Mixer

Efficient Many-to-All Broadcast in Dynamic Wireless Mesh Networks

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Why Many-to-All Communication?

Why Many-to-All

universal:

- can serve any possible traffic pattern (one-to-one, one-to-many, all-to-all, etc.)

fundamental for a growing number of emerging applications and services:

- coordination and distributed control in Cyber-Physical Systems
  - factory automation
  - collaborative agents, drone swarms
  - (I)IoT edge
- programming abstractions (based on data replication)
- fault tolerance mechanisms (based on state replication)
- over-the-air programming / updates, ...

Source: U.S.DOT

Requirements for Many-to-All

- fast (10…500 ms end-to-end)
- reliable
- support for dynamic mesh topologies
- support for adequate message sizes (tens of bytes)
- energy efficient (weight, cost)

[1] Akerberg et al., Future research challenges in wireless sensor and actuator networks targeting industrial automation, IEEE INDIN 2011

Current Solutions

- Multi-Sink Routing [1]:
  - degenerates under high network dynamics
- Sequential Flooding (S-Glossy) [2]:
  - suboptimal scaling $O(M \cdot T)$
- Pipelined Flooding [3]:
  - not universal (only one-to-all)
  - infeasible under high network dynamics

[1] e.g. Mottola et al., MUSTER: Adaptive Energy-Aware Multisink Routing in Wireless Sensor Networks, IEEE Transactions on Mobile Computing 2011
[2] e.g. Ferrari et al., Efficient network flooding and time synchronization with Glossy, ACM/IEEE IPSN 2011
[3] e.g. Du et al., When Pipelines Meet Fountain: Fast Data Dissemination in Wireless Sensor Networks, ACM SenSys 2015

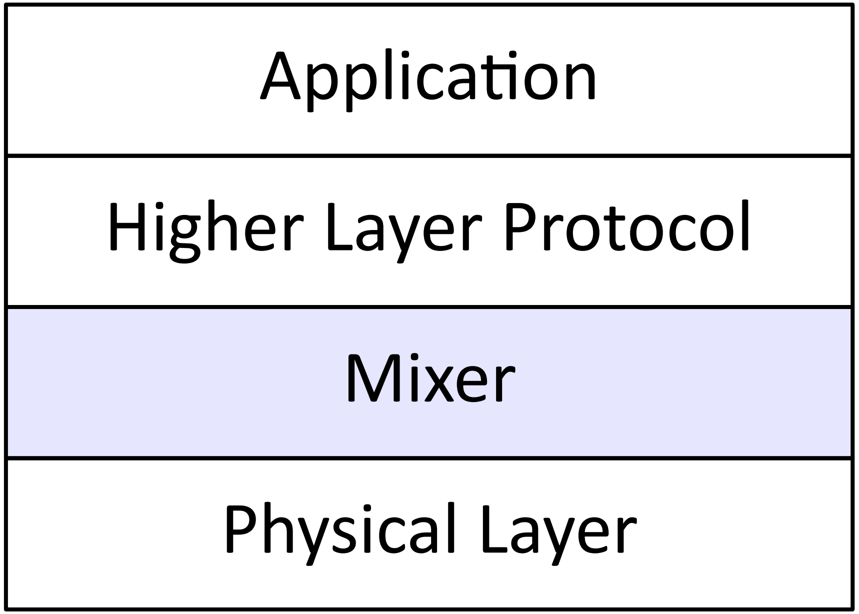
Our Contribution

Mixer, a new many-to-all broadcast primitive for dynamic wireless mesh networks

- significantly outperforms prior many-to-all solutions, approaches order-optimal scaling O(M + T)
- provides nearly perfect reliability despite significant network dynamics
- supports the full spectrum from one-to-all to all-to-all communication

Our Contribution

Mixer, a new many-to-all broadcast primitive for dynamic wireless mesh networks



Application

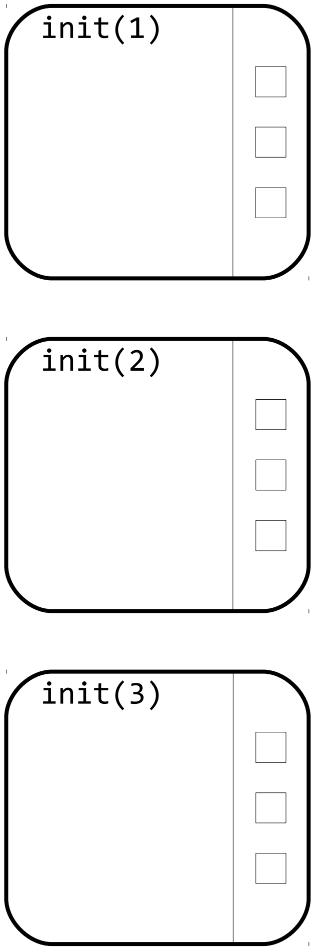
Higher Layer Protocol

Mixer

Physical Layer

Our Contribution

```
mixer_init(node_id)
mixer_write(index, *msg, size)
mixer_arm(mode)
mixer_start()
mixer_read(index)
```



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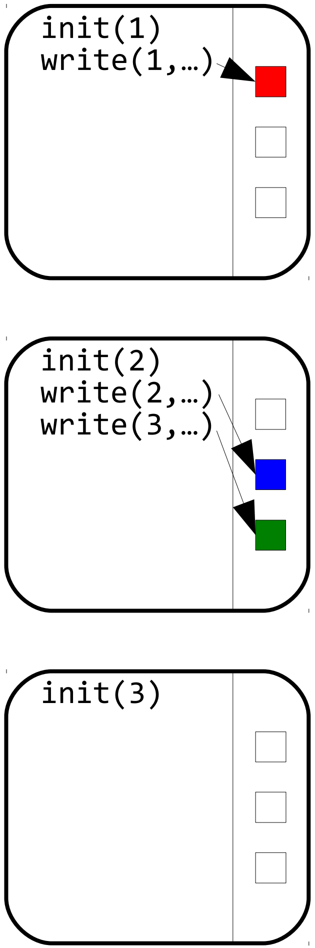

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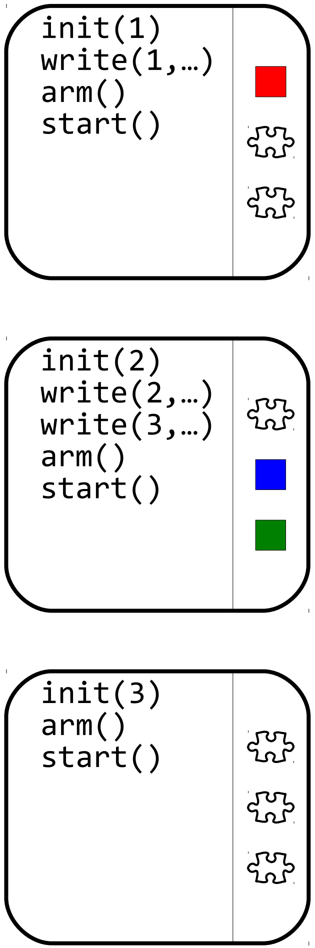

```
init(1)
write(1,…)
arm()
start()
```

```
init(2)
write(2,…)
write(3,…)
arm()
start()
```

```
init(3)
arm()
start()
```

