Routing Optimization of AVB Streams in TSN Networks

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Outline

- Motivation
- Time Sensitive Networking (TSN)

- Architecture and application models
- Problem formulation and motivational example

- Optimization strategy: GRASP
- Experimental results

- Summary and message

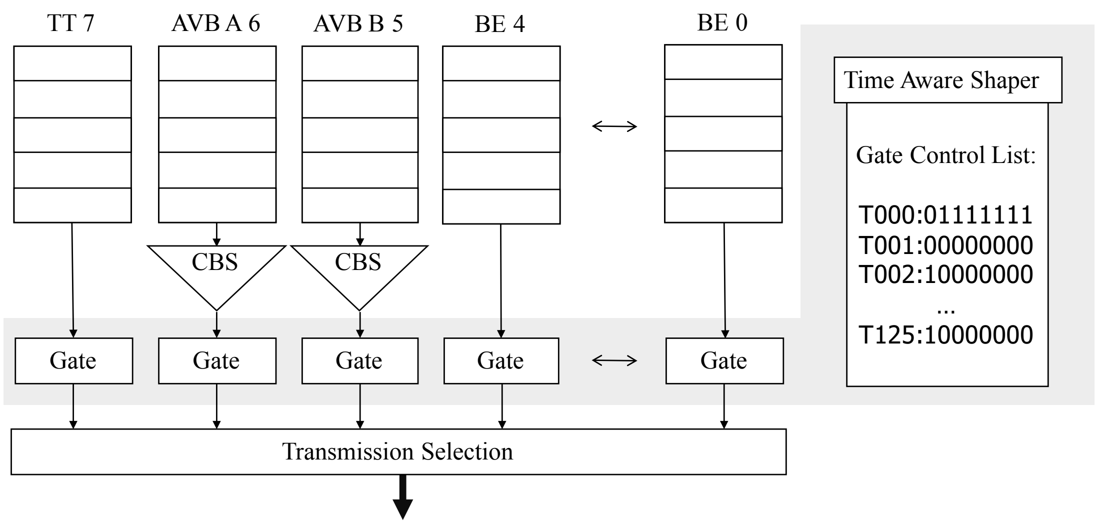
Motivation

Safety-critical communication protocols	Specialized protocols in several areas: Vehicles: CAN, FlexRay Avionics: SAFEBus Factories: ProfiNet
Trend:	**The wired protocol of the Industrial Internet of Things**
Deterministic Ethernet	IEEE 802.1 standards for real-time and safety-critical applications in process control, industrial automation, audio and video systems, vehicles and aerospace

What is Time Sensitive Networking (TSN)?

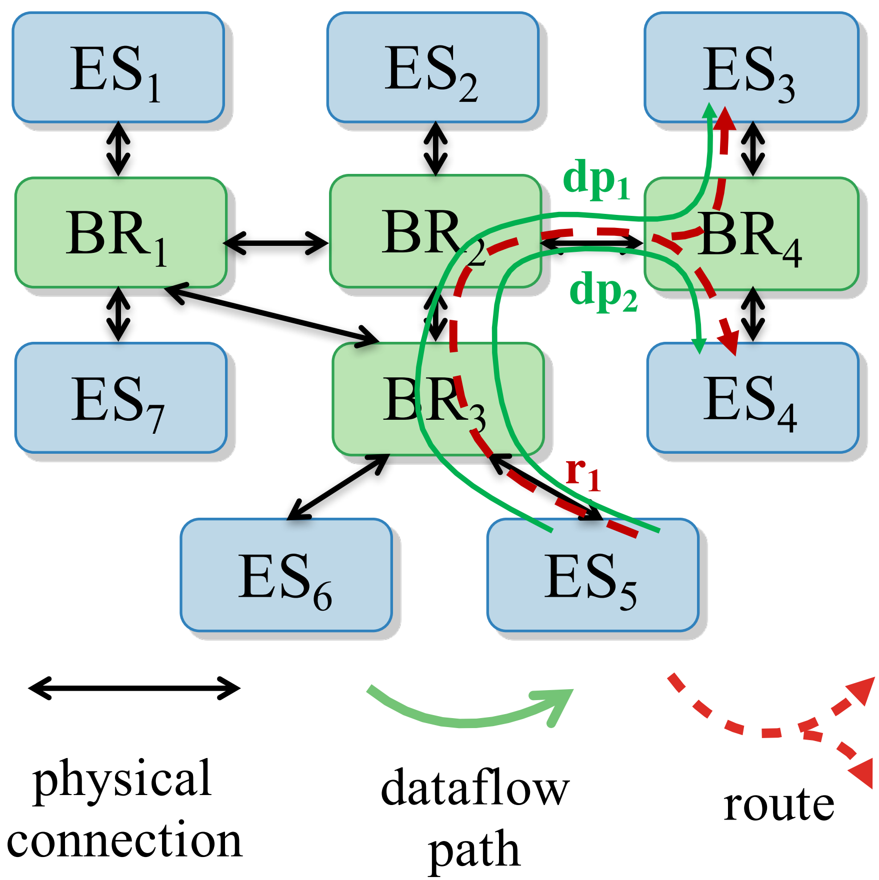
- IEEE 802.1 Ethernet standard enhanced for safety-critical and real-time applications
  - IEEE 802.1BA *Audio Video Bridging Systems*
  - IEEE 802.1Qav *Forwarding and Queuing Enhancements for Time-Sensitive Streams*
  - IEEE 802.1AS *Timing and Synchronization (based on IEEE 1588)*
  - IEEE 802.1Qbv *Enhancements for Scheduled Traffic*
  - IEEE 802.1Qbu *Frame Preemption*

