Replica: A Wireless Manycore for Communication-Intensive and Approximate Data

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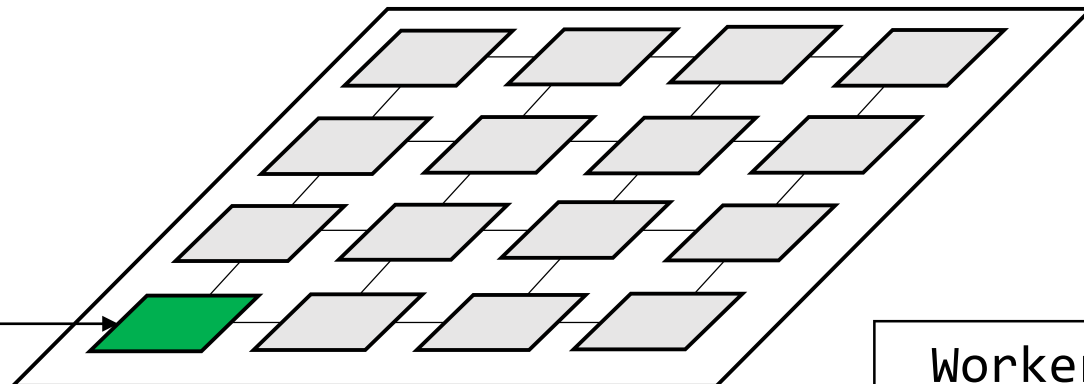
Motivation

Computations with broadcast and fine-grained data sharing do not scale well in shared-memory multiprocessor architectures

```
Master Thread

counter++;

barrier_wait(b)
```

```
Worker Threads

barrier_wait(b)

x = counter;
```

Manycore with a Network on Chip



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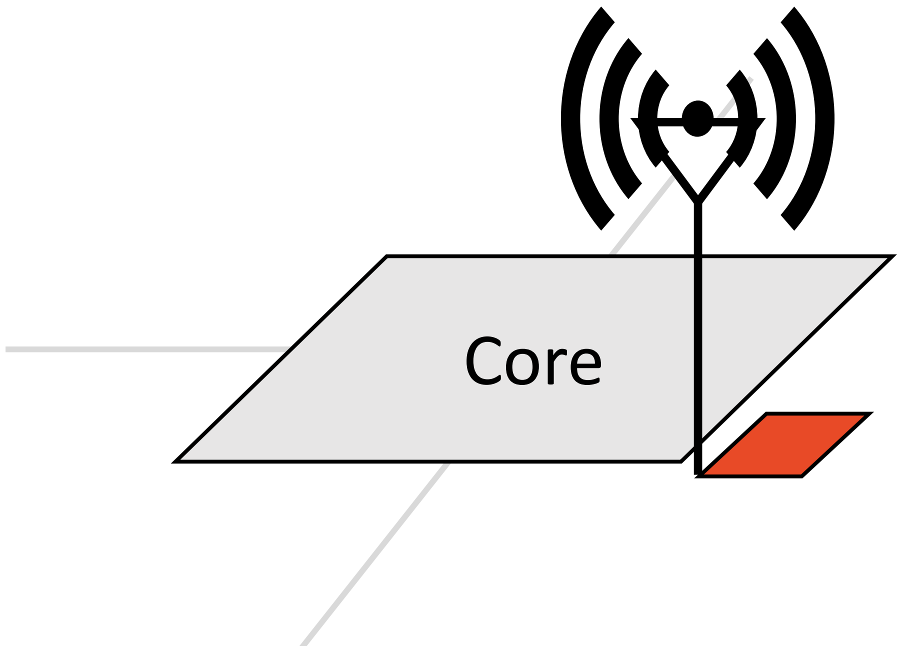
WiSync: On-chip Wireless Communication for Synchronization



Abadal et al. "WiSync: an architecture for fast synchronization through on-chip wireless communication." ASPLOS 2016

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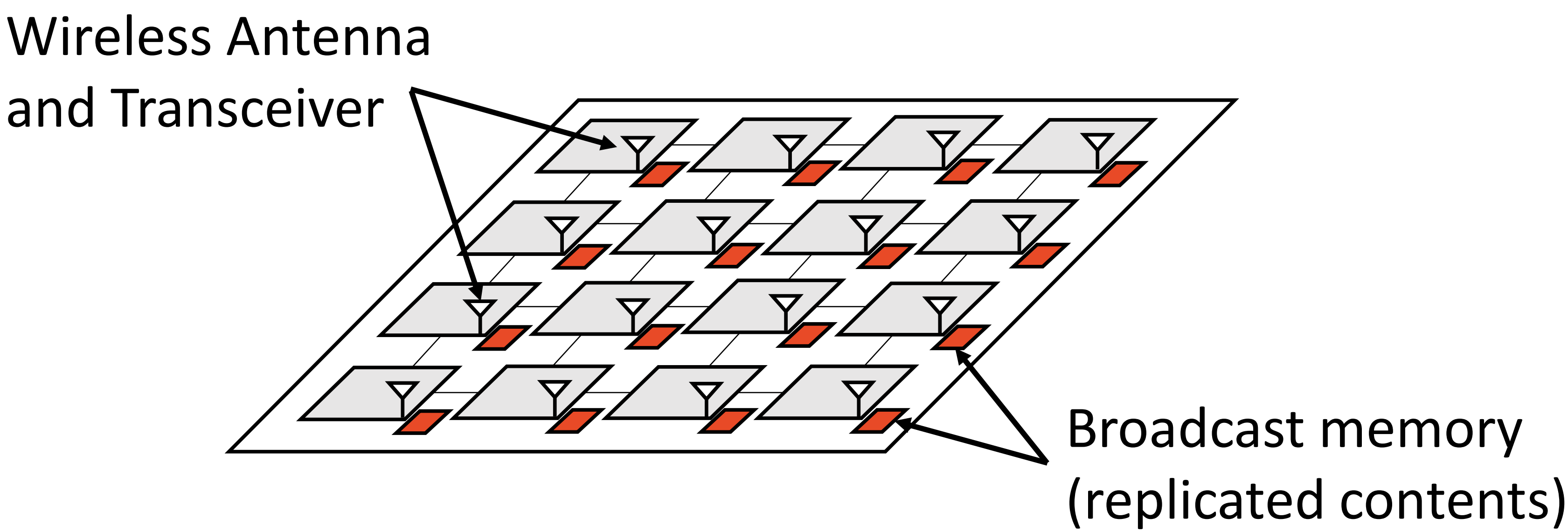

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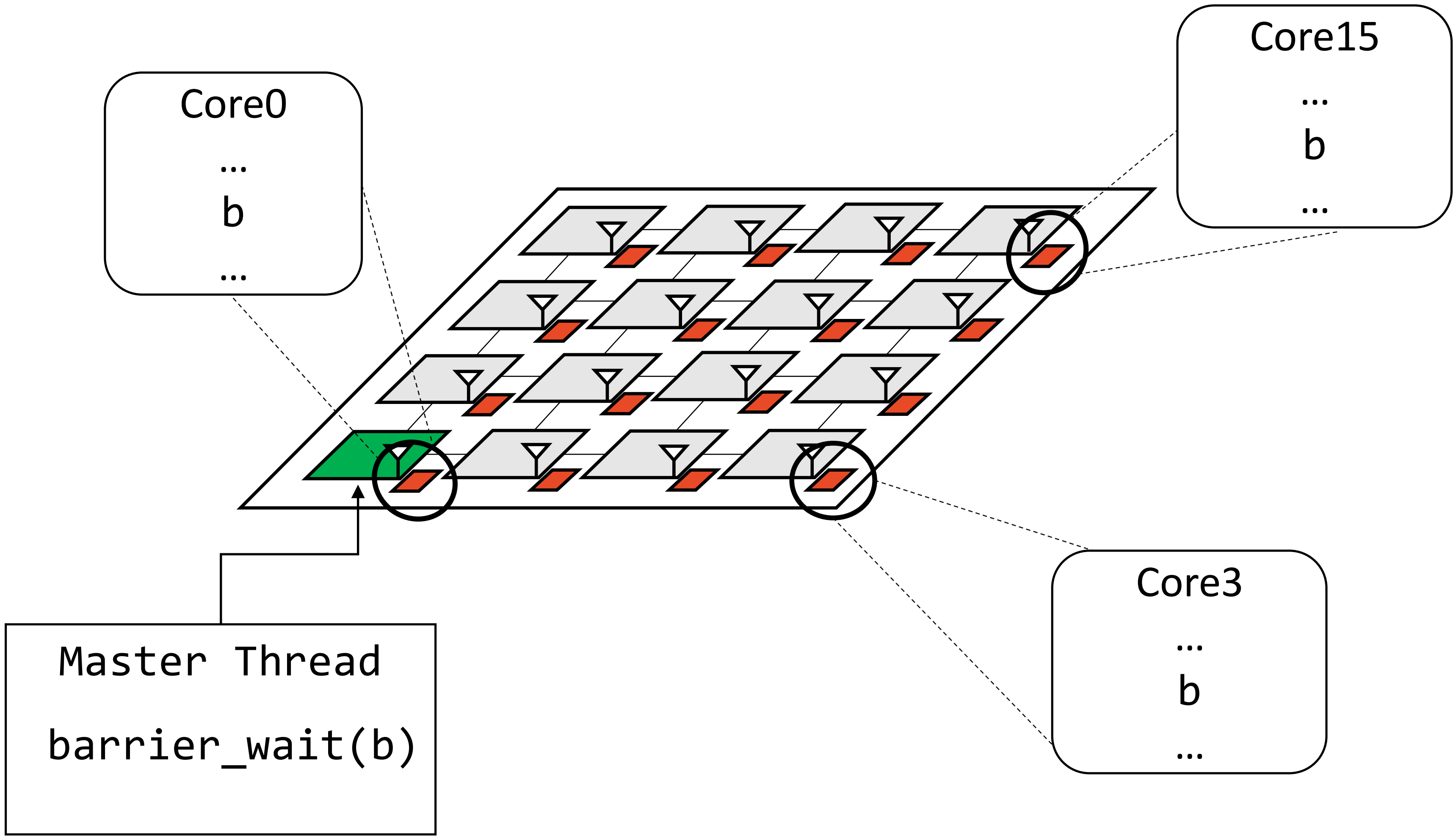