Our Contribution

```
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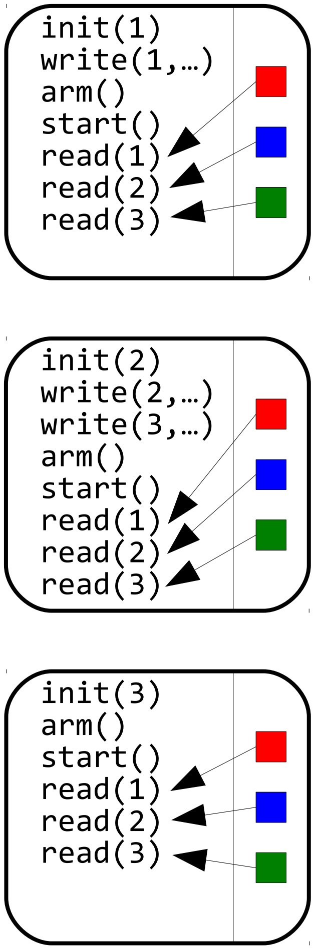

```
init(1)
write(1,…)
arm()
start()
read(1)
read(2)
read(3)
```

```
init(2)
write(2,…)
write(3,…)
arm()
start()
read(1)
read(2)
read(3)
```

```
init(3)
arm()
start()
read(1)
read(2)
read(3)
```

Ingredients of Mixer

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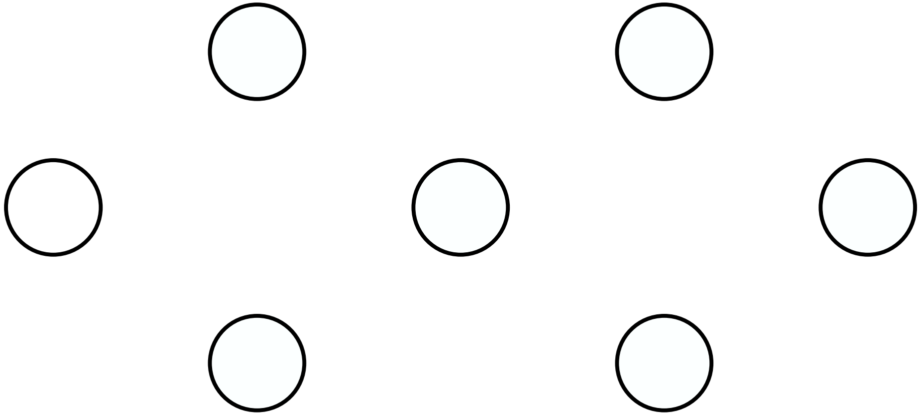
Key Concepts

- Random Linear Network Coding (RLNC)
  → overlay floods
- Synchronous Transmissions
  → enable capture and spatial reuse

Linear Network Coding

task: disseminate 3 messages	Sequential Flooding (S-Glossy)	Linear Network Coding (example)