- Three traffic types:
  - **Time-Triggered (TT)**
    GCL: Gate Control Lists
    (synchronized schedule tables)
  - **Audio-Video Bridging (AVB)**
    Shaped to provide guarantees and prevent the starving of BE
    CBS: Credit Based Shaper
  - **Best Effort (BE)**
    Regular non real-time traffic



Architecture and application models

Architecture



Application

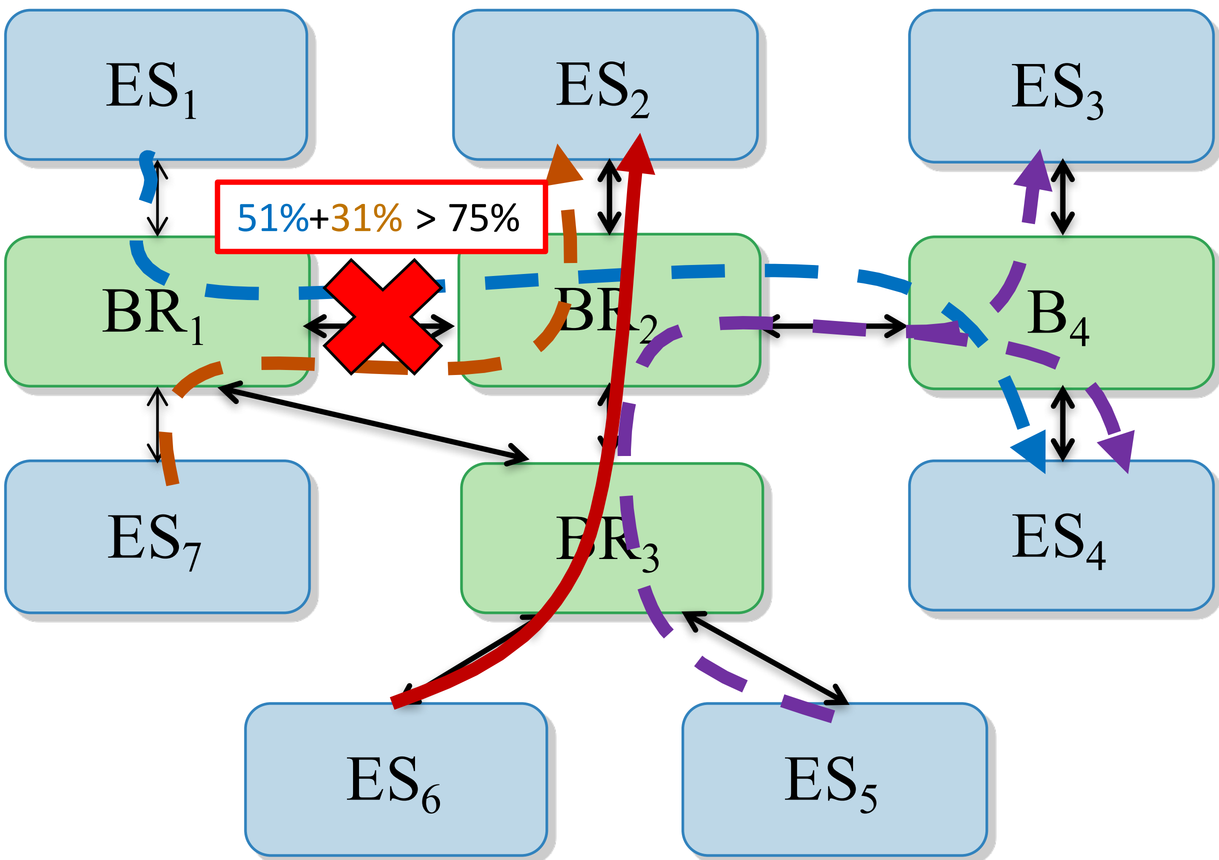
- AVB streams S^{AVB}
  - Endpoints, Size, Period and Deadline
- TT streams S^{TT}
  - Route and schedule tables (GCL)
- BE: Not explicitly modelled

