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Nanonetworking Center
in Catalunya

UPC

Graphene-based Wireless Network-on-chip: Enabling next-generation scalable manycore architectures

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1st International Workshop on Emerging Topics in NoC-aware Computer Architecture - ETNA
(held in conjunction with the 40th International Symposium on Computer Architecture - ISCA 2013)
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- The performance bottleneck of multiprocessors has shifted from clock frequency to inter-core communication capabilities.

Need for scalable communications for multiprocessors – Network-on-Chip (NoC)

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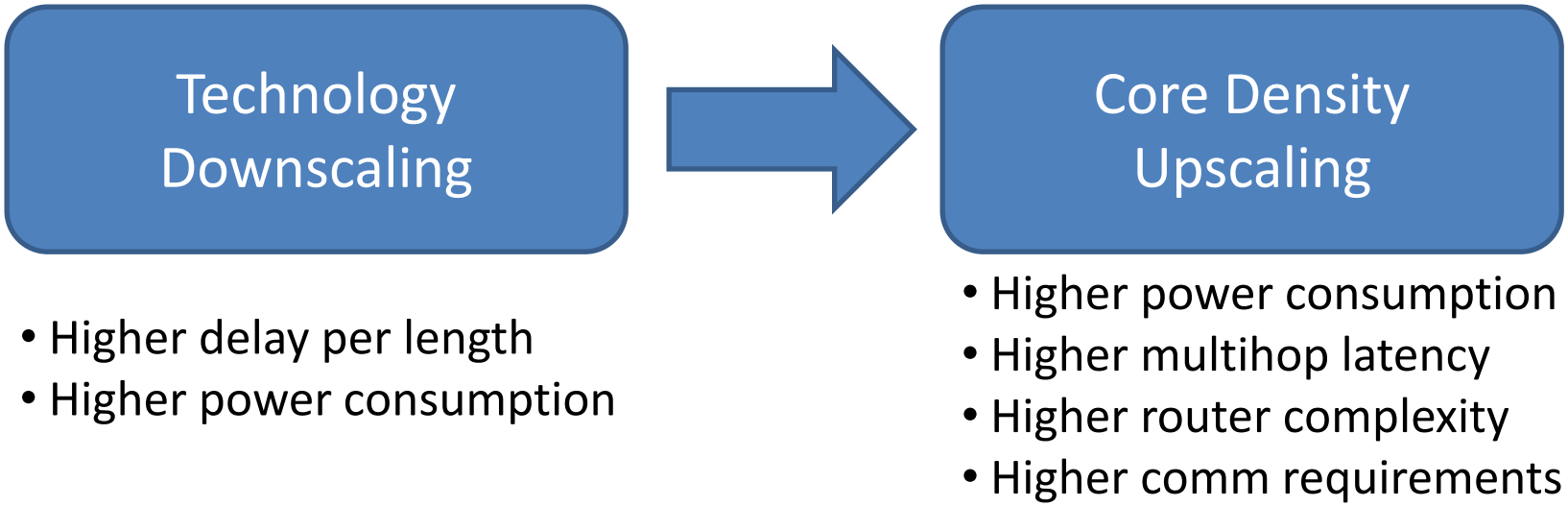
- As we move to the manycore era, the initial concept of NoC may become insufficient **from a communications perspective**.



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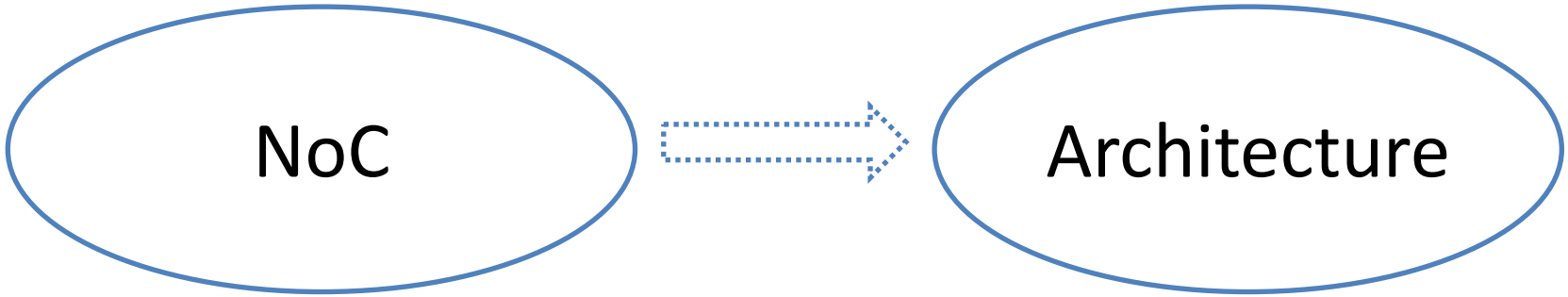
From the communications side, dominant trends in NoC are both **neglecting** and **oriented to** architecture



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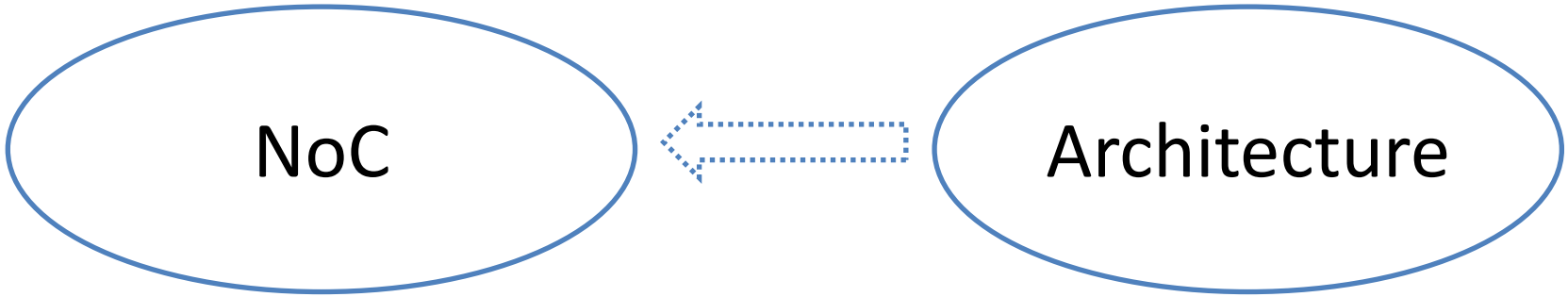
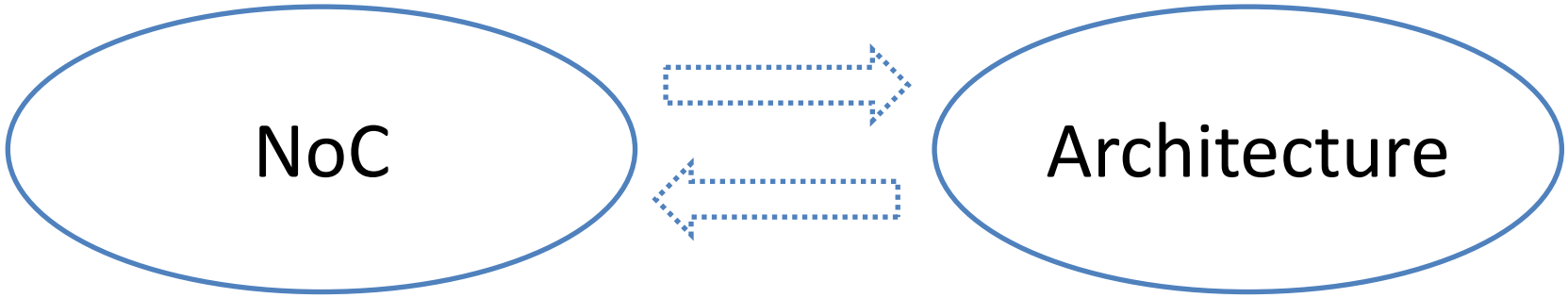
Does the same happen the other way around?



We observed a surge in NoC research, a large part of which has not found a corresponding architecture research – potential «deadlock» situations



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Take the role of broadcast and multicast:

- A vital part of on-chip traffic is broadcast/multicast:
  - Cache coherence
  - Synchronization
  - Etc…
- Some applications or algorithms could benefit from broadcast/multicast.
- However, broadcast has traditionally been costly and avoided when possible.