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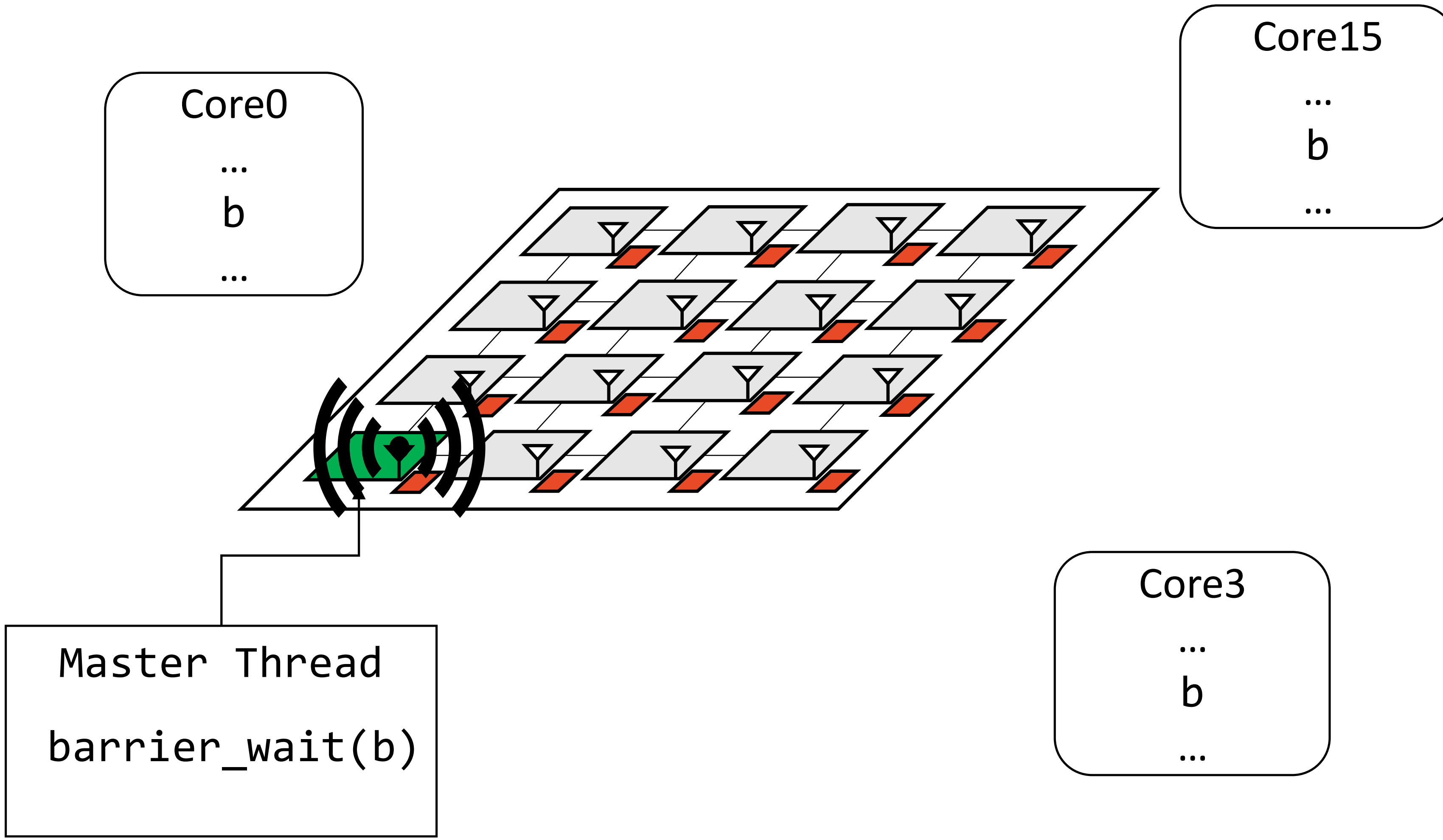
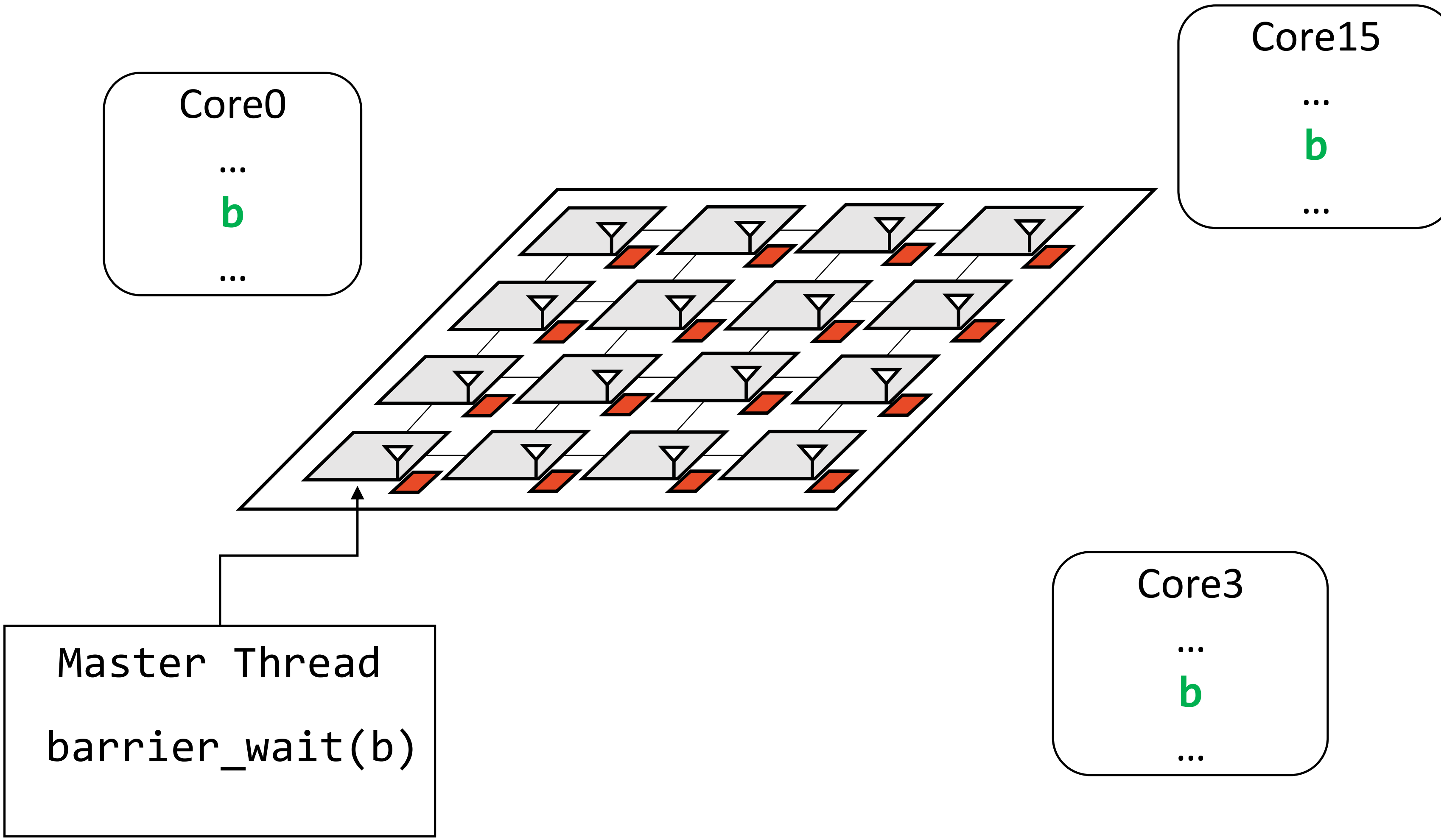
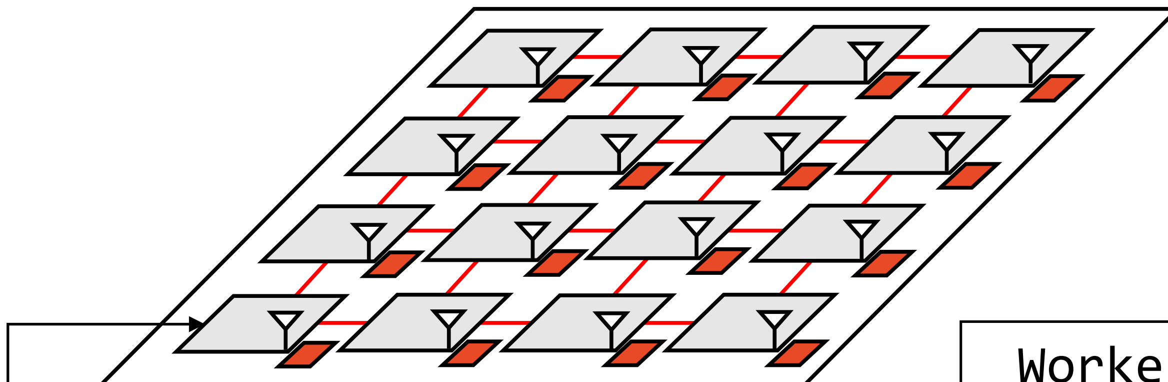


