Decentralized Slicing in Mobile Low-Power Wireless Networks

Piotr Jaszkowski, Pawel Sienkowski, Konrad Iwanicki
University of Warsaw

pj306249@students.mimuw.edu.pl
ps319383@students.mimuw.edu.pl
iwanicki@mimuw.edu.pl

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Decentralized Slicing Problem

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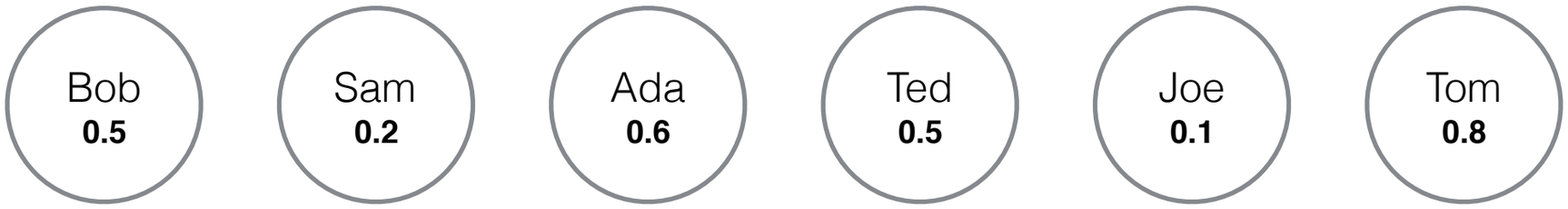
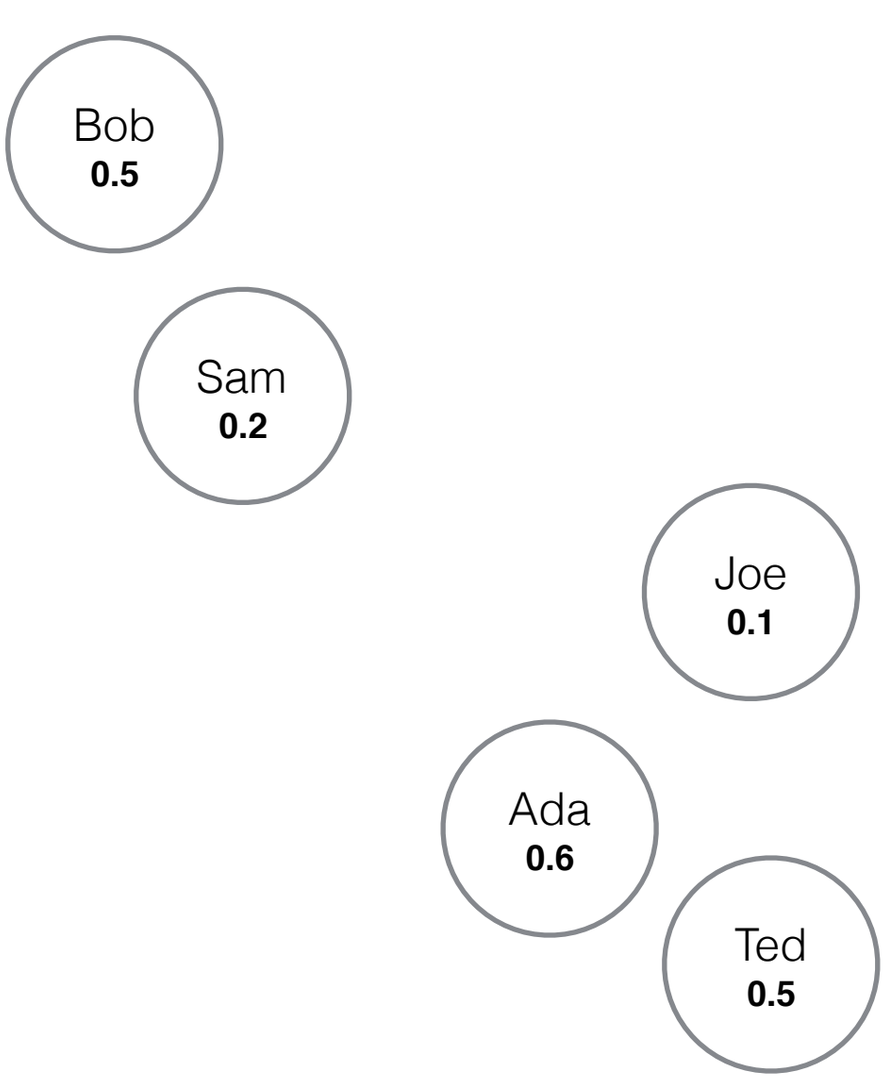


Decentralized Slicing Problem



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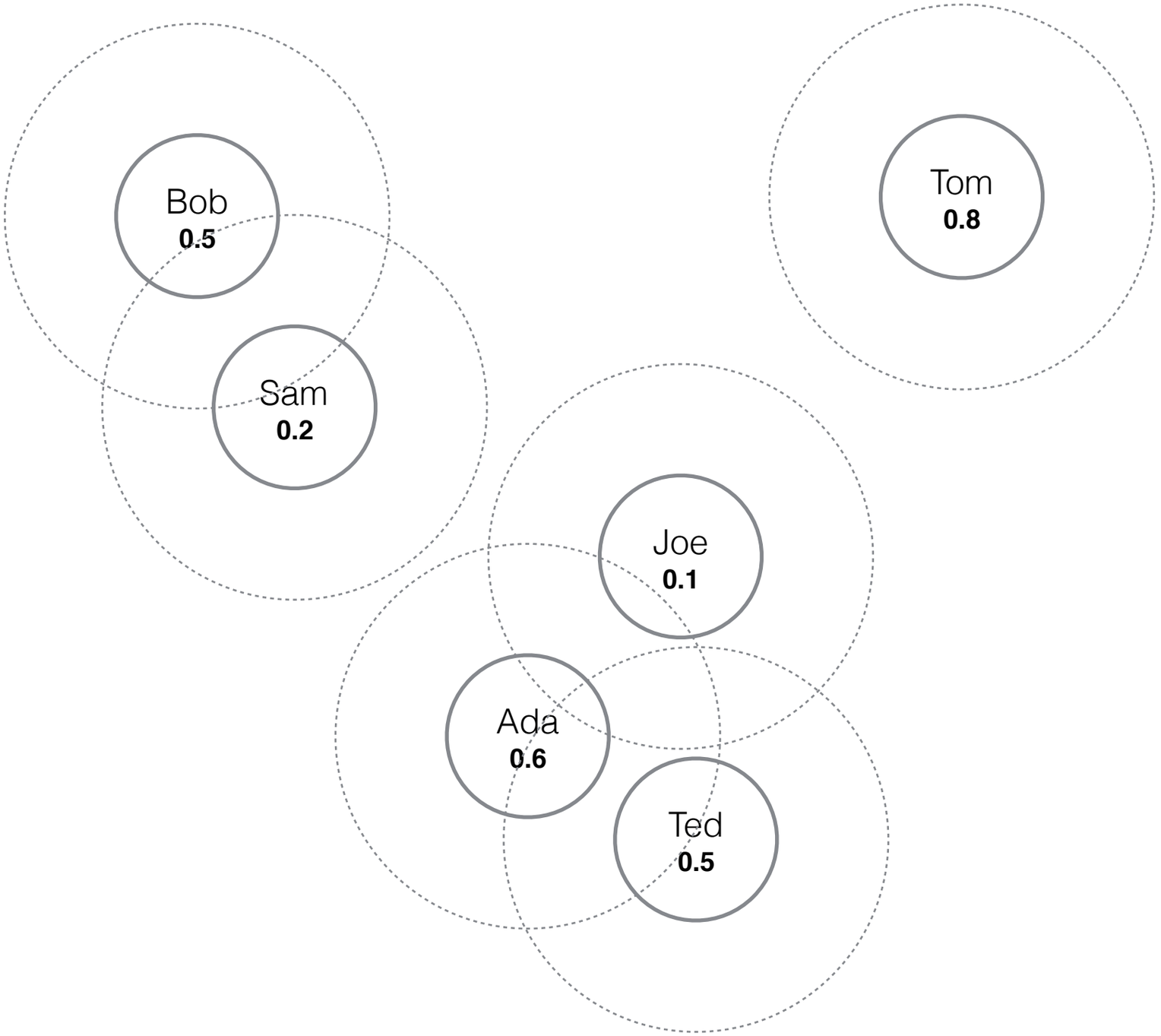
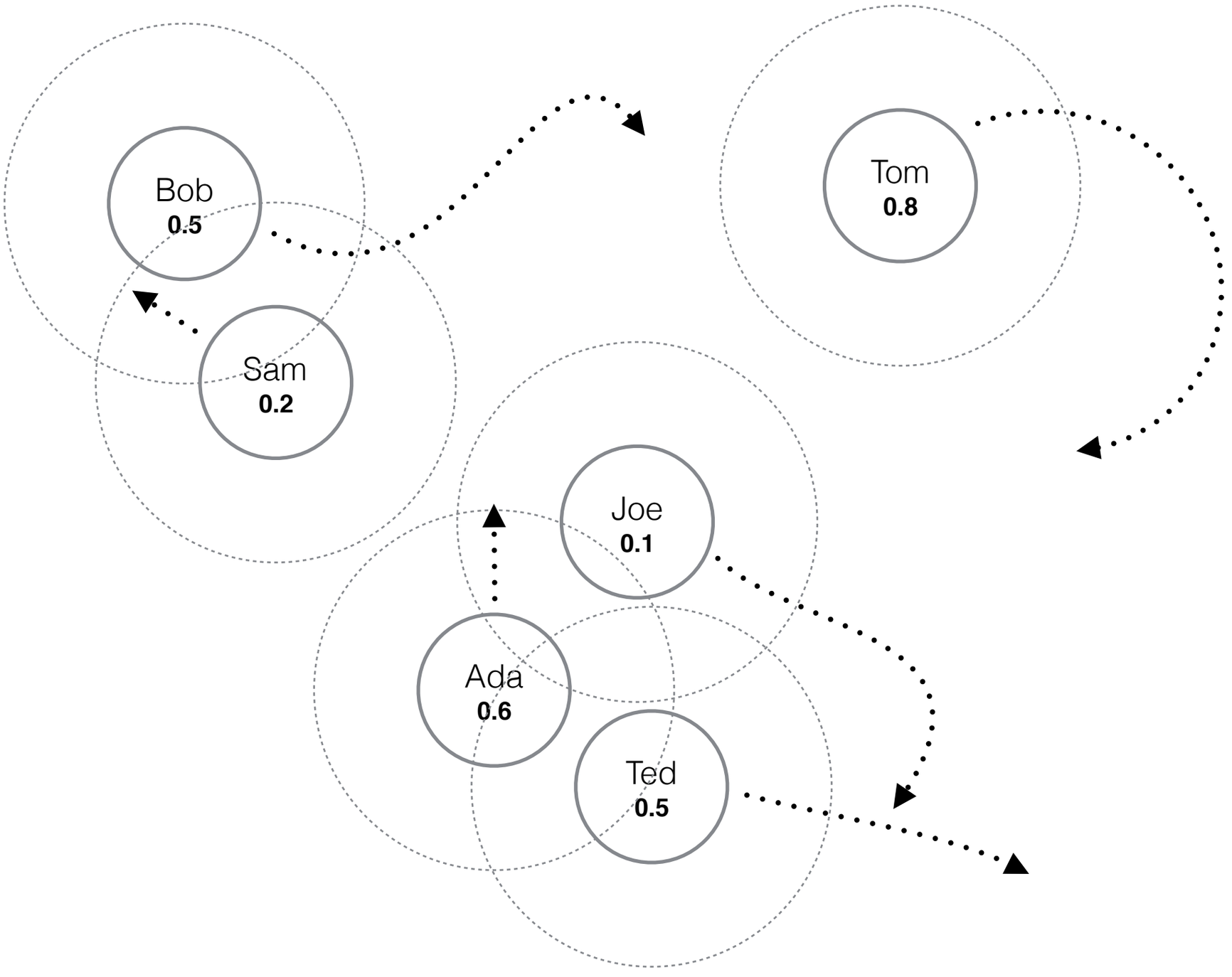


