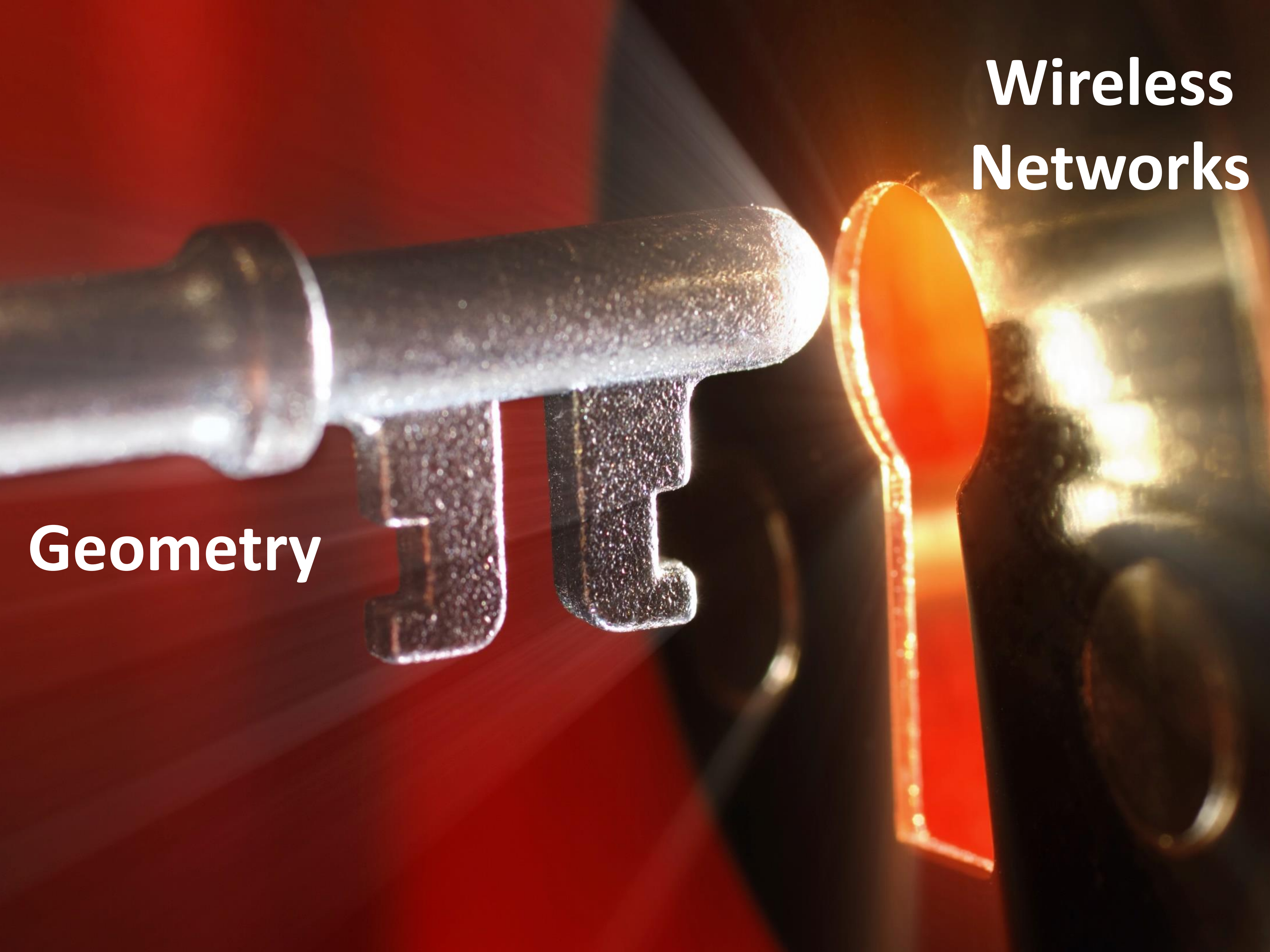
Wireless Networks

Do Not Disturb My Circles

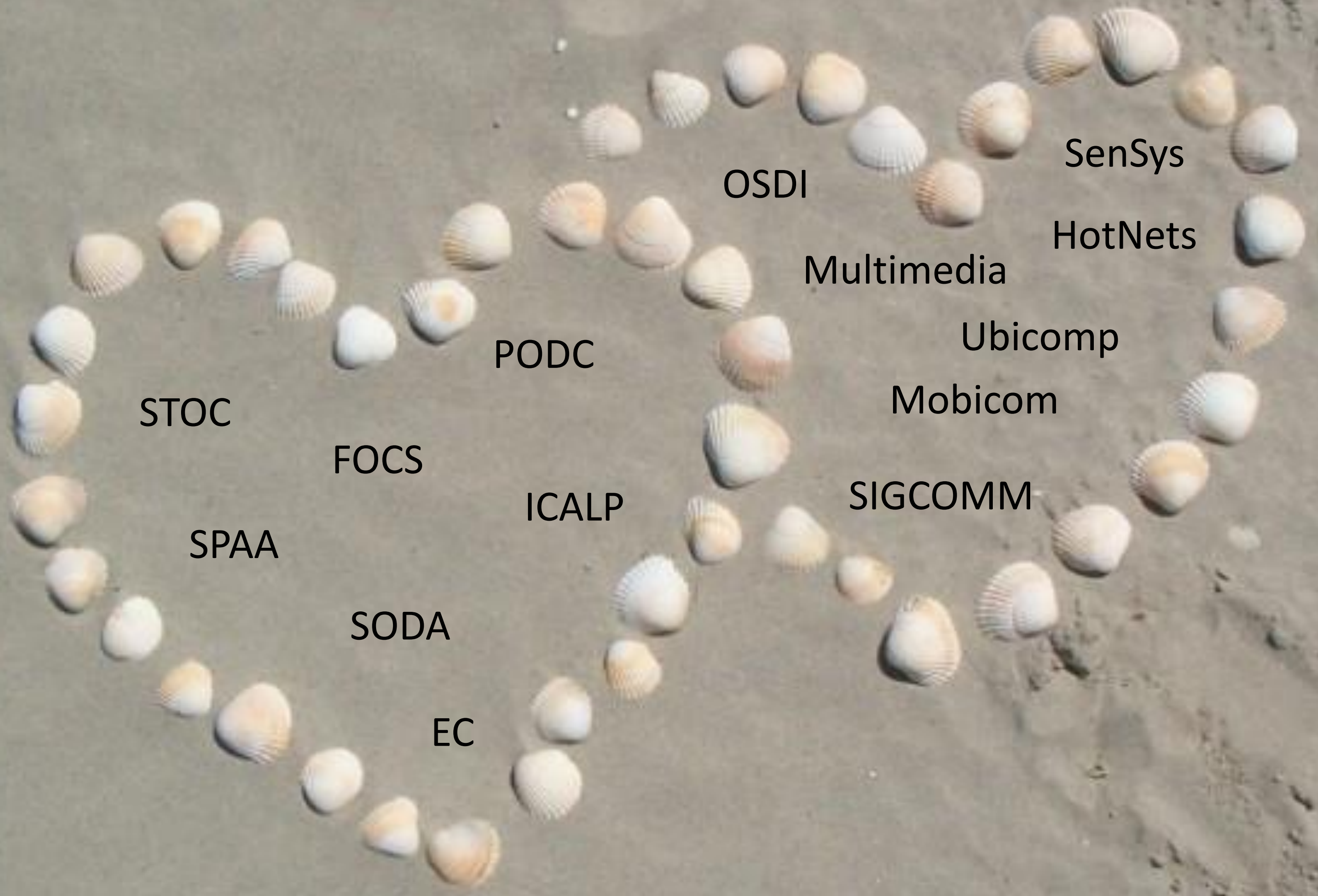
Roger Wattenhofer



Wireless
Networks

Geometry