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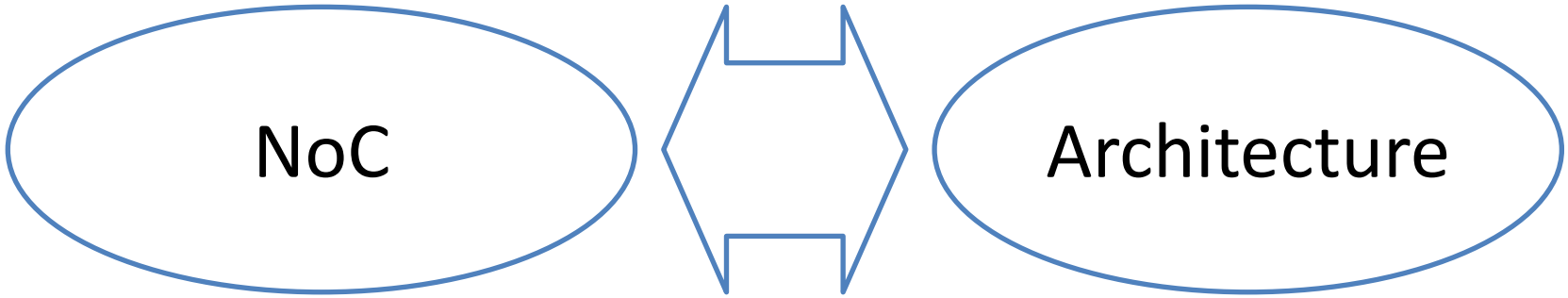
Should not there be a bridge between these two research lines?



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- Introduction
- **State of the Art in NoCs**
- Graphene-enabled Wireless Network-on-Chip
- Open Challenges and Conclusions

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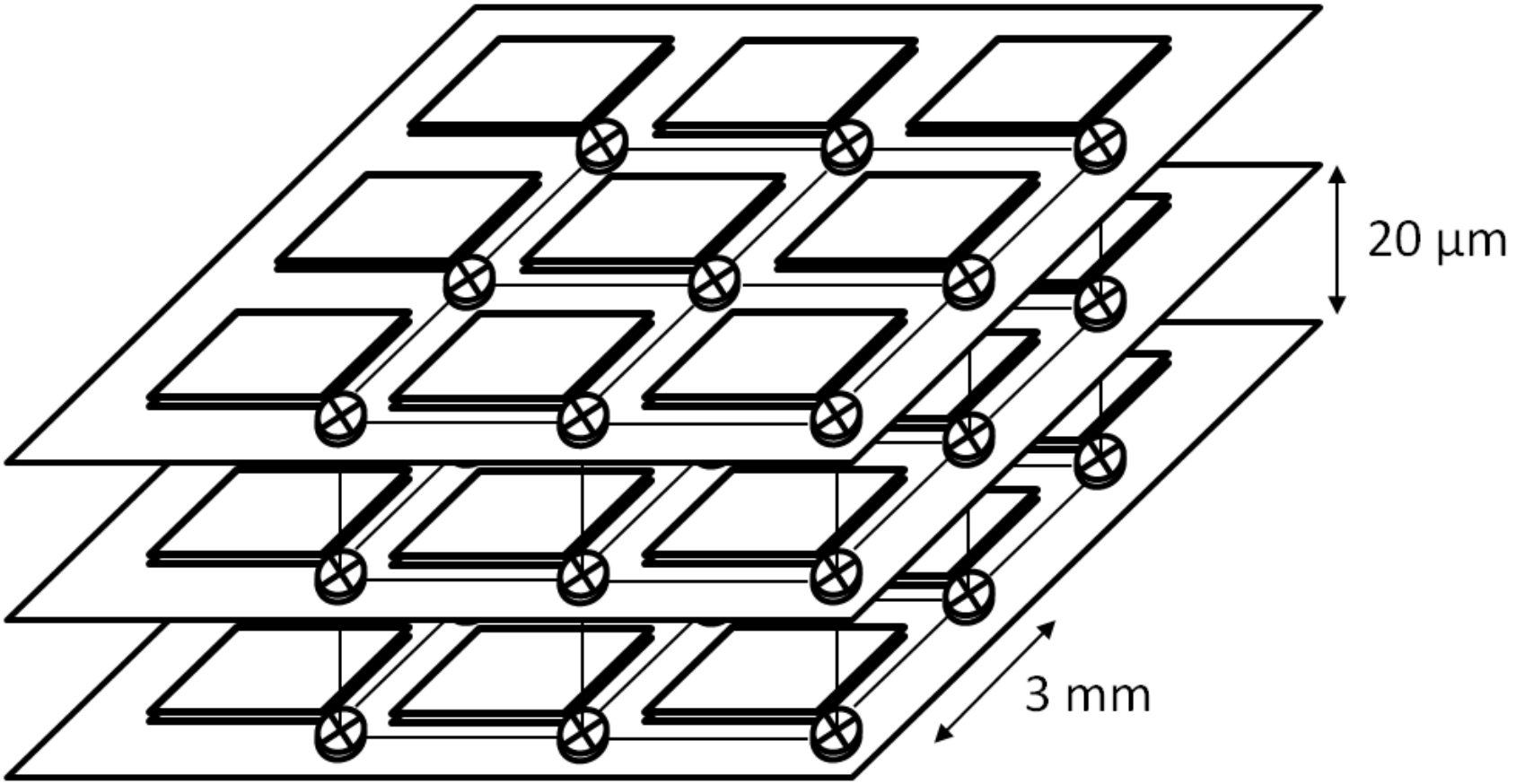
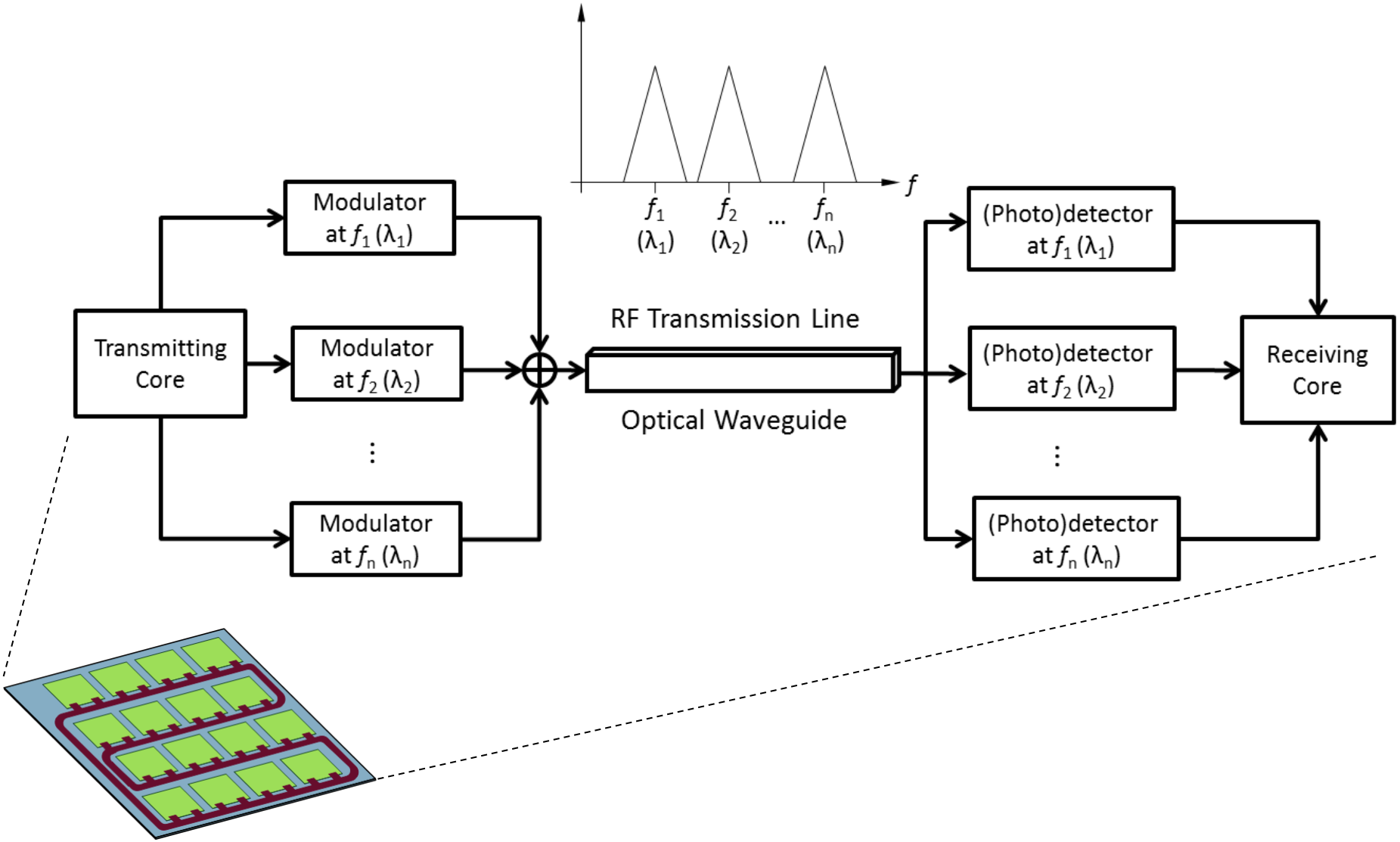
- Optimizing conventional wireline NoCs
  - Enhanced routers
  - Alternative topologies (~~mesh~~)
- Alternative interconnect technologies
  - Vertical Vias (3D)
  - RF Interconnects
  - Nanophotonics
  - On-chip Antennas