Problem formulation

- **Given**
  - The topology of the TSN network G(**E**, **V**)
  - The set of AVB streams $\mathbf{S}^{AVB}$ (endpoints, size, period, deadline)
  - The set of TT streams $\mathbf{S}^{TT}$ (routing, Gate Control Lists)
- **Determine**
  - A routing for each AVB stream
- Such that
  - The Worst-Case end-to-end Delays (WCD) of AVB streams are smaller than their deadlines
  - The WCDs and the “network utilization” are minimized

Motivational example

Shortest Path Routing

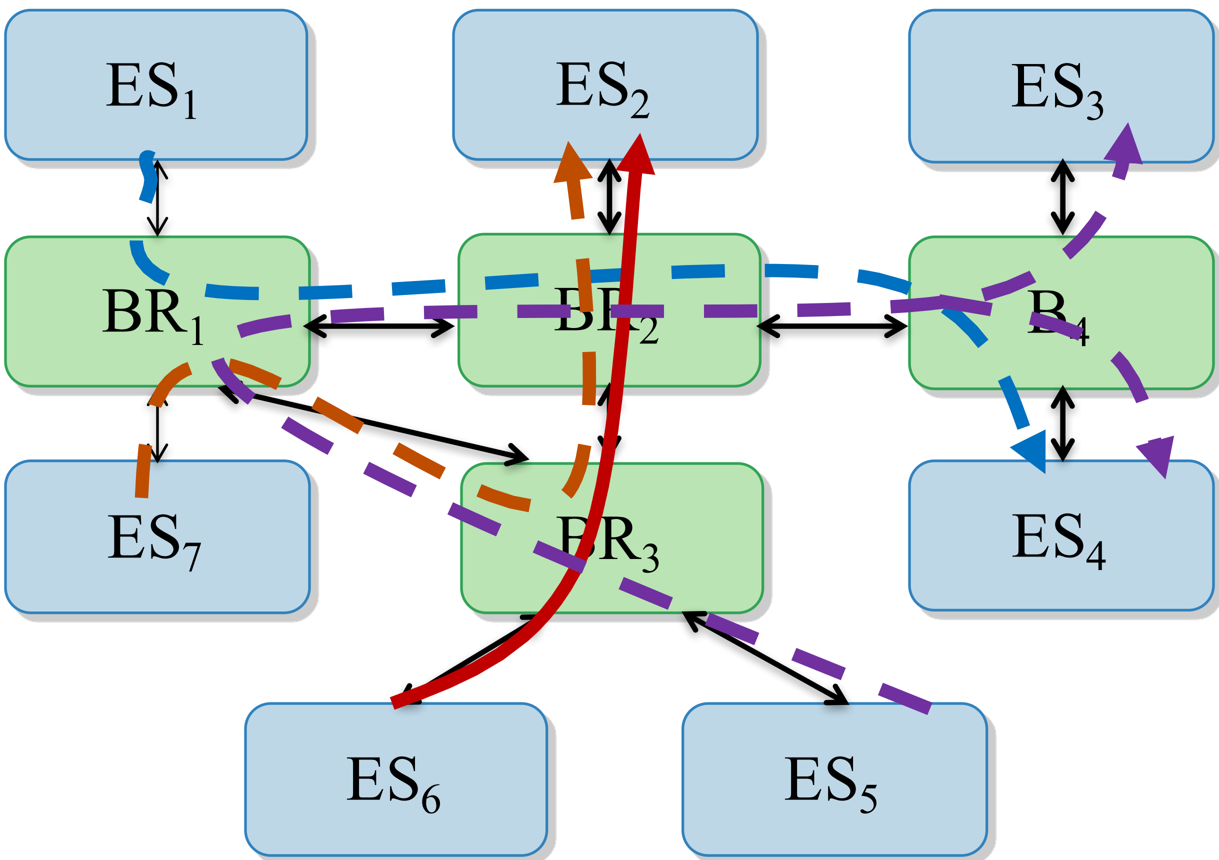


Streams :

- s_1 AVB A 51%
  $ES_1 \rightarrow ES_4$
- s_2 AVB A 22%
  $ES_5 \rightarrow ES_3, ES_4$
- s_3 AVB A 31%
  $ES_7 \rightarrow ES_2$
- s_4 TT 25%
- 25% is left for BE

Motivational example, cont.

Optimized Routing



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Optimization strategy

- **Search-Space Reduction**
  - Generate all the possible routes for the AVB streams using “K Shortest Paths”:
    - K unique routes of increasing length, starting from the shortest route
  - **Problem**: *selecting* a route for each AVB stream from this generated set

- **GRASP on the reduced space**
  - Greedy Randomized Adaptive Search Procedure
    - Meta-heuristic that searches for a solution that optimizes the **Cost Function**
    - Two phases:
      - **Phase 1**: Constructs a “Greedy Randomized” initial solution
        Select randomly a stream at a time, and try a number or routes, keeping the best one
      - **Phase 2**: Uses “Local Search” (“Hill Climbing”) to improve the initial solution

Optimization strategy: cost function

- $cost(R) = O_1(R) \cdot W_1 + O_2(R) \cdot W_2 + O_3(R) \cdot W_3$

  - O_1: The number of AVB streams exceeding their deadlines
    - We use a Worst-Case end-to-end Delay (WCD) analysis
      - This paper: extended “AVB Latency Math” (unsafe, pessimistic)