Zwei Seelen wohnen, ach! in meiner Brust



PODC

STOC

FOCS

ICALP

SPAA

SODA

EC

OSDI

SenSys

HotNets

Multimedia

Ubicomp

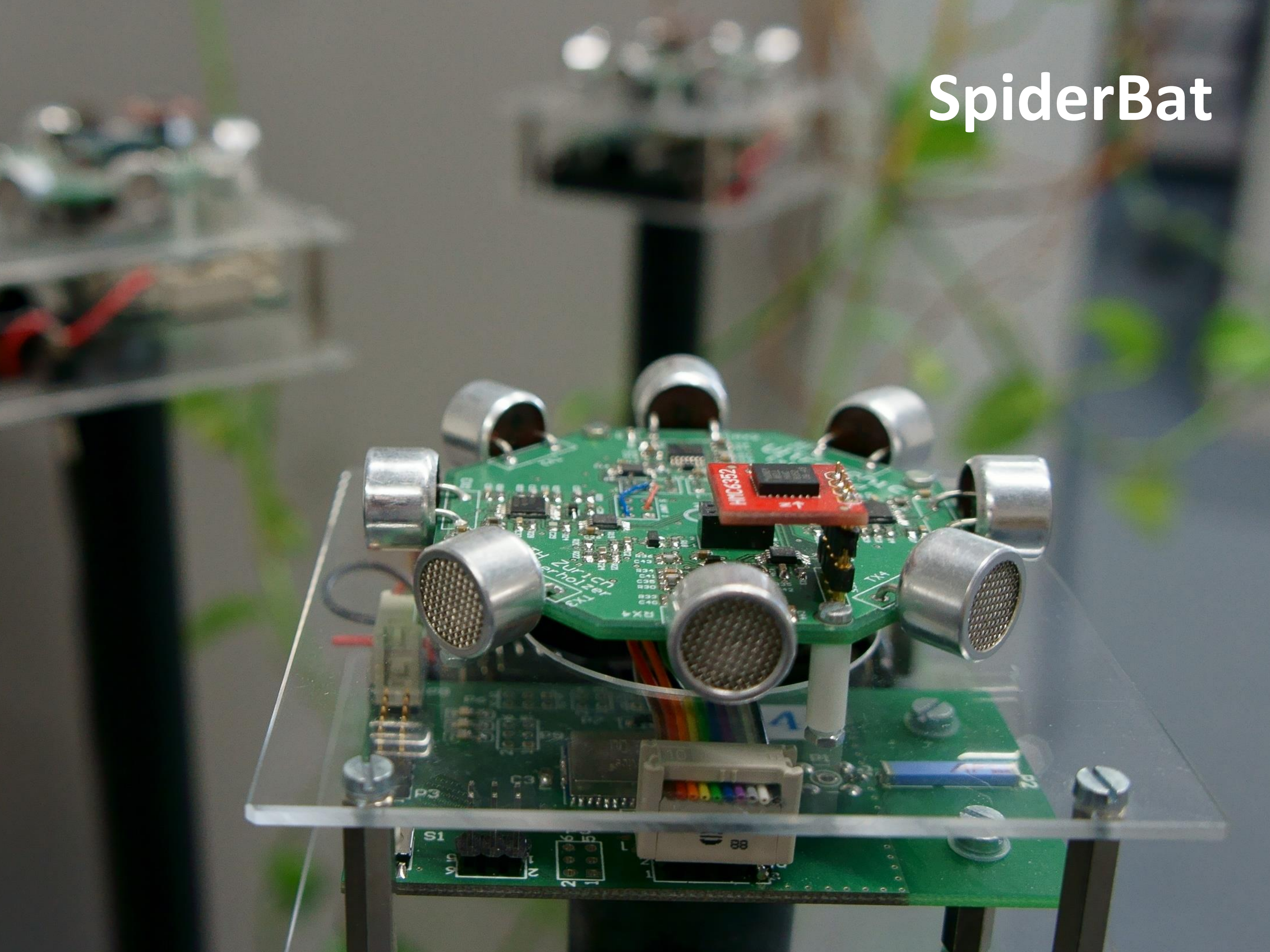
Mobicom

SIGCOMM