slot 1	`1 0 0 | 21`	`1 0 0 | 21`
...	`1 0 0 | 21`	`1 1 0 | 43`
	`0 1 0 | 22`	`0 1 1 | 45`
	`0 1 0 | 22`	`0 0 1 | 23`
...	`0 0 1 | 23`	-
slot 6	`0 0 1 | 23`	-
robustness	1 packet	1 packet
cost	6 slots	4 slots + computations

Sequential Flooding



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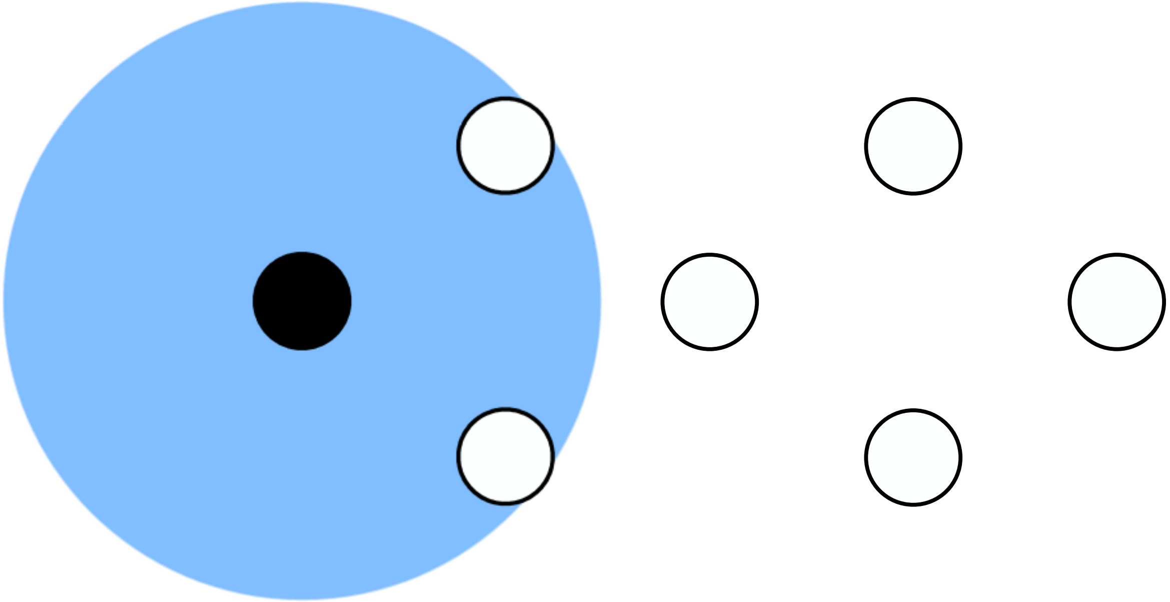

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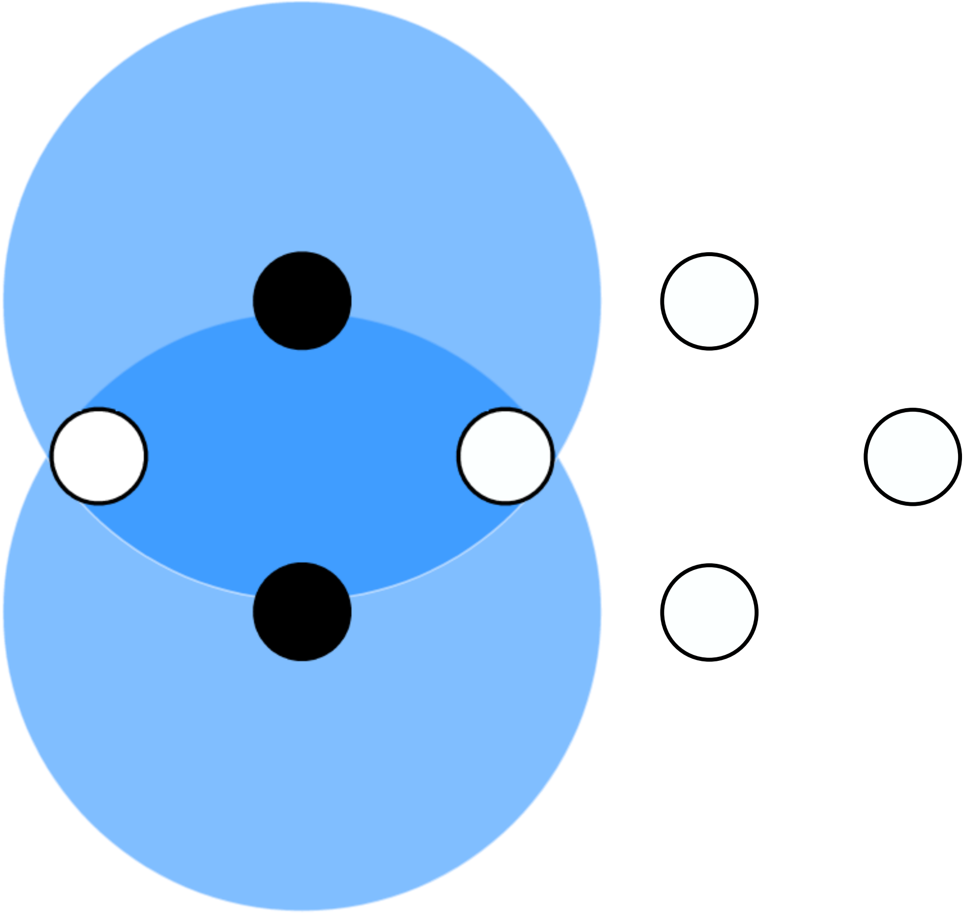

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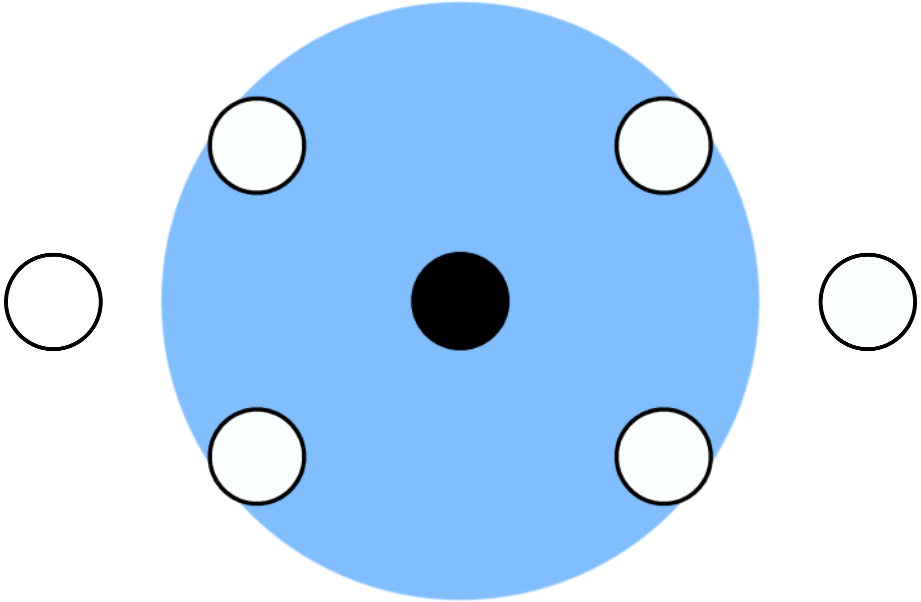

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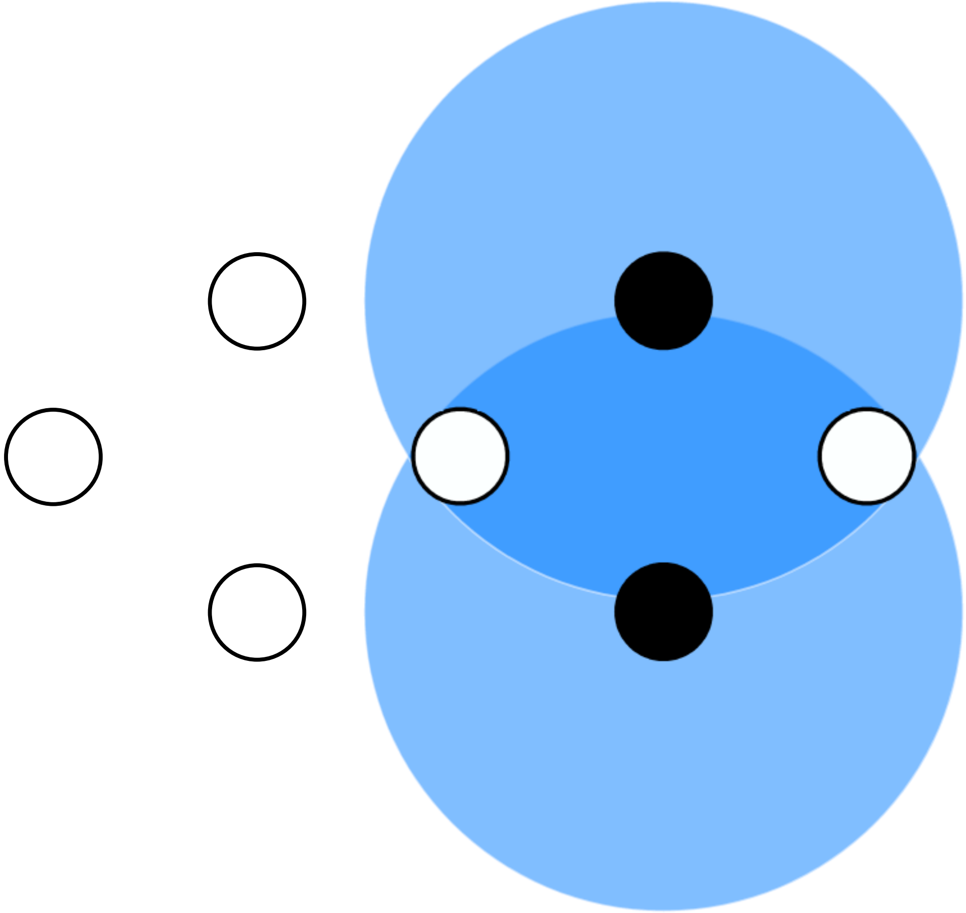

