



CISTER - Research Center in
Real-Time & Embedded Computing Systems

A module for FTT-SE protocol in ns-3

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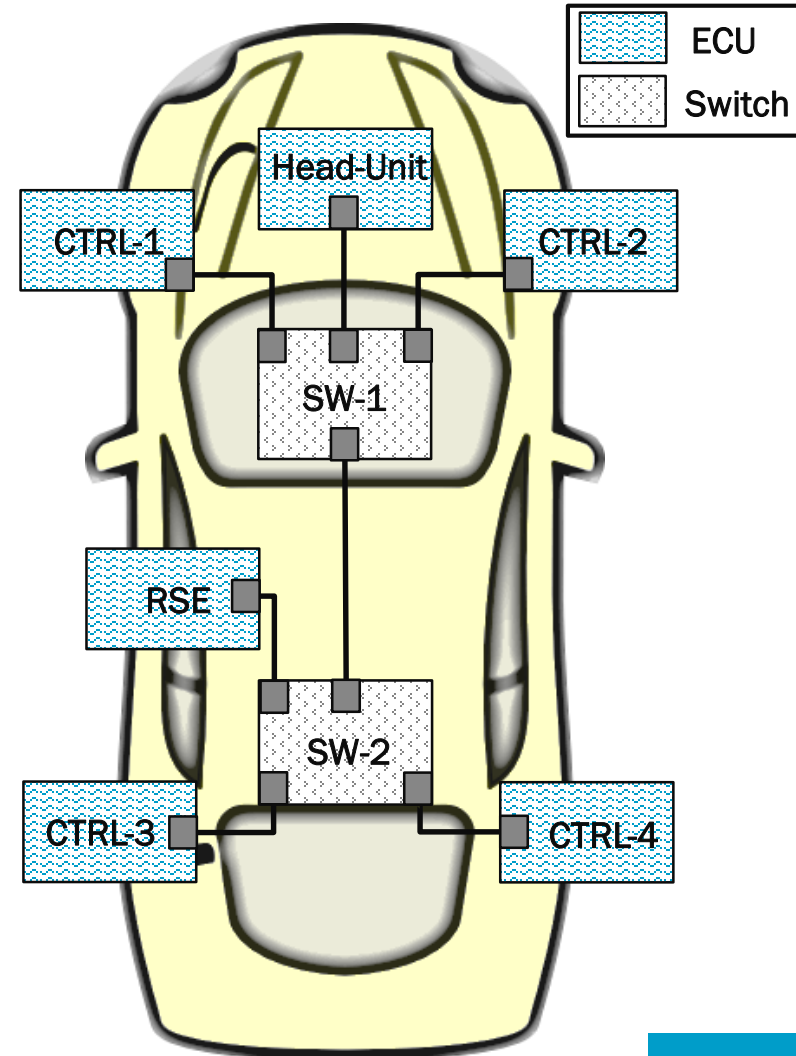
Outline

- Motivation
- FTT-SE protocol
- Simulator ns-3
- FTT-SE module
- Simulations results
- Parallel/Distributed Tasks
- Conclusions and Future work



Motivation

- **Modern real-time** applications such as **automotive** applications are becoming **larger** and **more complex**.
 - Tens of ECUs interconnected by different network technologies, **requiring high bandwidth** and computing power.
- The Flexible Time Triggered Switched Ethernet (**FTT-SE**) provides **higher bandwidth** and **conciliates** the transition of **best-effort** traffic and **real-time traffic** (synchronous and asynchronous).



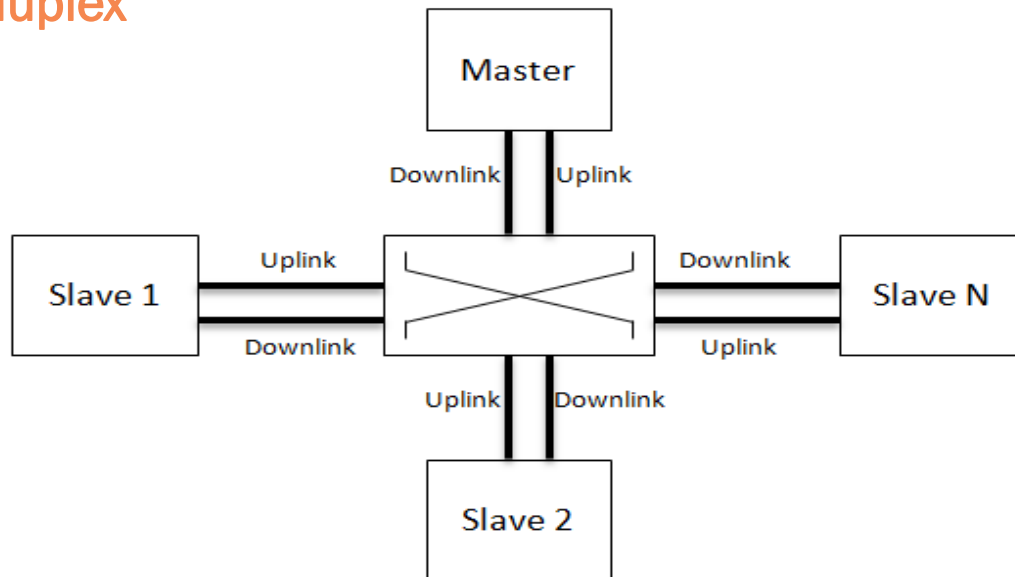
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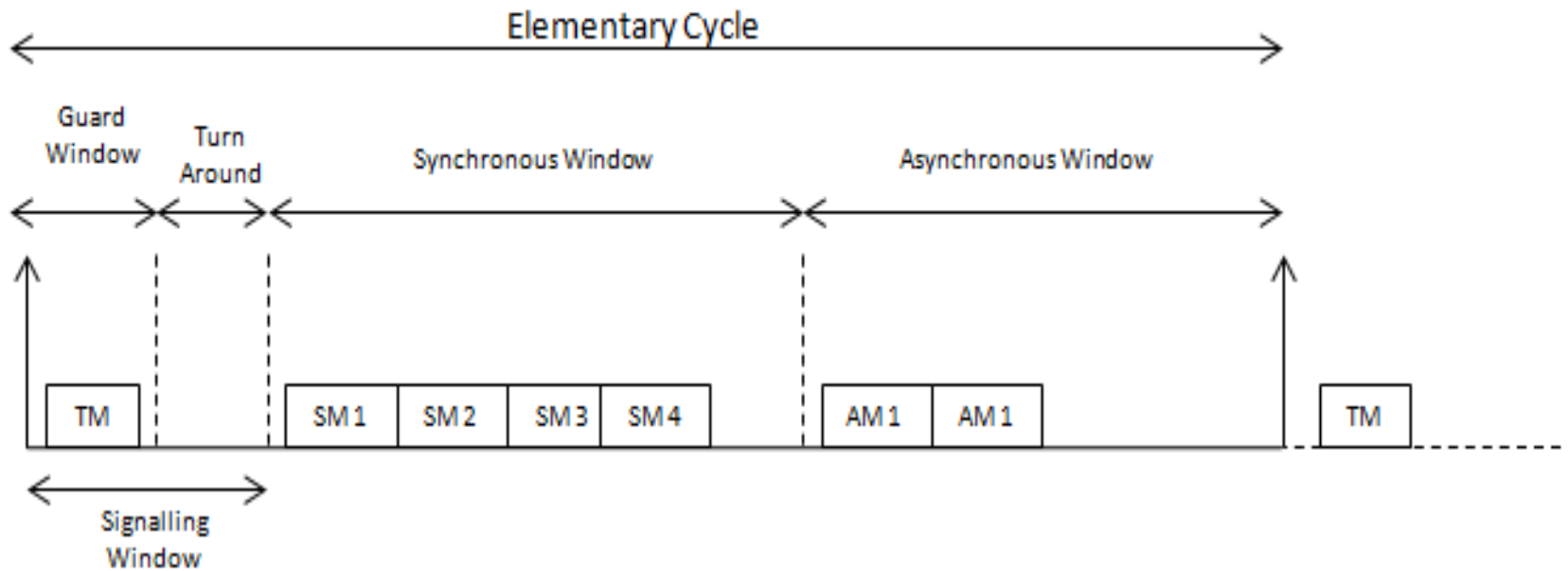