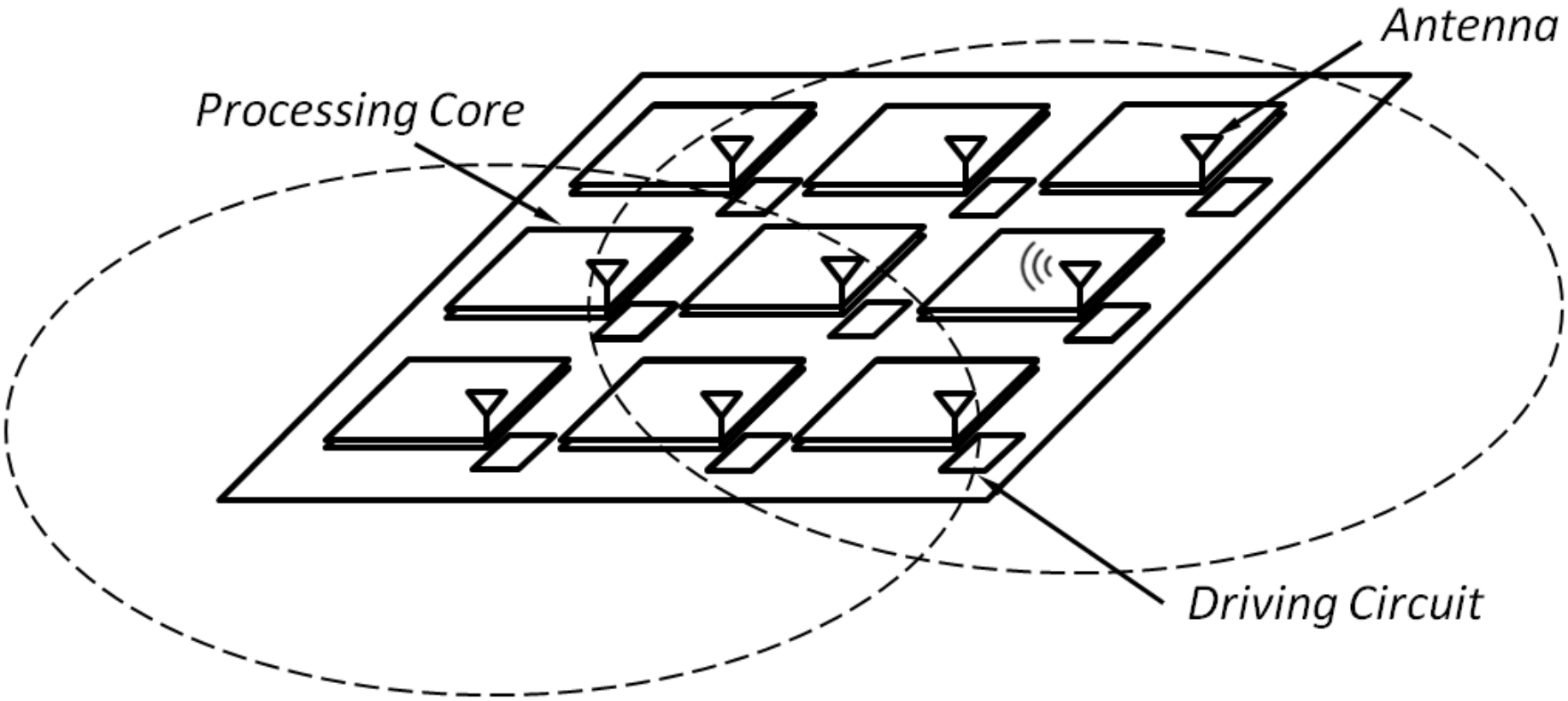
Emerging Interconnect Technologies – 3D NoC



Emerging Interconnect Technologies – RF/Photonic NoC



Emerging Interconnect Technologies – Wireless NoC



Emerging Interconnect Technologies (I)

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	Advantages	**Downturns**
3D NoC (short vertical interconnects for 3D stacked devices)	Reduced delay Reduced hop count New network topologies Hybrid approach	Heat effects Scalability still poor
RF NoC (RF signals over inprinted waveguides)	Speed-of-light propagation FDMA, CDMA schemes Reconfigurable bandwidth	Difficulty to lay down waveguides

Emerging Interconnect Technologies (II)

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	Advantages	Downturns
Photonic NoC (applying nanoscale on-chip photonics)	Speed-of-light propagation Low power Extremely high bandwidth	Need for infrastructure Need for non-photonic support plane to scale.
Wireless NoC (use on-chip antennas to wirelessly communicate cores)	Speed-of-light propagation One-hop communication Potential Reconfigurability Hybrid Possibilities	Large Antennas Still Low Bandwidth

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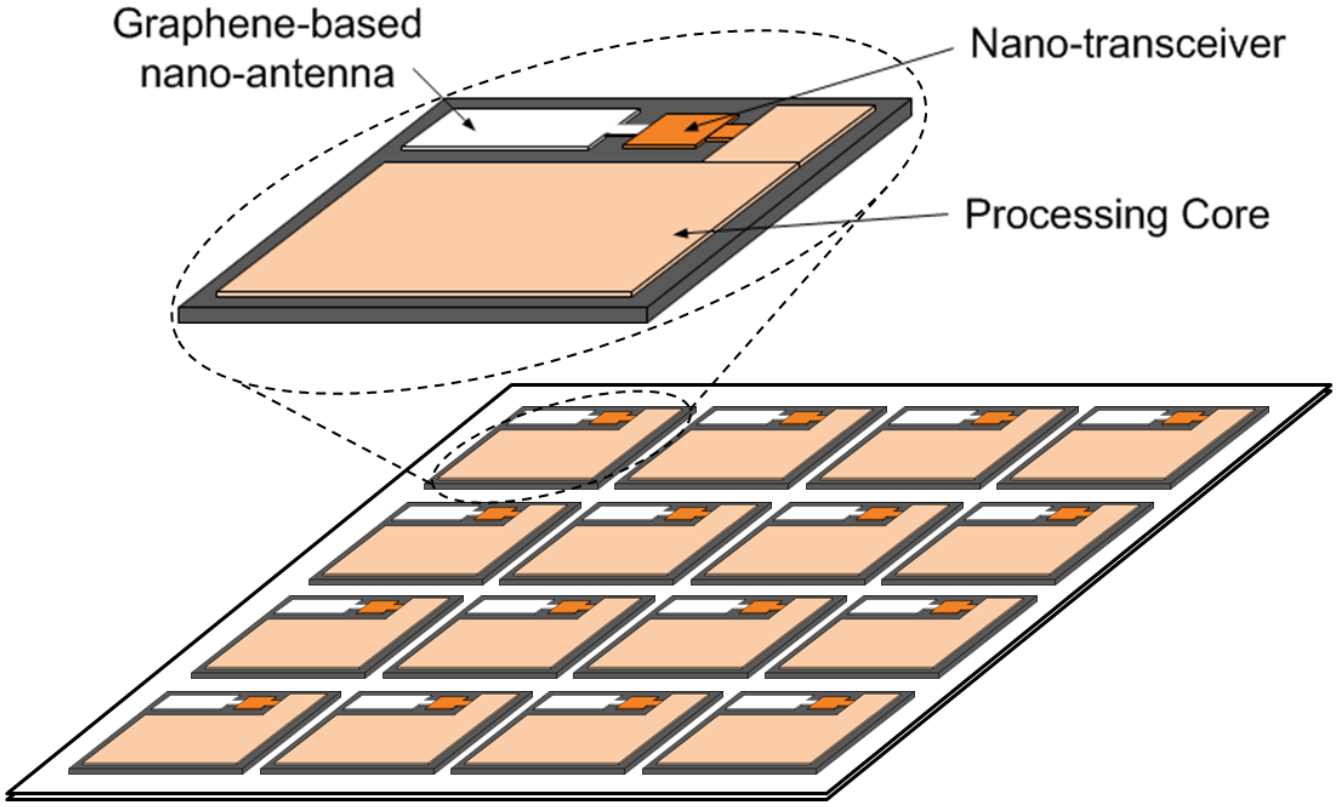
Graphene-enabled Wireless Network-on-Chip: interconnecting the cores of a chip using Graphene Wireless Communications.



