Université de Lorraine
LORIA – Laboratoire lorrain de recherche en informatique et ses applications
CNRS
Doctoral School IAEM

Path preselctions and warmstart strategies for Network-Calculus based routing optimizations

PHD PROJECT

Mekni Ouajih –

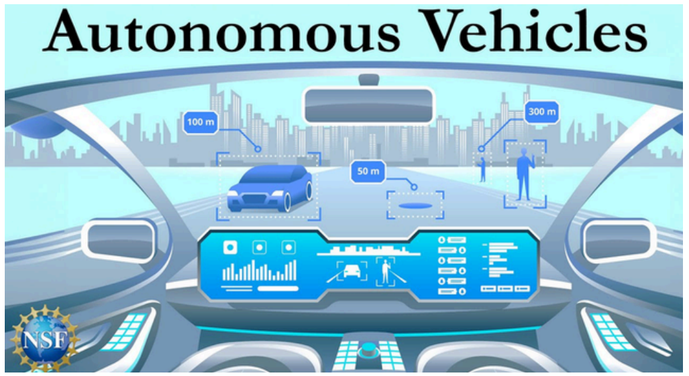
PhD Advisors: Ye-Qiong Song and Ludovic Thomas

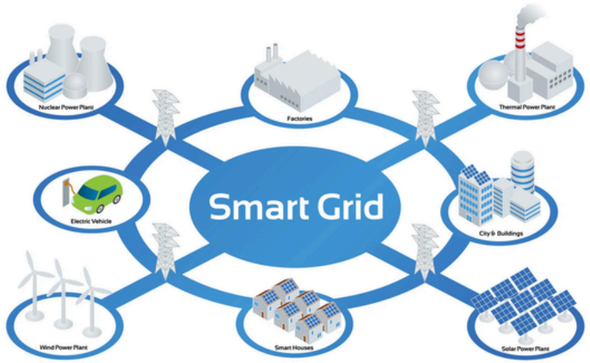
Research Team

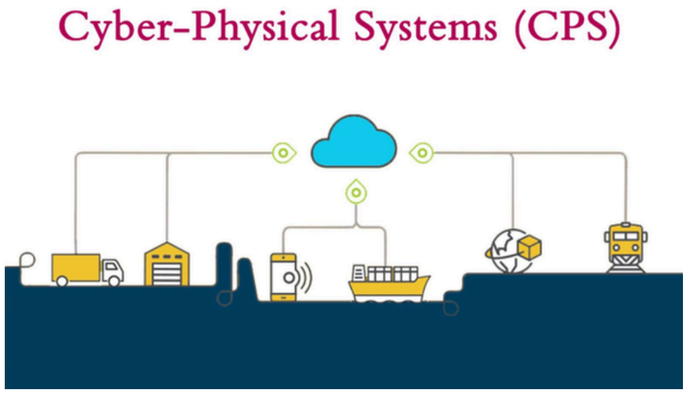
SIMBIOT

1

Introduction







- **Deterministic Communication**
- **Low End-to-End Latency**
- **Reliability**
- **Real-Time Guarantees**

What is the challenge ?

- Multiple traffic flows share network resources.
- Critical flows must satisfy strict end-to-end delay requirements.
- Routing decisions directly impact network performance and delays.
- Delay guarantees must be verified before deployment

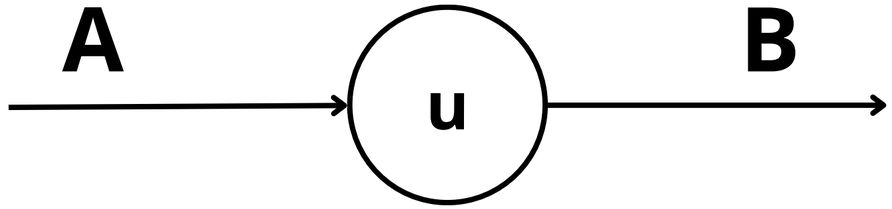
2

Network calculus framework

A : Arrival Curve

B : Output

u : Service curve



$$\otimes, \oplus, \oslash, \ominus : \mathcal{F} \times \mathcal{F} \to \mathcal{F}$$

