RUHR-UNIVERSITÄT BOCHUM
Institute of Automation and Computer Control
Prof. Dr.-Ing. Jan Lunze

Universitätsstr. 150 Phone +49-(0)234 32-28071
D-44805 Bochum Fax +49-(0)234 32-14101

Self-organizing control of autonomous agents

René Schuh
schuh@atp.rub.de

1 Introduction

This project deals with the command tracking in multi-agent systems with leader-follower structure (Fig. 1). A networked controller has to be designed such that the outputs $y_i(t)$ of the agents Σ_i follow the reference trajectory $y_s(t)$, which is generated by a leading agent Σ_0. The networked controller consists of local control units C_i that have access to the outputs $y_i(t)$ of the agents Σ_i and the communication network over which the control units C_i can exchange information (e.g. the output $y_i(t)$). The question arises:

When does information have to be exchanged?

The answer to be given in this project is that the control units C_i decide autonomously according to the current situation about sending and requesting information.

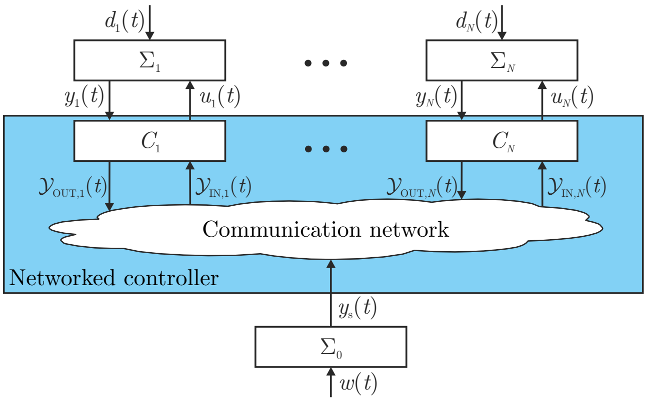

Figure 1: Self-organizing control of autonomous agents

2 Project aims

The goal of this project is to develop methods for designing a networked controller that decides which communicational interconnection is appropriate according to the current situation to achieve a claimed control performance. The networked controller fulfills the following constraints:

- There is no central coordinator which has access to all model information and measurement information.
- Every control unit C_i makes the decision of communicating with other control units autonomously and independently from the decision of the other control units.
- The decisions of the control unit C_i are based on local information only.

In the course of the project, answers will be given to the following questions:

- How can the control performance be improved by adapting the communication topology to the current control tasks?
- In which situations is an adaptation of the communication necessary?

3 Models and communication

The **agents** Σ_i, $(i=0,1,\dots,N)$ are described by

$$\Sigma_i: \begin{cases} \dot{\boldsymbol{x}}_i(t) = \boldsymbol{A}\boldsymbol{x}_i(t)+\boldsymbol{b}u_i(t)+\boldsymbol{e}d_i(t)+\boldsymbol{g}w_i(t), & \boldsymbol{x}_i(0)=\boldsymbol{x}_{0i} \\ y_i(t) = \boldsymbol{c}^{\mathrm{T}}\boldsymbol{x}_i(t), \end{cases}$$

where $\boldsymbol{x}_i(t)$ is the state, $\boldsymbol{x}_{0i}$ is the initial state, $u_i(t)$ is the input $(u_0(t)=0)$, $d_i(t)$ is the disturbance $(d_0(t)=0)$ and $w_i(t)$ is the command signal $(w_i(t)=0,\ i=1,\dots N)$.

The **communication structure** of the networked controller is represented by a directed time-varying labeled graph $\mathcal{G}(t)=(\mathcal{V},\mathcal{E}(t),\boldsymbol{K})$, with the set of vertices $\mathcal{V}=\{0,1,2,\dots,N\}$ representing the agents, the set of directed edges $\mathcal{E}(t)$ representing the communication links among the agents and the weighting matrix $\boldsymbol{K}$ representing the coupling strength among the agents. In general the communication topology can be divided into two modes:

- The *basic communication structure* is designed to guarantee necessary requirements on the overall system behavior as command tracking and disturbance accommodation with a minimum amount of communication links (e.g. Fig. 2(a), Fig. 4(a)).
- The *adjusted communication structure* has to improve the control performance by cutting or adding links to the basic communication structure. It depends on the current situation (e.g. Fig. 2(b), Fig. 4(b)-(c)).

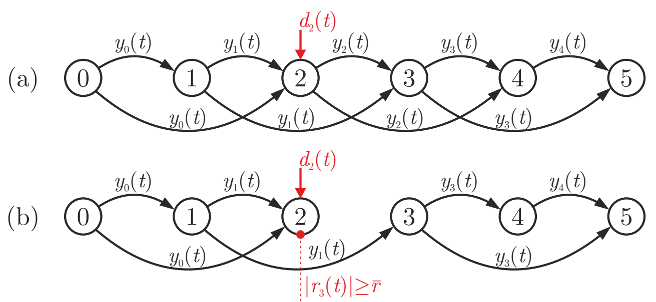

Figure 2: Basic communication (a) and adjusted communication structure (b) for disturbance attenuation [1]

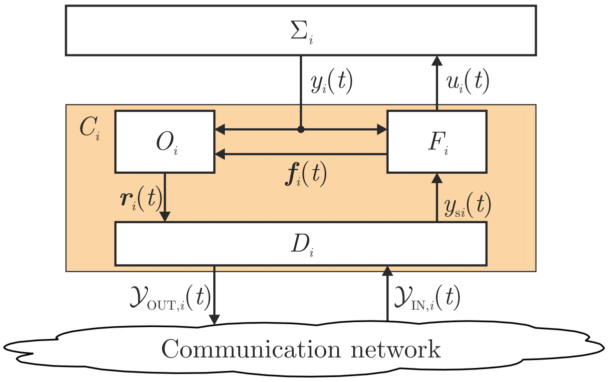

Figure 3: Control unit C_i

The **control units** C_i in Fig. 3 consist of 3 components:

- The **feedback unit** F_i generates the input $u_i(t)$ by getting the output $y_i(t)$ and the local reference signal $y_{si}(t)$ from the decision unit D_i.
- The **observation unit** O_i generates the signal $\boldsymbol{r}_i(t)$, that represents the deviation of the agent Σ_i from the desired behavior, by evaluating the output $y_i(t)$ and the information $\boldsymbol{f}_i(t)$ (e.g. $u_i(t)$) from F_i.
- The **decision unit** D_i generates the local reference signal $y_{si}(t)$ by evaluating $\boldsymbol{r}_i(t)$ and decides about the incoming information $\mathcal{Y}_{\mathrm{IN},i}(t)$ and outgoing information $\mathcal{Y}_{\mathrm{OUT},i}(t)$.

4 Approaches to self-organization of networked controllers

The **disturbance attenuation** in unidirectionally coupled agents is investigated in [1], where the presented control units C_i switch off the communication to the other agents, whenever the effect $r_i(t)$ of the disturbance d_i on the corresponding agent Σ_i exceeds a given bound $\bar{r}$ (cf. Fig. 2). It is shown that the control error $\Delta y_i(t) = y_i(t) - y_s(t)$ of the undisturbed agents can be bounded by an appropriate choice of $\bar{r}$.

The **command tracking** for a piecewise constant changing command signal $w(t)$ in unidirectionally coupled agents is investigated in [2], where the control units C_i request additional information from other agents, if the control error $e_i(t)$ of the agent Σ_i exceeds a given bound

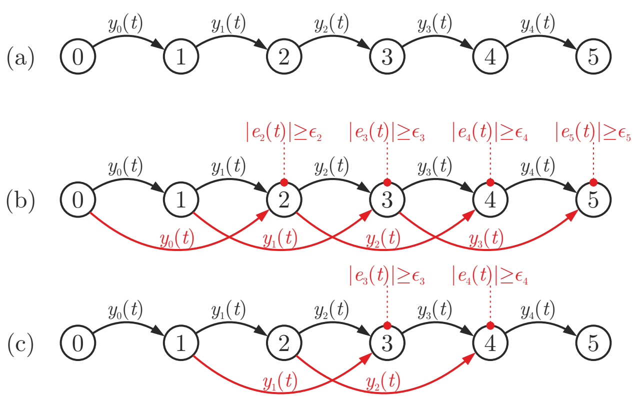

Figure 4: Basic communication (a) and adjusted communication structure (b)-(c) for command tracking [2]

ϵ_i (cf. Fig. 4). It is shown that the control error $\Delta y_i(t)$ can be bounded by an appropriate choice of the information activation condition.

In **future work** the results in [1, 2] should be extended to

- agents Σ_i with different dynamics,
- multidirectional communication structures,
- situations with simultaneously affecting disturbances and a changing command signal.

5 Application: Robot formation

The formation problem for robots is illustrated in Fig. 5, where the command signal $w(t)$ changes over time (see first plot of Fig. 6) [2]. The second plot of Fig. 6 shows

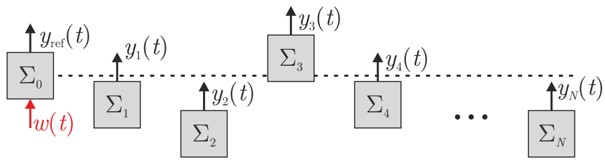

Figure 5: Robot formation control

that with the additional communication the control error of Σ_5 can be reduced by about 40%, from approximately $|\Delta y_5^*(t)| = 10\,\mathrm{m}$ without information request (dashed black line) to $|\Delta y_5(t)| = 6.3\,\mathrm{m}$ (solid magenta line).

The third plot of Fig. 6 (Req. Σ_i) shows the time intervals at which the robots Σ_i activate the additional communication links, which is indicated by a thick black horizontal bar, where the thin red vertical lines indicate the corresponding communication structures in Fig. 4. This example shows that the communication structure is adjusted to the currently acting command signal $w(t)$ and the communication is not activated if the set-point change is slight.

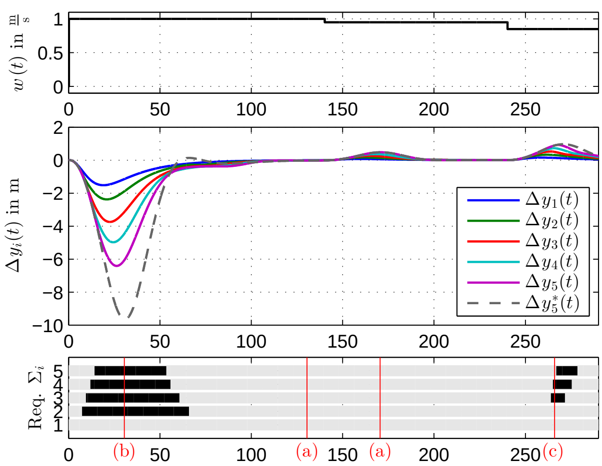

Figure 6: Command tracking of a robot formation

References

[1] J. Lunze. Self-organising disturbance attenuation in unidirectionally coupled synchronised systems. In *Proc. 19th IFAC World Congress*, 2014. accepted.

[2] R. Schuh and J. Lunze. Self-organizing control of unidirectionally coupled heterogeneous agents with information request. In *Proc. 53rd IEEE Conference on Decision and Control*, 2014. submitted.