Flexible Time Triggered - Switched Ethernet (FTT-SE)

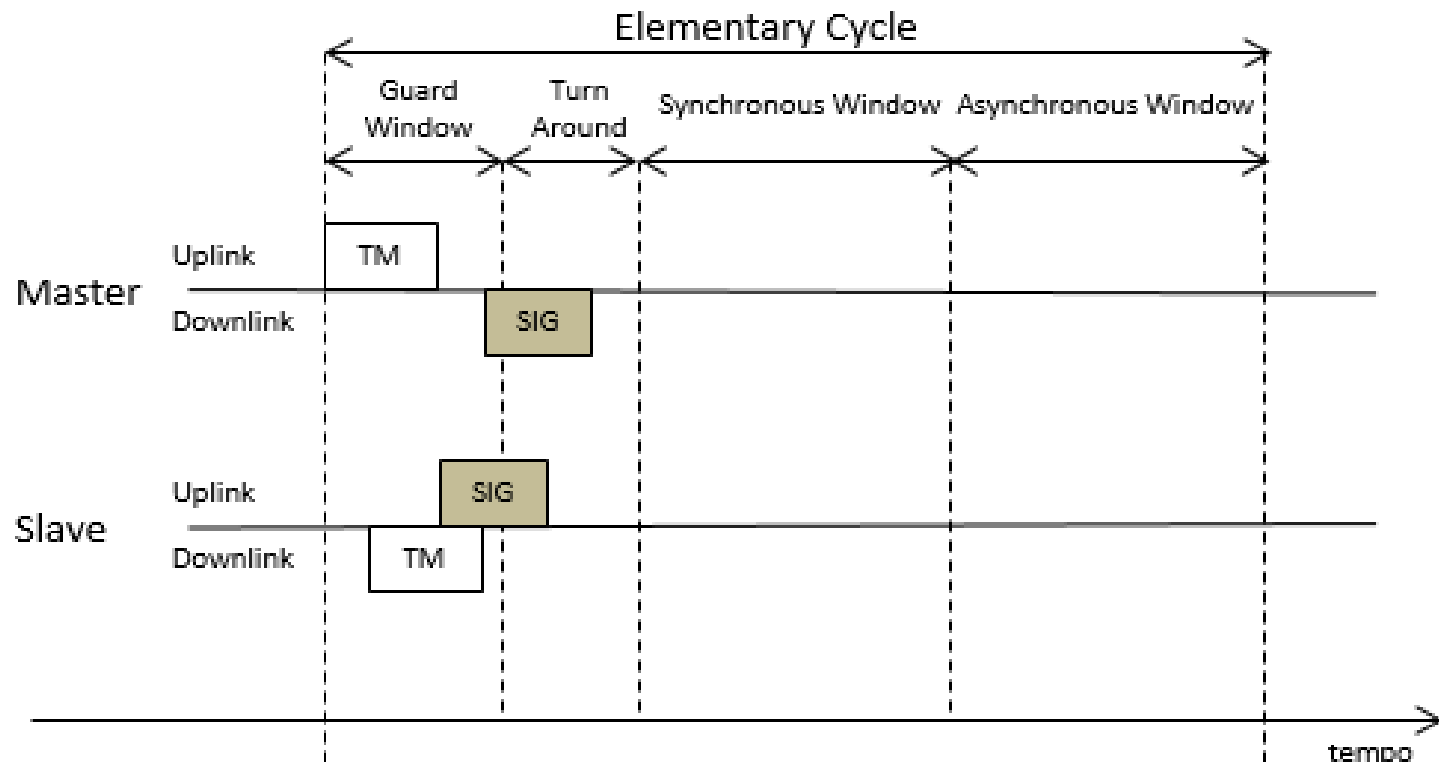
- Adaptation of the **FTT-Ethernet** protocol
- Follows the **Master/Slave** pattern
- Communication organized in cycles - **Elementary Cycles (ECs)**
- Master synchronizes the network sending a **Trigger Message (TM)**
- **Bandwidth guarantee** for different types of traffic
- Links **full-duplex**