Decentralized Slicing Problem



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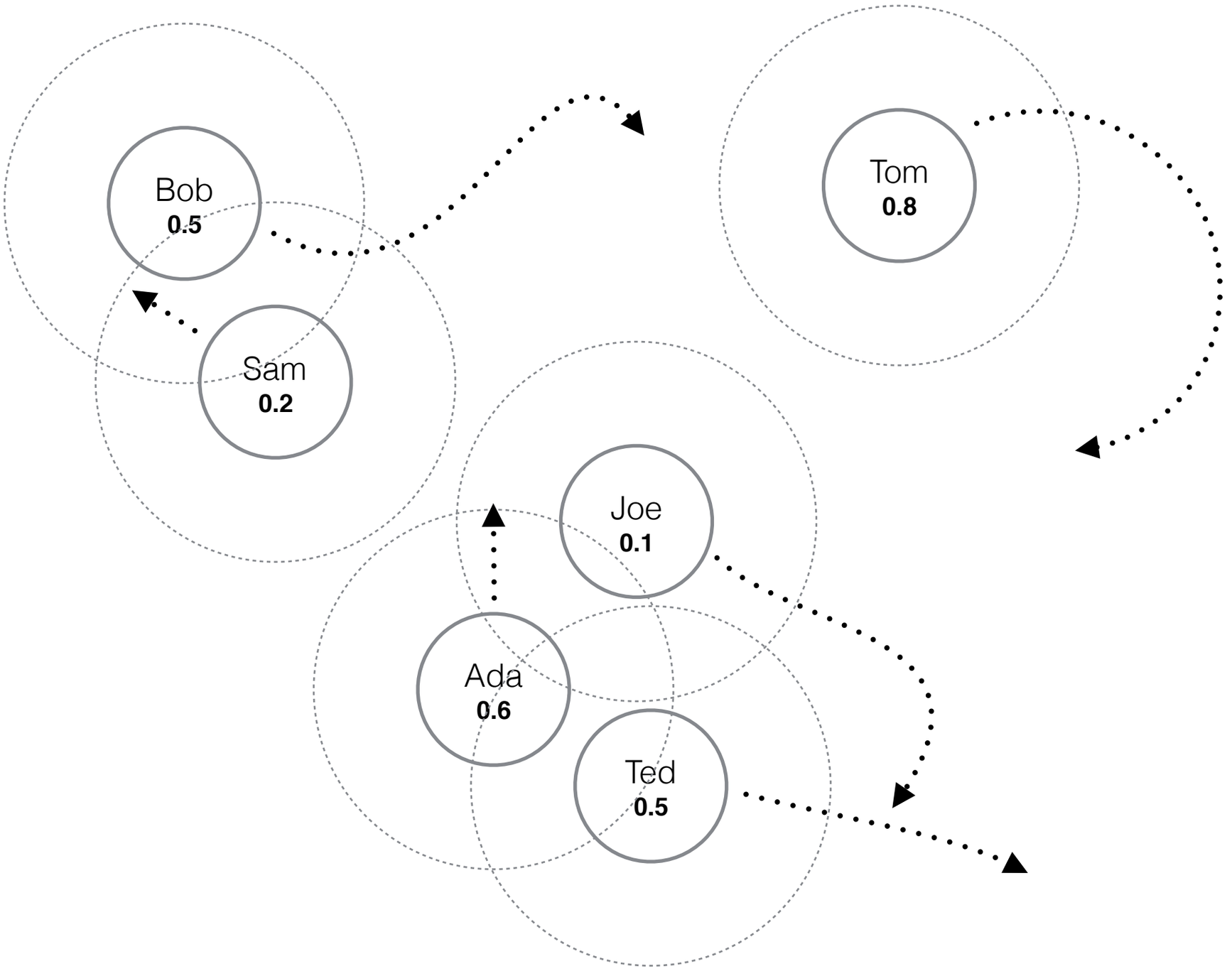
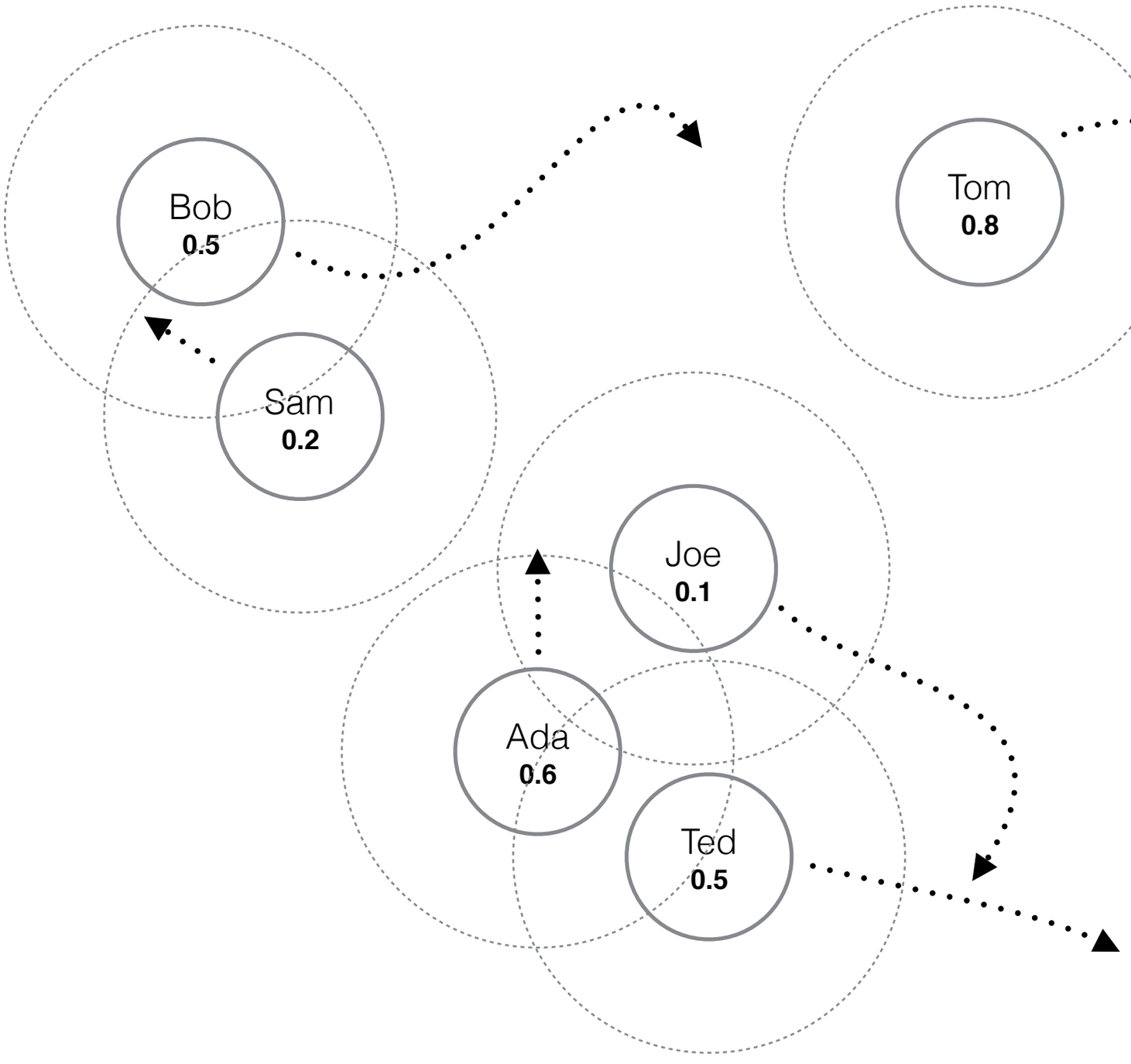


