A MAC protocol for Reliable Broadcast Communications in Wireless Network-on-Chip

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Current trends are leading to larger manycores

Wireless on-chip communication holds promise for the implementation of fast networks for these multiprocessors

In complement of a wired NoC, wireless provides

- Low latency
- Natural broadcast capabilities
- Flexibility
Motivation

- As the core density increases, more wireless interfaces can be expected on chip.
- Need for arbitration strategies (MAC protocols)
  - That provide low latency
  - That support broadcast traffic
  - That are reliable (packets cannot be lost)
  - That scale with number of wireless nodes
We propose a BRS-MAC, a protocol based on three pillars: **Broadcast**, **Reliability**, **Sensing**

We develop analytical models to explore the performance of BRS-MAC

We compare the obtained performance with that of token passing and a wired mesh
Emerging Interconnect Technologies

Nanophotonics
Vantrease et al, 2008

Transmission Line Interconnects
Oh et al, 2013

Wireless on-chip Communication
On-chip Antenna
Core

Transceiver (transmitter and receiver circuits)

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On-chip Wireless Communication

PROS
- Inherently broadcast
- Low latency
- Simplicity / Flexibility / Non-intrusiveness

CONS
- Less energy efficient than TL or photonics
- Low bandwidth

Wired-Wireless Network-on-Chip

Hybrid Network Interface (HNIF)

Controller

eNIF

wNIF

Router

Transceiver

MAC

PHY

Antenna

CORES + MEMORY
Wired-Wireless Network-on-Chip

Hybrid Network Interface (HNIF)

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CORES + MEMORY
Medium Access Control (MAC)

The MAC layer defines mechanisms to ensure that all nodes can access to a shared medium in a reliable manner.

Simultaneous accesses to the same channel collide and need to retry.
Chip scenario

Physically constrained – need for lightweight MAC

Unlike most environments, the chip scenario is \textit{static and known beforehand}

“Everyone sees everything”

Easy to reach consensus

Collisions can be detected

\textbf{Simpler protocols}
MAC Context Analysis

Application Requirements
- Low latency – need for fast solution
- Reliability – MAC cannot lose packets
- Scalability – protocol must scale to many cores

Traffic Characteristics
- Broadcast is the objective of our WNoC*
- Variable – flexibility is desirable

MAC in Wireless NoC

- **Channelization**: FDMA, TDMA, CDMA, ... 
  - Higher performance

- **Coordinated Access**: Token passing, reservation, ...
  - Higher simplicity, flexibility

- **Random Access**: ALOHA, CSMA/CA, CSMA/CD, ...

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MAC in Wireless NoC

- **Channelization**
  - Low latency, reliability due to multiple channels
  - Inherently rigid, hard to implement broadcast
  - Does not scale ➔ becomes area/power hungry

- **Coordinated Access (token passing)**
  - High throughput due to the absence of collisions
  - Still somehow rigid
  - Scaling problems ➔ protocol becomes slow

- **Random access?**

For all this, we propose BRS-MAC

- **Broadcast (B):** designed to serve broadcast fast
- **Reliability (R):** guarantee correct delivery
- **Sensing (S):** based on carrier sensing and collision detection principles

Seeks to provide the low latency, scalability, and flexibility desired via random access
BRS-MAC – Basic Assumptions

- Nodes can sense the medium
- In the event of a collision, at least one of the receivers can detect such situation and notify the transmitters
- At least one collision notification will reach all the colliding transmitters
**TX:** Check if the channel is free. If so, transmit a preamble. Then, listen for a Negative ACK:
- If there is a NACK, there was a collision. Back off (exponential) and retransmit
- If silence, preamble was OK. Continue with the rest of the transmission (cannot collide)
RX: listen for new transmissions. When a preamble is received, check for errors, then
- If errors, transmit a NACK.
- If no errors, stay silent.
There are several key design decisions

- Collision detection at the RX cannot normally be assumed, but here we have a static scenario
- Preamble contains the size of packet, receivers can calculate the transmission duration
- NACK mechanism is chosen because
  - Success will be more probable than collision
  - Only 1 NACK is needed to cancel a colliding tx
  - N-1 ACKs are needed to confirm a successful tx
Analytical Modeling – Equations

**Throughput:** \( S = \frac{E\{U\}}{E\{B\} + E\{I\}} \)
- \( U \) – occupancy of the channel (successful)
- \( B + I \) – time between transmissions (busy+idle)