WiSync: On-chip Wireless Communication for Synchronization



In WiSync, ordinary data uses the wired network



Master Thread

```
counter++;
```

Worker Threads

```
x = counter;
```

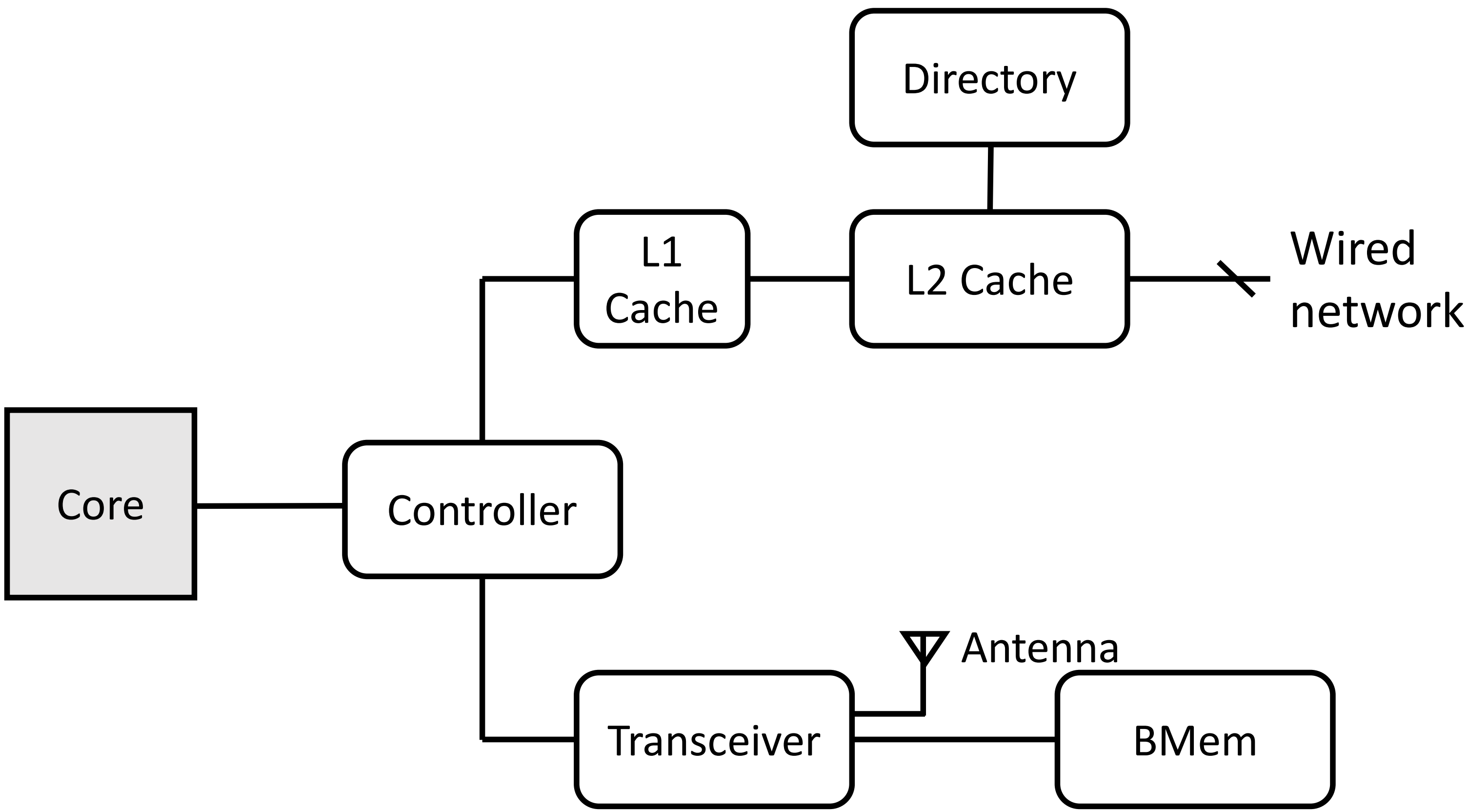
Key Question

Can we leverage wireless communication to speed-up transfers of ordinary shared data?

Contributions: Replica

- A manycore architecture and software interface for wireless communication (sync and ordinary data)
- Hardware innovations
  - Adaptive wireless protocol
  - Selective packet dropping
- Software innovations
  - Transformations and tools to adapt applications to wireless
  - Optimizations for approximate computing
- For 64 core execution: speedup applications by 1.89x over a conventional multicore