Tom	0.8
Ada	0.6
Ted	0.5
Bob	0.5
Sam	0.2
Joe	0.1

Decentralized Slicing Problem



Slice 1: 1/6	Tom	0.8
Slice 2: 3/6	Ada	0.6
	Ted	0.5
	Bob	0.5
Slice 3: 2/6	Sam	0.2
	Joe	0.1

Slice Disorder Measure

Definition

$$SDM = \sum_{node} |actual\_slice(node) - slice\_estimate(node)|$$

Slice Disorder Measure

Definition

$$SDM = \sum_{node} |actual\_slice(node) - slice\_estimate(node)|$$

Example

	id	value	estimate
Slice 1	Tom	0.8	**Slice 2**
Slice 2	Ada	0.6	Slice 1
	Ted	0.5	Slice 2
	Bob	0.5	Slice 3
Slice 3	Sam	0.2	Slice 3
	Joe	0.1	Slice 3

$$SDM = \underset{\text{Tom}}{|1 - 2|} + \underset{\text{Ada}}{|2 - 1|} + \underset{\text{Ted}}{|2 - 2|} + \underset{\text{Bob}}{|2 - 3|} + \underset{\text{Sam}}{|3 - 3|} + \underset{\text{Joe}}{|3 - 3|} = 1 + 1 + 1 + 0 = 3$$

Applications

- gamification mechanisms
- self-division of a robobee swarm
- finding potential cluster heads in an area hierarchy over sensors

Related work

- To this date, a few algorithms have been proposed:

JK, mod-JK, Dynamic ranking by sampling, Sliver, Q-digest

- All of the solutions proposed so far either:
  - relay on a global connectivity of a network (point-to-point communication)
  - assume that nodes are static (so an overlay network can be created)
  - were not designed for resource-constrained devices (memory or bandwidth)

Our algorithms: *BSort*

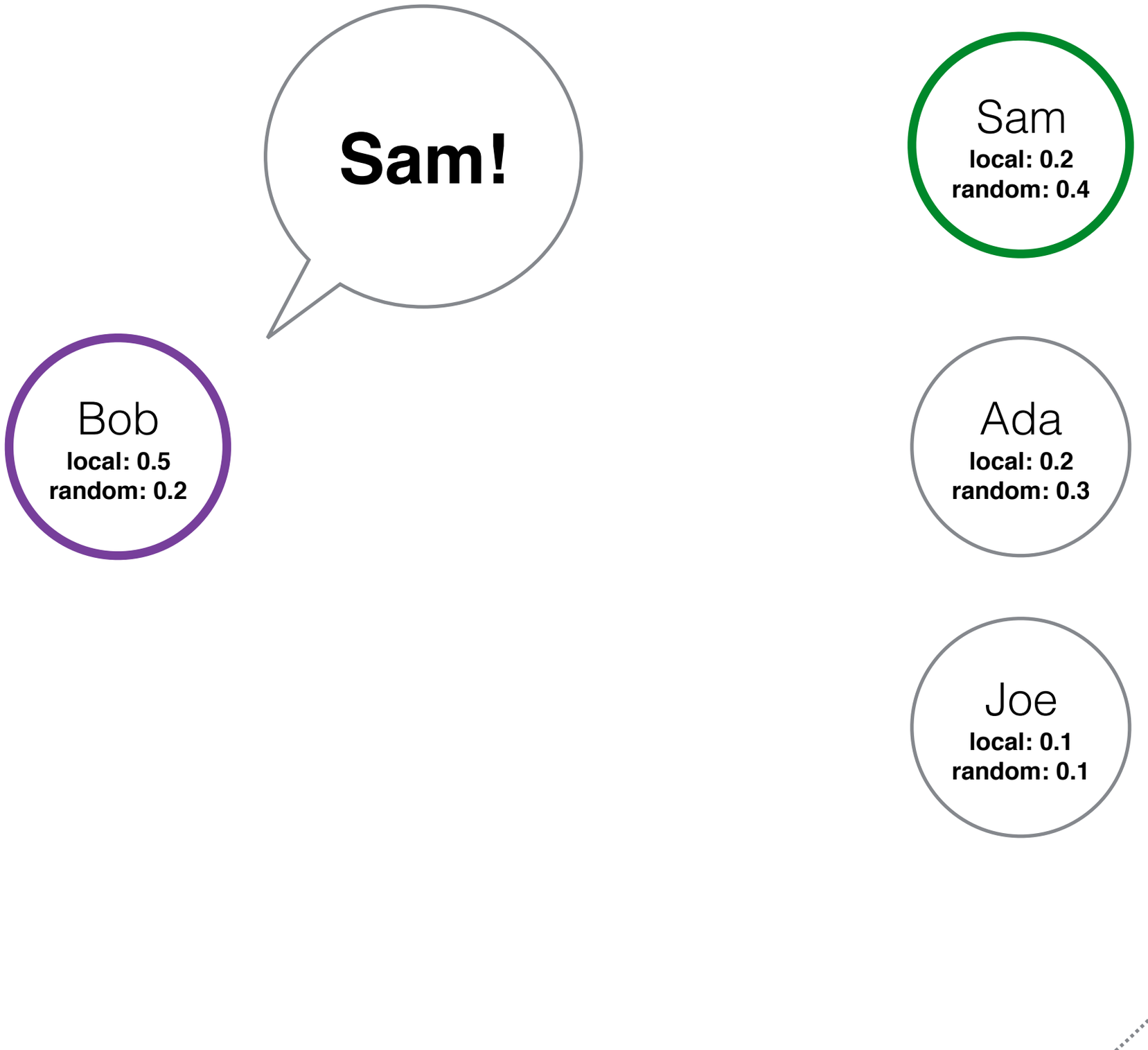
Sam
local: 0.2
random: 0.4

Bob
local: 0.5
random: 0.2

Ada
local: 0.2
random: 0.3

Joe
local: 0.1
random: 0.1

Our algorithms: *BSort*



Our algorithms: *BSort*

Hey Sam!
my local > your local,
but
my random < your random.