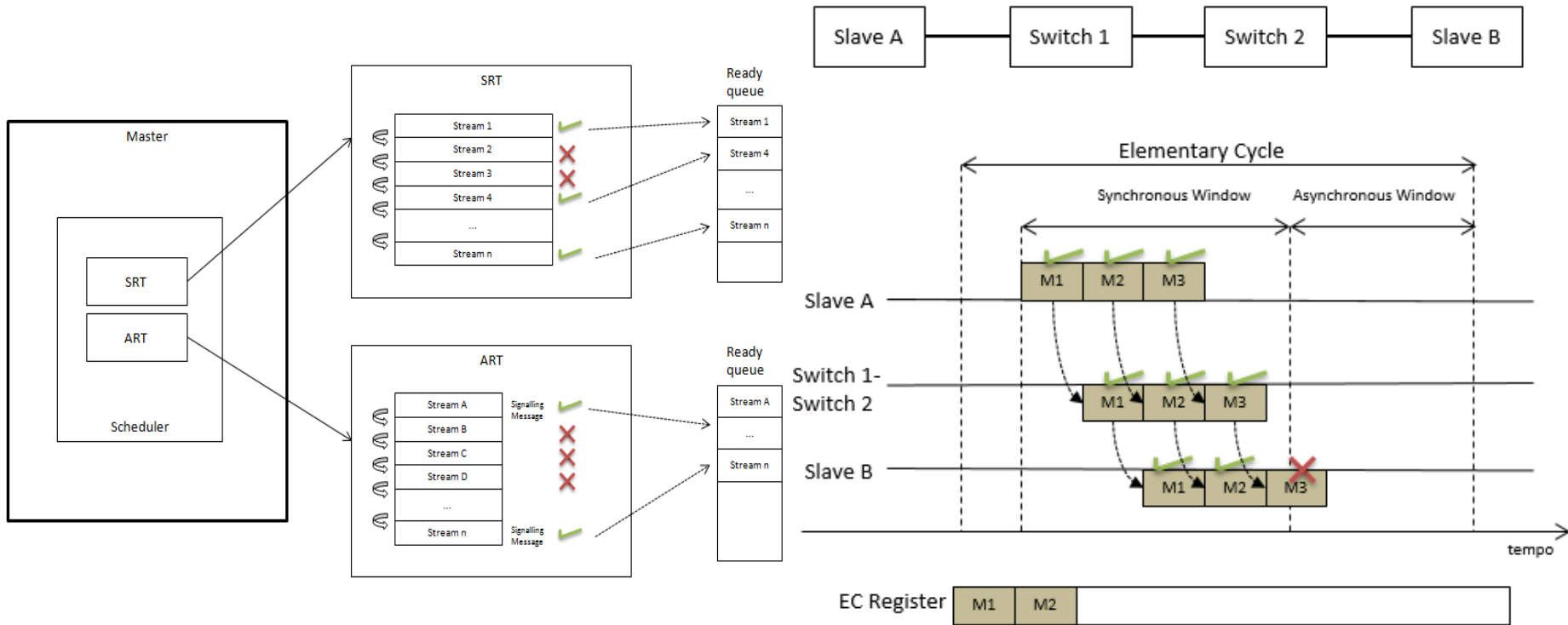
Elementary Cycle (EC)



Signalling mechanism



Building an Elementary Cycle



Outline

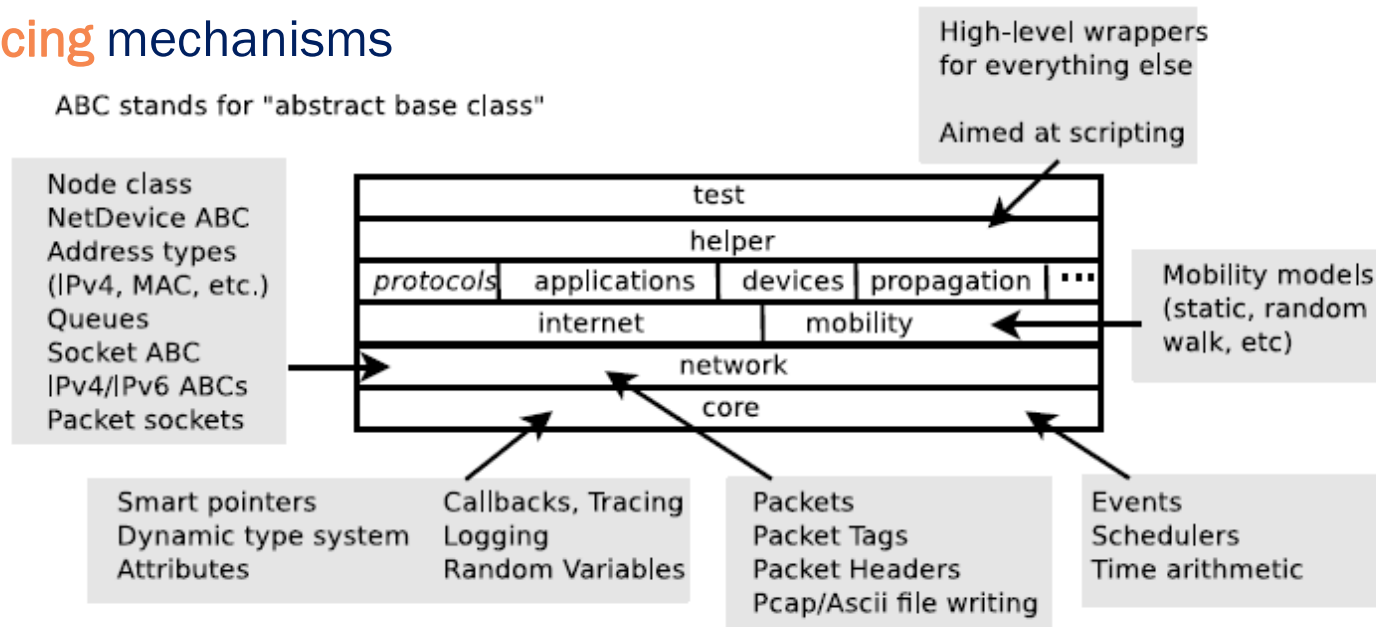
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Simulator ns-3



- Used in **research** and **development**
- Developed in **C++**
- **Modular** architecture
- Allows the study of **several technologies**
- Based in **discrete events**
- **Tracing** mechanisms