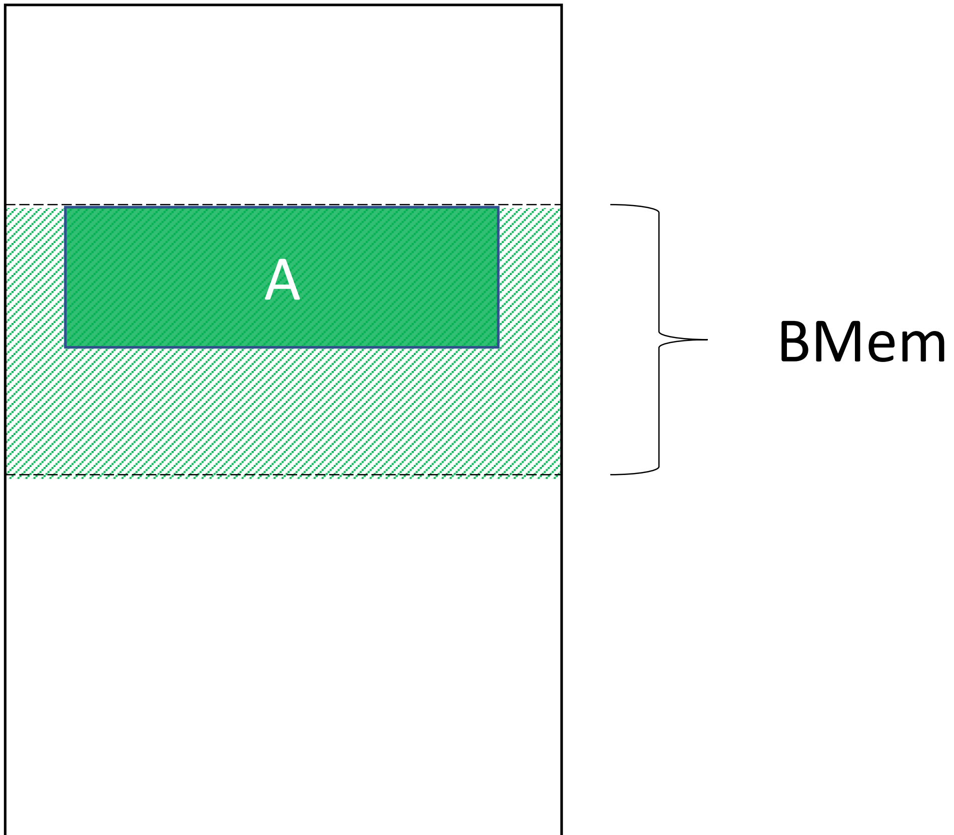
Replica Architecture



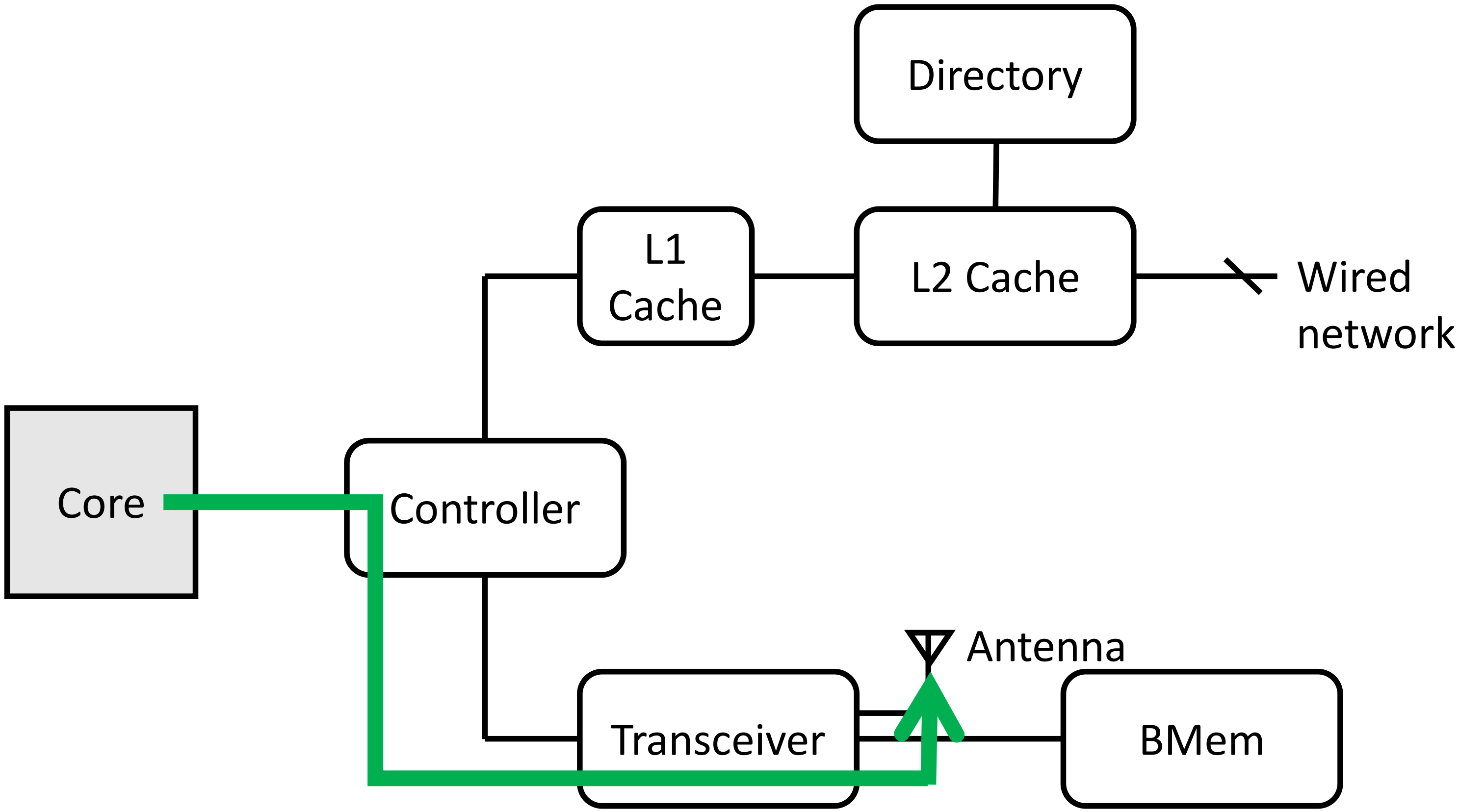
32-512 KB

Example

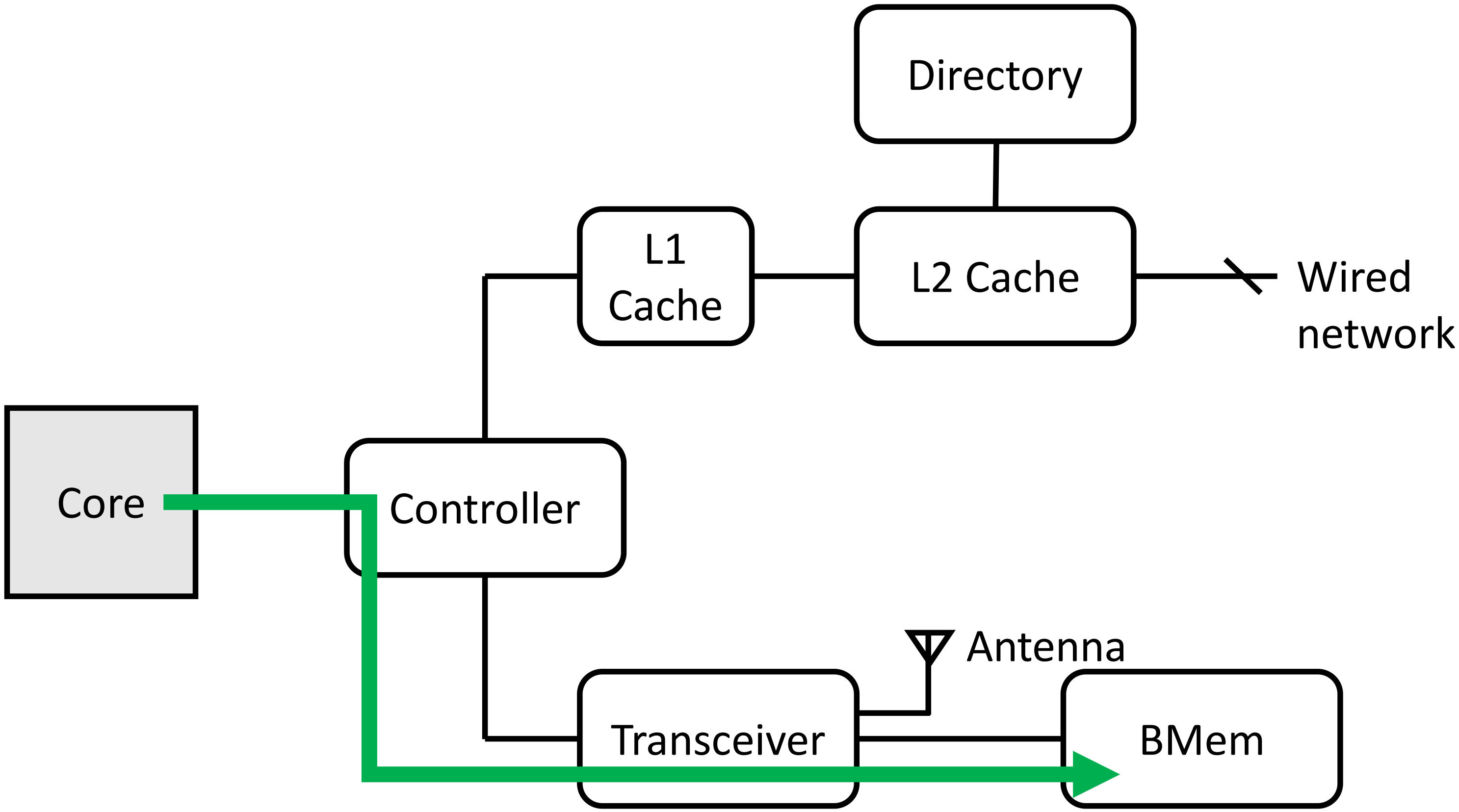
```
int* A = (int*) wireless_malloc(size)
```



Write

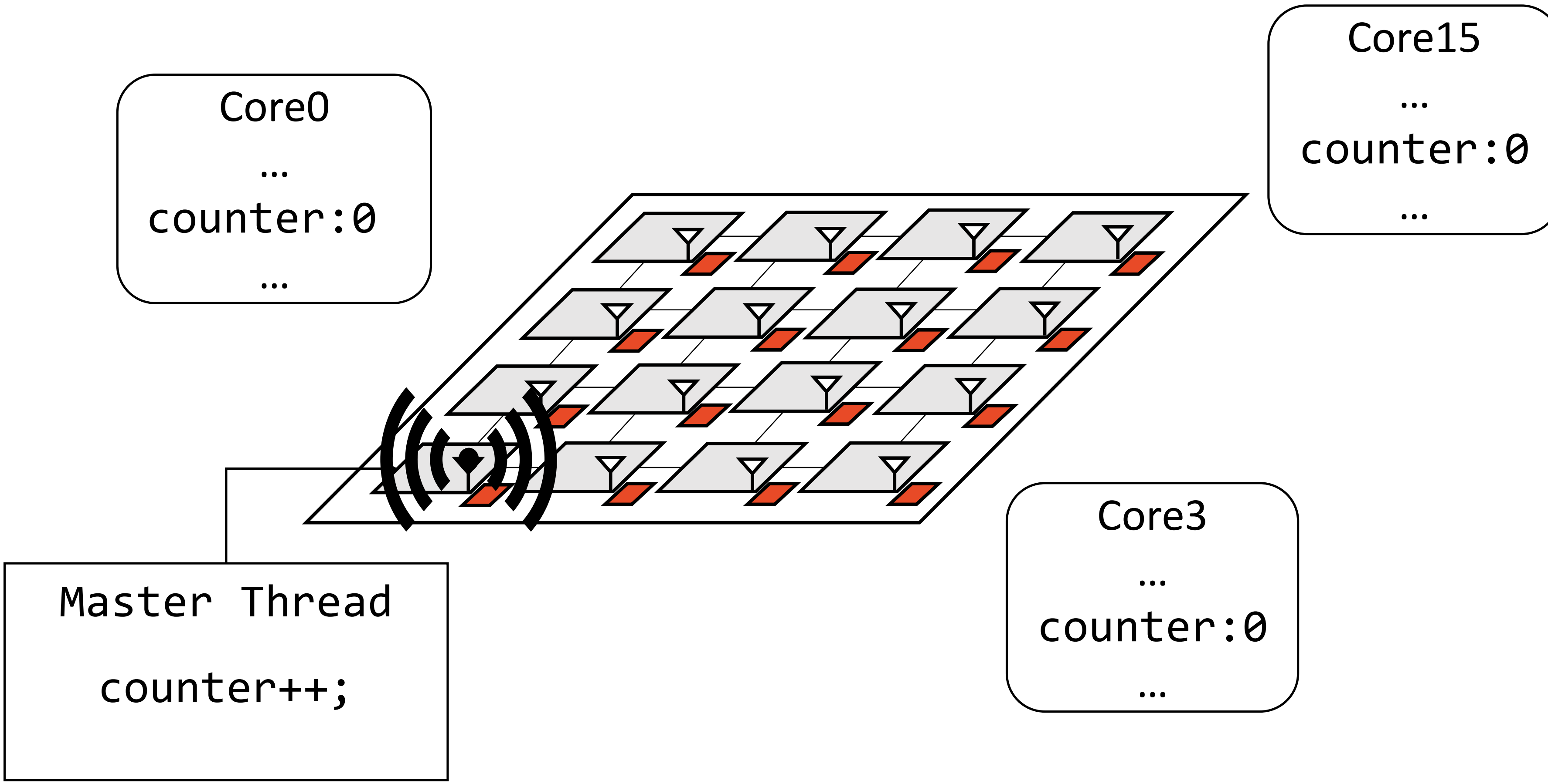

Directory
L1
Cache
L2 Cache
Wired
network
Core
Controller
Antenna
Transceiver
BMem

