MCSOC 2019

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

A Low-Latency and Flexible TDM NoC for Strong Isolation in Security-Critical Systems

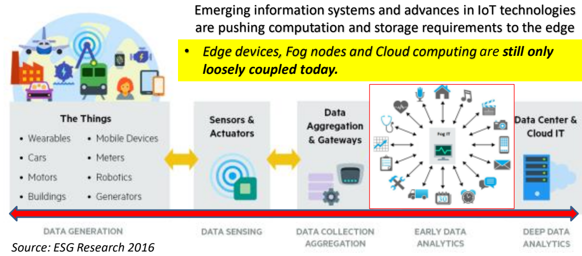
Davide Bertozzi, Mariem Turki
University of Ferrara (Italy)

Miguel Gorgues Alonso , José Flich
Universidad Politecnica de Valencia (Spain)

A Computing Continuum

Emerging information systems and advances in IoT technologies are pushing computation and storage requirements to the edge

- *Edge devices, Fog nodes and Cloud computing are **still only loosely coupled today.***



Source: ESG Research 2016

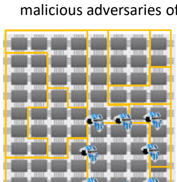
The future direction is clear: a Cloud-Things continuum along which IoT services will be flexibly instantiated.

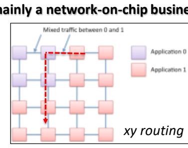
The ubiquitous and seamless computing environment will cause multiple IoT services to share the same hardware platform.

Sharing & Security

- The unprecedented levels of interconnection among computing devices and of aggregation of IoT services makes the protection from security threats from malicious adversaries of paramount importance.

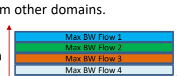
It's mainly a network-on-chip business!



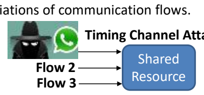


With irregular partition shapes, packet routes can «invade» other partitions

- Link-level QoS support can already prevent **DoS** and **bandwidth depletion attacks** from other domains.



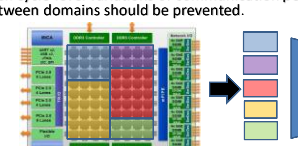
- QoS cannot easily avoid an information leak associated with latency and throughput variations of communication flows.



Motivation

- **REQUIREMENT: STRONG ISOLATION**

Even cycle-level variations of communication performance induced by interference between domains should be prevented.



Statically schedule domains on the network over time

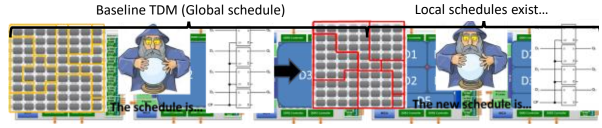
Time-division multiplexing

One fundamental issue is that communication performance in time-multiplexed NoCs is highly sensitive to the scheduling methodology of time slots.

Runtime reconfiguration of the generic global schedule is hard to make fast and cost-effective.

Baseline TDM (Global schedule)

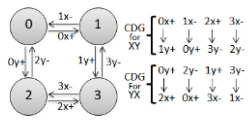
Local schedules exist…



Goal of the Work

The main goal of our proposal is to deliver the **strong isolation property**…

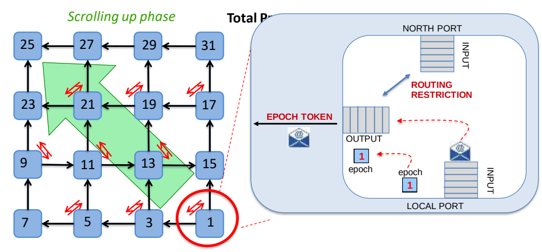
- ❑ for a **runtime-configurable number of domains**
- ❑ **optimizing the latency** of TDM communication flows
- ❑ **providing scalable latency** across the entire configuration space **without major architectural modifications**



TDM schedule and programming mechanism inspired by the Channel Dependency Graph of the network

Basic Idea

We can span the CDG by propagating a token that fires on an output port when all inputs with routing dependencies with that output have the token as well

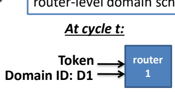


If the CDG is <u>acyclic</u> (i.e, deadlock-free) each port of each switch will receive the token exactly once

(*Olav Lysne et al.: "An Efficient and Deadlock-Free Network Reconfiguration Protocol. IEEE Trans. Computers 2008*)

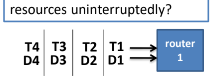
Synchronized Token Propagation

Why not using **tokens** to carry scheduling commands to local router-level domain schedulers?!

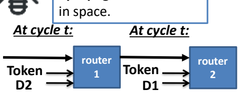


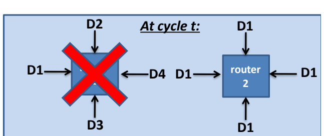
Effect: Only packets of domain D1 can move to switch allocation

Why **not injecting a token at every cycle** so to schedule NoC resources uninterruptedly?



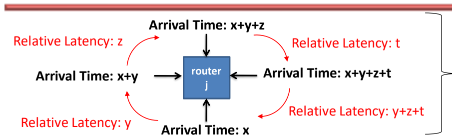
Resources are **scheduled Locally** so to «**propagate**» time slots in space.





<u>**Strong isolation between domains**</u> requires the timing of token propagation to be synchronized so that every router can schedule the same domain at each input port at each cycle.

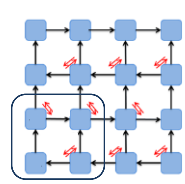
Synchronized Token Propagation: HOW?



