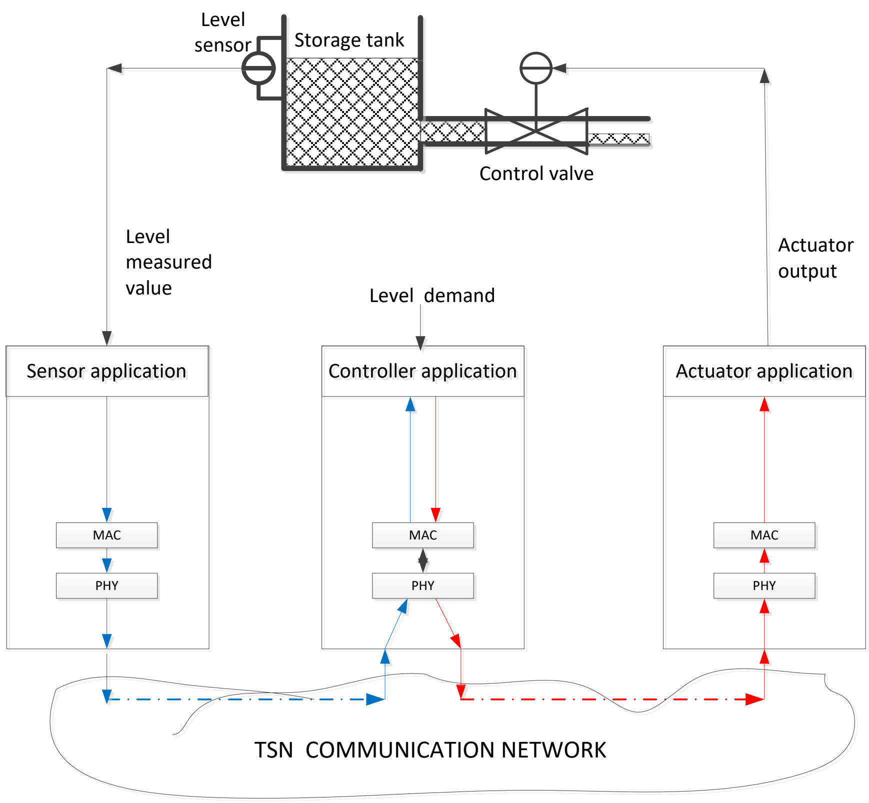

Figure 1 – Data flow in a control loop

In operation, the sensor application samples the measured value and the sampled values are transferred through the network as data packets for the controller to compare with the demand value. After any computational delay, the required output is transferred from the controller to the actuator for implementation as a change in the external process. This sequence repeats continuously as a regular cyclic operation using a local or network time base. For good control, the cyclic repetition rate needs to be 5 to 10 times faster than the time constant of the process response.

Latency or time delay between the sensor input and actuator output needs to be minimised and bounded as non-deterministic data transfer times can significantly degrade control performance.

Components of the control data latency are indicated by the blue and red arrows in Figure 1 and include;

- Computation time in device application layers
- Transfer time through device MAC and PHY layers
- Transfer time through the TSN

Time delays within devices are device specific and known to the manufacturers. Time delays through the TSN need to be predictable at the network design stage and measurable within an operating TSN.

4.1.2 Control models in Industrial Automation

Industrial control applications may be time driven or event driven and their supporting TSN may be synchronous or asynchronous giving four types of application.

Time driven synchronous. Device applications and network access are synchronised to the same time clock.

Time driven asynchronous. Device applications are synchronised to a system time clock, and network access is free running.

Event driven synchronous. Device applications are triggered by availability of network access or receipt of new data values, and network access is synchronised to a system time clock.

Event driven asynchronous. Device applications are triggered by availability of network access or receipt of new data values, and network access is free running

These applications and their supporting TSN services are shown in Table 5.

Table 5 – Control application types

		Time driven synchronous	**Time driven asynchronous**	**Event driven synchronous**	**Event driven asynchronous**
Device	**Application**	Synchronized to network clock		Synchronized to local timeclock	
	Network access	Synchronised to network clock	As available	As available	As available
	TSN support	Stream Class based scheduling, Preemption			
External network	**Network /Bridges**	Synchronized to network clock	Free running	Synchronized to network clock	Free running
	TSN support	Scheduled traffic + Strict Priority + Preemption	Strict Priority or other Shaper + Preemption	Scheduled traffic + Strict Priority + Preemption	Strict Priority or other Shaper + Preemption

Note; Entries in above new Table 5 need review.

Note; Don't understand the last column in the original table 5 copied below.

Original Table 5.

<table>
<tr><td>Level</td><td colspan="2">Isochronous Application</td><td colspan="3">Non-isochronous Application</td></tr>
<tr><td>Application</td><td colspan="2">Synchronized to network access</td><td colspan="3">Synchronized to local timescale</td></tr>
<tr><td>Network access</td><td colspan="4">Synchronized to network clock,
Stream Class based scheduling, Preemption</td><td>Synchronized to local timescale,
Stream Class based scheduling, Preemption</td></tr>
<tr><td rowspan="2">Network /Bridges</td><td>Synchronized to working clock</td><td>Free running</td><td>Synchronized to working clock</td><td>Free running</td><td>Free running</td></tr>
<tr><td>Scheduled traffic +
Strict Priority +
Preemption</td><td>Strict Priority or
other Shaper +
Preemption</td><td>Scheduled traffic +
Strict Priority +
Preemption</td><td>Strict Priority or
other Shaper +
Preemption</td><td>Strict Priority or
other Shaper +
Preemption</td></tr>
</table>

4.1.3 TSN requirements to support IA control

This document describes the requirements for a TSN profile suitable to support transfer of control data among industrial sensors, control devices and actuators.

Note; the requirements list needs checking against use cases.

These requirements shall include:

- a common time service available to all devices,
- network access for data transfer synchronized to a network clock or a local clock.
- configurable data transfer mechanisms which are repeatable on a fixed time base with limited jitter, these transfers are called isochronous or synchronous,
- configurable transfer mechanisms which are executed within a known worst case delay time or latency, these transfers are called non-isochronous or asynchronous.
- Predictable transfer time or latency for transfers through the TSN

Note: The accuracy of TSN latency estimates will be degraded if the Network Bridges are not synchronized to a common working clock as specified by Enhancements for Scheduled Traffic (IEEE 802.1Q-2018).