S. Abadal, E. Alarcón, M. C. Lemme, M. Nemirovsky, and A. Cabellos-Aparicio, **"Graphene-enabled Wireless Communication for Massive Multicore Architectures,"** to be published in IEEE Communications Magazine, 2013.

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"Apart from the latency and pontential reconfigurability benefits commented earlier, GWNoC could provide an efficient and scalable platform for broadcast and multicast on-chip communications ***at the core level****"*

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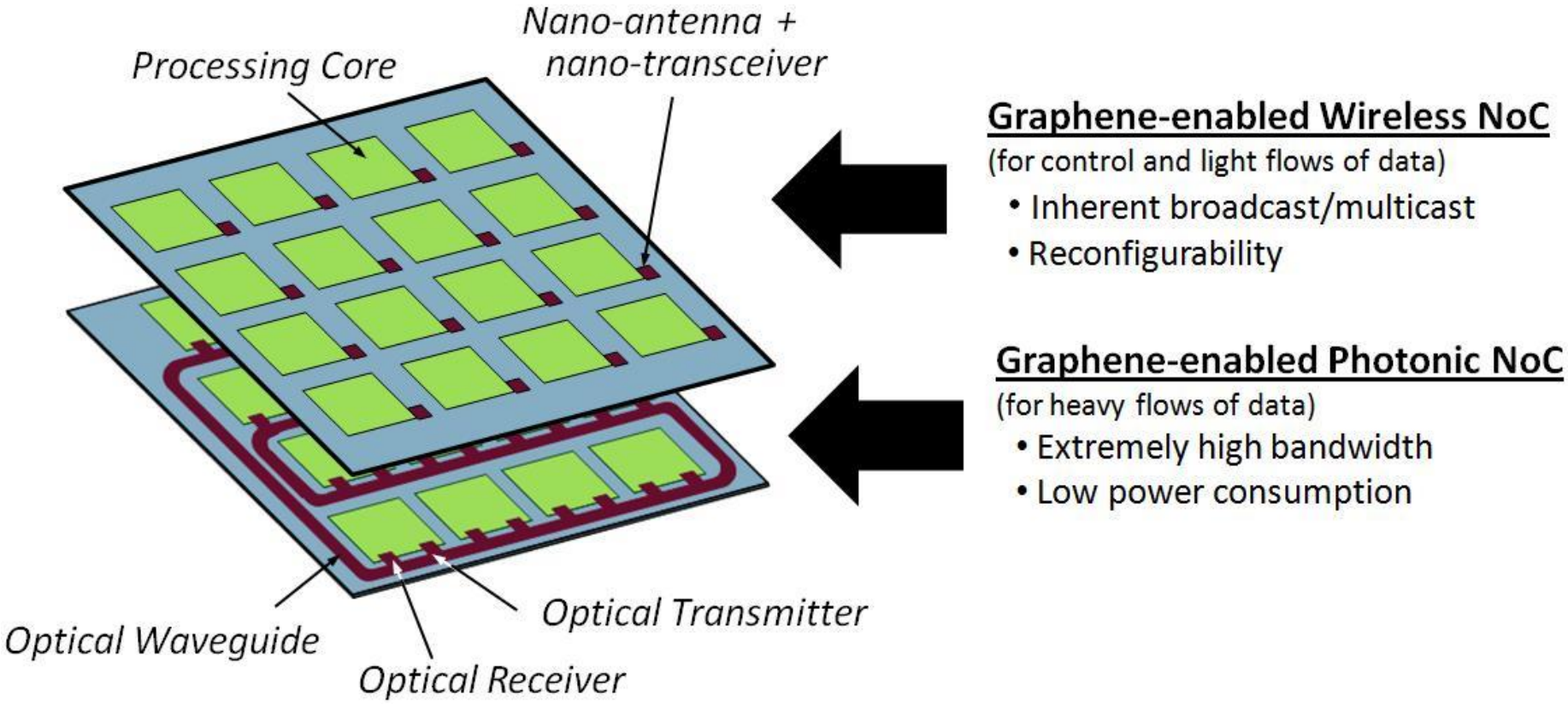
- The grand vision includes a parallel communication plane implemented by means of an optical NoC.



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- Introduction
- State of the Art in NoCs
- **Graphene-enabled Wireless Network-on-Chip**
  - Vision
  - **Enablers of GWNoC**
  - Scalability-based Feasibility Study
- Open Challenges and Conclusions

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This vision will be possible by virtue of:

1. Graphene-based Antennas – *Graphennas*
2. Very High Speed Transceivers
3. Communications and networking solutions suited to the scenario

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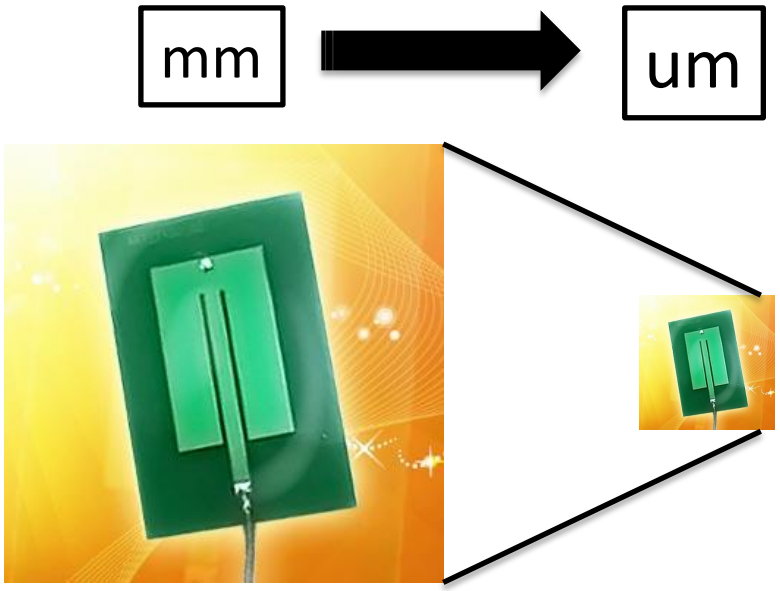
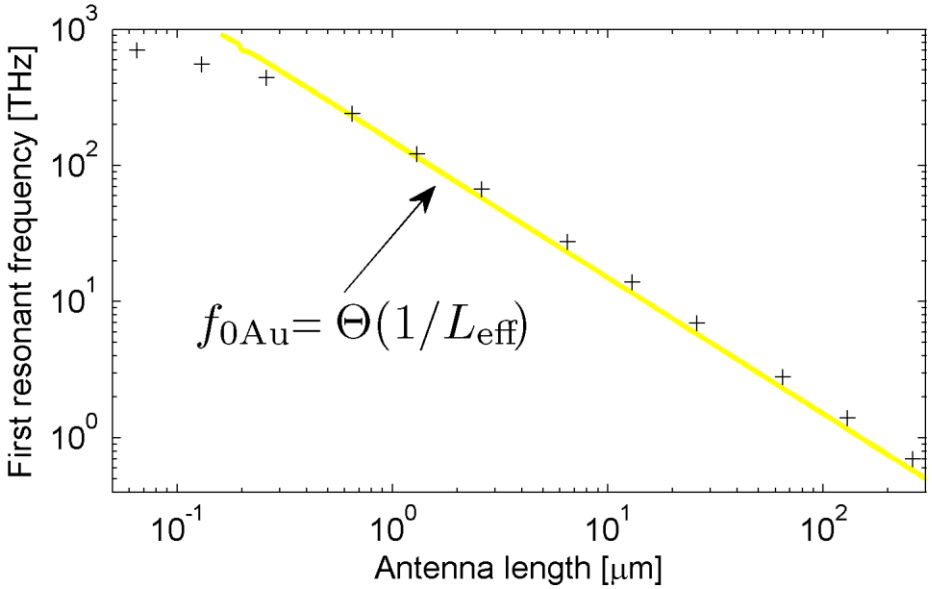
- Why graphennas?
  - Bandwidth insufficient as the number of cores grows for metallic antennas.
  - Metallic antennas too large with respect to core sizes
    - Current approaches use wireless for inter-CLUSTER communication

