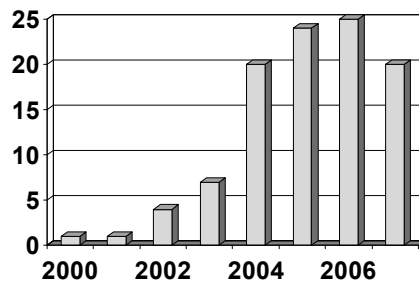


## Overview

9:30 State of the art,	A. Jantsch
10:00 NoCs in the context of applications and memory organization,	P. van der Wolf
11:00-11:30 Break	
11:30 NoC Middleware,	L. Benini
13:00 – 14:30 Lunch	
14:30 Throughput-driven NoC design,	T.M. Pinkston
15:30 Quality of service in NoCs,	K. Goosens
16:00 – 16:30 Break	
16:30 Quality of service in NoCs cont'd	
17:00 ARTERIS NoC power management,	C. Janac
17:30 The Spidergon NoC,	M. Coppola

## Historical Perspective

- Established Research Field



# of reserach papers at DATE attributed to NoC

## Topic of Research

- Topology
- Routing, switching, flow control
- QoS
- Clocking
- Design tools, mapping
- Programming model
- Platform services
- Traffic generation
- Debug, diagnosis, testing

## Topology

- Fat tree (SPIN)
  - Torus (Dally&Towles)
  - Ring (Proteo, Octagon)
  - Mesh
  - Irregular and application specific
- Status:
    - Mesh for a general platform
    - Irregular for application specific architectures

## Routing, Switching, Flow control

- Deterministic / adaptive routing
  - Dimension order / source based addressing
  - Wormhole switching
  - Credit based flow control
- 
- Status:
    - Deterministic routing
    - Wormhole switching

## Quality of Service

- Combining Best Effort (BE) and Guaranteed Bandwidth (GB) traffic
  - Time Division Multiplexing (TDM) based (Aetherial, Nostrum)
  - Priority based QoS (Bolotin 2004)
  - QoS on Asynchronous networks (Bjerregaard et al. 2005)
  - Mapping with QoS guarantees (Murali et al. 2005)
  - Performance analysis for predictable systems (Huang et al. 2007)
  - Abstract performance models of NoC platforms (Jantsch 2006)
- 
- Status:
    - Very active research area
    - Aiming at architecture+mapping tools+system methodology for predictable, efficient systems

## Clocking

- Synchronous / asynchronous NoCs
- Fully synchronous ( $\Delta f=0$ ,  $\Delta\phi=0$ ) networks are unrealistic
- Mesiochronous ( $\Delta f=0$ ,  $\Delta\phi=\text{unknown}$ ) or pseudo-chronous ( $\Delta f=0$ ,  $\Delta\phi=\text{const}$ ) (Nilsson 2004, Oberg 2003)
- Fully asynchronous GALS networks ( $\Delta f=\text{unknown}$ ,  $\Delta\phi=\text{unknown}$ ) (MANGO – Bjerregaard et al. 2005)
- Status:
  - Active research area
  - Asynchronous circuit techniques
  - System design techniques and tools for GALS NoCs

## Design Tools

- Router and NI configuration, resource allocation, mapping (Murali et al. 2004, 2005, 2006, Hansson et al. 2005, Hu et al. 2003)
- Communication synthesis (Lu et al. 2006)
- Functional verification (Schmaltz et al. 2004)
- Performance analysis (Huang et al. 2007)
- Status:
  - Very active research area and by far not completed
  - Application domain specific tools
  - More system level tools connection to application and programming models
  - Many specialized point tools missing

## Programming Model

- Shared memory based is the default due to legacy code
- Remote procedure call (Paulin et al. 2004)
- Stream based / message passing (van der Wolf et al. 2005)
- Status:
  - Just at the beginning
  - Part of the search for concurrent programming models, e.g. Software Transactional Memory (Shavit et al. 1995, Harris et al. 2005)

## Platform Services

- Resource management (Nollet et al. 2005)
- Monitoring and diagnostics (Ciordas et al. 2006)
- Status:
  - Just at the beginning
  - What shall be part of the NoC platform?

## Traffic Generation

- Real application traffic: None
  - Stochastic traffic (Varatkar et al 2004, Soteriou et al. 2006)
- 
- Status:
    - No good real applications
    - Sophisticated stochastic traffic models
    - Benchmark initiative started

## Testing, Diagnosis, Debug

- Network centric debug (Goossens et al. 2007)
  - NoC based testing methodology (Petersen et al 2007)
- 
- Status:
    - Off and on-line testing is being address
    - Debugging aids are integrated into the network
    - On-line monitoring and diagnosis is emerging

## **Development in Industry**

- Full fledged NoC approach:
  - Arteris: start-up focusing on NoC
  - NXP's Aetherial
  - ST's Spidergon
- Evolutionary development from bus to network:
  - AMBA protocol family
  - Sonics
  - OCP
  - STBus
  - CoreConnect
  - IBM's Cell interconnect
  - Xilinx
  - etc.

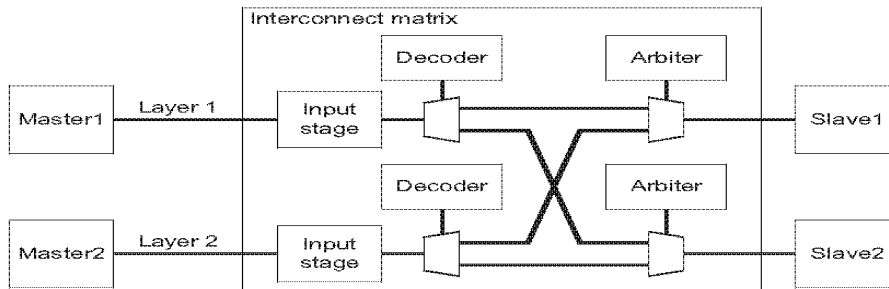
## **AMBA**

### **ARM's Advanced Microcontroller Bus Interface**

- AMBA 1995:
  - APB (Advanced Peripheral Bus)
  - ASB (Advanced System Bus)
    - Multiple masters
    - Pipelined operations
- AMBA 2 1999:
  - AHB (Advanced High Performance Bus)
    - Multiple masters
    - Pipelined operations
    - Burst transactions
    - Split transactions, multiple outstanding transactions
    - Single cycle master hand-over
    - Exclusive bus control
    - Single- centralized decoder for slave select

## AMBA 3 - 2004

- Multilayer AHB



- Not yet a NoC
  - Multiple parallel connections
  - Pipelined bursts
  - Only 2-stage network
  - Central  $n \times m$  switch matrix

## AMBA 3 - 2004

- AXI  
(Advanced eXtensible Interface)
  - Abstract interface protocol
  - No central bus or switch matrix assumed
  - Multiple parallel transactions
  - Multiple outstanding transactions
  - Transactions may complete out of order
  - IDs to group transactions for ordering control
  - Master/slave and read/write transaction based protocol
- AXI protocol does not preclude NoC implementations



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