Write



Atomic update of local and all remote BMems

Broadcast Memory for ordinary data



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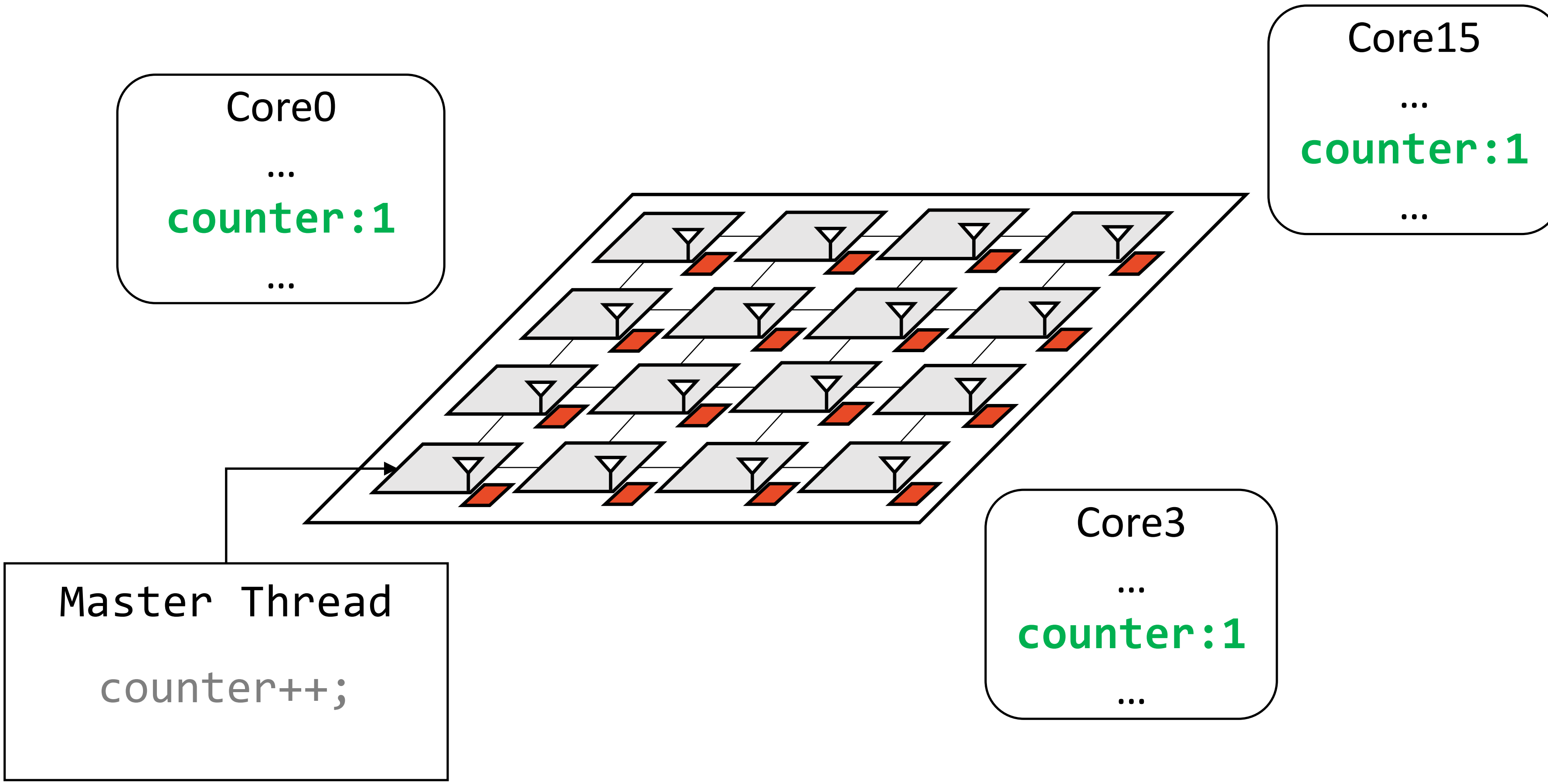
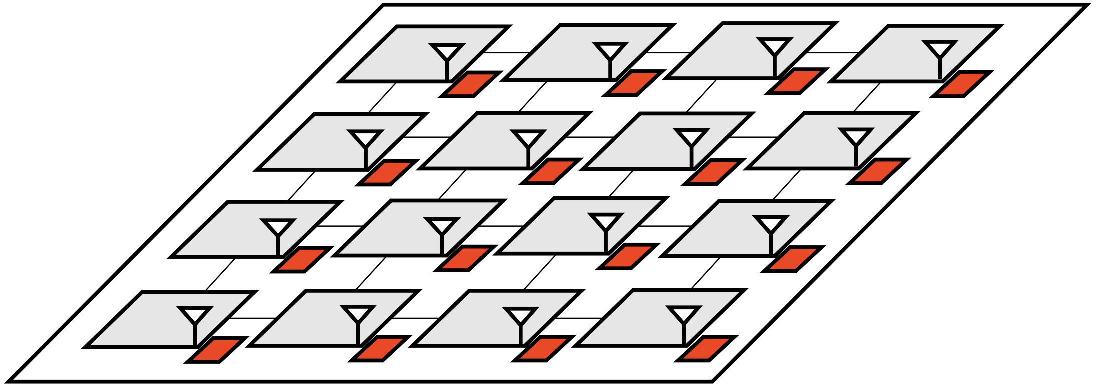
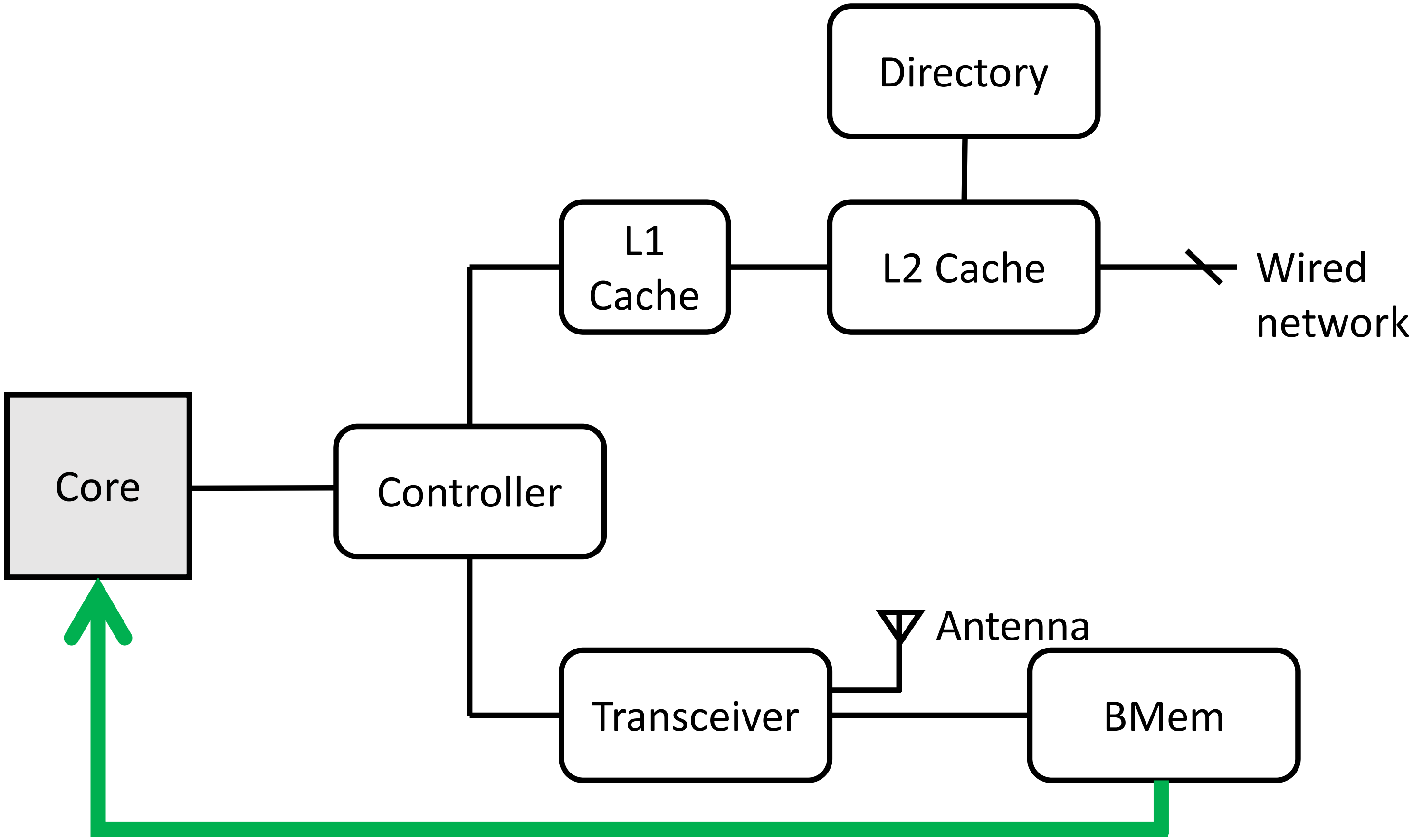


Replica: Wireless channel

- One channel shared by all the cores
- Everyone receives what one core transmits
- Only one core can transmit at a given time
  - ensures the same order of updates across all BMems



Reads



Read: Local access

Challenges

- Limited wireless bandwidth: Only one core can transmit at a time

- Bounded size of the BMem: Arbitrary data structures will not fit

Solutions

- Limited wireless bandwidth: Only one core can transmit at a time
  - Adaptive wireless protocol
  - Selective message dropping
  - Approximate transformations to use less bandwidth
- Bounded size of the BMem: Arbitrary data structures will not fit

Solutions

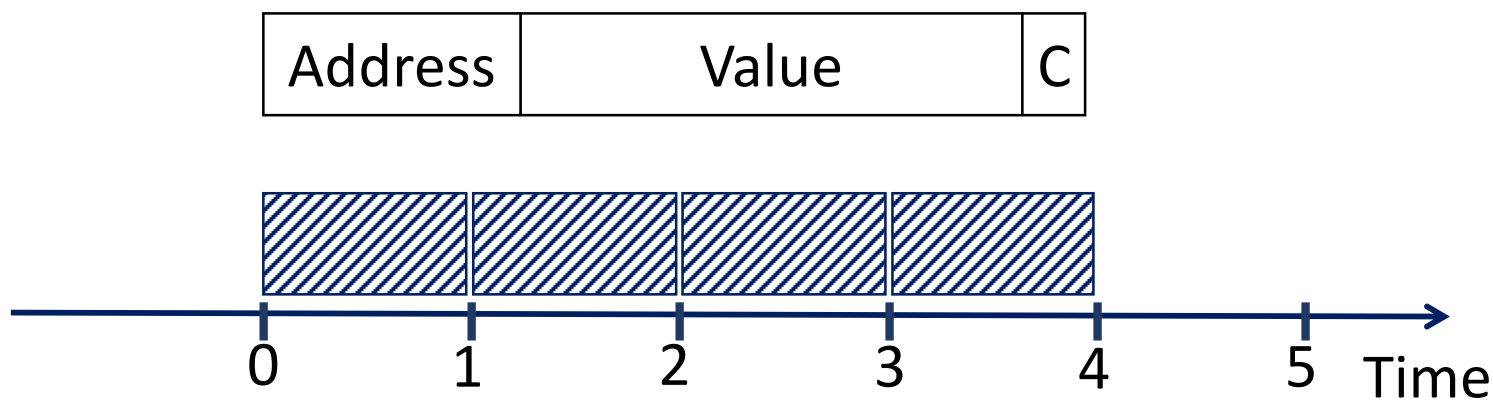
- Limited wireless bandwidth: Only one core can transmit at a time
    - Adaptive wireless protocol
    - Selective message dropping
    - Approximate transformations to use less bandwidth

- Bounded size of the BMem: Arbitrary data structures will not fit
    - Software transformations to fit most important structures in BMem
    - Approximate transformations to use BMem effectively
    - Tools to identify/autotune highly-shared data structures

Wireless Protocol

- Wireless protocol organizes the accesses to the wireless network
- Two wireless protocols can be used based on application behavior
  - Broadcast Reliability Sensing protocol (BRS)
  - Token Ring protocol

Wireless Message

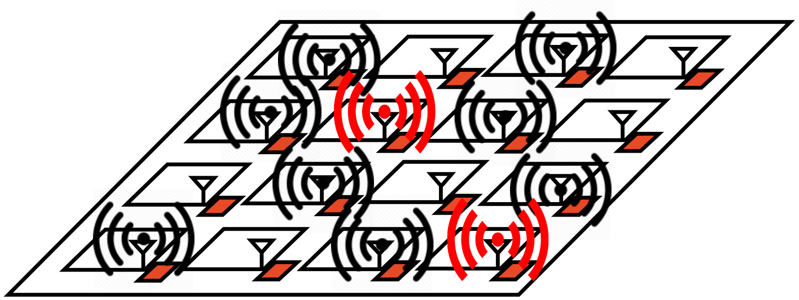


4 cycles at 20Gb/s*

* Yu, et al. “Architecture and Design of Mul5-Channel Millimeter-Wave Wireless Network-on-Chip,” IEEE Design & Test, 2014 (scaled)

Broadcast **R**eliability **S**ensing Protocol (BRS)

- Start sending message if the medium is free
- Two cores starting at the same time results in a collision



