Evaluation of Secure Distributed TLM-based Co-Simulation over Wide Area Networks

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Motivation and Approach

Mathematical models need to be distributed and simulated in a secure manner, because of:

- *Model protection.* Manufacturers and sub-contractors normally don't share simulation models.
- *Local expertise*. Large companies often have departments spread over the world.
- *Resource sharing.* Expensive simulation environments may not be available in the same location where the simulation takes place.

Approach

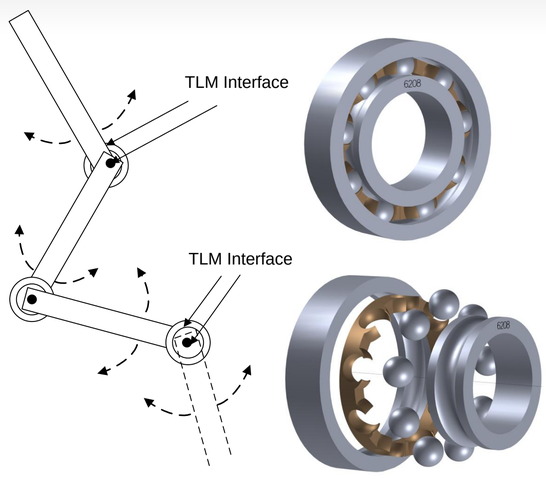
Sub-models are distributed and simulated at different locations using a transmission line modeling (TLM) framework developed by SKF. SKF has earlier successfully tested meta-model based co-simulation for different application areas, such as spindles with rotordynamics problems, simulations of large medical scanners, and hub-unit simulations for cars.

Research Questions

- Is it *practically feasible* to co-simulate models over a WAN (e.g. the Internet) and stil obtain the simulation result within reasonable time?
- Will the *total simulation* time increase significantly if the model to be co-simulated is scaled up with many distributed sub-models?
- Which *parameters are affecting* the total simulation time when a model is distributed and co-simulated?

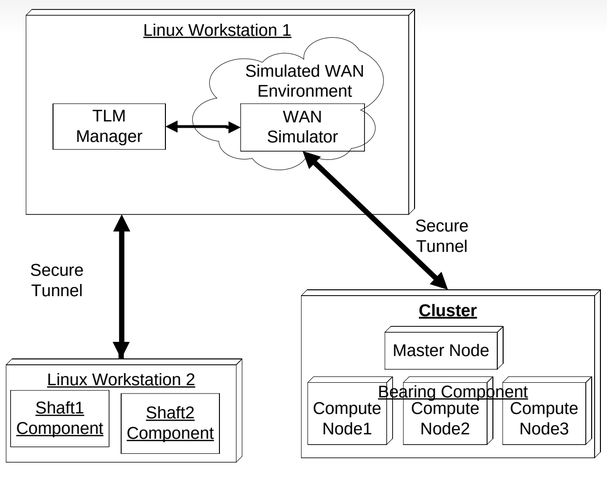
Experiments

Pendelum with Bearings

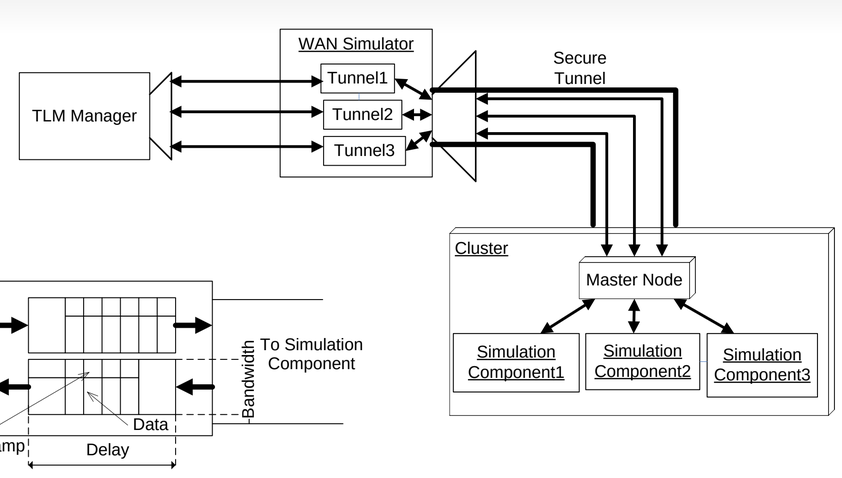


- Approximately 430 hours of simulation time using cluster environment and WAN simulator.

