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Simulation of wireless communication link for control purposes

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Author(s) deliverable:	Tiberiu Seceleanu (ABB) Alf Isaksson (ABB) Mauro De Biasi (ABB) Carlo Snickars (ABB) Krister Landernas (ABB)	**Report/deliverable classification:** ☐ Deliverable ☒ Milestone Report ☐ Three-Monthly Activity Report ☐ Six-Monthly Activity Report	
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1. Introduction

An automation system should be a **deterministic, secure and fault-tolerant system** of networked embedded devices, where diverse heterogeneous physical objects co-operate to achieve a given goal. Wireless devices become increasingly interesting since a growing part of the real cost is associated with the installation (wiring) of the devices.

However, not only is wireless communication sensitive to interference from background noise, but also to competing wireless networks. If wireless communication finds its way into industrial communication, which we believe, we must handle the situation where several different wireless networks will compete for the shared media. Possibly, new scheduling mechanisms need to be developed to handle the possible conflict and traffic congestion.

In order to find solutions to the plenitude of issues affecting the communication based on wireless protocols, we start by assessing in a non-intrusive manner, that is, by simulation, the possible effects of disturbances on communication content and timing on wireless connections. We proceed here by checking the following aspects:

- Generic sources of errors in wireless communication
- Modeling errors
- Analysis of the simulated models
- Scheduling communication

2. Roadmap for reaching milestone 4.3

2.1. Task 4.1

Task 4.1. started and finished as planned, executing in the interval M1 – M12.

The ultimate objective of task 4.1. was to propose an architecture for wireless communication, addressing communication *and* control strategies. The communication scheme in figure 1. can be said to present the most general case of wireless communication in a control system [1].

Basically, the issues to be answered in MS.4.2. are established during the development of task 4.1. Additional information is offered by the results contained in the report of MS.4.2. [2]. The present work is a continuation of both [1] and [2].

2.2. Milestone 4.2.

Milestone 4.2. document describes the problems to be considered when implementing control systems over wireless connections. The problems come in the area of synchronization, and most interesting ones were identified as: jitter, clock drift, delays, packet losses.

2.3. Activity development

We have decided to analyze through simulation communication aspects regarding: delay compensation, packet loss, clock synchronization / drift effects. The detailed results on these are contained in [3, 4]. For brevity reasons, we show here only snapshots of the extensive studies.

The latest standard in wireless communication is the one describing the WirelessHART protocol [6]. We have decided to explore the possibilities of this protocol in order to asses its suitability for application in automation processes. Limitations and benefits are to be analyzed and are part of the report [3].

The TrueTime environment was selected for simulation. TrueTime is a Matlab/Simulink-based simulator for real-time control systems. TrueTime facilitates co-simulation of controller task execution in real-time kernels, network transmissions, and continuous plant dynamics. [5]

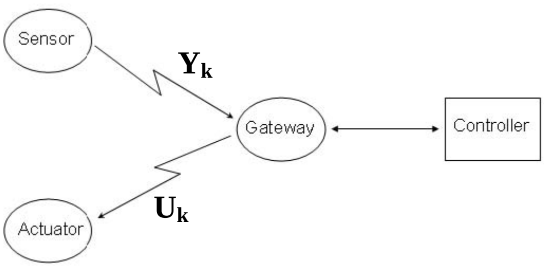

Fig.1. A simple controller system

2.3.1. Environment and setup.

We have considered a simple system as the one in Fig. 1.
The TrueTime tools required new features for wireless communication simulation. However, Only two network

protocols were supported originally: IEEE 802.11b/g (WLAN) and IEEE 802.15.4 (ZigBee). WirelessHART has been added as a result of the work in the SOCRADES project [3]. The radio model used includes support for:

- Ad-hoc wireless networks.
- Isotropic antenna.
- Inability to send and receive messages at the same time.
- Path loss of radio signals modeled as 1 / *da* where *d* is the distance in meters and *a* is a parameter chosen to model the environment.
- Interference from other terminals

In [2] we have introduced the problems that a delay can cause in a system and which are the more sensitive cases. In order to improve the performance of the control loop, some techniques are here described and compared. The solutions proposed are the following:

- Digital PI controller
- Digital PI controller detuned
- PPI (predictive PI) controller
- Modified Smith predictor (integrating case only)

We have established that the most important errors in control are delivered by delays due to clock drift and by packet loss [2]. We have also experimented considering the scheduling policies applicable to the ABB AC800 M controller [7, 8].