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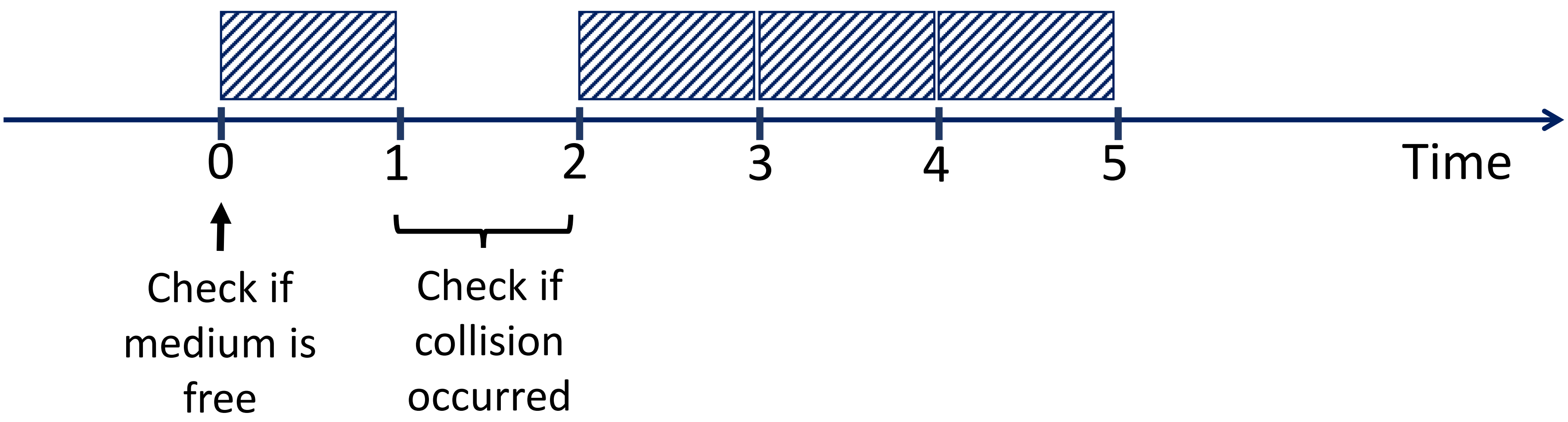

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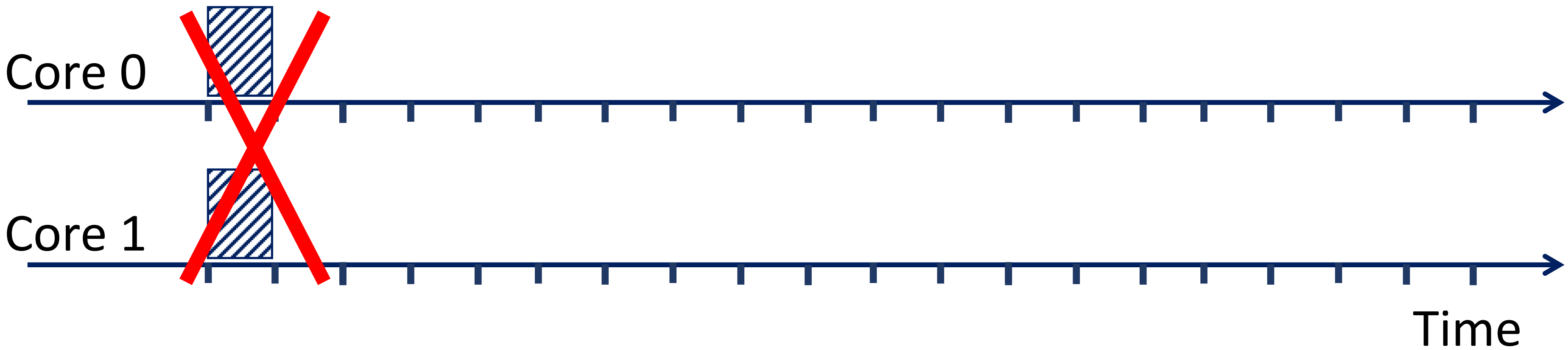

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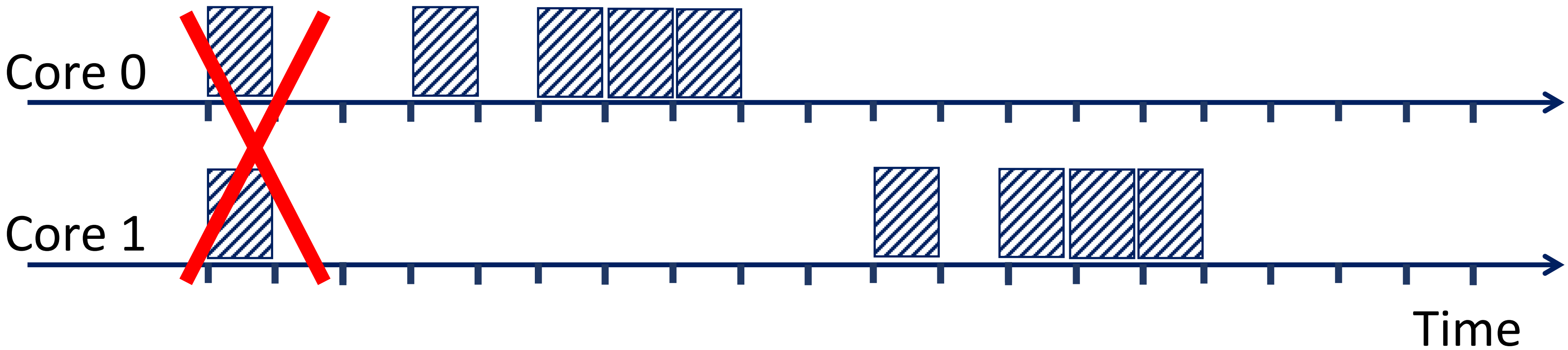
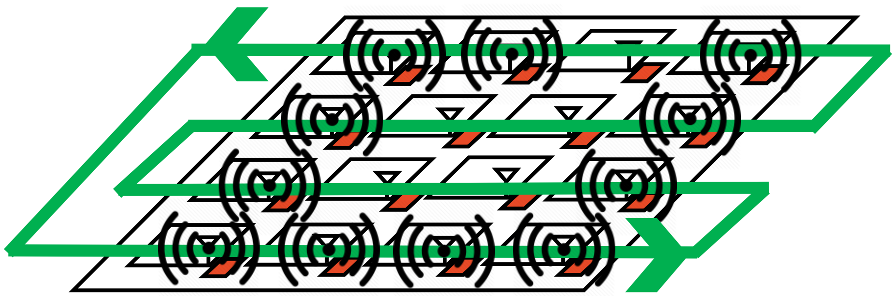


\+ No wasted cycles if low contention

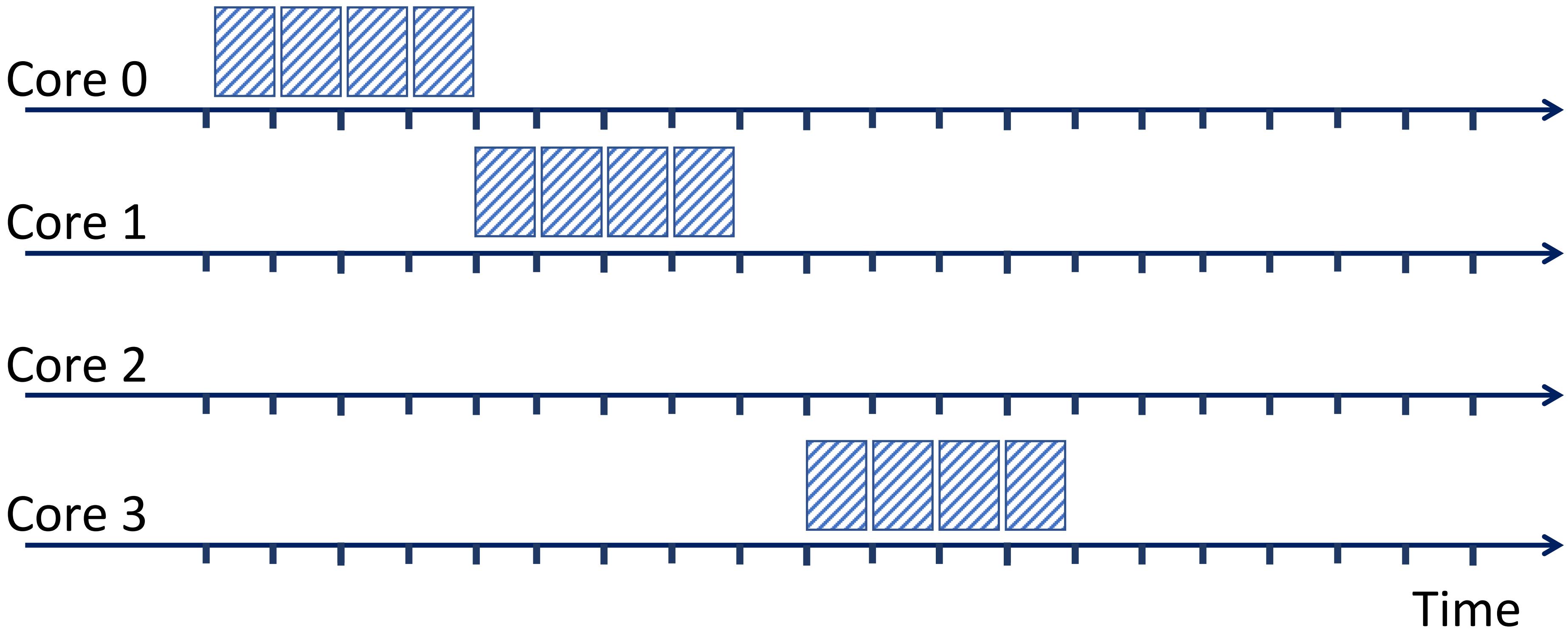
\- Lot of collisions if high contention

Token Ring Protocol

- Pass conceptual token among cores
- Can send wireless message only if the core *owns* the token



Token Ring Protocol



+ No wasted cycles if high contention

− Unnecessary delays if low contention

Adaptive Wireless Protocol

- In Replica, the utilization of the wireless network vary across applications and within an application
  - Sparse traffic – BRS
  - Bursty traffic – Token Ring

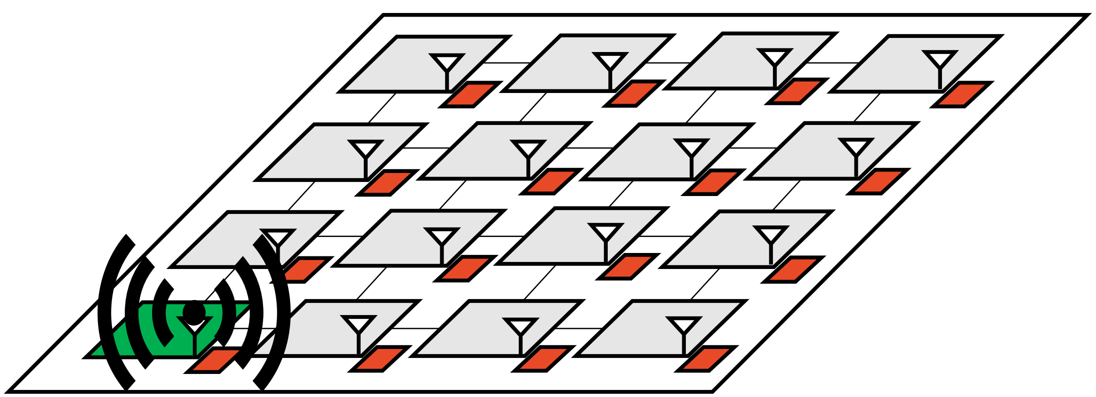
- Replica uses an adaptive dynamic protocol that switches between the two by observing communication behavior
  - Number of collisions
  - Number of skipped token slots