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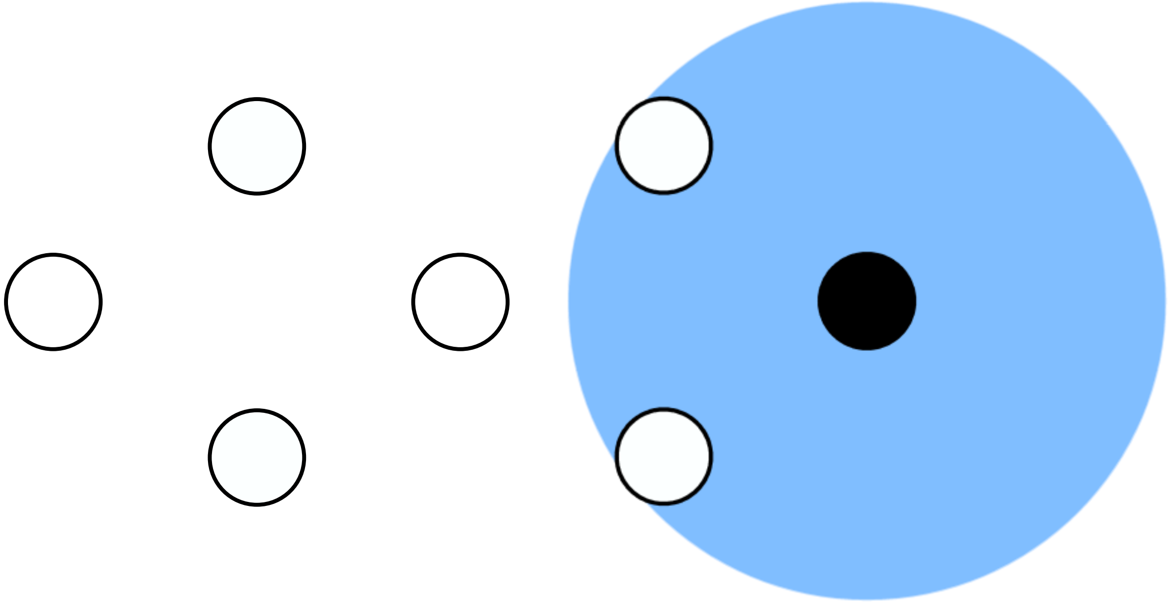

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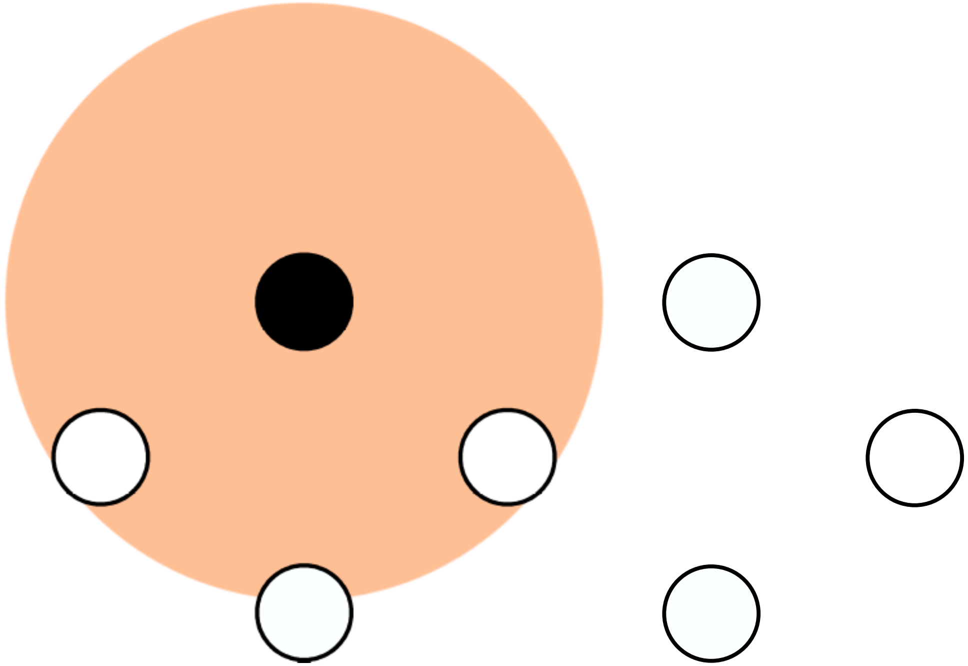

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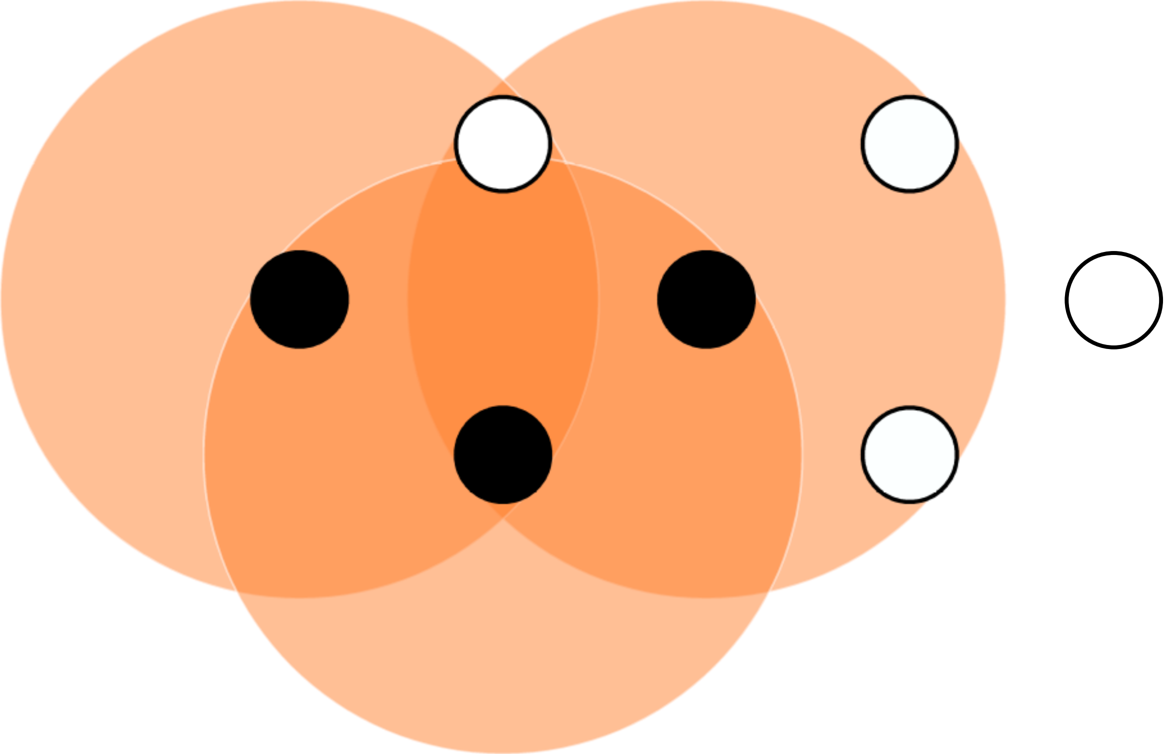

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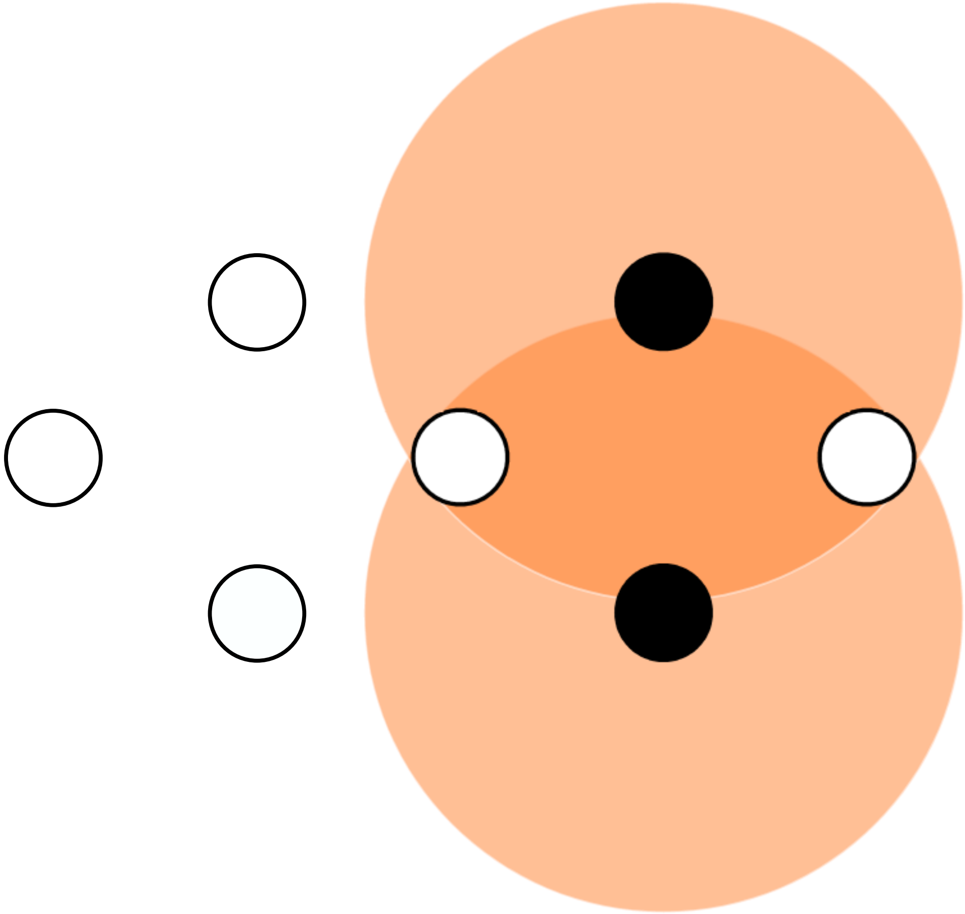

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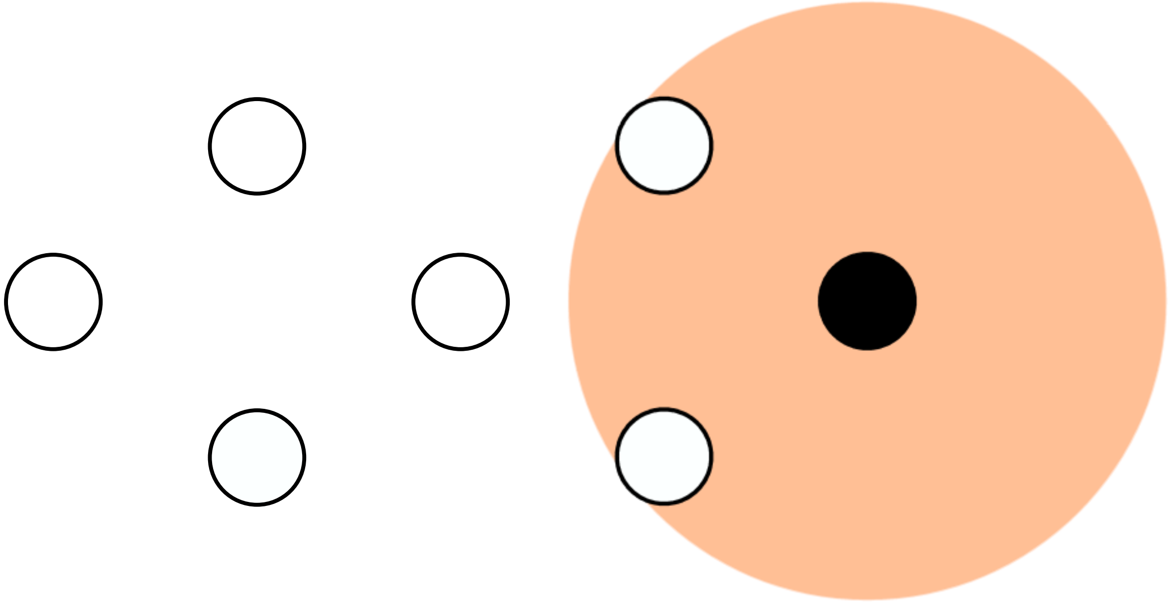
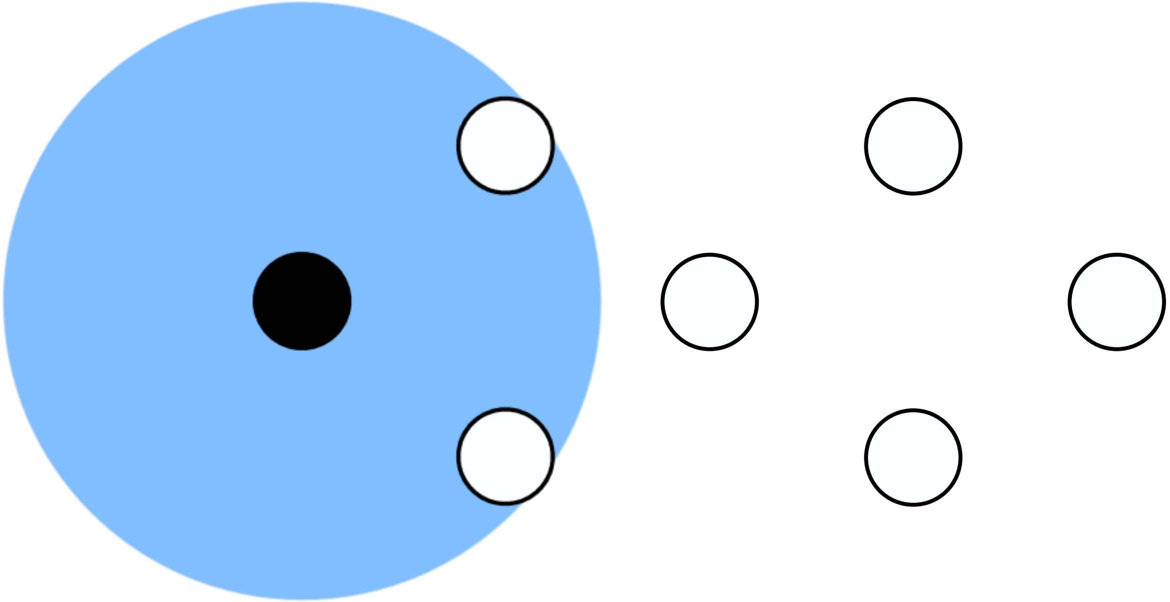


Mixer



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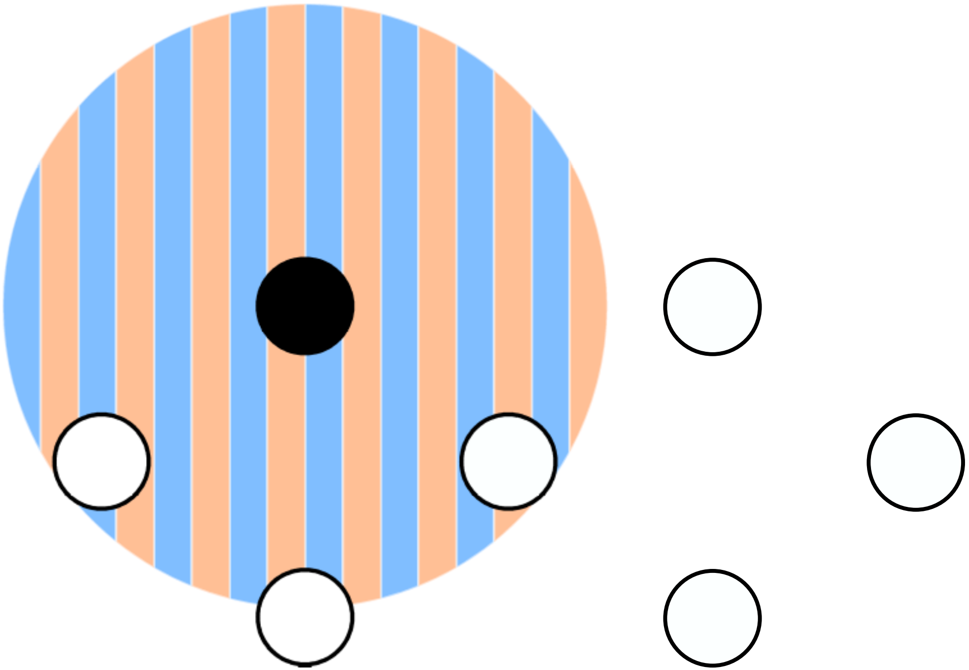