Downscaling a traditional antenna





- Downscaling a traditional antenna to a few μm is not possible
- Radiation frequency in the Optical Regime
- Downscalability factor: $\Theta(1/L_{eff})$

I. Llatser, C. Kremers, A. Cabellos-Aparicio, E. Alarcón and D. N. Chigrin, ***"Comparison of the Resonant Frequency in Graphene and Metallic Nano-antennas"***, in AIP Conference Proceedings, 2012

Motivation for graphennas

- **Objective:** antennas size compatible with core sizes
- Resonant frequency of a 1 μm-long metallic dipole antenna

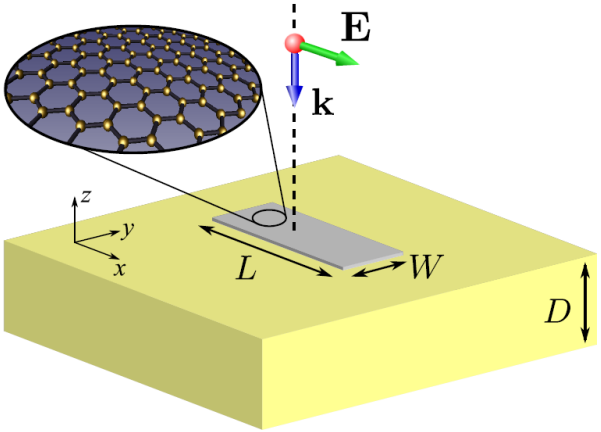
$$f = \frac{c/\sqrt{\varepsilon_r}}{2L} \approx 100\ THz \longrightarrow \text{optical domain}$$

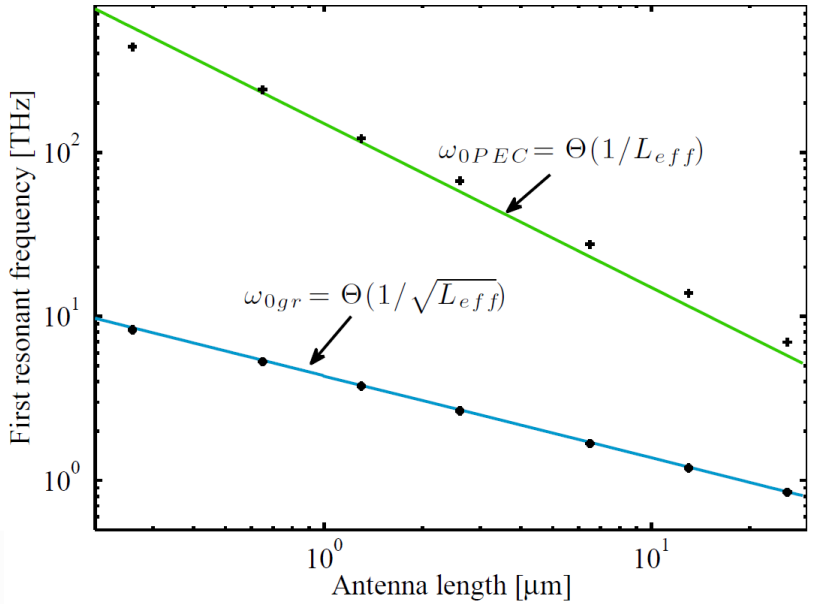
f: radiation frequency
c: speed of light
ε_r: dielectric relative permittivity
L: antenna length
d: transmission distance

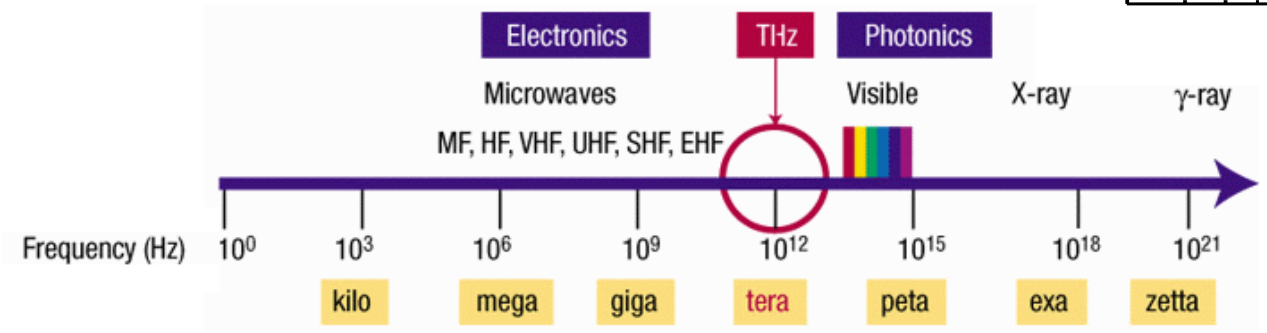
- Not appropriate for omnidirectional wireless communications
  - Very high channel attenuation: $A \sim f^2$
  - Low radiation efficiency due to limitations of the material
  - Need for complex and expensive optical transceivers

Motivation for graphennas

- Graphene-based miniaturized antennas
  - Size in the μm range
  - Predicted to radiate in the THz band (plasmonic effects)