      - Ongoing work: Network Calculus
    - If all AVB streams meet their deadlines, first term is zero, otherwise we use a large penalty value W_1

  - O_2: WCD values are minimized
    - If all AVB streams meet their deadlines, we prefer a solution where WCDs are smaller

  - O_3: Total number of datalinks used for the AVB streams
    - If all AVB streams meet their deadlines, we prefer a solution that uses less datalinks for routing

Experimental results

ID	Architecture $\|ES\|$	$\|BR\|$	Rate	Application $\|\mathbf{S}^{\text{AVB}}\|$	$\|\mathbf{S}^{\text{TT}}\|$	SFS O_1	O_3	RO O_1	O_3	cost
MOTIV_T1	7	4	100 Mbps	3	1	1	12	0	14	20.60
SYNTH_T1	10	4	100 Mbps	4	1	4	14	0	18	24.04
ORION_T1	31	15	1 Gbps	20	3	3	139	0	136	170.49
ORION_T2				35	5	8	226	0	223	303.12
ABB_T1				18	1	7	175	0	167	206.99
ABB_T2	20	36	1 Gbps	16	3	5	155	0	145	179.94
ABB_T3				16	6	7	155	1	151	—

- Algorithms
  - SFS: **S**traight**f**orward **S**olution, uses shortest routes
  - RO: Our **R**outing **O**ptimization strategy
- Results
  - O_1: The number of AVB streams exceeding their deadlines
  - O_3: Total number of datalinks used for the AVB streams
- Setup: $\alpha = K/2$, $\beta = |\mathbf{S}^{\text{AVB}}|$ and $K = 50$, $W_1 = 10{,}000$, $W_2 = 3$ and $W_3 = 1$
  - Java programing language on Intel i7-2600K (15 min. time limit)

Summary and message

- Summary
  - We have addressed the optimization of the TSN protocol
  - The AVB stream routes are determined such that the AVB streams meet their timing constraints, the WCDs and the network utilization are minimized
  - We have proposed a GRASP based optimization solution that uses “K Shortest Paths” to reduce the search space

- Message
  - Configuration and analysis tools are are needed for TSN
  - Tools can help to answer “What if?” questions during the development of TSN