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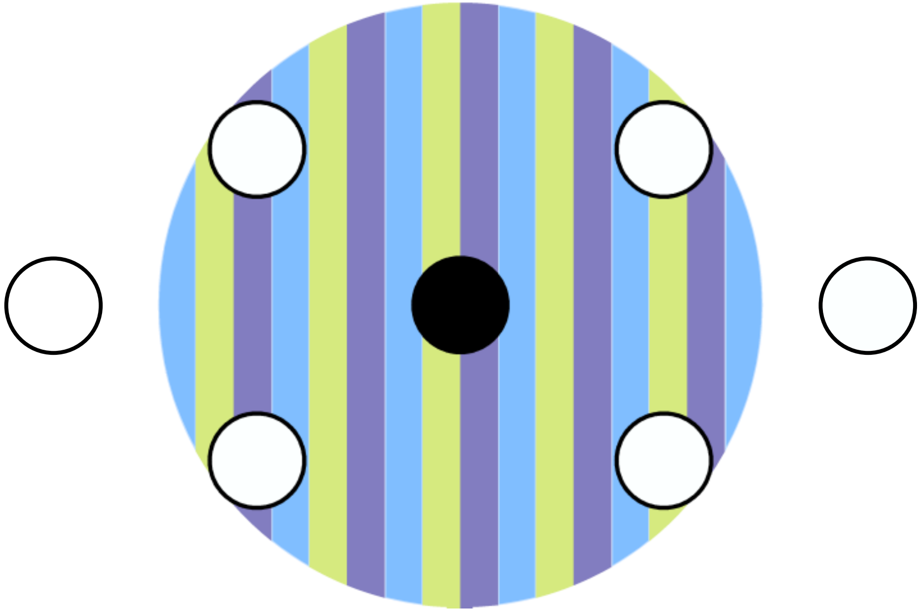

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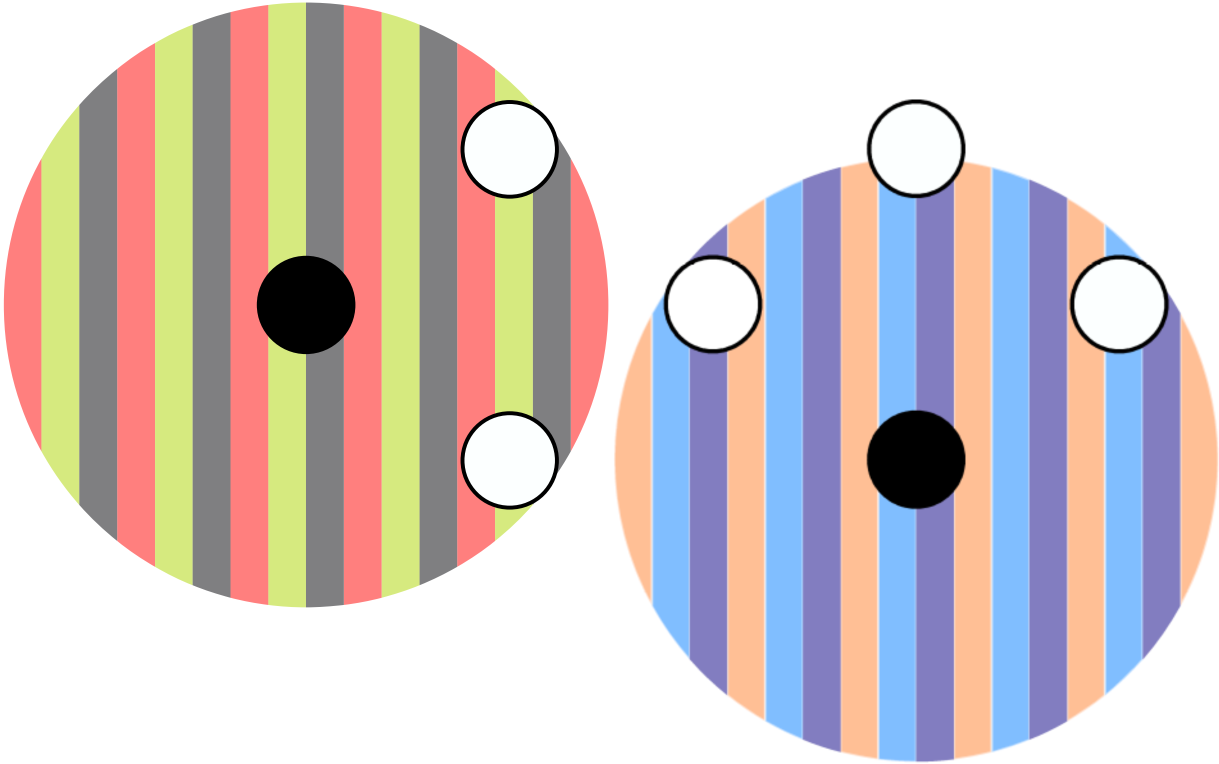

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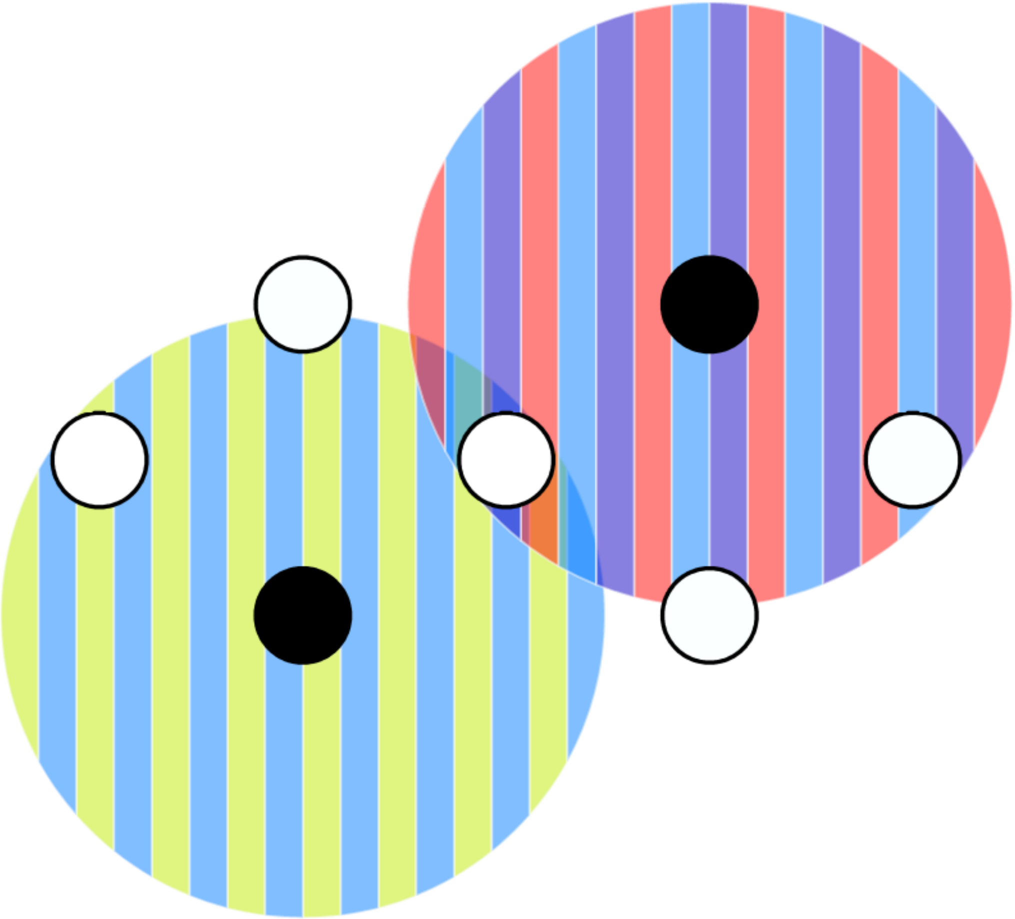


Ingredients of Mixer

Key Concepts

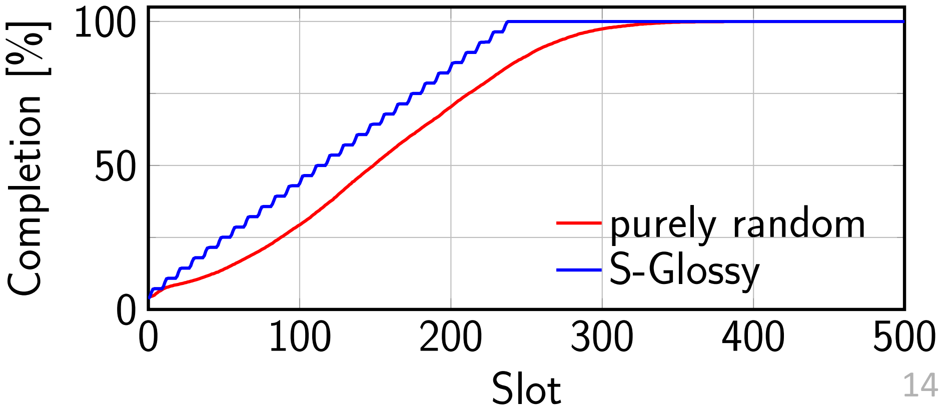
- Random Linear Network Coding (RLNC) → overlay floods
- Synchronous Transmissions → enable capture and spatial reuse

Challenges

- When should a node send or listen?
- What should a node send (combine)?

Efficient Architecture

- transport layer with sideload feature
- deliberate scheduling of (matrix) operations