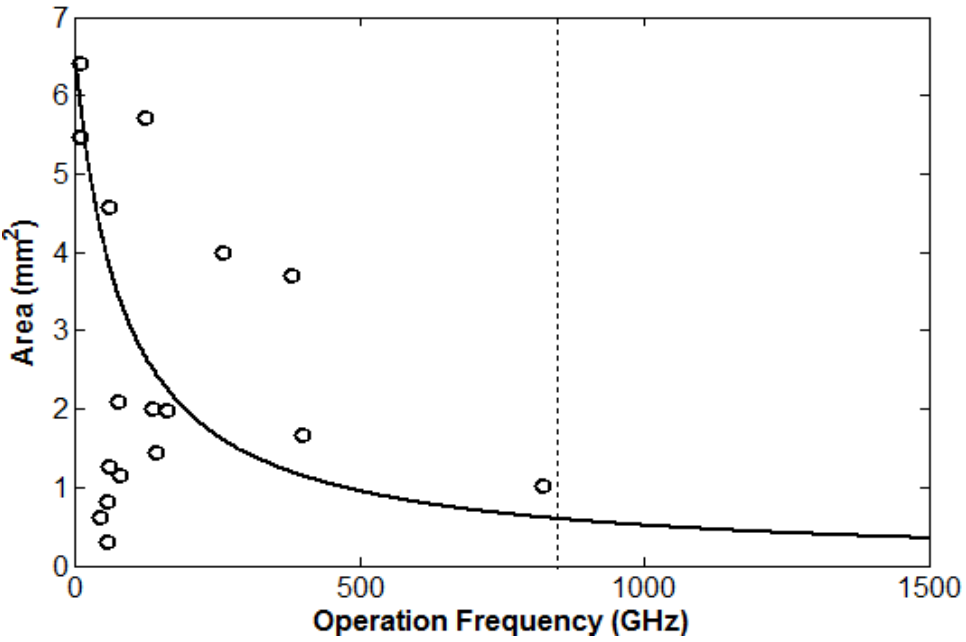


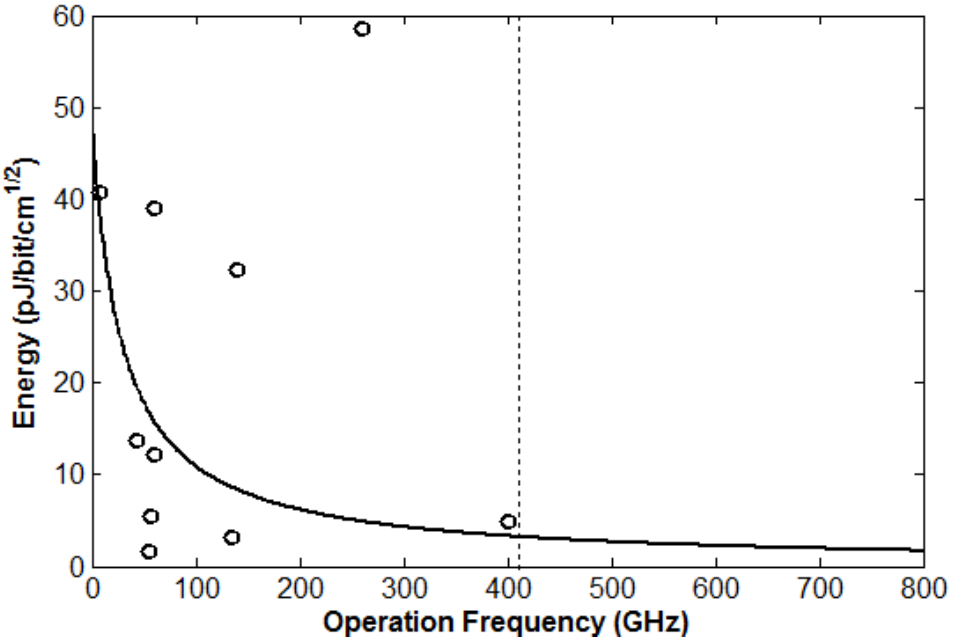


- Why graphennas?
  - ~~Bandwidth insufficient as the number of cores grows for metallic antennas.~~
  - Bandwidth is enough as we expect to work and radiate in the THz band
  - ~~Metallic antennas too big with respect to core sizes~~
    - ~~Current approaches use wireless for inter-CLUSTER communication~~
  - Graphene antennas are size compatible with cores
    - Wireless communication at the core level could be achieved.

Enablers of GWNoC - Transceivers

- Transceivers are needed to drive the signals to the antenna.
- They must operate at the same frequency.
- Tendencies pointing towards multigigabit rates and approaching THz frequencies.





A new set of communication and networking solutions must be developed for this unique scenario

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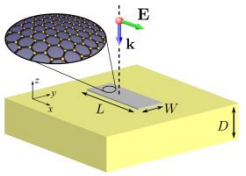
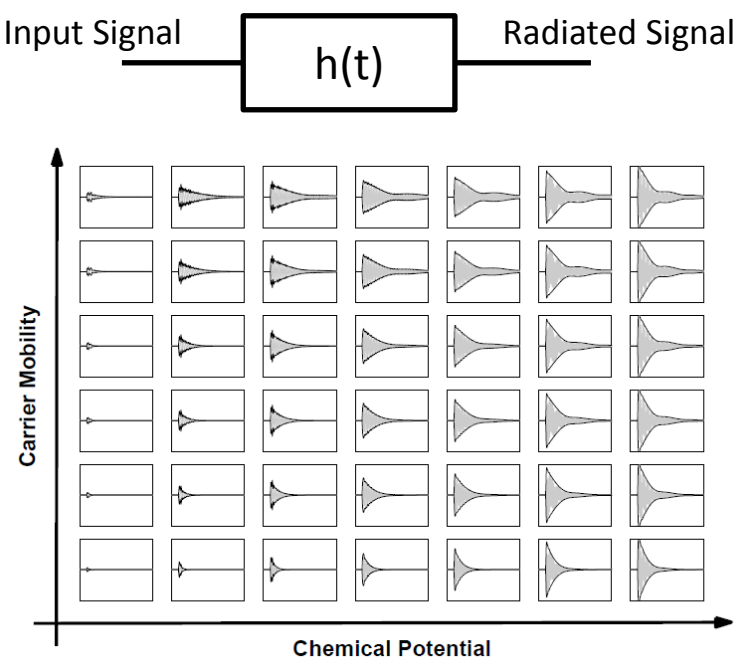
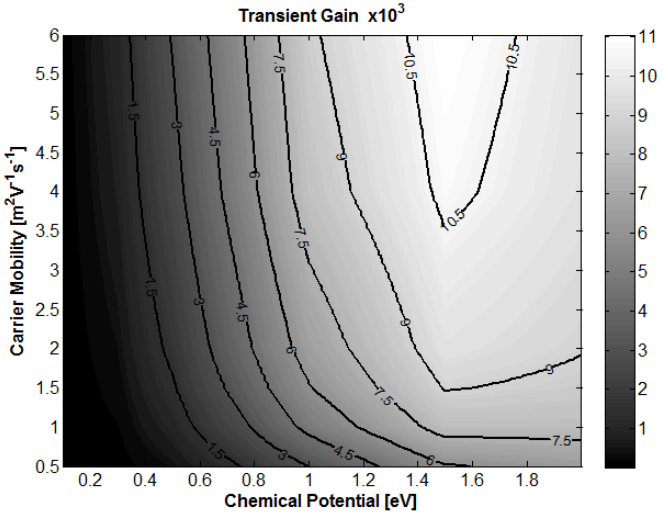
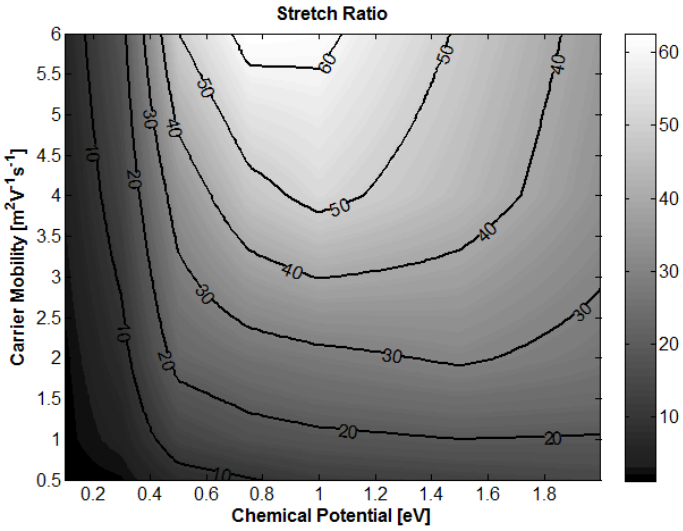
Impulse response design space exploration oriented to the design of feasible modulation schemes approaching terabit per second speeds







Signal Amplitude



Signal Width

S. Abadal, I. Llatser, A. Mestres, E. Alarcon, H. Lee and A. Cabellos-Aparicio, **"Time-Domain Analysis of Graphene-based Miniaturized Antennas for Ultra Short-range Impulse Radio Communications",** submitted for journal publication, 2013.