Relative latencies are dictated by the ***CDG***

Requirement for Router-Level Strong Isolation:

Relative latencies should be a multiple of the number of domains
(number of domains is the **MCD of all relative latencies)**



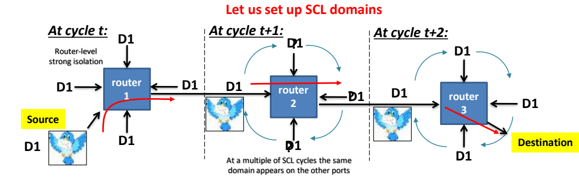
Requirement for Network-Level Strong Isolation:

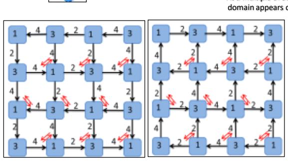
A- compute the MCD for each router
B- **The MCD of the router-level MCDs (if any) is the ideal number of domains** *for which the **network as a whole** works with strong isolation of domains.*
C- With SR routing on a 2D mesh, such an MCD is also **the latency of the smallest cyclic path (SCL) spanned by a token to reach two different ports of the same router (SCL=4).**

Perfect Scheduling

If this property holds, then as a side effect we have the onset of unstopped propagating waves of synchronized same-domain tokens throughout the network

Let us set up SCL domains





- **A 2D-mesh with periodic horizontal segment-based routing and single-cycle switches and links fulfils the property.**
- **AT REGIME, it enables perfect scheduling with SCL=4 domains.**

Supporting a Higher Number of Domains

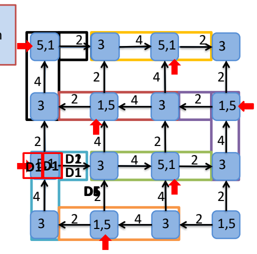
How to handle Number_Domains D > SCL while preserving strong isolation and perfect scheduling and without major changes of the architecture?

1- Split the **critical path** of token propagation throughout the CDG into **subnets of length SCL clock cycles:** all **I/Os of these subnets will be in the same domain** at a given time slot.

2- Place domain propagation DELAYS selectively within subnets, in the same position, to realign token propagation!

3- The number of **delays** in each **subnet** should be set to **D - SCL**

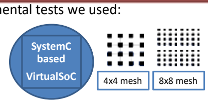
FLEXIBILITY/RECONFIGURABILITY
No major architectural changes like state-of-the-art (pipelining, input speedup), but simply delay reprogrammability as a function of the number of domains.



Support for 5 domains by delay placement

Experimental Results

- In our experimental tests we used:



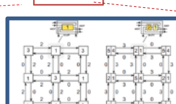
Both Intra-domain traffic and memory controller traffic

- To test flexibility/scalability, four mechanisms were evaluated across a different number of running domains: **Global-TDM**, **Optimized Global TDM**, **PhaseNoC**, **Token-based TDM**

	0	1	2	3
RC	D0	D1	D2	D3
VA	D9	D0	D1	D2
SA	D8	D9	D0	D1
ST	D7	D8	D9	D0

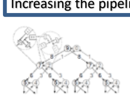
The PhaseNoC router architecture also delivers **perfect scheduling and strong isolation**....

....**but not for all system configurations** (i.e., number of domains).



Major architecture change, higher latency

Increasing the pipeline depth

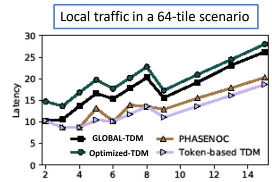


No perfect scheduling across subnets. No strong isolation

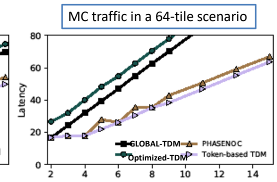
Splitting the network into subnetworks (e.g., X+Y+/X+Y+)

Experimental Results

Local traffic in a 64-tile scenario



MC traffic in a 64-tile scenario



The improvement of Token-based TDM oscillates between 20% (5 domains) and 9% (15 domains).

Token-Based TDM reaches the best performance improving up to 30% the PhaseNoC network latency.

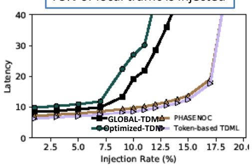
Token-based TDM offers better latency scalability over the whole configuration space

Token-based TDM is fully re-programmable while PhaseNoC architecture should be changed at each configuration

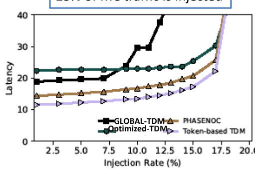
Experimental Results

5 simulated domains

75% of local traffic is injected



25% of MC traffic is injected



➢ **Local schedules consistently perform better than global schedules** from both a latency and a throughput viewpoints.
➢ **Token-based TDM** reduces **PhaseNoC** latency by roughly **10%** and **20%** for local and MC traffic, respectively, while matching the saturation bandwidth.

Token-based TDM selectively introduces a configurable number of delays at specific routers, while PhaseNoC spreads the latency overhead everywhere.

Conclusions

- Emerging applications increasingly call for strongly isolated & high performance NoCs

- TDM NoCs have to be brought into new ground:
  - ✓ Scheduling of slots should be optimized for latency
  - ✓ Reconfigurability becomes a must

- We propose a CDG-inspired approach to derive TDM slot scheduling and a reprogramming framework for such scheduling

- We consistently provide generalized perfect scheduling across the whole configuration space.

- Each configuration can be supported without major architectural modifications, unlike state-of-the-art.

Thank you for your attention !