Ref: Manual NS-3

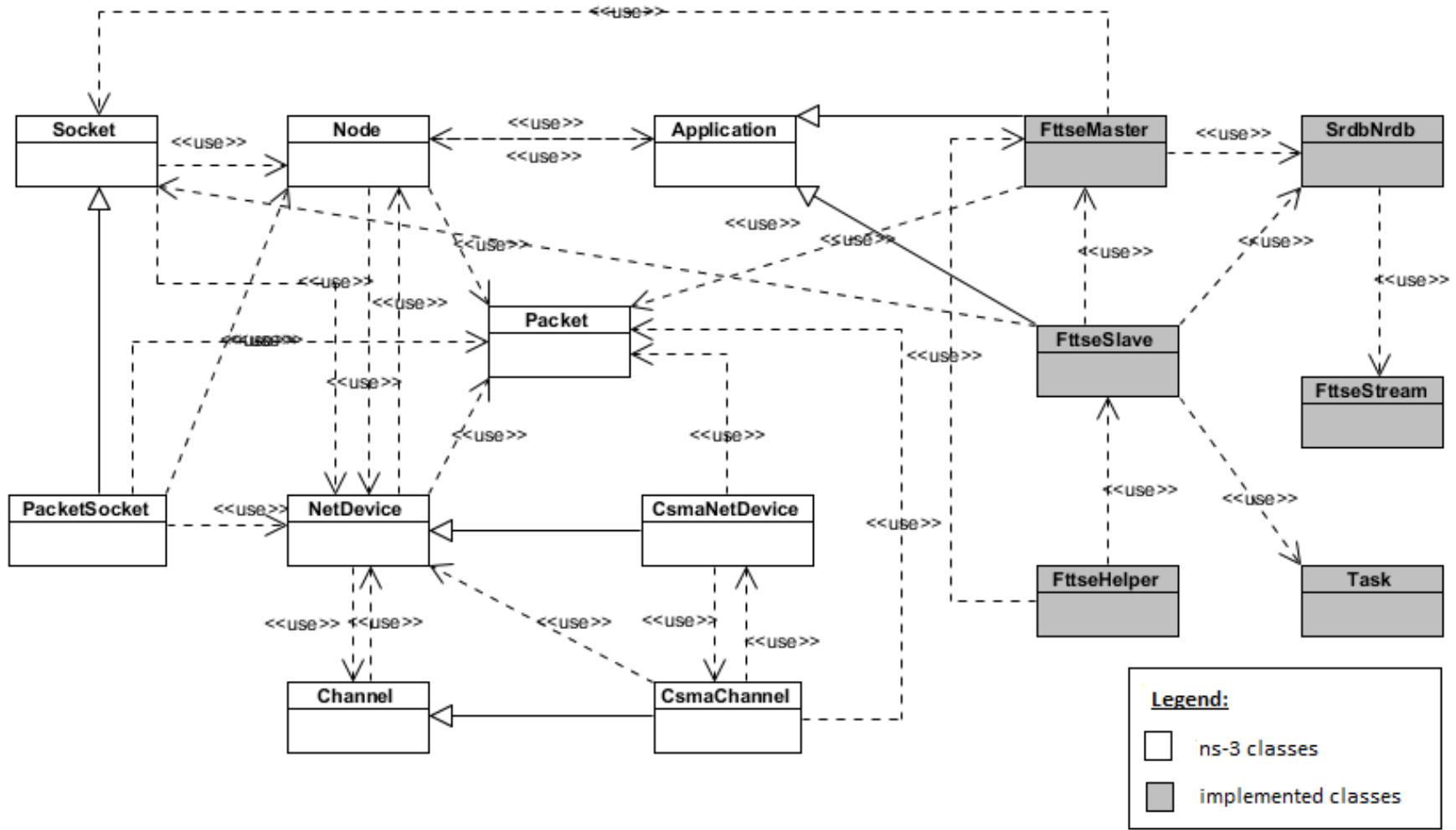


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FTT-SE module



Implemented features

- It implements the FTT-SE protocol:
 - **Helper to configure** FTT-SE network,
 - The *Plug-and-Play* scenario in runtime for the registration of stream (messages),
 - **Traffic scheduling** by the **Master** node according to the **Rate Monotonic (RM)** algorithm,
 - **Trigger Message (TM)** for the formation of the Each **Elementary Cycles (ECs)**,
 - Bandwidth **guarantee** for both types of traffic: **Synchronous** and **Asynchronous**.
- Fork-Join Parallel/Distributed paradigm
 - **Concurrency modelling** for single core distributed nodes,
 - **Export capabilities** of response times of each stream.

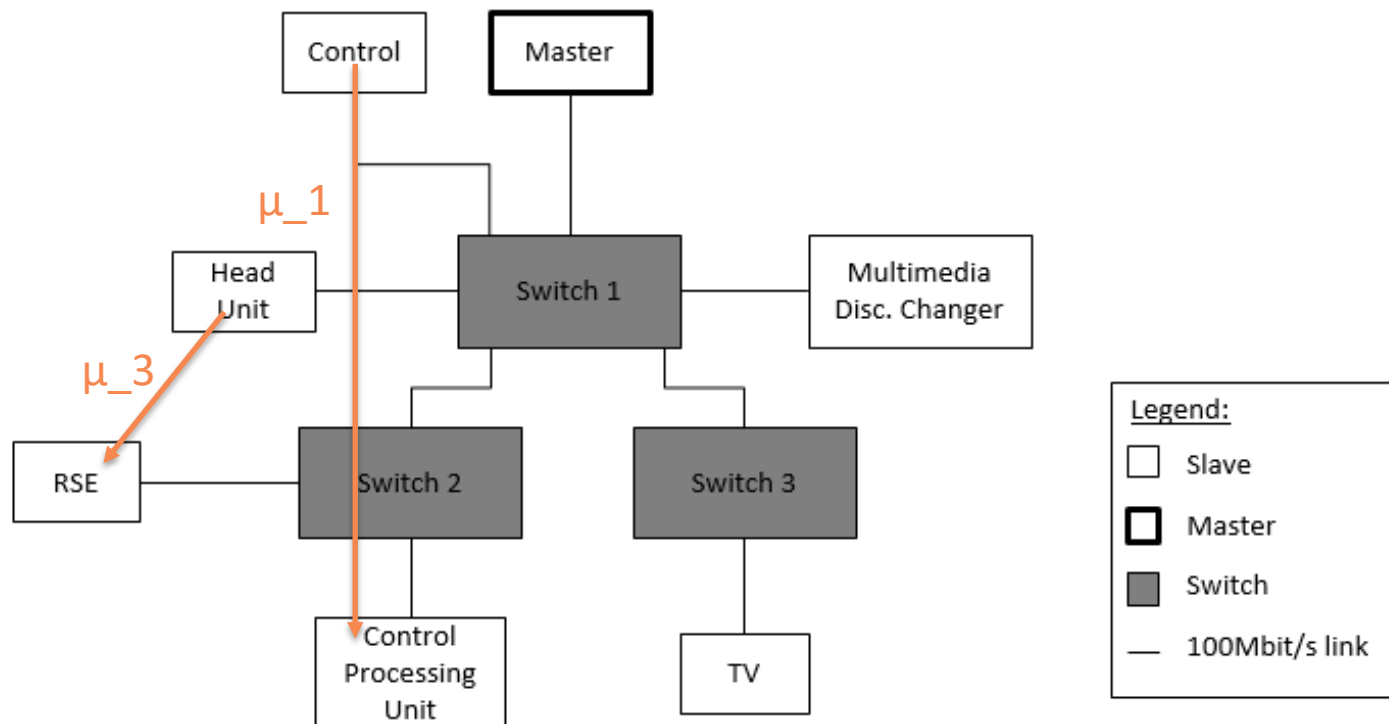
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Simulations results (sequential applications)