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Efficient Architecture

- transport layer with sideload feature
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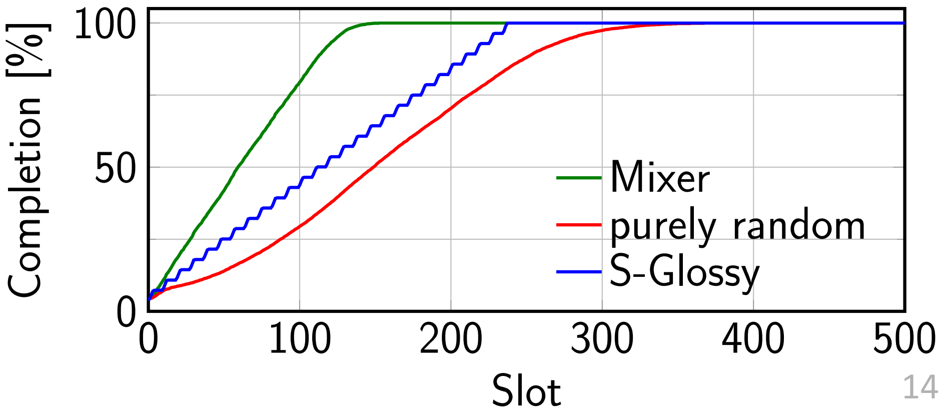
Smart Policies / Features ("Spices")

- Semi-Coordinated Transmissions
- Explicit Innovation Forwarding
- Knowledge-based Startup Behavior
- Active Requests
- Smart Shutdown



Mixer in Action

…

Evaluation

Setup

- implementation on TelosB
  - MSP430, 4 MHz, 10KB RAM, IEEE 802.15.4
  - ARM port is in progress…
- extensive tests on
  - FlockLab (ETH Zürich, 27 nodes, 4 hops)
  - Indriya (NU Singapore, 94 nodes, 8 hops)

Experiments

Reliability