Let's swap!

Sam
local: 0.2
random: 0.4

Bob
local: 0.5
random: 0.2

Ada
local: 0.2
random: 0.3

Joe
local: 0.1
random: 0.1

Our algorithms: *BSort*

Cool Sam! Now
my local > your local,
and
my random > your random.
That's what I like!

Sam
local: 0.2
random: 0.2

Bob
local: 0.5
random: 0.4

Ada
local: 0.2
random: 0.3

Joe
local: 0.1
random: 0.1

We have **10 slices**,
random values are from **[0.0, 1.0)**
and my random value is **0.4**.
So, I think I'm in the **4th** slice!

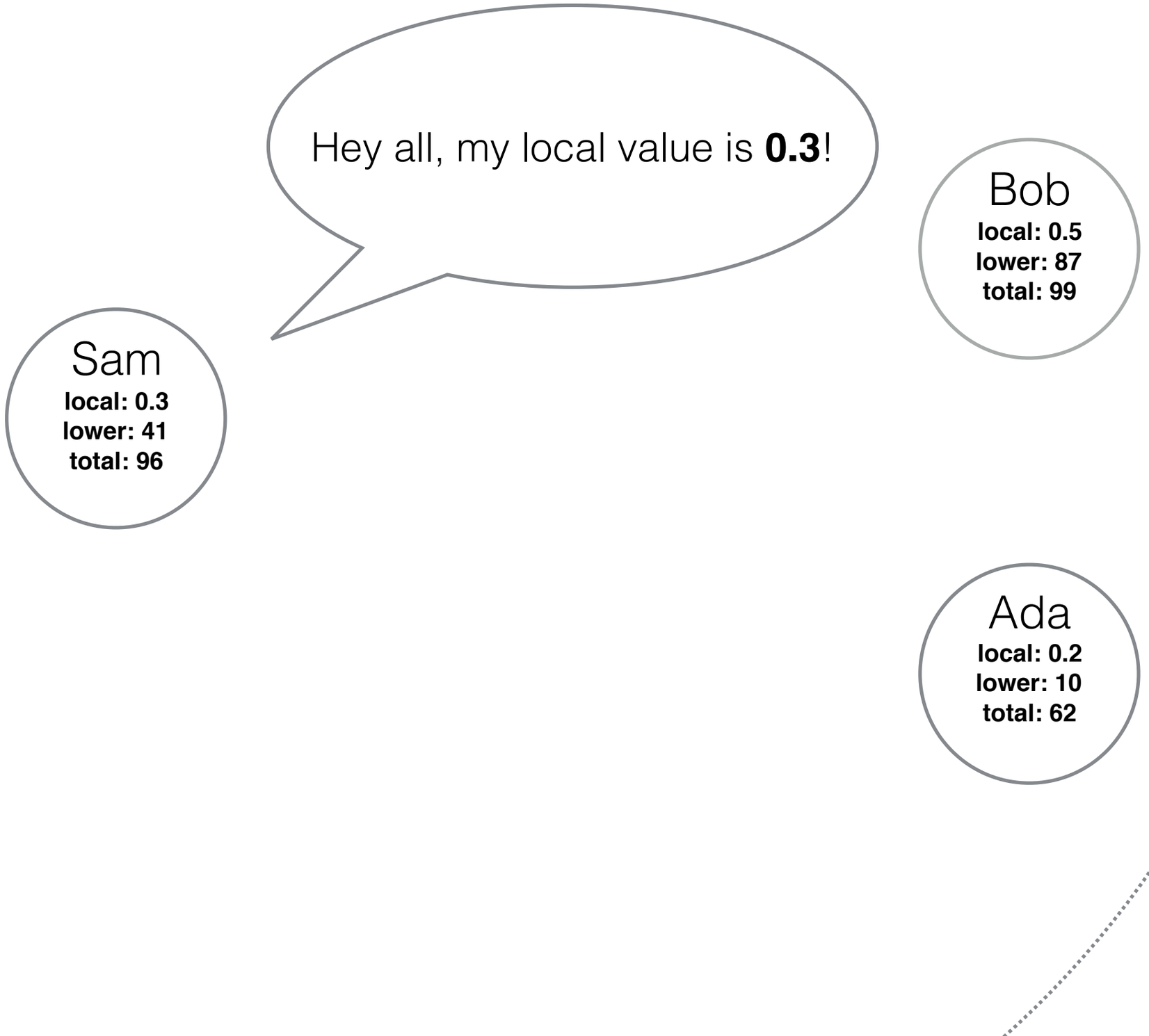
Our algorithms: *ICount*

Bob
local: 0.5
lower: 87
total: 99

Sam
local: 0.3
lower: 41
total: 96

Ada
local: 0.2
lower: 10
total: 62

Our algorithms: *ICount*



Our algorithms: *ICount*

0.3, huh? Less than my value…

Bob
local: 0.5
lower: 87 + 1
total: 99 + 1

Sam
local: 0.3
lower: 41
total: 96

0.3 is more than my **0.2** :(

Ada
local: 0.2
lower: 10
total: 62 + 1

Our algorithms: *ICount*

Sam
local: 0.3
lower: 41
total: 96

We have **10** slices,
84% of nodes I met
had greater values then mine,
so I think I am in the **9th** slice.

Bob
local: 0.5
lower: 88
total: 100

Ada
local: 0.2
lower: 10
total: 63

Digression: SharedState

- A scheme for data distribution in a wireless network
- Idea:
  - Each node maintains a set of values
  - Initially nodes store only own values in their sets
  - Each node periodically broadcasts a subset of its set
  - Recipients merge local and received sets
  - Random entries are discarded to meet size limits

Our algorithms: *LCount*

Sam

local: 0.3
lower: 12
total: 54

{**(Sam, 0.3), (Ada, 0.6),** (Joe, 0.2)}

Bob

local: 0.5
lower: 30
total: 64

{(Bob, 0.3), (Ted, 0.6), (Joe, 0.2)}

Our algorithms: *LCount*

Hey all,
here is a sample of our population:
{(Sam, 0.3), (Ada, 0.6)}

Sam

local: 0.3
lower: 12
total: 54

{**(Sam, 0.3), (Ada, 0.6),** (Joe, 0.2)}

Bob

local: 0.5
lower: 30
total: 64

{(Bob, 0.3), (Ted, 0.6), (Joe, 0.2)}

Our algorithms: *LCount*

Sam

local: 0.3
lower: 12
total: 54

{**(Sam, 0.3), (Ada, 0.6)**, (Joe, 0.2)}

Sam's value is lower,
Ada's is greater.

Bob

local: 0.5
lower: 30 + 1
total: 64 + 2

{(Bob, 0.3), (Ted, 0.6), (Joe, 0.2),
(Sam, 0.3), (Ada, 0.6)}

Our algorithms: *LCount*

I need to discard some entries from my local set to satisfy the limit.

Sam

local: 0.3
lower: 12
total: 54

{(Sam, 0.3), (Ada, 0.6), (Joe, 0.2)}

Bob

local: 0.5
lower: 31
total: 66

{(Bob, 0.3), ~~**(Ted, 0.6)**~~, (Joe, 0.2), ~~**(Sam, 0.3)**~~, (Ada, 0.6)}

Our algorithms: *LCount*

Sam

local: 0.3
lower: 12
total: 54

{(Sam, 0.3), (Ada, 0.6), (Joe, 0.2)}

We have **10** slices, **53%** of nodes I met had greater values then mine, so I think I am in the **6th** slice.