- Asynchronous applications



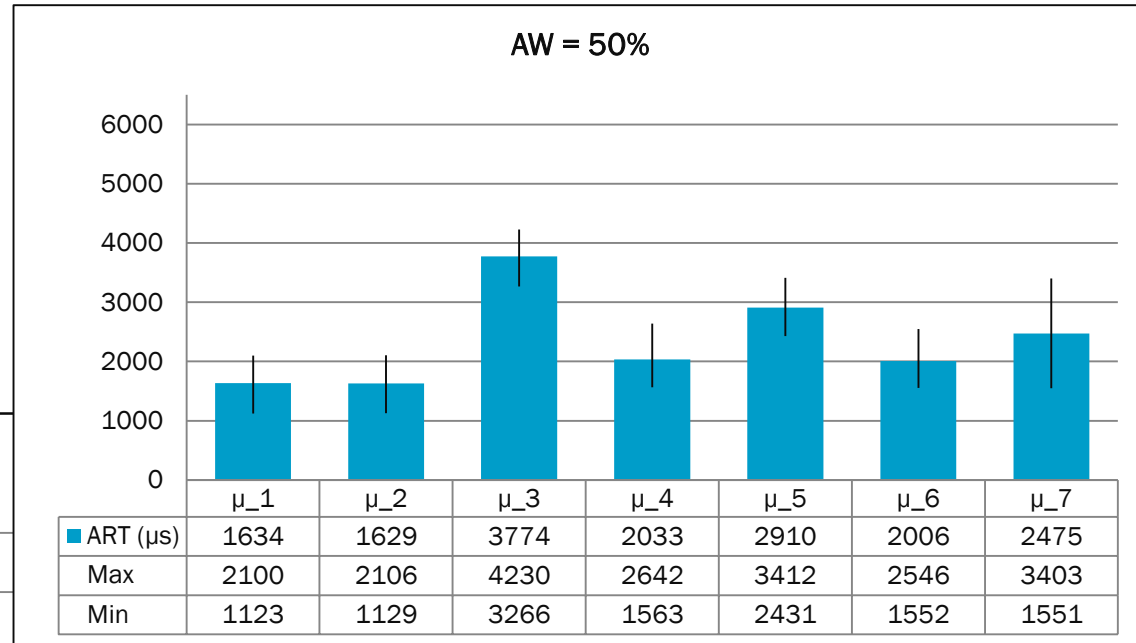
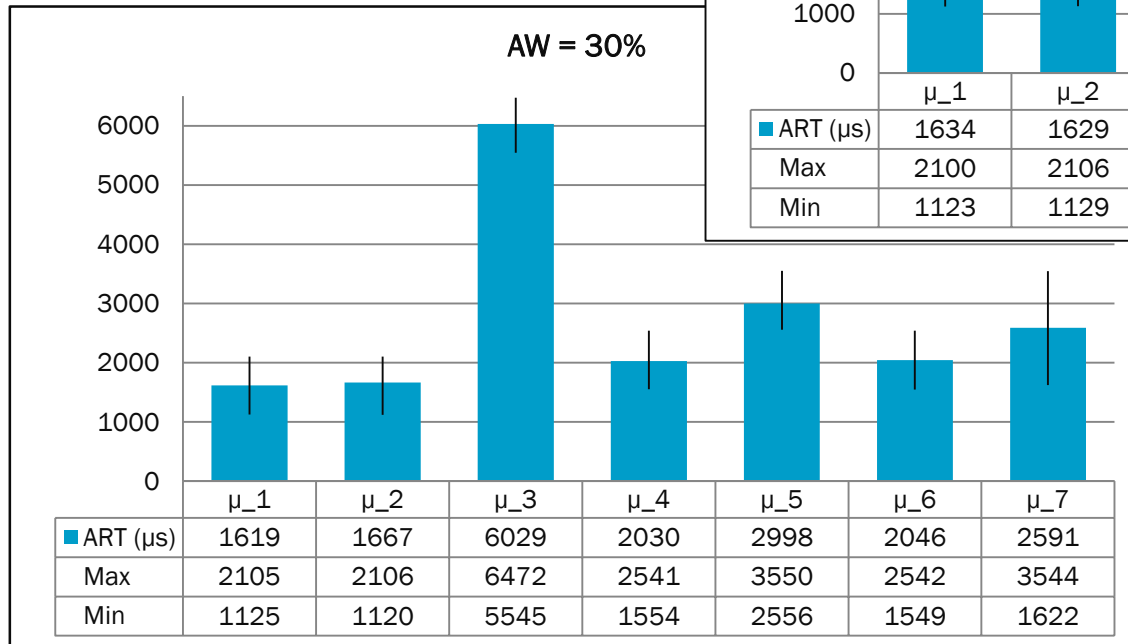
Simulations results (sequential applications)

- Variation of the **Asynchronous Window**

Elementary Cycle	1000 μ s	1000 μ s
Synchronous Window	50% (450 μ s)	70% (630 μ s)
Asynchronous Window	50% (455 μ s)	30% (270 μ s)
Singnalling Window	100 μ s	100 μ s