2.3.2. Simulations of systems with delay due to clock drift using wireless HART protocol

The global scheme of the control system is illustrated in Fig.2. It was constructed in a Simulink environment.

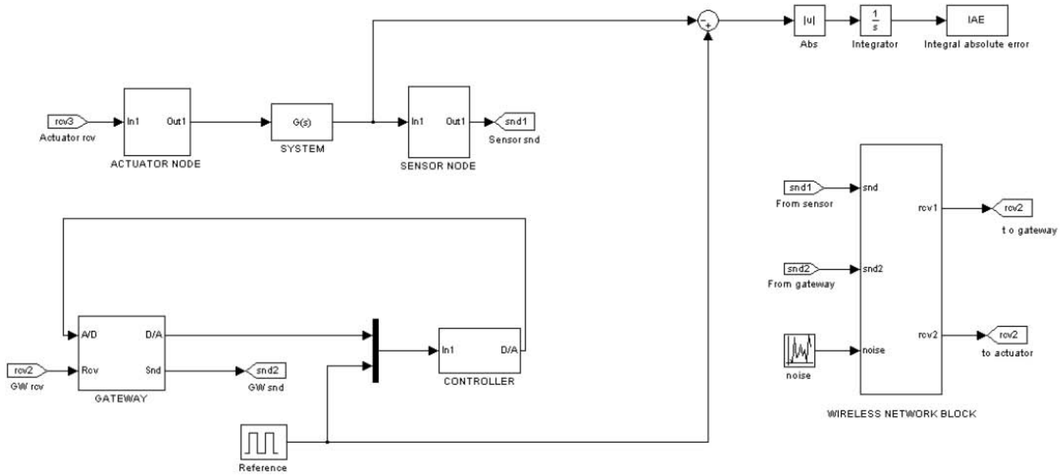

Fig. 2. Representation of the simulated control system.

In this control system there is only one loop. The sensor sends the measurement to the gateway that is responsible to communicate with the controller using a wired protocol (like Profibus or Fieldbus) and to send the control signal to the actuator using the wireless network. The communication between sensor, gateway and actuator is provided by the WirelessHART protocol with a superframe size of 1s and a time slot of 10 ms.

In case the controller suffers from clock drift, the performance decreases as it is shown in Fig. 3, where it is compared to the case without drift.

In fact, the drift of the clock causes a delay of one cycle (in this scenario 1 s) when the control signal is computed after the actuation so the dead-time becomes equal to 1.5 s instead of 0.5 s. Looking at Fig. 3, it is possible to notice an overshoot in the

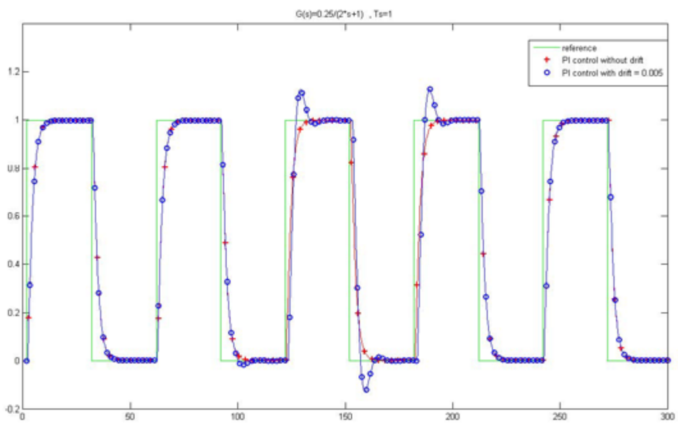

Fig. 3. Reference tracking using the PI controller with and without drift

reference tracking when the system is affected by the extra delay. This overshoot disappears when the drift is equal to one cycle and the actuator task executes again after the controller.

Looking at Fig. 4, it is possible to notice that when the system is affected by the delay, the step response of the PPI is better than the one of the PI. However, it is of course worse when the system has not extra delay, since the PPI is implemented considering a fixed delay of 1 s.