Bob

local: 0.5
lower: 31
total: 66

{(Bob, 0.3), (Joe, 0.2), (Ada, 0.6)}

Digression: Counting Sketch

- Probabilistic data structure
- Aims cardinality estimation problem
- Uses sublinear-space
- Operations:
  - *add(element)* - idempotent
  - *merge(sketch)* - idempotent, associative and commutative
  - *count()* - retrieves cardinality approximation

Our algorithms: *SCount*

Hey all, here is some info:
{(Sam, 0.3, lower, greater)}

Sam

local: 0.3
sketches: lower, greater

{(Sam, 0.3, lower, greater),
(Ada, 0.6, lower, greater)}

Bob

local: 0.5
sketches: lower, greater

{(Bob, 0.5, lower, greater),
(Joe, 0.2, lower, greater)}

Our algorithms: *SCount*

$local_{Sam} < local_{Bob}$, so $lower_{Bob} := merge(lower_{Bob}, lower_{Sam})$
and
$local_{Sam} > local_{Joe}$, so $greater_{Joe} := merge(greater_{Joe}, greater_{Sam})$

Sam

local: 0.3
sketches: lower, greater

{(Sam, 0.3, lower, greater),
(Ada, 0.6, lower, greater)}

Updating sketches…

Bob

local: 0.5
sketches: lower, greater

{(Bob, 0.5, **lower**, greater),
(Joe, 0.2, lower, **greater**)}

Our algorithms: *SCount*

Sam

local: 0.3
sketches: lower, greater

{(Sam, 0.3, lower, greater),
(Ada, 0.6, lower, greater)}

Adding received entries…

Bob

local: 0.5
sketches: lower, greater

{(Bob, 0.5, lower, greater),
(Joe, 0.2, lower, greater),
(Sam, 0.3, lower, greater)}

Our algorithms: *SCount*

Sam

local: 0.3
sketches: lower, greater

{(Sam, 0.3, lower, greater),
(Ada, 0.6, lower, greater)}

Discarding entries to meet the limit.

Bob

local: 0.5
sketches: lower, greater

{(Bob, 0.5, lower, greater),
~~**(Joe, 0.2, lower, greater)**~~,
(Sam, 0.3, lower, greater)}

Our algorithms: *SCount*

count(greater$_{Bob}$) / (count(lower$_{Bob}$) + count(greater$_{Bob}$)) = 12 / (12 + 68) = **15%**

Sam

local: 0.3
sketches: lower, greater

{(Sam, 0.3, lower, greater),
(Ada, 0.6, lower, greater)}

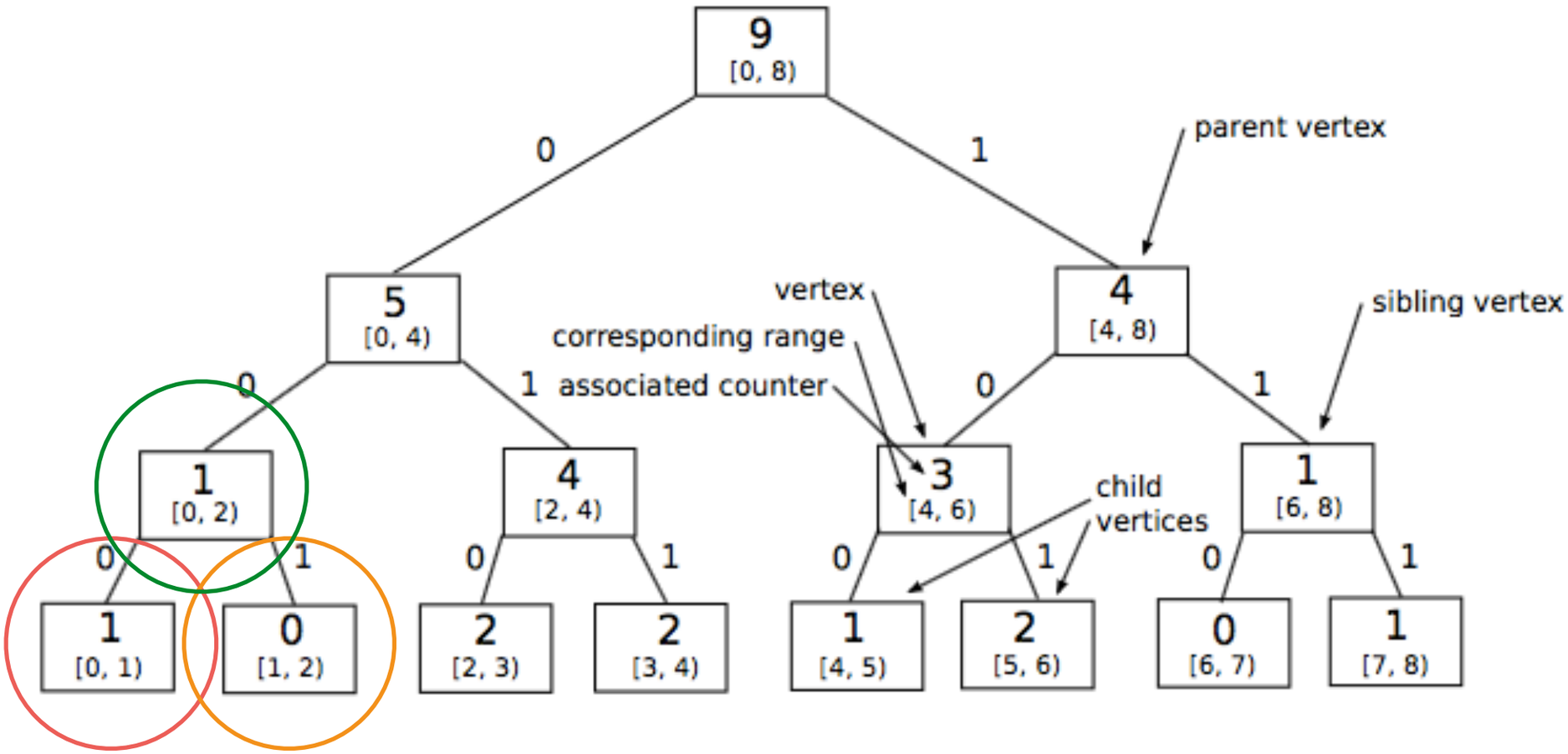
We have **10** slices,
15% of nodes I met had greater values.
I think I'm in the **2nd** slice.