Application	Category	Period (ECs)	Size (bytes)	WCML	Source	Destination
μ _1	Control	11	64	7 μ s	Control	CPU
μ _2	Control	11	64	7 μ s	Control	RSE
μ _3	Navigation	24	5000	406 μ s	Head Unit	RSE
μ _4	MM Video	3	2800	227 μ s	Mult. Disc	RSE
μ _5	MM Audio	6	2800	227 μ s	Mult. Disc	RSE
μ _6	TV Video	6	2800	227 μ s	TV	Head-Unit
μ _7	TV Audio	9	2800	227 μ s	TV	Head-Unit

Simulations results (sequential applications)

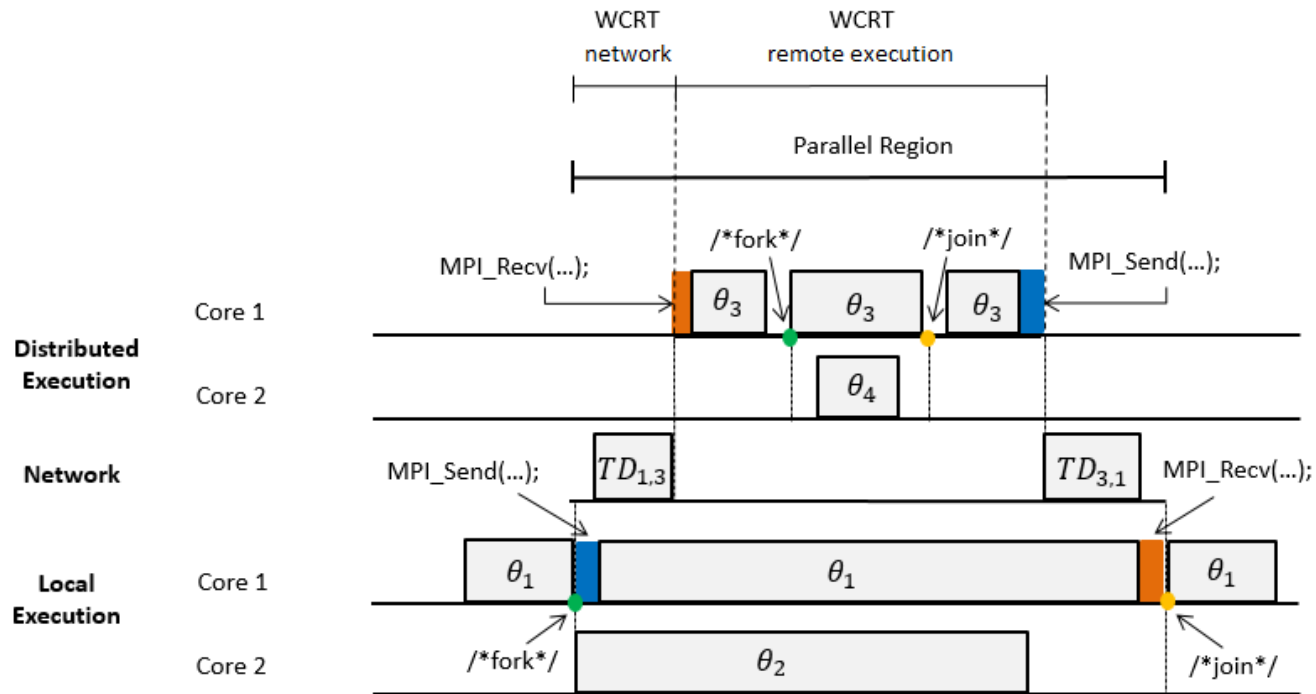


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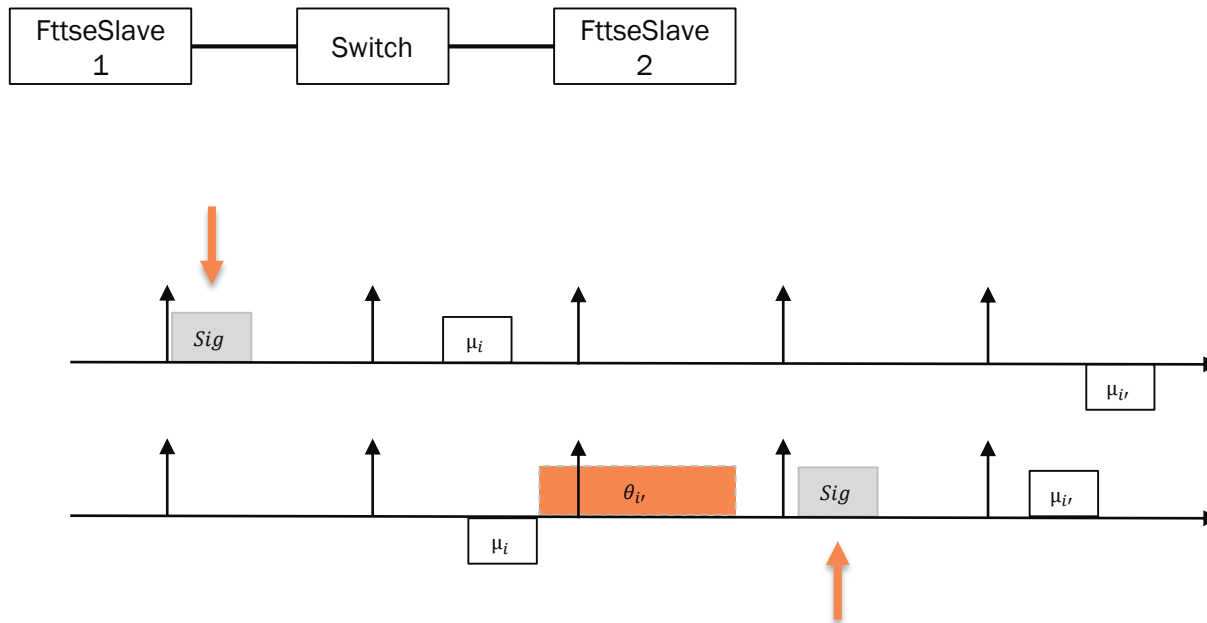
Fork-Join Parallel/Distributed model



Fork-Join Parallel/Distributed Task Model (P/D tasks) [1]