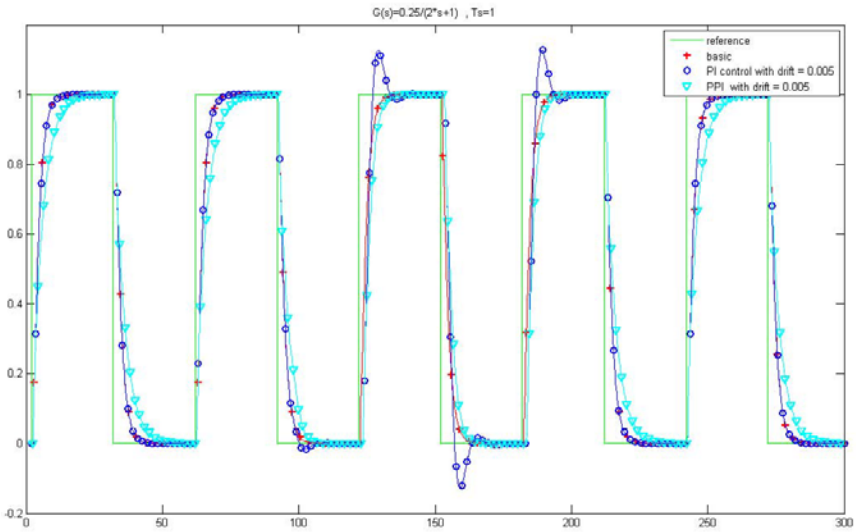

Fig. 4. Comparison of reference tracking between PI and PPI

2.3.3. Performance of the PPI and the PI with input disturbances

We analyze next the effect of disturbances overimposed on the delay caused by clock drift.

In Fig. 5. the Simulink model of the control system with an input disturbance is shown.

