System-Level Design Space Exploration for SoCs Integrating Optical Networks on Chip

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March 2015
1st OPTICS Workshop
Multi-Processor Systems-on-Chip (MPSoC) Design Trends

- **SoC Design – two contradictory trends**
  - Rising platform development cost
    - Embedded software – over 50% of the total cost
    - Complexity increasing with 140% per year
  - Reducing the product market window

- **Directions to tackle these challenges**
  - Exploit domain-specific MPSoC reusable platforms
    - Several interconnected processors
    - Networks-on-Chip

- **Classical Network-on-Chip Issues**
  - High power consumption
  - Limited bandwidth
  - Long latency
  - Poor scalability

Studies have shown that global metallic interconnects will consume kilowatts of power to achieve the communication bandwidth that will be required by MPSoCs by 2020 using the 14 nm process.
Multi-Processor Systems-on-Chip (MPSoC) Design Trends

- Integration of Heterogeneous Technologies
  - Promising paradigm
    - Multiple technologies
    - Functions will use the best technology available
      - Ex. computing $\rightarrow$ electronics / communication $\rightarrow$ optics
Multi-Processor Systems-on-Chip (MPSoC) Design Trends

- **Integration of Heterogeneous Technologies**
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![Diagram showing Optical Layer and Electric Layers](image)

![Diagram showing Network-on-Chip](image)
Optical Integration Today

- Intel
  - Integration of high-speed switches and optical fabrics
- HP
  - MACHINE project
    - approximately 75% of the researchers involved
    - silicon photonics is employed to link a multicore system-on-chip to a bank of memristor memory cards
- IBM
  - $3 Billion Research Initiative to Tackle Chip Grand Challenges for Cloud and Big Data Systems
    - Silicon Photonics is one of the explored technologies
Configuration Parameters in MPSoC Design

- Type of Network on Chip
- Type of routing
- Type of processors
- No. of proc. in the architecture
- No. of proc. per layer (tier)
- No. of layers (tiers)
- Technology used for each layer
- Application Mapping

Diagram:
- Network-on-Chip
- Proc 1
- Proc 2
- Proc n
- T0
- T1
- T2
- T3
- T4
- T5
- T6
- T7
- T8
- T9
- T10
- T11
Huge solutions space

- Fast and accurate system-level tools for design-space exploration are mandatory
Integrating Optical Network on chip Models to an existing System-Level Platform

- **HellFire Framework**
  - Proposed design-flow for the deployment of embedded applications
  - Set of tools to aid the designer on the project
    - HellfireOS
    - Simulator
    - Web-GUI
Integrating Optical Network on chip Models to an existing System-Level Platform

- **HellFireOS**
  - Modular Structure
  - *POSIX Like*
  - Real-time support
  - Easily portable
  - Parametrizable
  - Stack size (each task)
  - Heap size
  - *Number of user tasks*
  - *Tick size*
  - *Scheduling police*
Integrating Optical Network on chip Models to an existing System-Level Platform

- Hellfire GUI and

![Image of GUI and components]
The next step

- Research is technology-dominated
  - Physical level research
  - New devices and architectures are defined
- System-level vision required
  - Optical engineers
  - Computer engineers
  - Computer scientists
- Multi-disciplinary project
The next step

- Nowadays describing methods are well suited for optical components
  - Focus on improving those methods for better express the interactions for an entire system
- Extend available tools in order to provide real-time feedback
  - Available models don’t work well on real case scenarios, not expressing variations, like cross-talk and heating dissipation
- Speed X Accuracy
  - Find a reliable and yet computationally feasible method for measuring dynamic system variations
The next step

Final Goal

- Provide a tool for the complete design of Optical-based MPSoCs
  - Library of switches, routers and pre-defined networks
  - Dynamic behaviour of components and devices
  - High-speed simulator
  - High-level programming support through an embedded OS
**Work in progress**

- **Optical Network simulator**
  - Based on an in-house network model
  - Connects eight IPs
  - Composed by five MZI-based switches
  - Electronic control layer
Work in progress

- MZI-based switch
  - 4x4 switch
  - Prototyped for data extraction
  - Low delay design (20 ps)
  - Wavelength based switching
  - Allows simultaneous communications on all ports
Work in progress

- Network modeled in RLT level (VHDL)
- Integrated with a MIPS-like processor
- High-level support available through HFOS
Work in progress

Network + HFOS

```c
void task_send(void)
{
  uint8_t buf[30] = "hello!";
  uint16_t dest = HF_CurrentCpuId() + 1;

  while(1)
  {
    HF_Send(dest, 2, buf, sizeof(buf));
    printf("\nnode %d to node %d", HF_CurrentCpuId(), dest);
    HF_TaskYield();
  }
}
```

```c
void task_recv(void)
{
  uint16_t source_cpu;
  uint8_t source_id;
  uint16_t size;
  uint8_t buf[31];

  while(1)
  {
    HF_Receive(&source_cpu, &source_id, buf, &size);
    printf("\nthread %d -> message from node %d thread %d size %d -> %s\n", 
           HF_CurrentTaskId(), source_cpu, source_id, size, buf);
    HF_TaskYield();
  }
}
```
CONCLUSIONS

- Standard NoC implementations show important drawbacks
- Optical-NoC comes as a possible solution
- Design methods for basic devices are well matured
- Lack of tools for system-level design
- Extension of HFFW
Multi-disciplinary Project Team

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SYSTEM-LEVEL DESIGN SPACE EXPLORATION FOR SOCs INTEGRATING OPTICAL NETWORKS ON CHIP

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