Deployment Structure



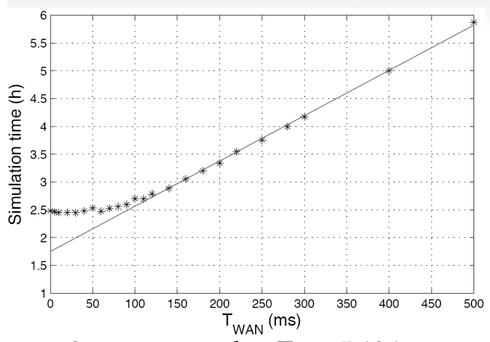
WAN Simulator



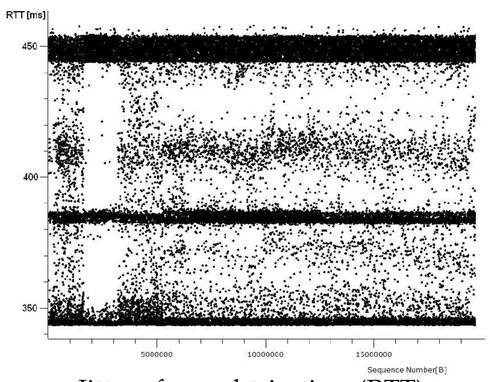
- Realtime experiment between Sweden and Australia via an encrypted tunnel.

Results and Analysis

Datacom Latency



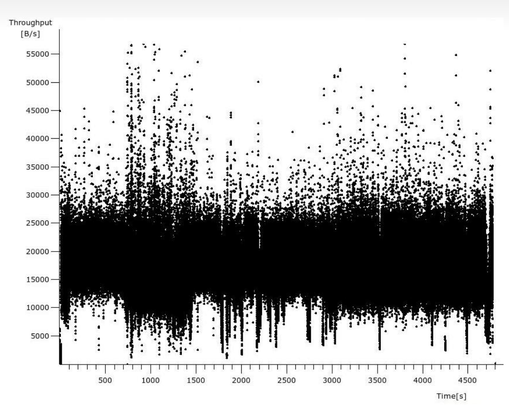
3 compute nodes. $T_{TLM}=5 \cdot 10^{-6}$ sec.



Jitter of round-trip-time (RTT) during simulation between Sweden and Australia.

- Latency has significant impact on simulation time.
- There is a smooth breakpoint. After it, growth is linear.
- Jitter has to be considered when estimating total simulation time.

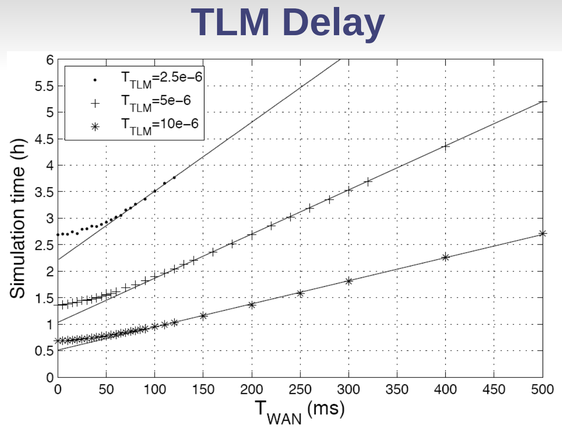
Datacom Bandwidth



2 compute nodes. $T_{TLM}=10 \cdot 10^{-6}$ sec. 8 bearings.

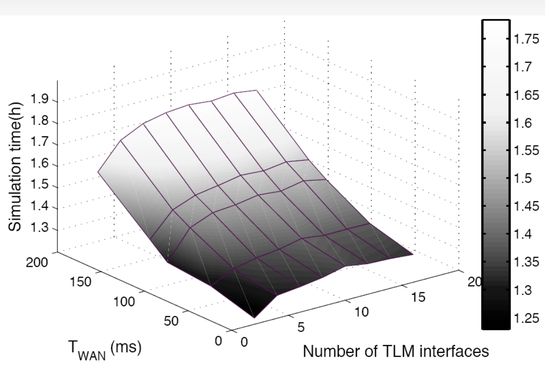
- Bandwidth is currently not a bottleneck, but it grows linear to the number of TLM-interfaces.

TLM Delay



- Approximately, the simulation time doubles when T_{TLM} is halved.
- Main reason that numerical solvers can take longer time steps when T_{TLM} is increased.

Number of TLM Interfaces



- Adding TLM interfaces have marginal impact when there are several interfaces.

Conclusions

- It is *usable in practice* to co-simulate over long distances over WANs on the globe. This is demonstrated by co-simulating between Sweden and Australia, with an increased total simulation time of ≈ 170% compared to a local environment without encryption.
- It is *more resource efficient* to increase the number of compute nodes in an external simulation environment if the network latency is lower than a specific bottleneck breakpoint.
- The method is *scalable* in regards to the number of connected simulation components.

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