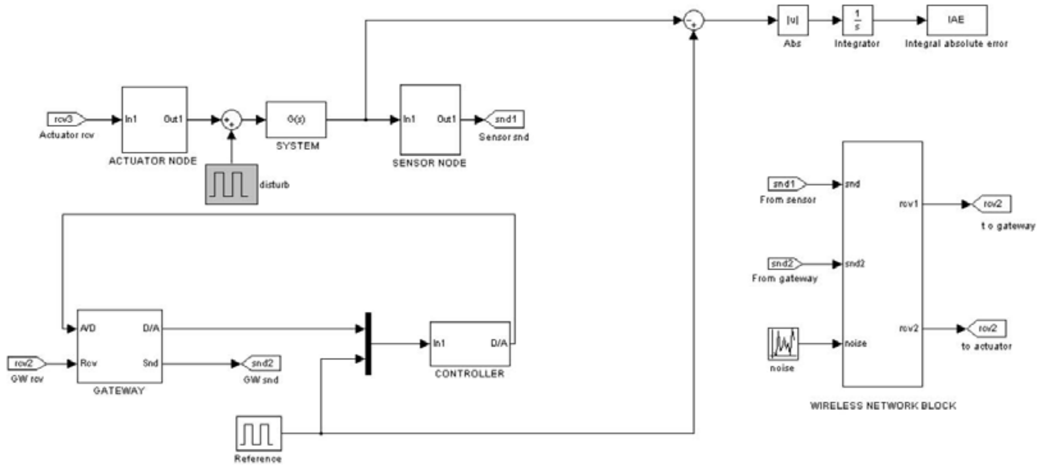

Fig.5. Simulink model of the system with input disturbance

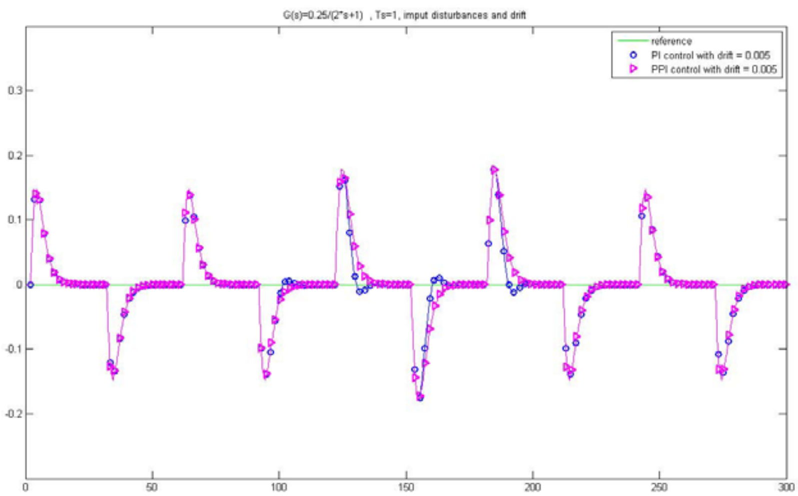

Fig. 6. System output with disturbance and drift

The disturbance is a square wave with an amplitude equal to 1, a period of 60 s and a duty cycle of 50%. The plot of the output signal and the IAE for both PPI and PI controllers is shown in Fig. 6.

2.3.4. Packet loss analysis

We have started our analysis by comparing packet loss effects on three wireless protocols, WLAN, ZigBee and wirelessHART.

Out of our simulations (Simulink / TrueTime) we have reached the following conclusions:

- ZigBee is the protocol with most lost packets (due to low power design).
- WLAN has the best behavior in terms of number of packets reception, but the power consumption of this protocol is very high and the battery life of the devices could be too short.
- A good trade-off is represented by the use of WirelessHART (the TDMA MAC protocol provides less contention than the CSMA/CA of the WLAN).
- On the other hand, to use WirelessHART in a networked control system it is necessary to ensure that the system to control has a time constant of the order of tens of milliseconds. If the system is faster, WirelessHART cannot be used.

There are a few options on how to address packet loss situations, as follows.

1. When a packet is lost, the controller sends a signal equal to zero ($U_k = 0$).
2. When a packet is lost the controller sends the previous control signal ($U_k = U_{k-1}$). A buffer is needed in the controller.
3. If no new information on the system output values is available, the controller continues working using the last data received ($Y_k = Y_{k-1}$). The controller needs a buffer in which to memorize, at each execution, the last feedback signal received.
4. Output estimation. To deal with disturbances on the path controller-actuator, a Luenberger observer / predictor can be employed to alleviate the effects.
5. Employment of multi-hop methods.