**Delay:** \( D = N_{re} R + N_{c} T_{KO} + T_{OK} \)
- \( N_{re}, N_{c} \) – number of retransmissions, collisions
- \( R \) – duration of the backoff periods
- \( T_{OK}, T_{KO} \) – time lost in a collision, delay of successful transmission
Modeling Approaches

- **Classical (worst-case)**
  - Position of nodes is unknown, they can move
  - Assume a constant propagation time

- **Network-on-Chip (exact)**
  - Positions are known a priori
  - Propagation time can be calculated exactly
  - Homogeneous deployment is assumed
Necessary assumptions (Kleinrock et al)

- All arrivals follow Poisson process
- Traffic uniformly distributed among infinite population (reasonable in manycores)
- Negligible time to switch between TX and RX
- Negligible time to sense the channel busy

Closed-form expressions

\[ S = e^{-aG} / e^{-aG} (1-b) + b + 2a + 1/G \]

\[ S^e \approx 1 - G\alpha a / 1 + (2+\alpha) a - (1-b) G\alpha a + 1/G \]

\[ N\downarrow c = a + 1/G/E\{B\} + E\{I\} G/S - 1 \quad \text{worst-case} \]

\[ N\downarrow c^e = a\alpha + 1/G/E\{B^e\} + E\{I\} G/S^e - 1 \quad \text{exact} \]
Closed-form expressions

\[ S = e \uparrow - \alpha G / e \uparrow - \alpha G (1-b) + b + 2\alpha + 1/\Gamma \]

\[ S \uparrow e \approx 1 - G\alpha a / 1 + (2 + \alpha) a - (1-b) G\alpha a + 1/\Gamma \]

\[ N\downarrow c = \alpha + 1/\Gamma / E\{B\} + E\{I\} G/S - 1 \]

\[ N\downarrow c \uparrow e = \alpha a + 1/\Gamma / E\{B \uparrow e\} + E\{I\} G/S \uparrow e - 1 \]

Worst-case propagation time appears in all expressions.

Parameter relating average exact propagation with worst-case propagation time.
Closed-form expressions

\[ S = e^{\frac{-aG}{e^{\frac{-aG (1-b)}{b+2a+1/G}}}} \]

\[ S^e \approx 1 - Gaa/1 + (2+a)a - (1-b)Gaa + 1/G \]

\[ N_{\downarrow c} = a + 1/G/E\{B\} + E\{I\} G/S - 1 \]

\[ N_{\downarrow c^e} = a + 1/G/E\{B^e\} + E\{I\} G/S^e - 1 \]

Length of the preamble and NACK period.
Implemented BRS-MAC within event-based simulator to validate models

- Propagation times modeled accurately
- Overlapping transmissions ➜ collision

As baseline, we implemented classic CSMA with ideal acknowledging

Explored impact of $a$ and $b$ parameters

Validation of the model
Impact of propagation time

Throughput (S)

Offered Load (G)

Delay (D) [ns]

Throughput (S)
Impact of preamble length

![Graph showing the impact of preamble length on throughput and delay.

Throughput (S) vs. Offered Load (G)

- BRS-MAC
- CSMA

Delay (D) vs. Throughput (S)

- BRS-MAC
- CSMA

b = {0.1, 0.3, 0.6, 1}

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Performance Comparison

- **Wireless Token Passing**
  - Passing the token takes 1 clock cycle
  - Cannot be overlapped with data transmission

- **Aggressive Wired Mesh**
  - Each hop takes 2 clock cycles without contention
  - Tree multicast
  - Multiport allocation and multicast crossbar

- Same per-link bandwidth in all cases
- 100% broadcast traffic
Performance Comparison

\[ a = 0.1 \]
\[ b = 0.1 \]
Latency increases with number of nodes due to increasing token round-trip time (TOKEN) or network diameter (MESH)
BRS-MAC has the best latency of all options

BRS-MAC has a reasonable saturation throughput

![Graph showing performance comparison between different MAC protocols.](image-url)
Conclusions

- We presented BRS-MAC, a random access protocol for Wireless Network-on-Chip
- We accurately modeled and explored its performance
- BRS-MAC achieves much lower latency than token passing or mesh networks, with reasonable saturation throughput
Thanks for your attention.
Questions?