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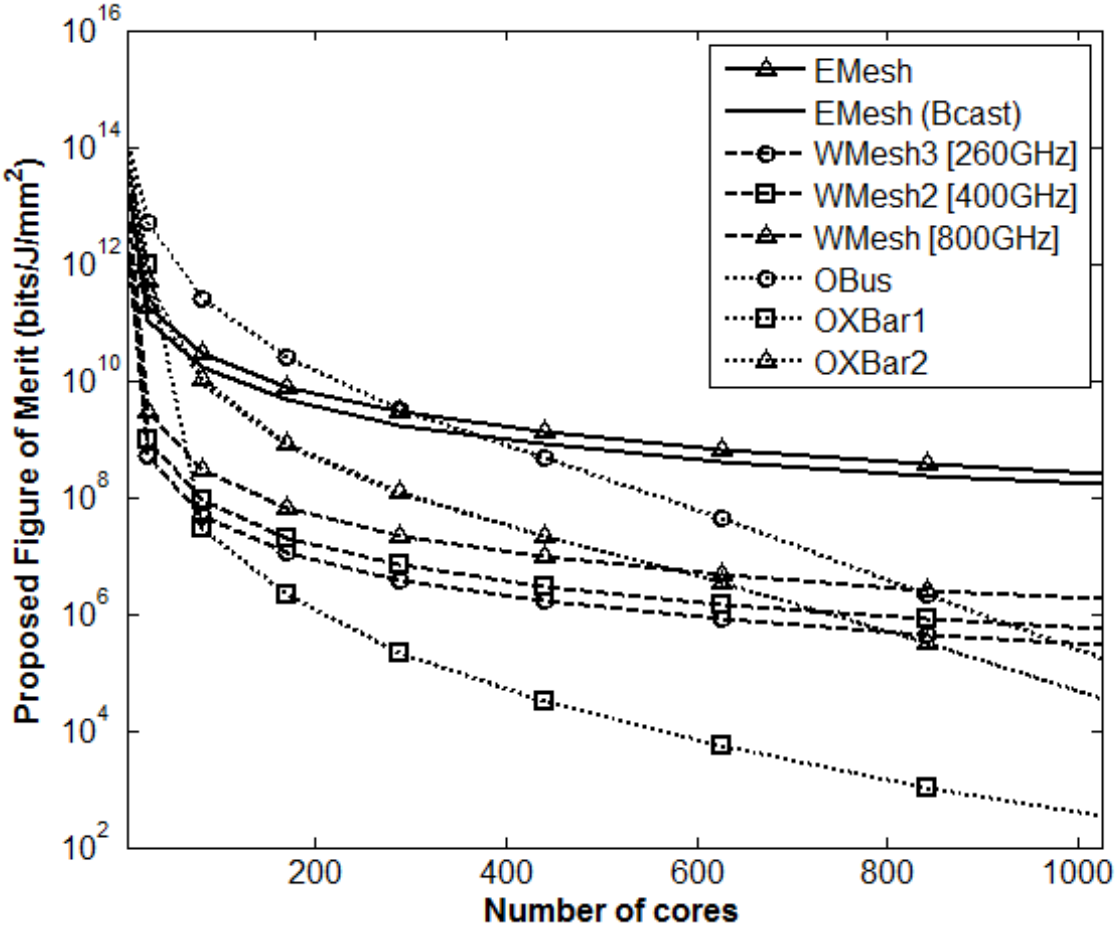
Scalability-based feasibility study, to:

- Justify the suitability of GWNoC and in which conditions
- Inspect the hybrid design space (e.g. Optical-wireless)
- Provide design guidelines to implementation layers.
- Provide potential performance to architecture layers.

Scalability-based Feasibility Study (II)

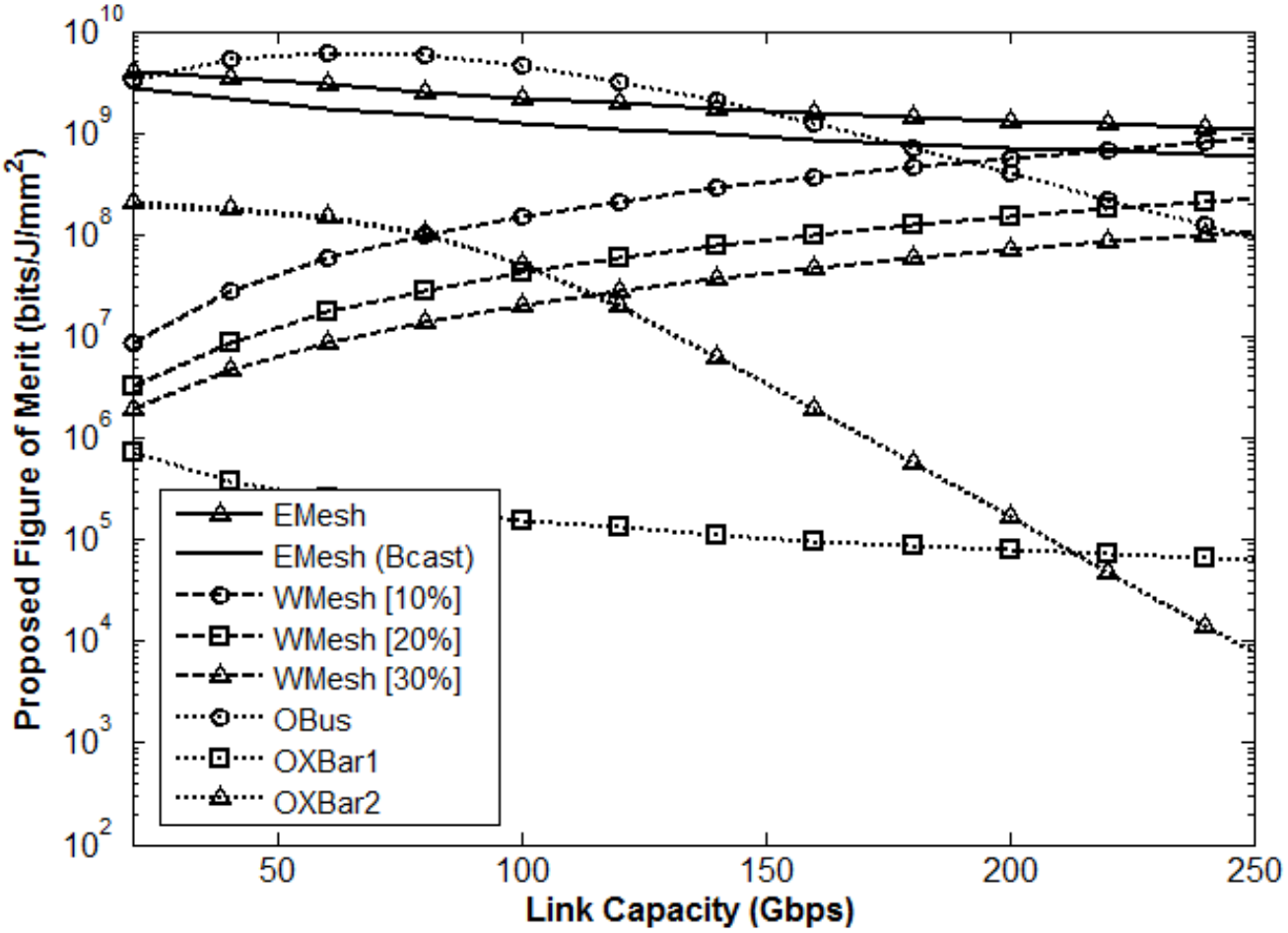
- Area and energy scalability of different interconnect technologies and network architectures.



S. Abadal, M. Iannazzo, M. Nemirovsky, A. Cabellos-Aparicio, H. Lee, E. Alarcón, "**On the Area and Energy Scalability of Wireless Network-on-Chip: A Model-based Benchmarked Design Space Exploration**", submitted for journal publication, 2013.

Scalability-based Feasibility Study (III)

- Area and energy scalability of different interconnect technologies and network architectures.



S. Abadal, M. Iannazzo, M. Nemirovsky, A. Cabellos-Aparicio, H. Lee, E. Alarcón, "**On the Area and Energy Scalability of Wireless Network-on-Chip: A Model-based Benchmarked Design Space Exploration**", submitted for journal publication, 2013.