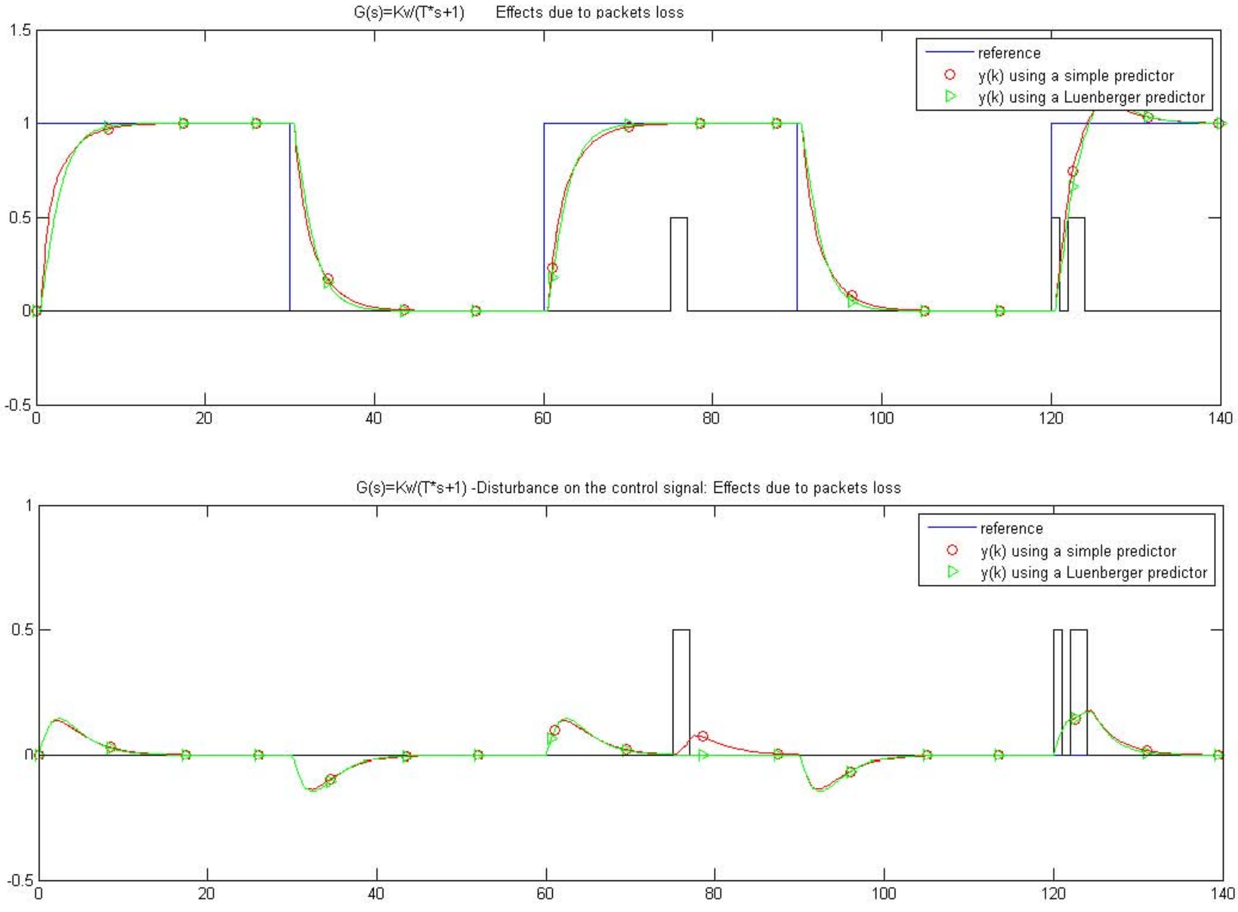

Fig.7. The performances of predictors. (reference signal in the lower figure is null)

The application of the above solutions to the system of Fig. 1. and in the mentioned context is illustrated in Figures 7 to 9.

3. Problems and common results

Delay analysis. It has been shown that delays in delivery of the data packets may produce sensible undesired effects in the output of the controller. One proposed solution is the realization of a hybrid (PI & PPI) controller. Briefly, when the system is not affected by the delay, the controller is a normal PI. Then, when the drift of the clock causes a delay, the control switches to the PPI. More details on the system are described in [4]. We concluded that the hybrid controller permits to have an integral absolute error of the same order of the PI but it is characterized by a better step response. The hybrid controller is, hence, the best solution for this kind of process.

Packet loss. The executed simulations showed that packet loss may provide larger erroneous behavior than delay effects, if the loss appears in “key time locations”. There are several solutions to mitigate the issue, as illustrated, but their utility may differ from case to case.

