Minimizing Communications in Decentralized Supervisory Control with Communication Delay

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A Discrete-Event System(DES) is a discrete-state, event-driven system, that is, its state evolution depends entirely on the occurrence of asynchronous discrete events over time. In this paper, we study minimal communication problem in decentralized discrete-event systems with communication delay. As a result, we show that the minimal communication problem with communication delay belongs to the NP-hard class. In addition, we propose an approximation algorithm for this problem.

Systems which are considered as discrete-event systems studied in this research covers various application areas such as computer hardware/software, motion control for robot, plant control. There are several methods for modeling discrete-event systems, some of them are Petri-nets, Automata and Process Algebra.

Supervisory control proposed by Ramadge et al. is a formalisim for controlling discrete-event systems. In supervisor control, control objective, control specifications, and controllers (*agent* or *supervisor*) are represented by automata.

In the supervisory control scheme, the controller can restricts occurrence of events and the aim is to design a controller so that the system satisfy a control specifications.

In the original scheme of supervisor control, the number of controllers is one, and this is called centralized control. Recently, decentralized control has been proposed in the supervisory control scheme from the rise of intention for decentralization of system control. Decentralized control is a control scheme such that one plant is controlled by two or more controllers. First proposal for decentralized control did not allow communication among controllers. Afterwards, the research on decentralized control using communication has been proposed. Also for decentralized control with communication,Tripakis proved that the problem of checking the existence of controllers under unbounded-delay communication was undecidable.

In previous researches, the specification is satisefied if the language generated by controlled system and the language generated by specification is equal. However, in decentralized control with communication, even if the language generated by controlled system is equal to the language generated by spacification, there are no guarantees that the controlled system and the specification to behave equally. Therefore, in decentralized control with communication, we need another criterion for checking "*specification is satisfied or not*". It is proposed to use bisimulation with respect to events generated by the plantas one of the criteria for this. However, no algorithm for designing controllers such that controlled system and specification are bisimilar has been proposed yet.

For minimizing communication events in decentralized control, there are some privious works, but all of them uses language equivalence as a criterion for checking "*specification is satisfied or not*". In addition, minimizing communication problem with communication delay has not been reported yet.

In this thesis, we aim to propose solutions for those problems stated above. Tha is, the problems studied in this thesis are:

- **Algorithms for designing decentralized controllers**
  We propose an algorithm for designing decentralized controllers such that the controlled system and the specification are bisimilar for plant events.

- **Formulating minimizing communication problem**

We formulate minimizing communication problem.

- **Analysis of complexity of minimizing communication problem**
  We analyze complexity of minimizing communicationproblem with communication delay.

- **Algorithms for minimizing communication problem**
  We propose an algorithm for minimizing communication problem.

As a result of this research, we proposed an algorithm for designing decentralized controllers such that the controlled system and the specification are bisimilar. Futhermore, we formulated minimizing communication problem and proved that minimizing communication problem belongs to the NP-hard class. Finally, we proposed approximation algorithm for minimizing communication problem.

The obtained results are summarized as follows:

- **An algorithm for designing decentralized controller**
  We proposed an algorithm for designing decentralized controller. In this algorithm, we obtain decentralized controllers by decomposing centralized controller. Note that this algorithm does not always gives optimal solution.

- **NP-hardness for minimizing communication problem**
  We showed that minimizing communication problem belongs to NP-hard class.

- **An approximation algorithm for minimizing communication problem**
  We showed reduction from the minimizing communication problem to the minimal colored cut problem, which was already investigated in literature. Finally, for the minimal colored cut problem, we proposed an approximation algorithm with approximation ratio 0.5th power of number of edges.

In this research, we modeled decentralized control system with communication under several assumptions. However, some of these assumptions are seems not to be realistic.

We should make effort to study formalism without these assumptions. Future works can be listed as follows:

- **Decentralized control with partial communication**
  In this research, we assume that communication events are broadcasted to all other controllers. However, broadcasting communication events to all other controller is very expensive in real application. Therefore, it is necessary to study decentralized control in which some controllers cannot observe communication events.

- **Decentralized control with communication loss**
  In actual applications, there is no guarantee that communication events are surely sent by the destination. However, in this research, we assume that all communication event are broadcasted to all other controllers without any loss. Therefore, it is necessary to study decentralized control with loss of communication events.