Scheduling with Optimized Communication for Time-Triggered Embedded Systems

Summary

- Scheduling algorithms proposed can be used both for performance estimation and for system synthesis.
- System model capturing both the flow of data and that of control.
- Communication using time-triggered protocol (TTP) implementation.
- Improved schedule quality by considering the overheads of the real-time kernel and communication protocol.

Hardware Architecture

- Safety-critical distributed embedded systems.
- Nodes connected by a broadcast communication channel.
- Nodes consisting of a TTP controller, a CPU, a RAM, a ROM and an I/O interface to sensors and actuators.
- Communication is based on the TTP.

Software Architecture

- Real-time kernel on the CPU in each node.
- Local schedule table in each kernel.
- The worst case administrative overheads:
  \[ U_t \] timer interrupt routine
  \[ \delta_{PA} \] process activation overhead
  \[ \delta_{S} \] sending a message on the same node
  \[ \delta_{KS} \] sending a message between nodes
  \[ \delta_{KR} \] receiving a message from another node

Problem Formulation

Input: Safety-critical application modelled by a conditional process graph.
Mapping of processes to nodes is given.
Worst case execution delay of a process \( P_i \) is:
\[ T_{P_i} = (\delta_{PA} + \delta_{S} + \theta_{C_i} + \theta_{C_i} \cdot (1 + U_t)) \]
where:
\[ \theta_{C_i} = \sum_{j=1}^{N_{\text{entry}}(P_i)} \delta_{S_j} + \sum_{j=1}^{N_{\text{remote}}(P_i)} \delta_{KS_j} + \sum_{j=1}^{N_{\text{remote}}(P_i)} \delta_{KR_j} \]
Output: Local schedule tables and MEDL, delay (smallest) on the system execution.

Scheduling Strategy

- Sequence and lengths of the slots in a TDMA round are determined to reduce the delay.
- Previous work extended to handle scheduling of messages within TTP for a given TDMA configuration.
- Two approaches: Greedy heuristic, Simulated Annealing.
  Two variants: Greedy 1 tries all slot lengths, while Greedy 2 uses feedback from the schedule_message.
  SA parameters are set to guarantee finding near-optimal solutions in a reasonable time.

Time-Triggered Protocol

- TTP was designed for distributed real-time applications that require predictability and reliability.
- The bus access scheme is time-division multiple-access (TDMA).
- Each node can transmit only during a predetermined time interval, its TDMA slot. A sequence of slots for all nodes is a TDMA round. Several rounds can form a cycle that is repeated periodically.
- Every node has a TTP controller.
- The TDMA access scheme is imposed by a message descriptor list (MEDL) located in every controller.
- MEDL serves as a schedule table for the TTP controller which knows when to send/receive a message.

Problem Formulation

- Input: Safety-critical application modelled by a conditional process graph.
- Mapping of processes to nodes is given.
- Worst case execution delay of a process \( P_i \) is:
  \[ T_{P_i} = (\delta_{PA} + \delta_{S} + \theta_{C_i} + \theta_{C_i} \cdot (1 + U_t)) \]
  where:
  \[ \theta_{C_i} = \sum_{j=1}^{N_{\text{entry}}(P_i)} \delta_{S_j} + \sum_{j=1}^{N_{\text{remote}}(P_i)} \delta_{KS_j} + \sum_{j=1}^{N_{\text{remote}}(P_i)} \delta_{KR_j} \]
- Output: Local schedule tables and MEDL, delay (smallest) in the context of current TDMA round.