Approximate transformations to use less bandwidth

- Every write to data in the BMem results in a message being broadcasted
- We can reduce the pressure on the network by skipping some of the writes
  - Reducing communication at the cost of accuracy
- Many programs have shared data structures that are amenable to approximations

Opportunity in Replica: Dropping Messages

- All cores see the contention in the wireless network
- Can drop messages while maintaining the same state across all cores

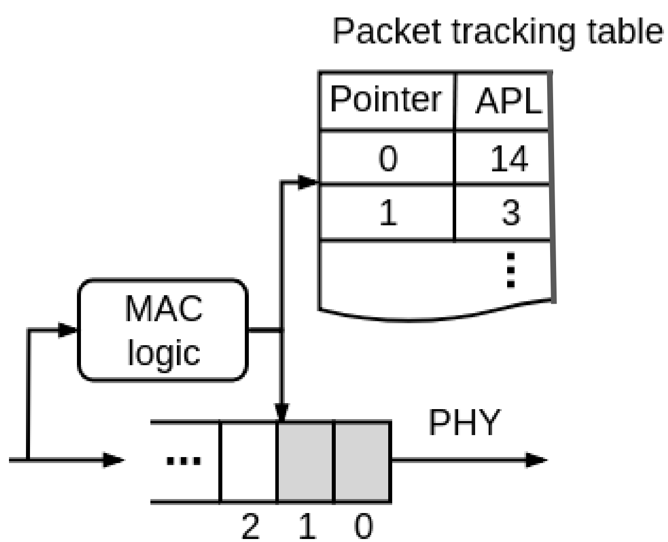


Approximate stores

- Developers indicate approximable data structures

  `approx_wireless_malloc(size)`

- Stores to approximable variables are dropped if they cannot access the wireless network before a given threshold



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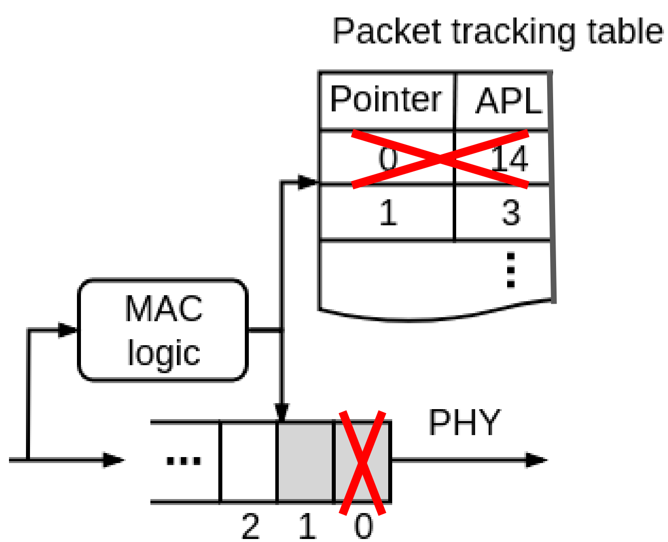


Approximate transformations to use less bandwidth

- We used the approximate stores to implement primitives such as Approximate Locks
  - Spin lock that gives up trying to acquire a lock after some time

- Existing approximate techniques that reduce communication more useful in this resource constrained setting
  - Example: Skipping negligible updates to shared data

Addressing Bounded size of the BMem

- Software transformations to fit most important structures in BMem
- Approximate transformations to use BMem effectively
  - Example: Numerical precision reduction, Cyclic collection update
- Tools to identify highly-shared data and tune the application

See the paper for more details

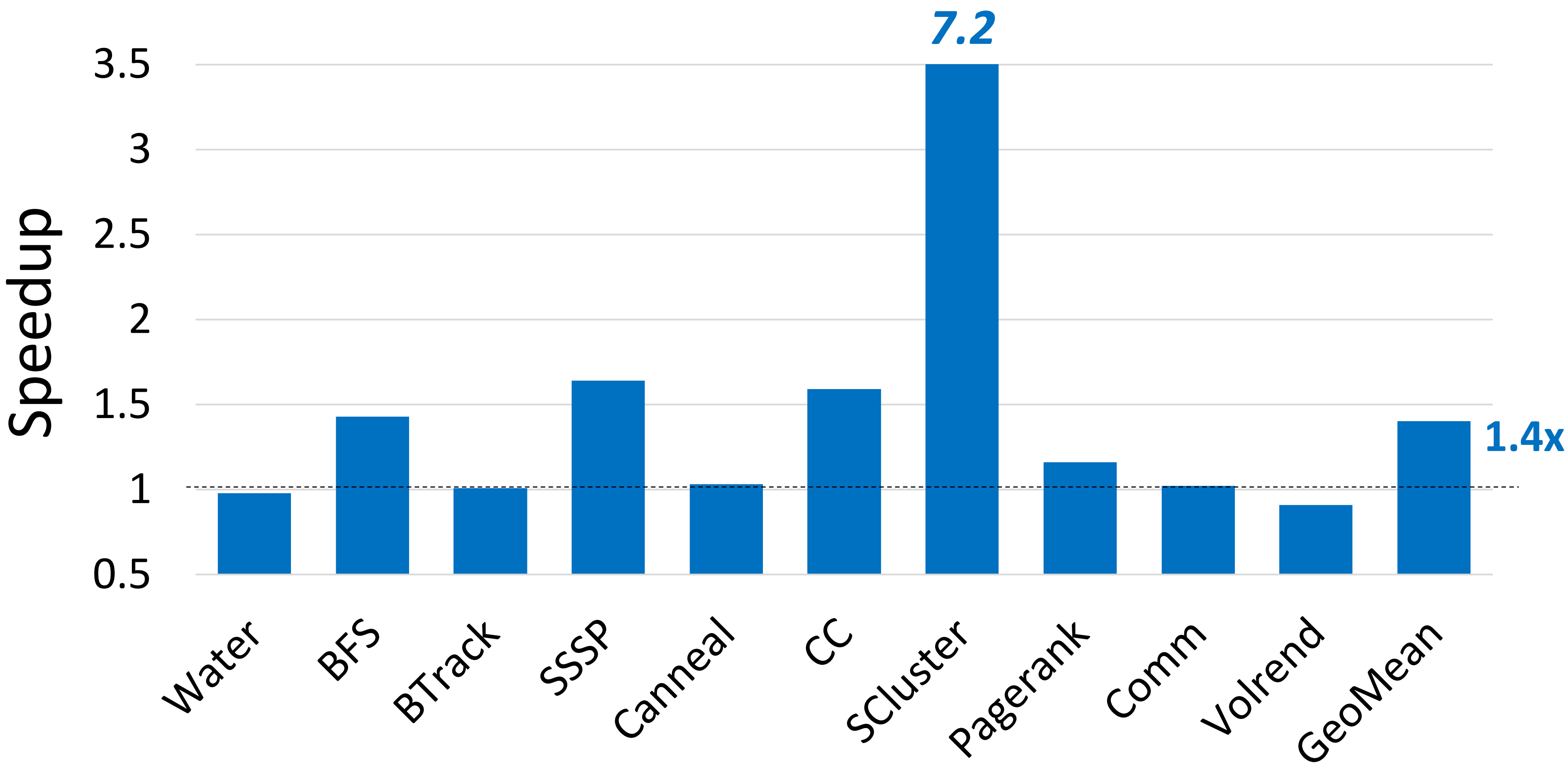
Evaluation

- Cycle-level architectural simulations using Multi2sim
  - 64 core chip
  - 32-512 KB BMem
  - 2D Mesh wired network
- Applications
  - 10 benchmarks from PARSEC and CRONO
  - Multiple domain: Scientific simulations, computer vision, and graph applications

Benchmarks: Communication Patterns

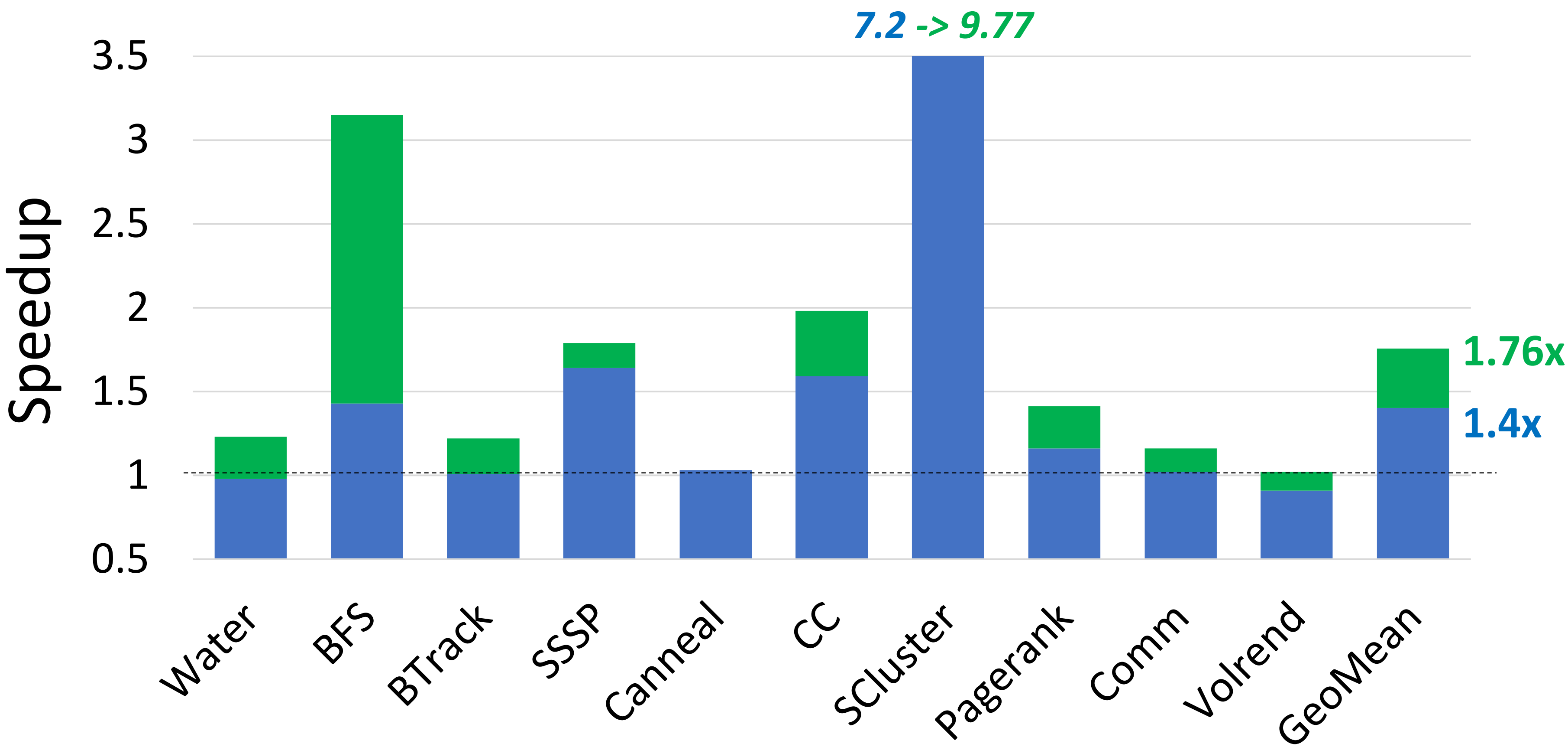
Benchmark	Sharing Pattern
Water	Broadcast
BFS	Irregular: many-to-many
Bodytrack	One-to-many
SSSP	Irregular: many-to-many
Canneal	Irregular
CC	Irregular: many-to-many
Streamcluster	One-to-many, reduction
Pagerank	Irregular: many-to-many
Community	Irregular: many-to-many
Volrend	One-to-many