$$A \otimes B(t) \mapsto \inf_{0 \le s \le t} \{A(s) + B(t-s)\}$$

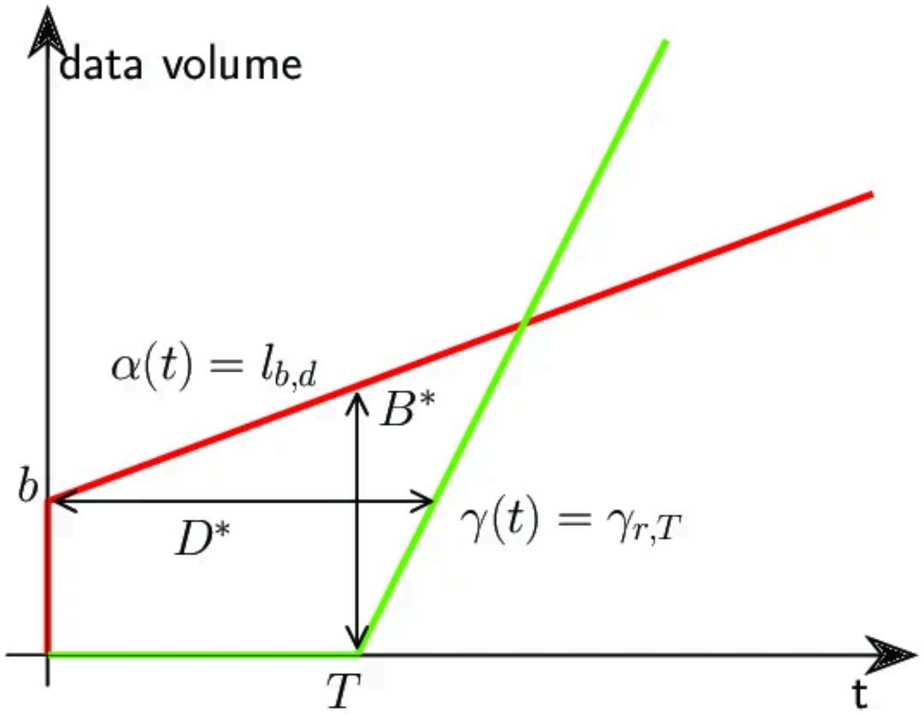
$$A \oplus B(t) \mapsto A(t) + B(t)$$

$$A \oslash B(t) \mapsto \sup_{0 \le s} \{A(t+s) - B(s)\}$$

$$A \ominus B(t) \mapsto A(t) - B(t).$$

D* : Worst-case delay bound

B* : Worst-case backlog bound



Arrival Curve Service curve

3

MILP AND PATH PRESELCTIONS

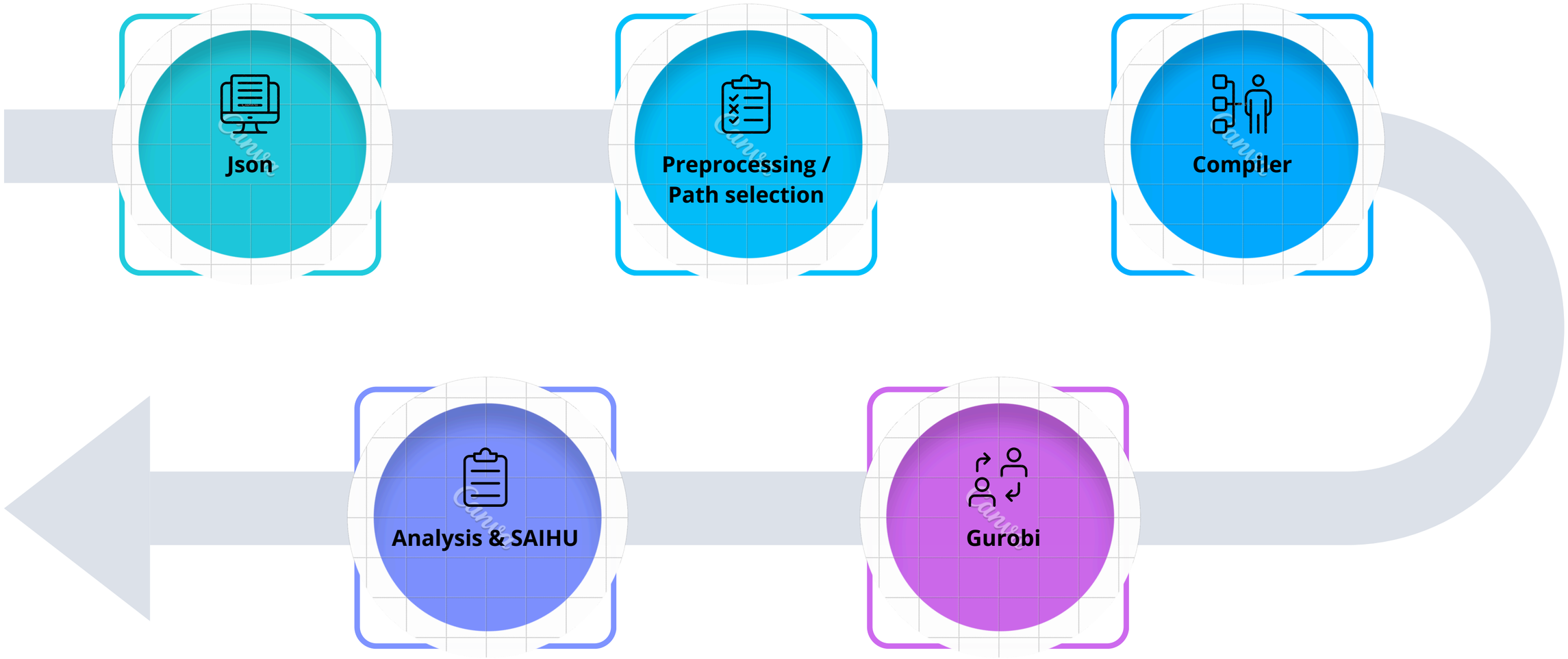
Routing with TFA++

TFA : Total flow analysis

TFA to TFA++ : Transmission-Link Shaping

We formulates routing and delay constraints as a Mixed Integer Linear Program (MILP)

Global pipeline



4. RESULTS

K=4 / 381 file	algorithm 1	algorithm 2	Enumerate ALL
Excecution time(s)	295	314	7490
Number of successful solve	330/381	344/381	372/381

4

Perspectives

Perspectives

Extend the optimization framework to incorporate scheduling constraints.