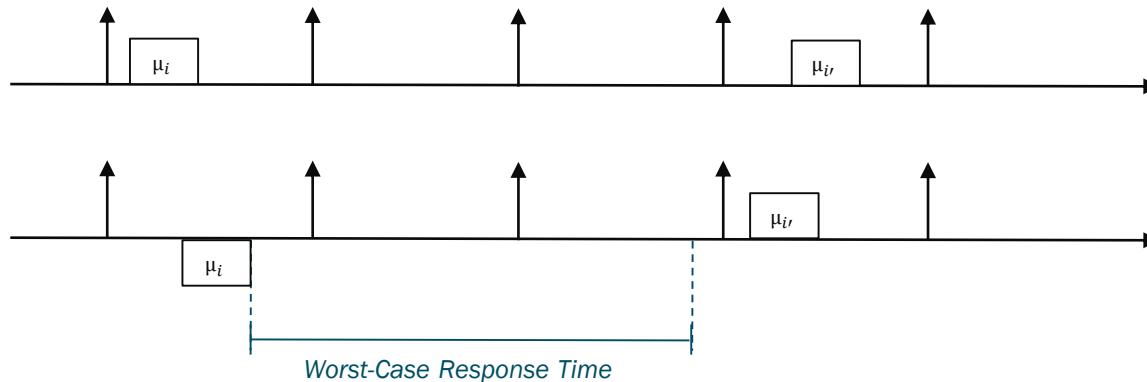
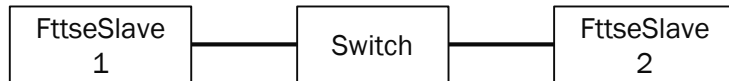
Fork-Join Parallel/Distributed model

Asynchronous applications



Fork-Join Parallel/Distributed model

Synchronous applications



Worst-Case Response Time

- WCRT in the network

$$WCRT_i = \left\lceil \frac{t^*}{EC} \right\rceil$$

$$t^* = \min(t > 0) : sbf(t) \geq rbf(t)$$

-Request bound function (rbf)

$$rbf_i(t) = C_i + sn_i \times (SFD_i + \Delta) + Wl_i(t) + Wr_i(t)$$

$$Wl_i(t) = \sum_{\substack{\forall j \in [1, n], j \neq i \\ \wedge R_j \cap R_i \neq \emptyset \\ \wedge m_j \in hp(m_i) \\ \wedge m_j \in WT(m_i)}} \left\lceil \frac{t}{T_j} \right\rceil (C_j) + Is_i(t)$$

$$Is_i(t) = \sum_{l=1}^{z(t)} G_i^{sort}(t)[l] \quad z(t) = \left\lceil \frac{t}{EC} \right\rceil$$

$$Wr_i(t) = \sum_{\substack{\forall k, j \in [1, n], k \neq j \neq i \\ \wedge R_k \cap R_j \neq \emptyset \wedge R_k \cap R_i = \emptyset \wedge R_j \cap R_i \neq \emptyset \\ \wedge m_k \in hp(m_j) \\ \wedge m_k \in WT(j)}} \left\lceil \frac{t}{T_k} \right\rceil (C_k)$$

-Supply bound function (sbf)

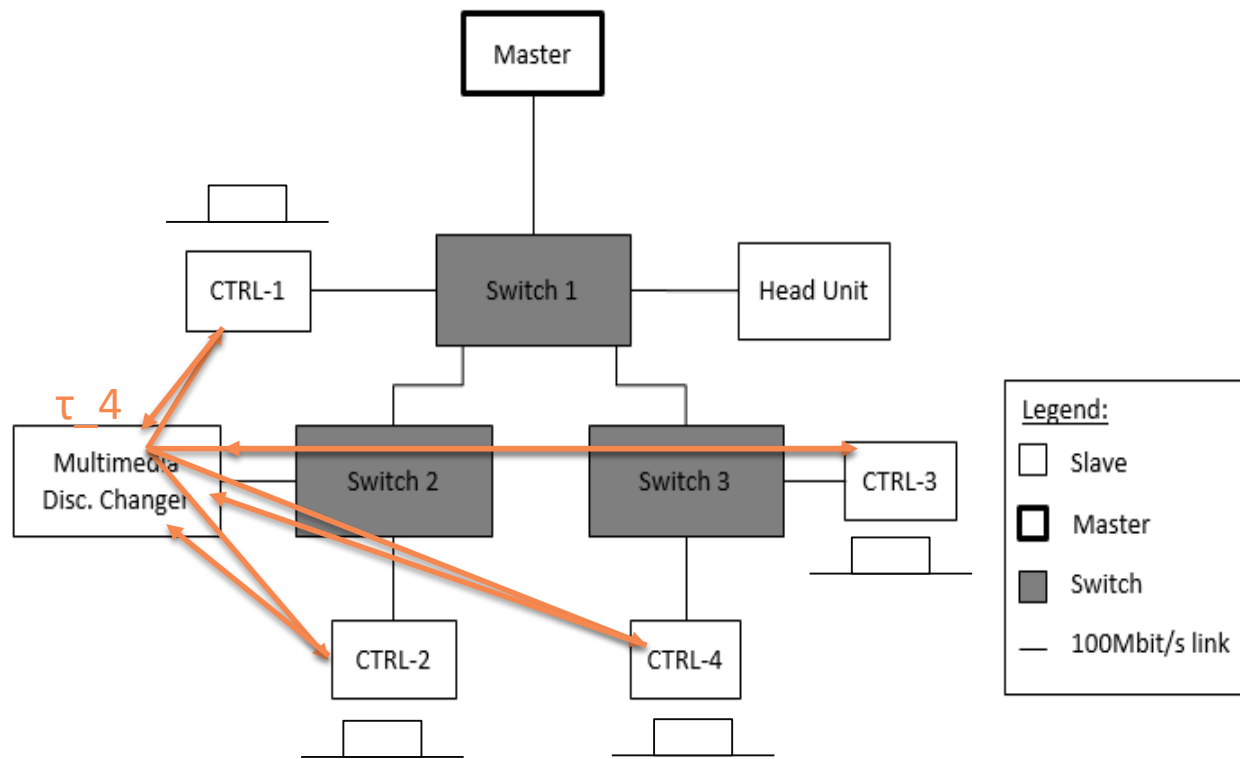
$$sbf(t) = \left(\frac{BW - I}{EC} \right) \times t$$

- WCRT of the remote execution

$$r_{\theta_i}^{n+1} = C_i + \sum_{\theta_i \in hp(\theta_i)} \left\lceil \frac{r_{\theta_i}^n}{T_j} \right\rceil \times C_j$$

Simulations results (P/D applications)