BMem for sync variables (WiSync)



1.4x speed up over conventional wired multicore (Geometric Mean)

BMem for shared data

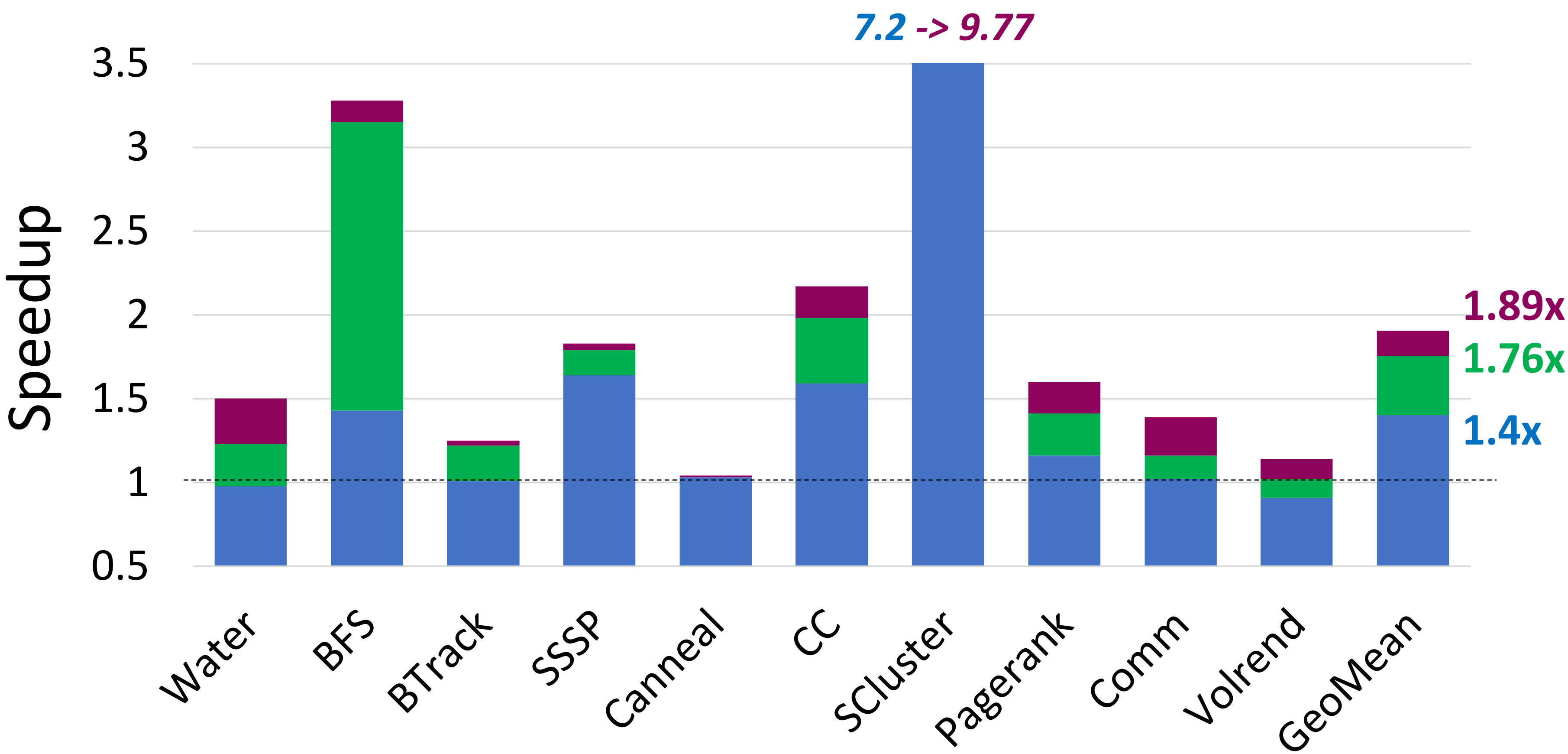


1.76x speed up (Geometric Mean)

Benchmarks: Approximation

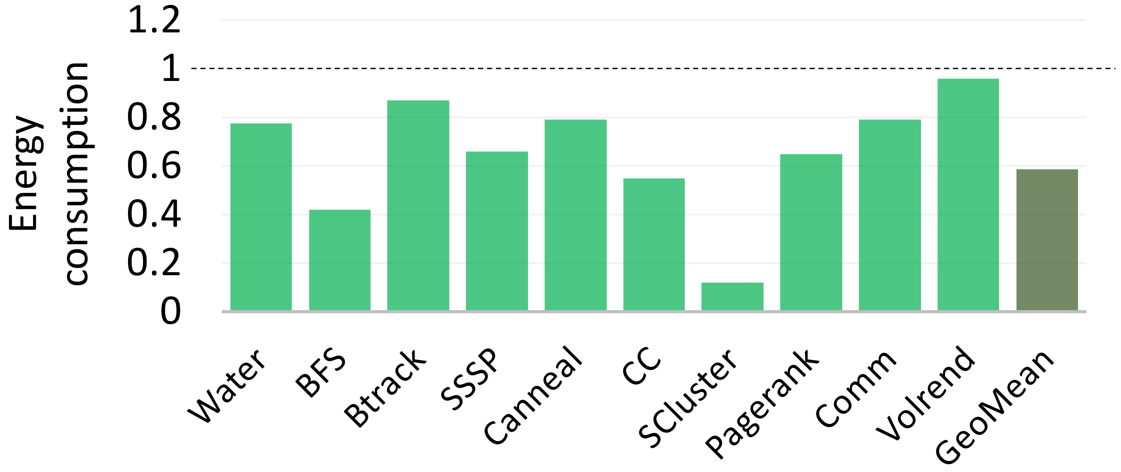
Benchmark	**Sharing Pattern**	**Approximations**
Water	Broadcast	Precision reduction and Approximate Locks
BFS	Irregular: many-to-many	Approximate Stores
Bodytrack	One-to-many	Approximate Stores
SSSP	Irregular: many-to-many	Approximate Stores
Canneal	Irregular	Approximate Locks
CC	Irregular: many-to-many	Approximate Stores
Streamcluster	One-to-many, reduction	Cyclic collection updates
Pagerank	Irregular: many-to-many	Skipping negligible updates
Community	Irregular: many-to-many	Approximate Stores
Volrend	One-to-many	Approximate Stores

BMem for shared data + approximations



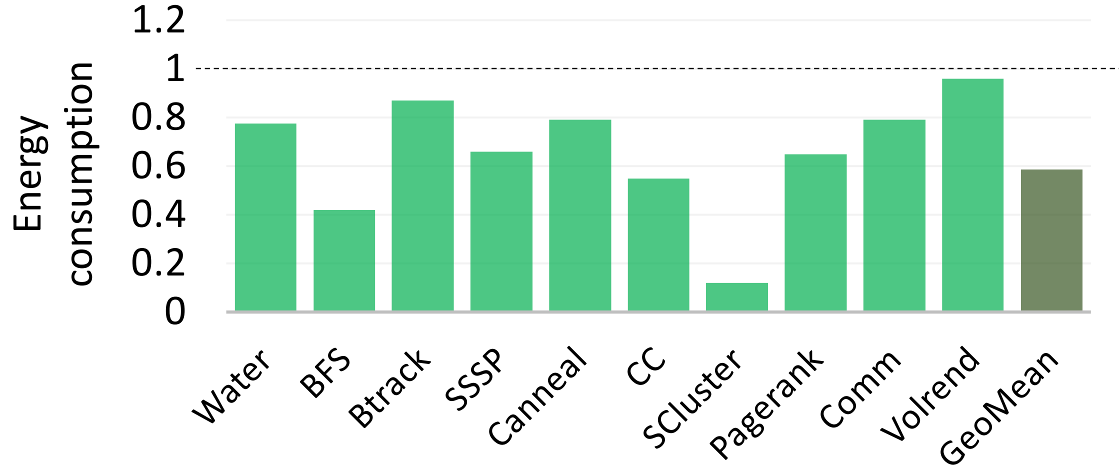
On average 1.89x speed up

Energy and area



- Since faster execution: 33% energy reduction
- Replica components: 9% of total energy consumed

Energy and area



- Since faster execution: 33% energy reduction
- Replica components: 9% of total energy consumed

- 15% increase in the area
  - 11% from the BMem + 4% from the transceiver/antenna
  - Using the same area to increase the L2 cache has little impact on performance (1.04x speedup)

Also in the paper

- Scalability analysis
- Power evaluation
- Area consumption
- Architecture sensitivity analysis
- Effectiveness of profiler and autotuner
- Statistics on developer effort to adapt programs

Conclusions

- Replica: a manycore that uses a wireless NoC to communicate ordinary data
- Hardware and Software innovations
  - Adaptive wireless protocol
  - Selective packet dropping
  - Software techniques to identify and allocate shared data in BMem
  - Software transformations for approximate computing
- Effectively supports communication-intensive computations
- Average speedup of 1.89x over conventional machines