Bob

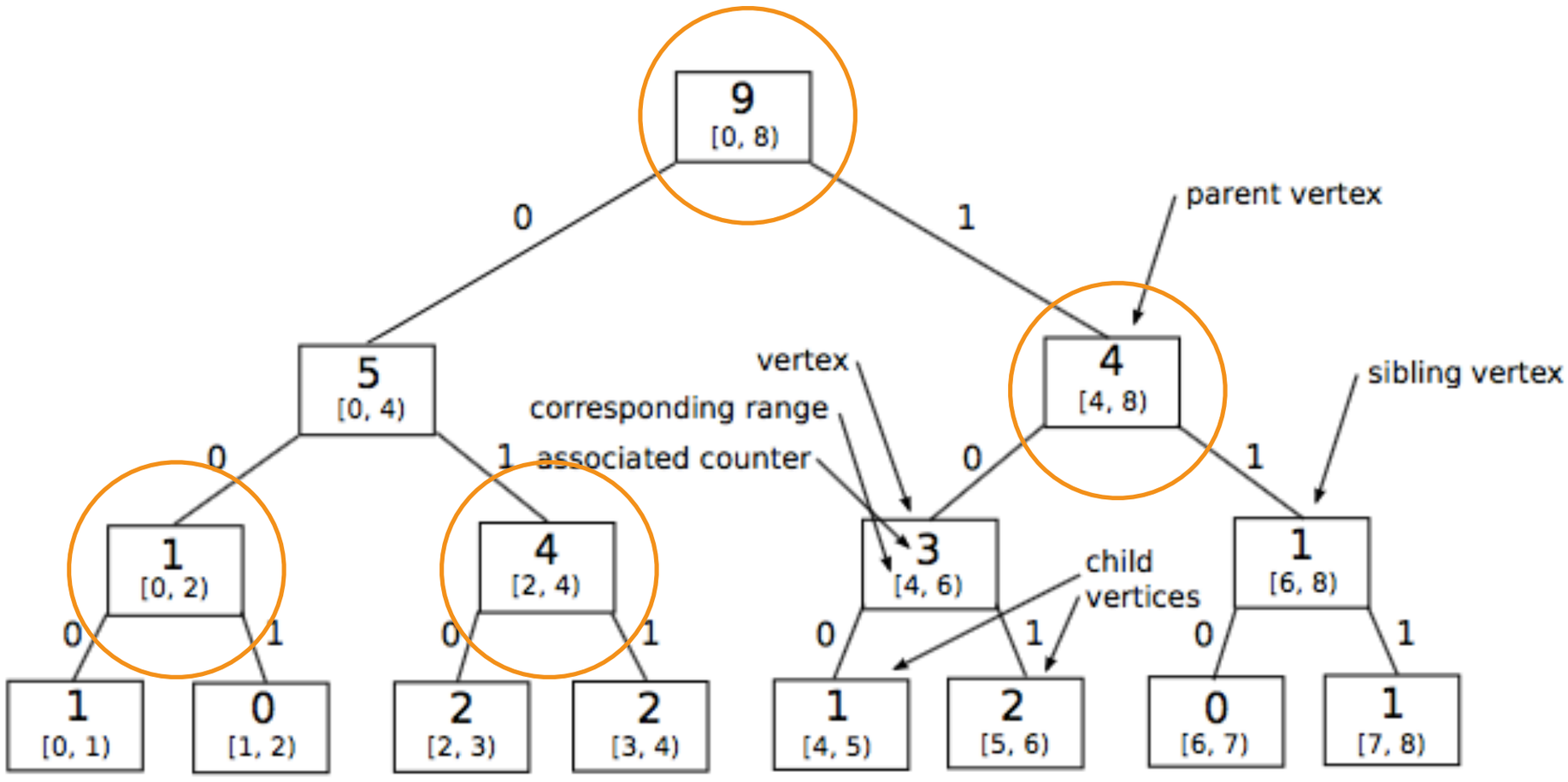
local: 0.5
sketches: lower, greater

{(Bob, 0.5, lower, greater),
(Sam, 0.3, lower, greater)}

Our algorithms: *DTree*



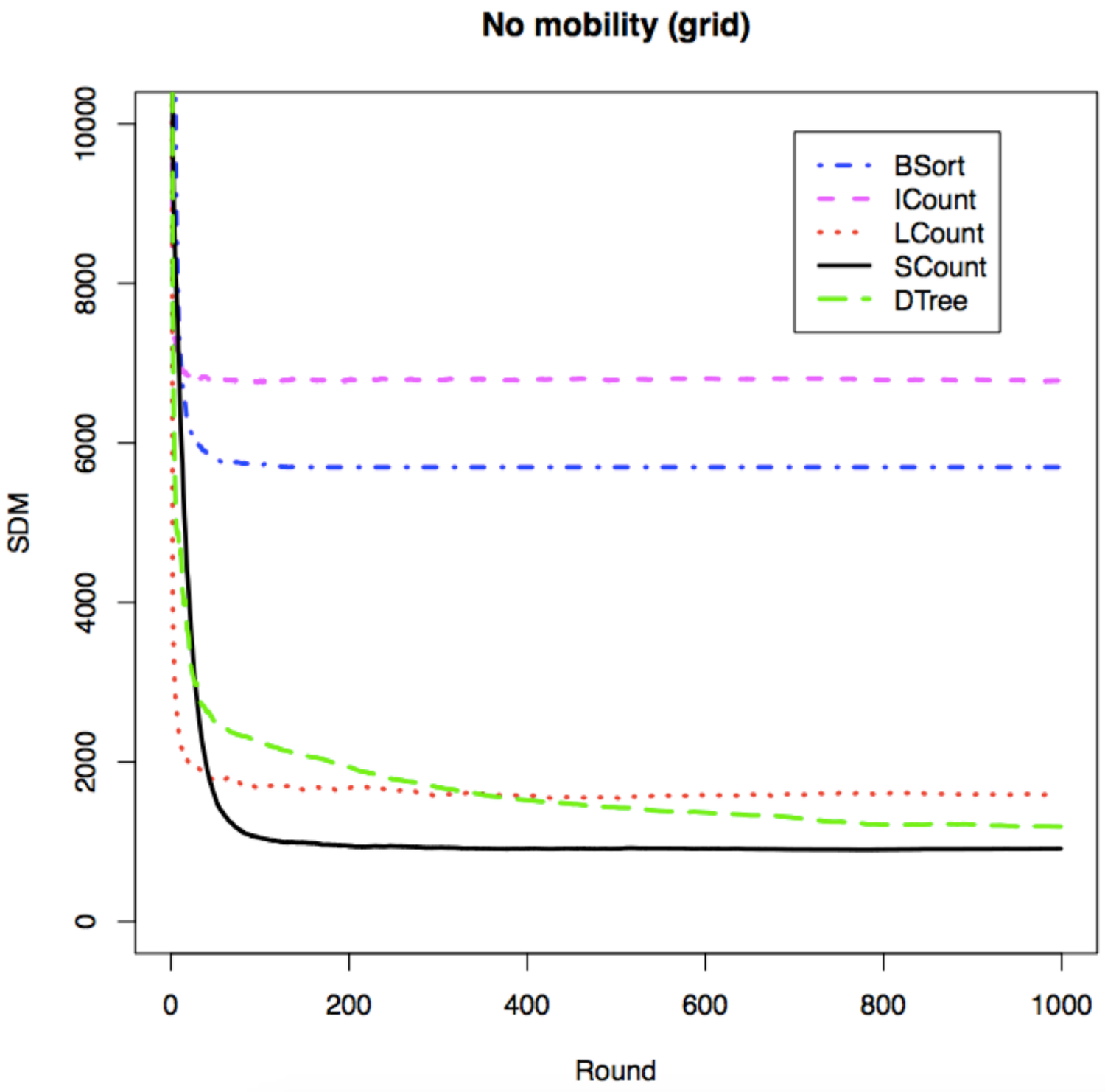
Our algorithms: *DTree*



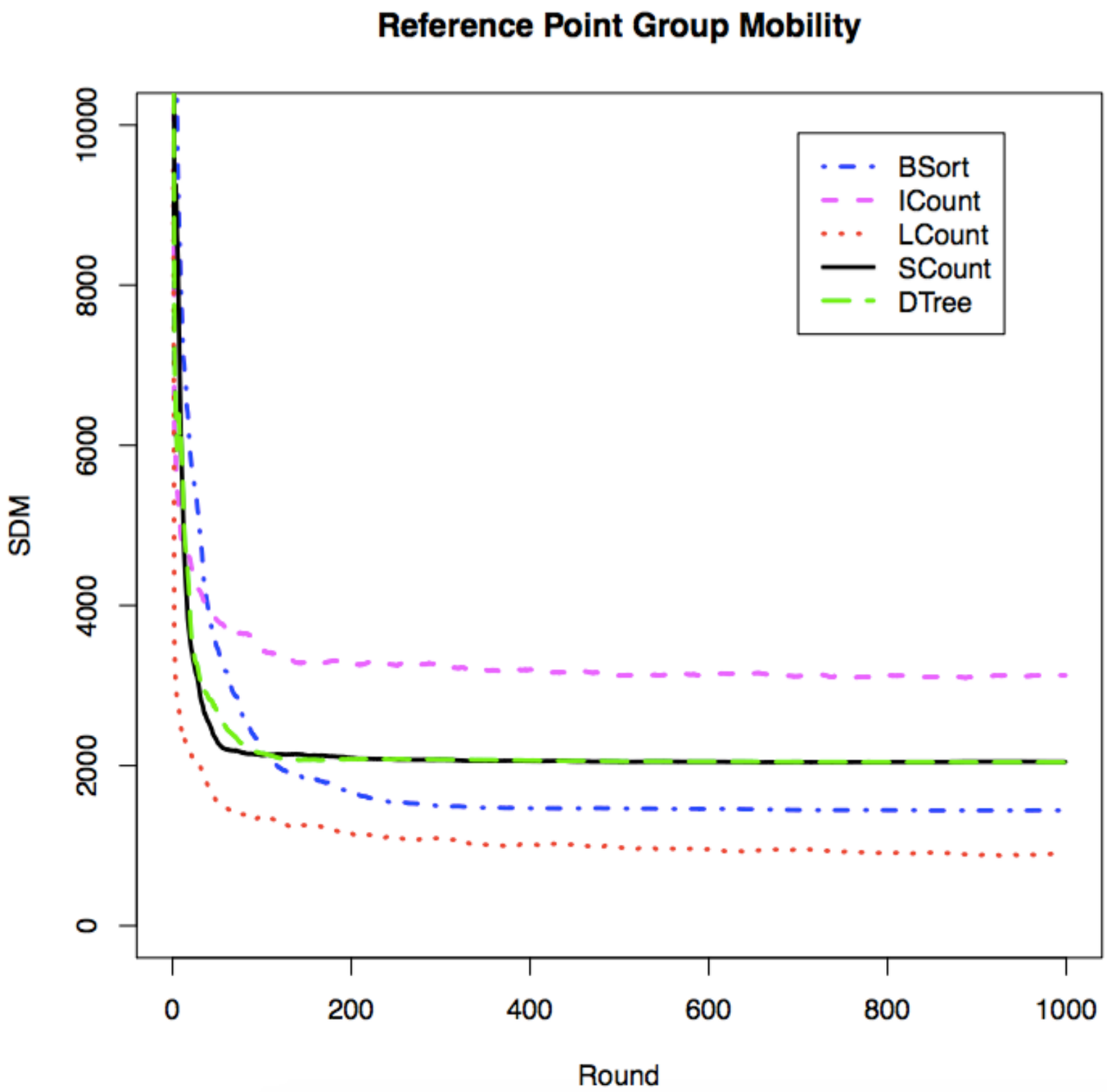
Simulations

- 1024 nodes
- effective radio range: 50 meters, 100 bytes per message
- square-shaped area, side length: 1024 meters
- 100 slices
- 3 mobility patterns:
  - static grid
  - Reference Point Group Mobility
  - Random Waypoint Mobility