Explore hybrid MILP–ML methods for routing and network configuration.

Thank you
for your attention !

-Q&A-

Path Preselection and Warm-Start Strategies for Network-Calculus-Based Routing Optimization

MEKNI OUAJIH supervised by Ludovic Thomas and Ye Qiong-Song

LORIA, Université de Lorraine, CNRS, Nancy, France

Framework Overview

Introduction

TSN / DetNet

- TSN and DetNet require strict end-to-end delay guarantees.
- Network Calculus provides deterministic worst-case delay bounds.

In this work

- We integrate TFA++-based delay analysis into a MILP routing model.
- We propose path preselection and warm-start heuristics to reduce solving time.

Problem Statement

Given a network and a set of flows, we search for a routing configuration that:

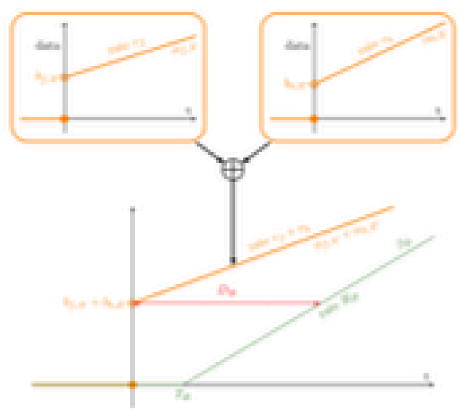
- satisfies end-to-end delay constraints,
- respects network resource constraints,
- minimizes worst-case delays.

The optimization becomes computationally expensive as the number of candidate paths considered for each flow increases.

Network Calculus: TFA, TFA++ and rTFA

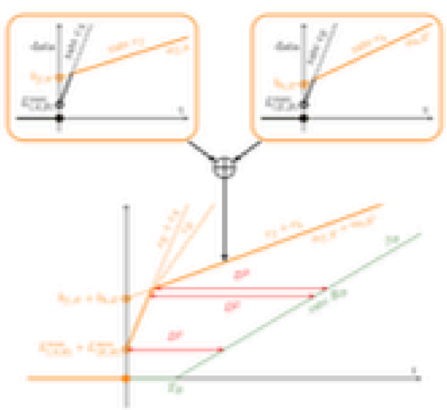
TFA computes delay bounds from aggregate arrival and service curves. **TFA++** improves these bounds using **link shaping**, while **rTFA** simplifies the computation for integration into the MILP model.

TFA



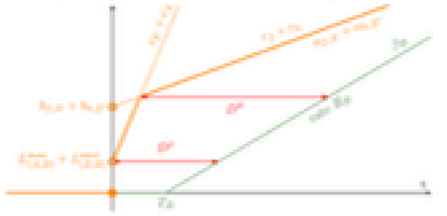
Aggregate arrival curve and horizontal delay bound.

TFA++



Link shaping provides a tighter delay bound.

Simplified curve used by our MILP



simplified curve

Instead of the TFA++ aggregate arrival curve

$$\left(\gamma_{\ldots} \wedge \alpha_{f,E'}\right) + \left(\gamma_{\ldots} \wedge \alpha_{h,E'}\right),$$

rTFA uses the simpler upper bound

$$\left(\gamma_{\ldots} + \gamma_{\ldots}\right) \wedge \left(\alpha_{f,E'} + \alpha_{h,E'}\right).$$

This curve **upper-bounds the TFA++ arrival curve**, preserving a valid delay bound while reducing the computation to only **two relevant horizontal distances**.

Contributions

- **Classic Path preselection :** Reduce the candidate-path search space before optimization and take topk candiate path .
- **Seq-greedy path preselection :** Exploit previous routing decisions for flows when routing new flows.
- **Warm starts:** Provide initial feasible solutions to accelerate Gurobi.

Saihu Validation

Saihu independently validates the routing solutions generated by the optimization framework.

- Routed network as input.
- Worst-case delay analysis with xTFA.
- Verification of end-to-end guarantees.
- Comparison with MILP predictions to validate the results.

Experimental Evaluation

Evaluation on the **Geyer–Bondorf benchmark**.

Results on the Geyer–Bondorf benchmark

Method	Time (s)	Successful solves
All paths	7490	372/381
Classic	295	330/381
Seq-Greedy	314	344/381

Conclusion

Path preselection and warm-start strategies reduce the routing optimization complexity while preserving solution quality. Saihu/xTFA is used to independently validate the obtained worst-case delay guarantees.