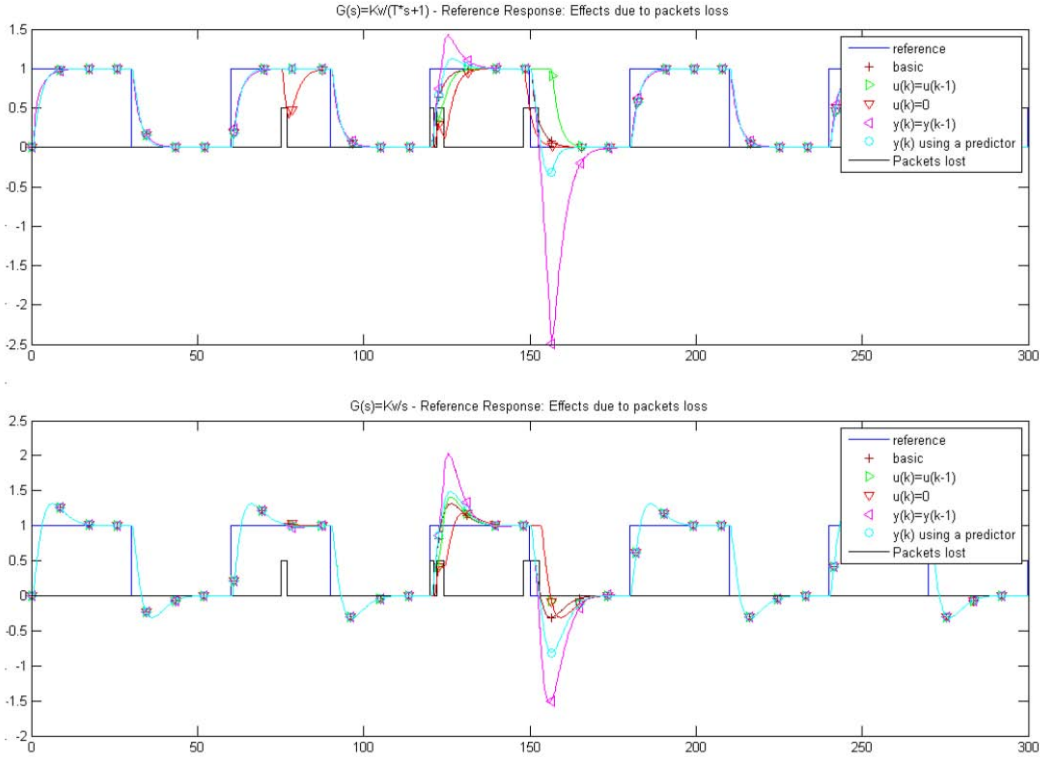

Fig. 8. Results using various methods: reference response.

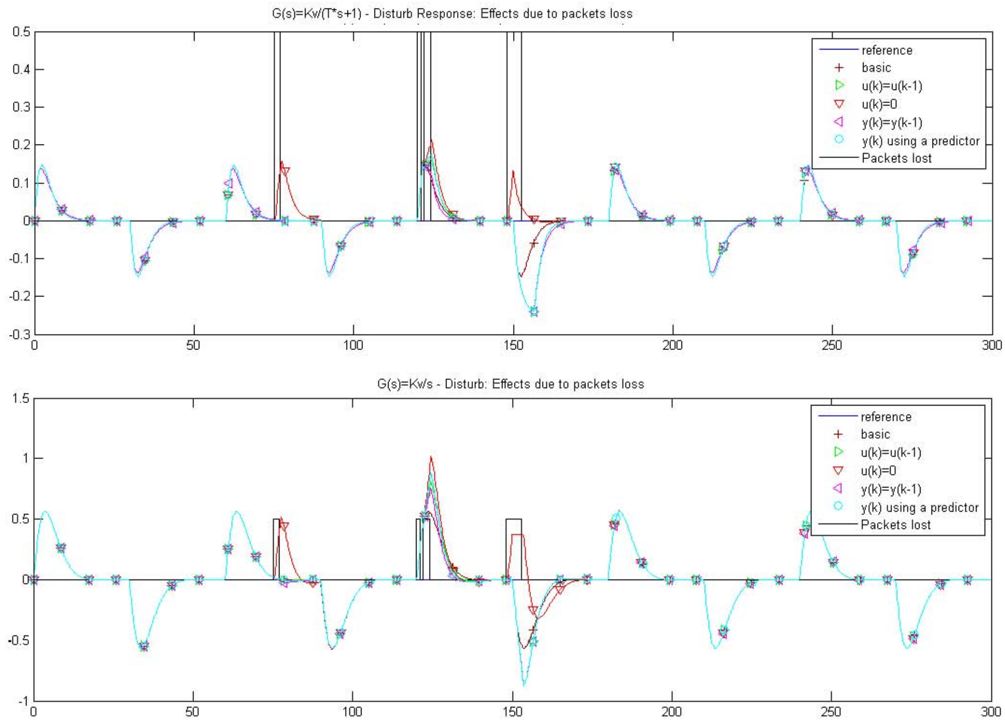

Fig.9. Results using various methods: disturbance rejection.

4. Conclusion

The results contained in the previous sections, and especially the detailed reports [3] and [4] show the importance of analyzing the communication over wireless networks. Even the latest standards do not offer immunity to effects of delays and package loss. However, several solutions to lessen the impact can be developed. Possibly combining such solutions with appropriate (dynamic) scheduling policies may reduce even further the undesired effects noted in wireless connectivity.

While the results in the development of the report are indicative, they may not be considered extensive, therefore certain caution may be exercised in their possible direct application.

Additional protocols (such as 6LowPan) are under study, too, in parallel activities.

In this idea, a real situation was analyzed (the Boliden plant at Garpenberg). The results will be visible in the forthcoming deliverables of the project.

References

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