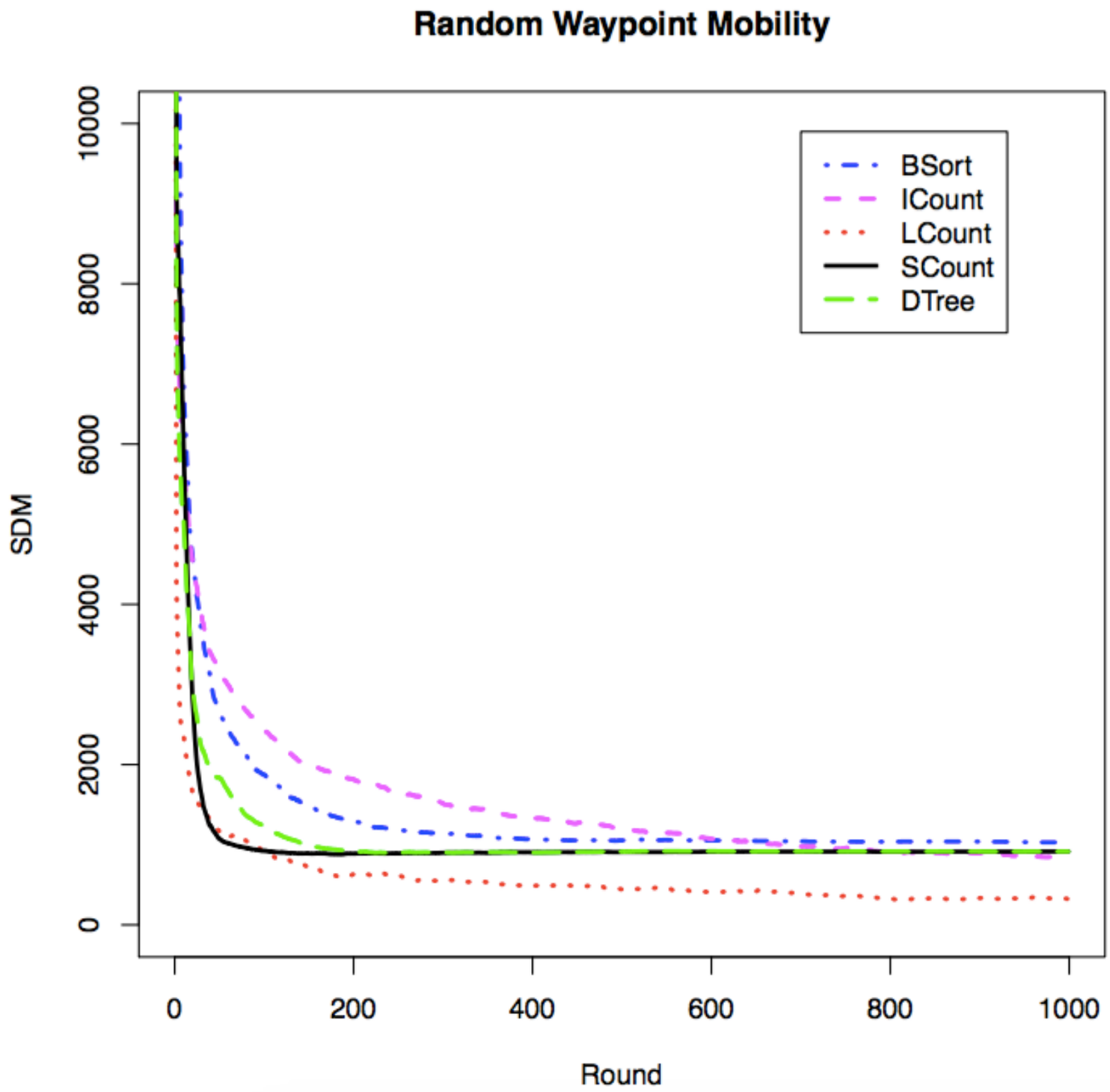
Performance comparison



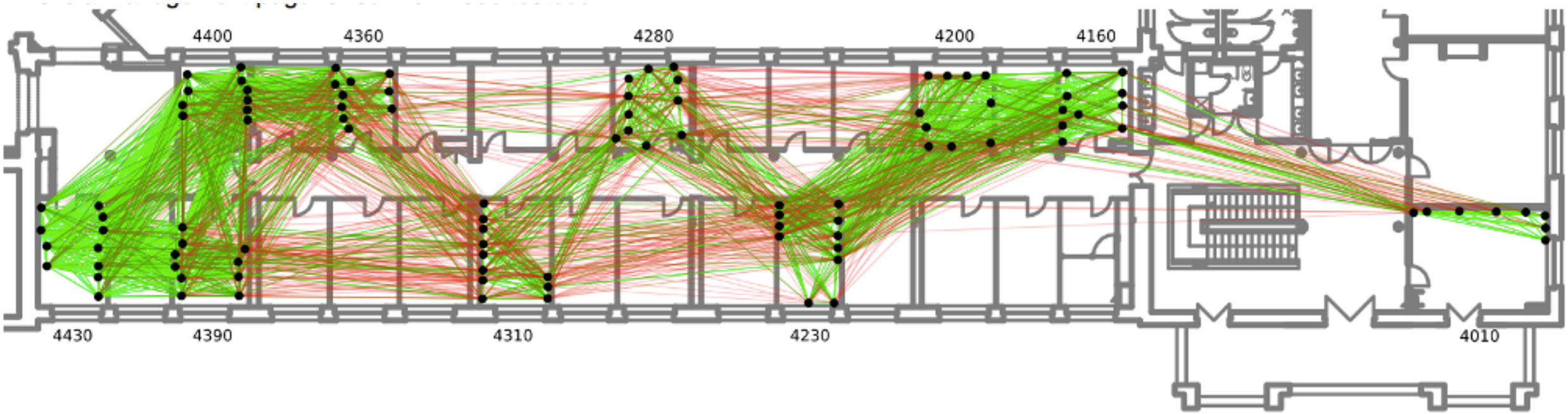
Performance comparison

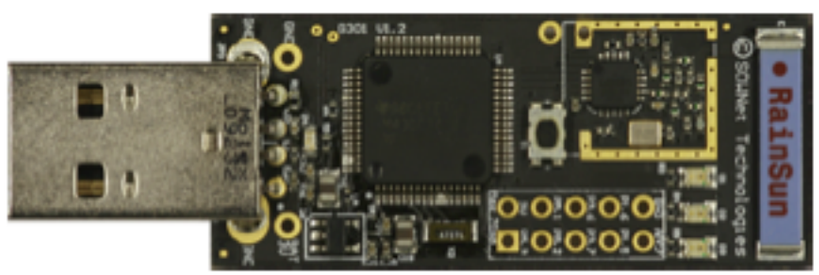


Performance comparison



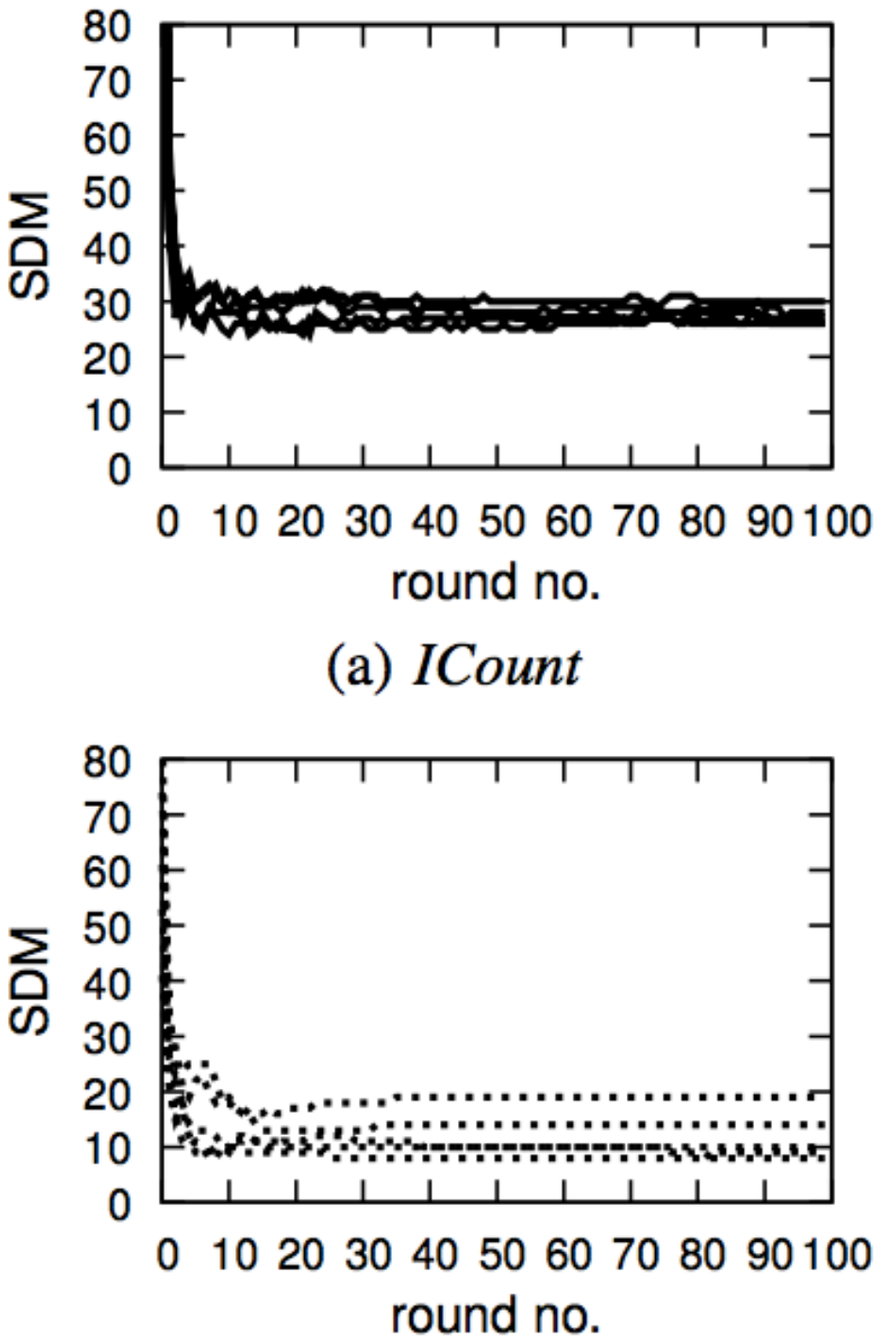
Testbed experiments



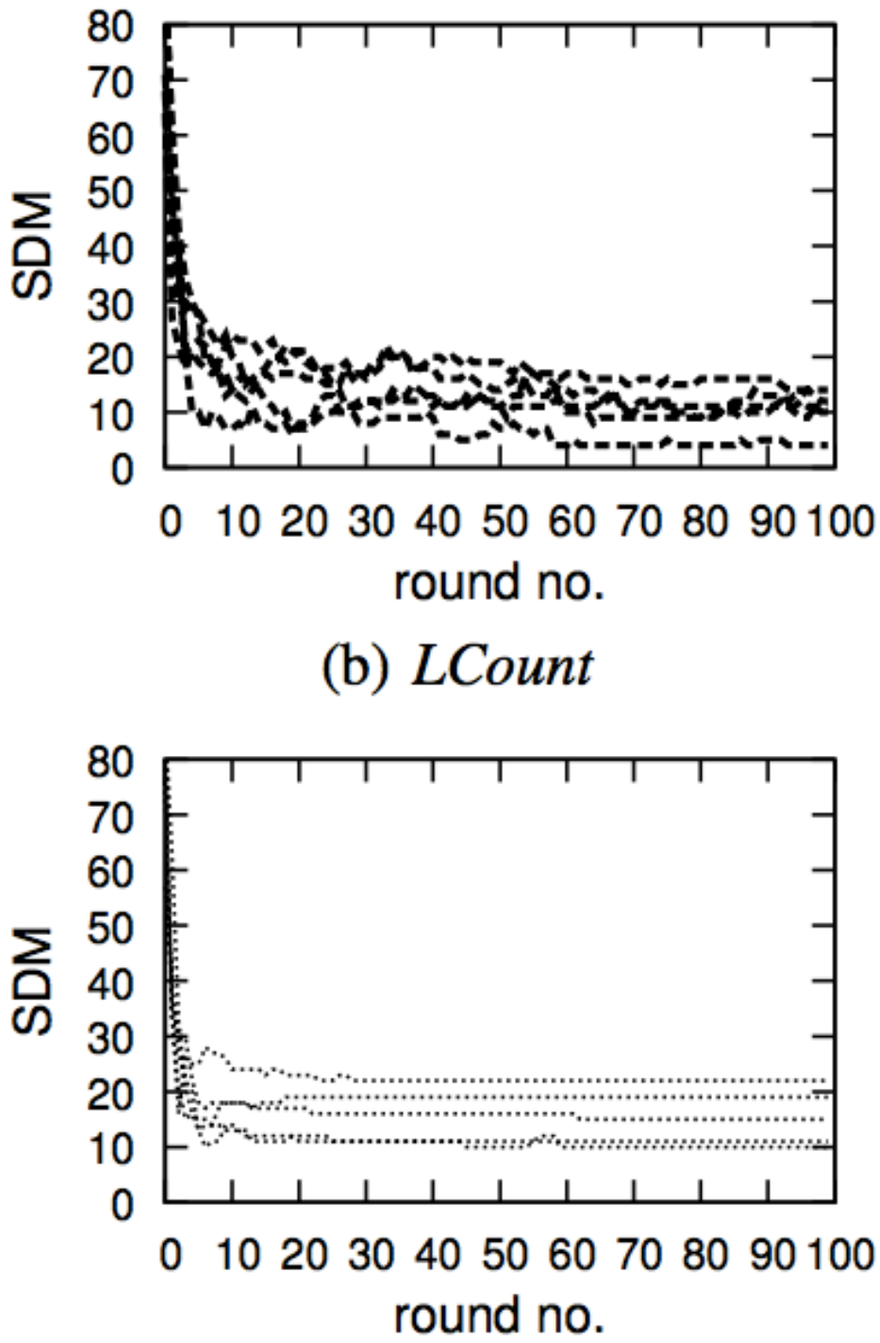


	G-Node
CPU	8 MHz
RAM	8 kb
ROM	116 kb
Radio	500 kb/s

Testbed experiments



(a) *ICount*



(b) *LCount*

(c) *SCount*

(d) *DTree*

Conclusions

- There were some solutions to the Decentralised Slicing Problem
- None of them worked in highly dynamic, low-powered networks
- 2 algorithms have been adapted, 3 new has been designed
- Our new algorithms yield promising results
- Unfortunately, there is no best algorithm - performance depends on configuration, network size and mobility patterns

Thank You

Questions?

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NATIONAL SCIENCE CENTRE

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Conclusions

Algorithm	Advantages	Drawbacks
BSort	Uses a fixed amount of memory and bandwidth. Guarantees that slice estimates finally converge.	Does not perform well in static networks. Converges slowly. May be difficult to implement.
ICount	Uses a fixed amount of memory and bandwidth. Is easy to implement.	Does not perform well in static and mobile clustered networks. Converges slowly. Has its slice estimates fluctuate even if *SDM* is low.
LCount	Converges fast initially. Has a relatively low final *SDM*. Is easy to implement. Benefits from an increased network throughput.	Converges slowly in later stages. Has its slice estimates fluctuate even if *SDM* is low.
SCount	Converges fast. Has its final *SDM* independent of the device density. Benefits from an increased network throughput. Is relatively easy to implement. Guarantees that slice estimates finally converge.	Has its final *SDM* limited by the accuracy of counting sketches.
DTree	Converges relatively fast. Has its final *SDM* independent of the device density. Benefits from an increased network throughput. Guarantees that slice estimates finally converge.	Has its final *SDM* limited by the accuracy of counting sketches. Is difficult to implement.