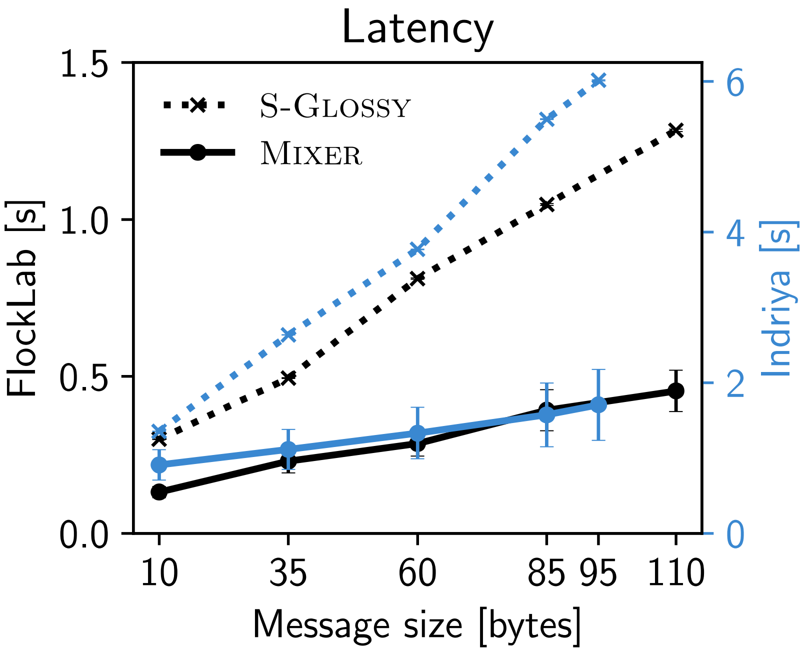
100%

Mixer delivered all messages
in all FlockLab and Indriya experiments

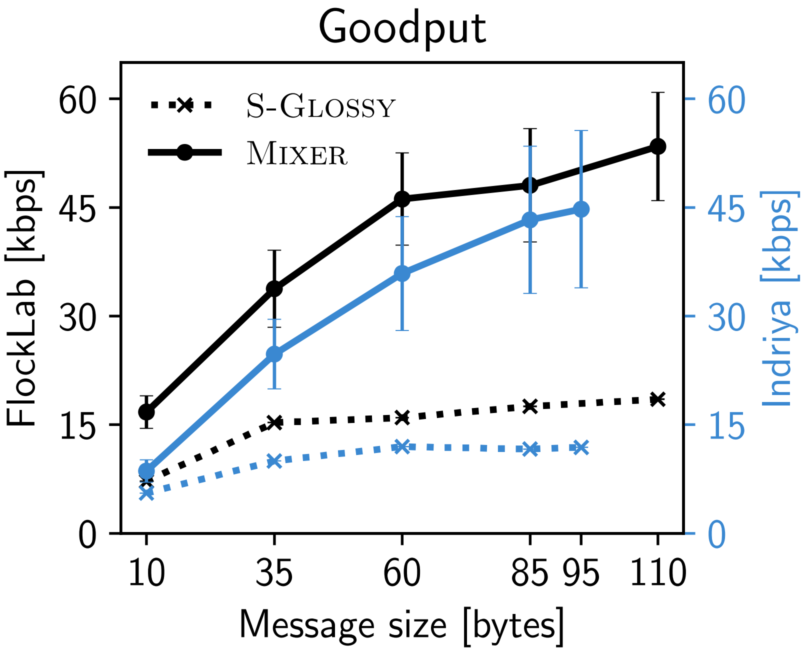
Experiments

- general performance: impact of
  - **message size**

Performance all-to-all



Latency



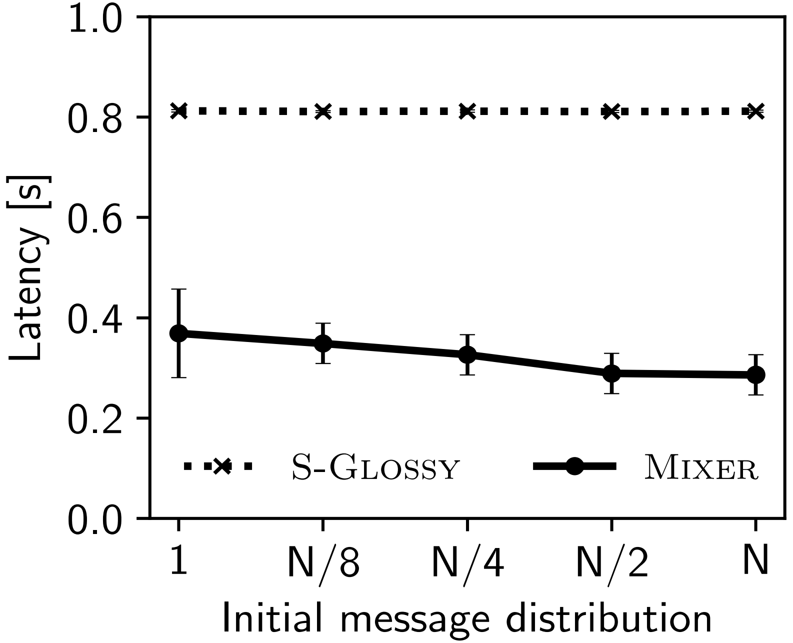
Goodput

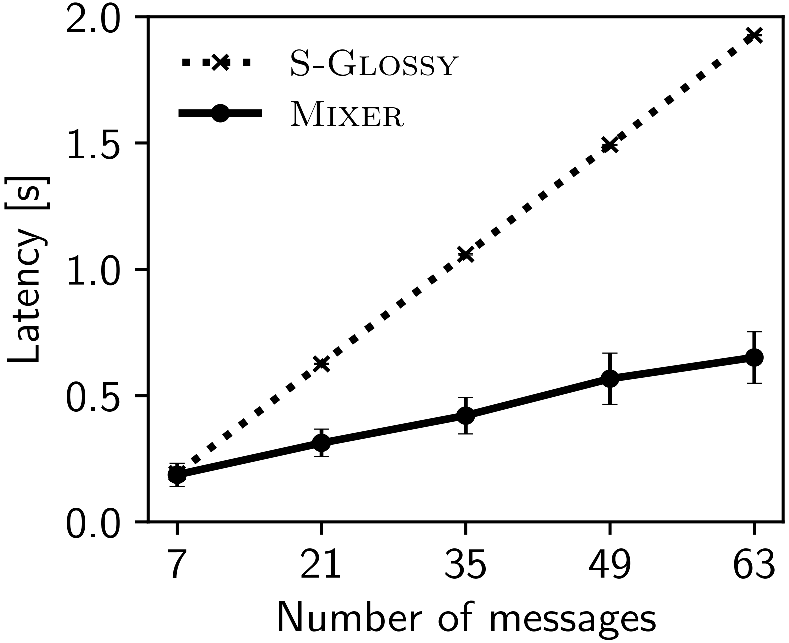
Mixer outperforms S-Glossy by up to **3.8x**

Experiments

- general performance: impact of
  - message size
  - **number of messages**
  - **initial message distribution**

Performance many-to-all





Mixer is versatile and scales well

Experiments

- general performance: impact of
  - message size
  - number of messages
  - initial message distribution
- impact of node failures
- impact of node mobility
- potential of faster CPUs and physical layers

Conclusion

Conclusion

Mixer, a many-to-all broadcast primitive

- designed for dynamic wireless mesh networks
- embeds **RLNC and synchronous transmissions** into an efficient architecture and adds smart policies to make the combination **„spicy“**
- supports any initial message distribution, i.e., complete to-all to all-to-all communication patterns

Visit https://mixer.nes-lab.org

→ source code, tutorial projects, documentation, …

→ TelosB (MSP430) available right now, ARM coming soon