- Synchronous applications



Sending requests to remote nodes
Sending the response message

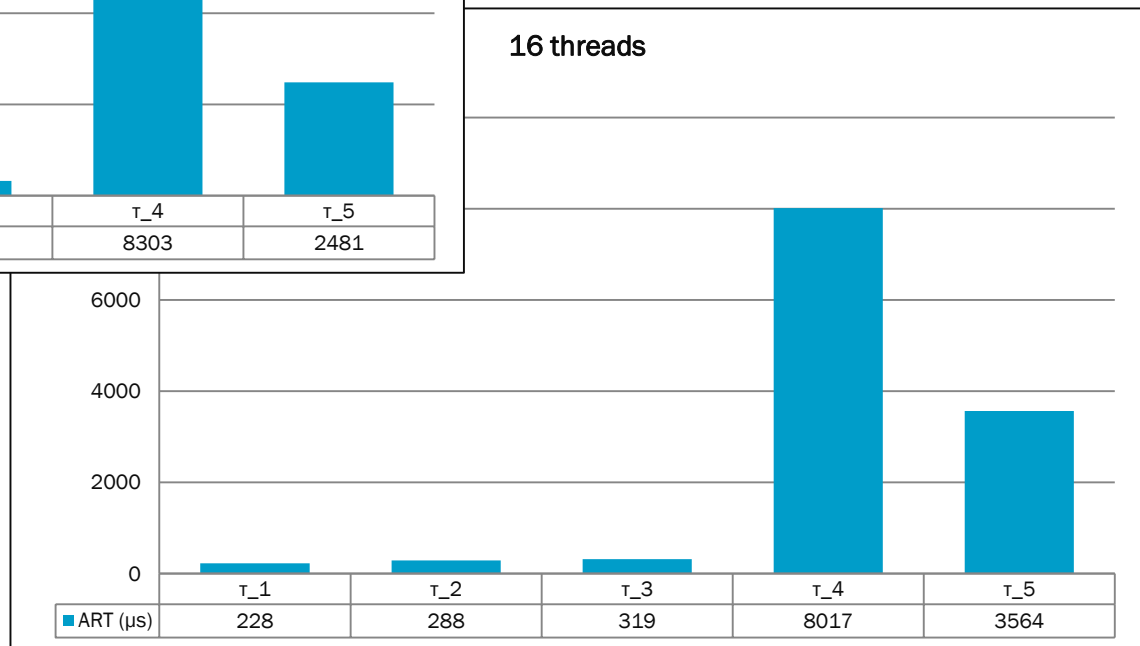
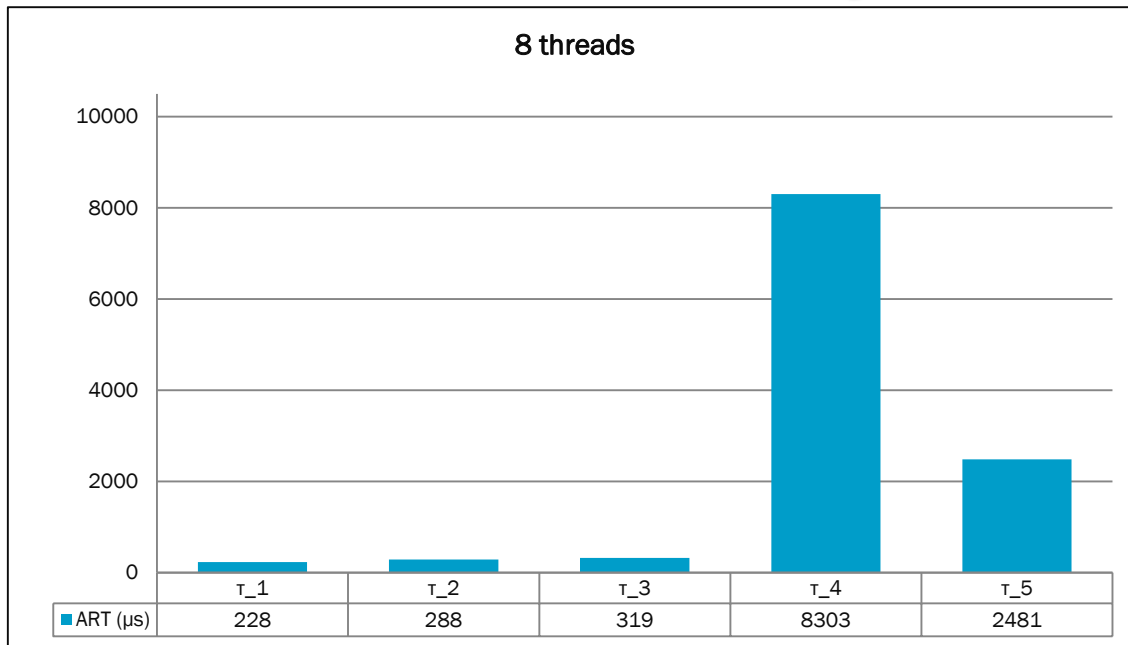
Simulations results (P/D applications)

- Variation in the **number of threads**

Elementary Cycle	1500 μ s
Synchronous Window	50% (700 μ s)
Asynchronous Window	50% (700 μ s)
Signalling Window	100 μ s

App	Categ.	Period (ECs)	WCET (F/J)	WCET (Rem.)	Size (bytes)	WCML	Source	Destination
τ_1	Control	5	-	80 μ s	350	30 μ s	Head Unit	CTRL-1
τ_2	Control	5	-	80 μ s	350	30 μ s	Head Unit	CTRL-2
τ_3	Control	5	-	80 μ s	350	30 μ s	Head-Unit	CTRL-3
τ_4	MM Video	10	150 μ s	800 μ s	1400	114 μ s	Mult. Disc	CTRL-1 - CTRL-4
τ_5	MM Audio	30	-	350 μ s	2000	163 μ s	Mult. Disc	CTRL-1

Simulações (aplicações P/D)



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Conclusions and Future work

- **Contributes**
 - **First implementation** of the FTT-SE protocol in a simulator
 - **Applications** inherent to the protocol
 - Communications according to **Fork-Join Parallel/Distributed** paradigm
 - **Task processing** model
 - **Export of results** for text files
 - **Simulations and analysis**
- **Future work**
 - Integration of the module in a **official release** of the ns-3 (in processing)
 - **Multicast** communications
 - **Admission control** mechanism



Thank you for your attention