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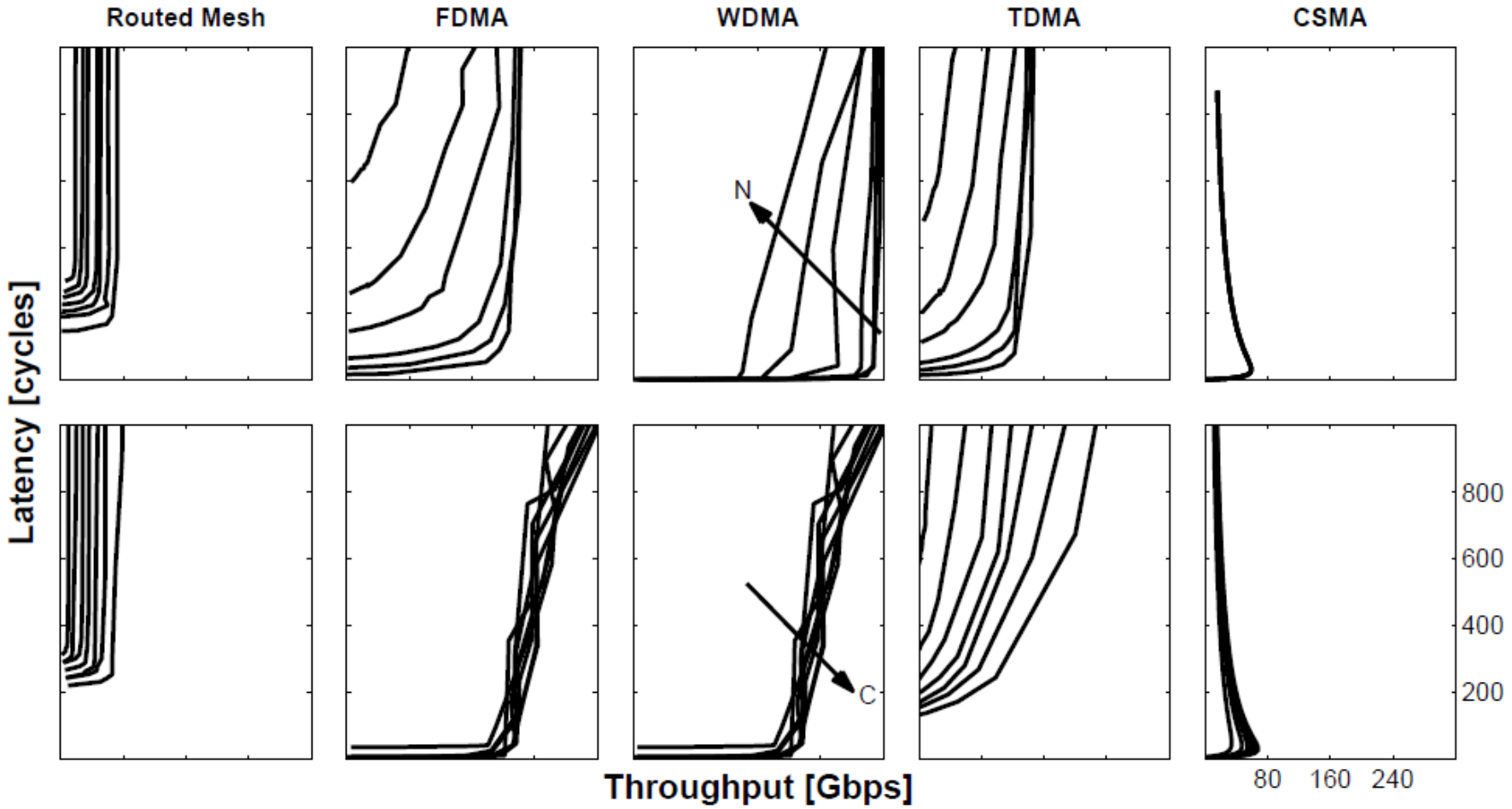
- Latency/Throughput scalability of different network architectures (enabled by emerging technologies)



S. Abadal, A. Mestres, E. Alarcón, M. Nemirovsky, H. Lee, A. Cabellos-Aparicio, **"Scalability of Broadcast Performance in Wireless Network-on-Chip"**, submitted for journal publication, 2013

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Open Challenges

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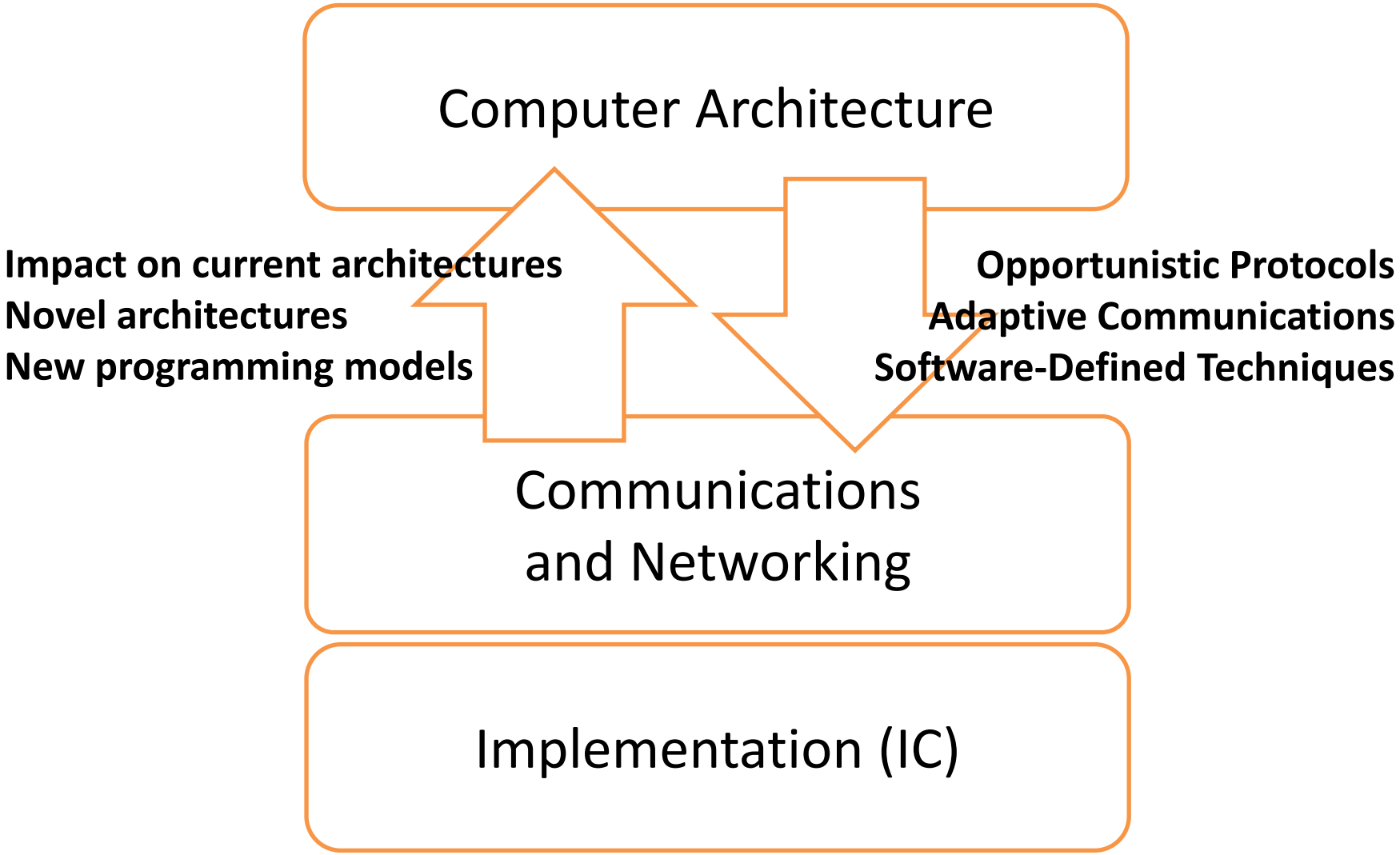
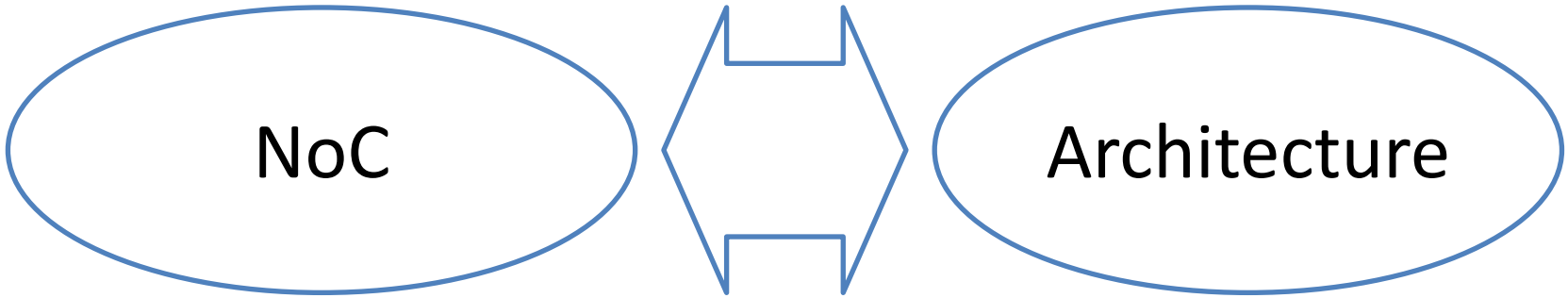


- We hope this will trigger quality frontier research arising from the interaction of NoC and Architecture design layers.
- So that, among others, GWNoC will enable scalable next-generation manycore architectures.



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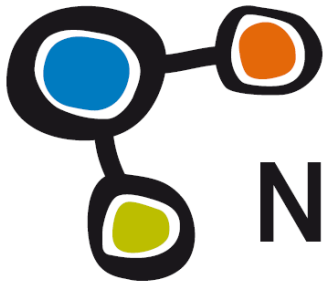
Thank you for your attention!

Any question?



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