„People who are really serious about software should make their own hardware."

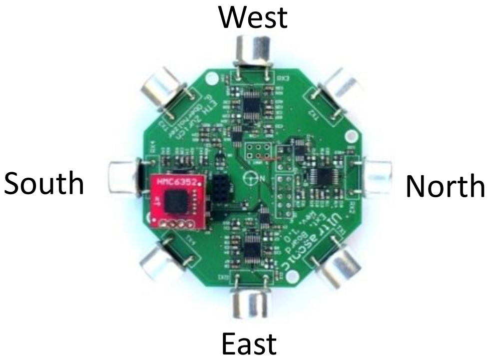
Alan Kay

SpiderBat

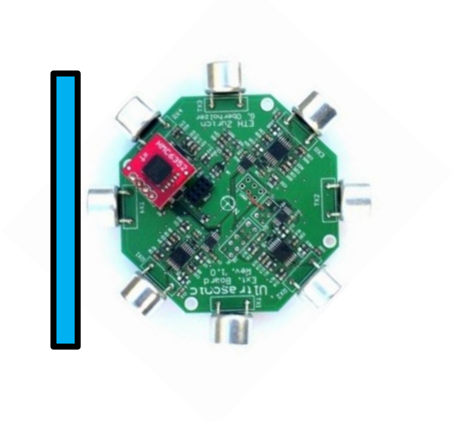


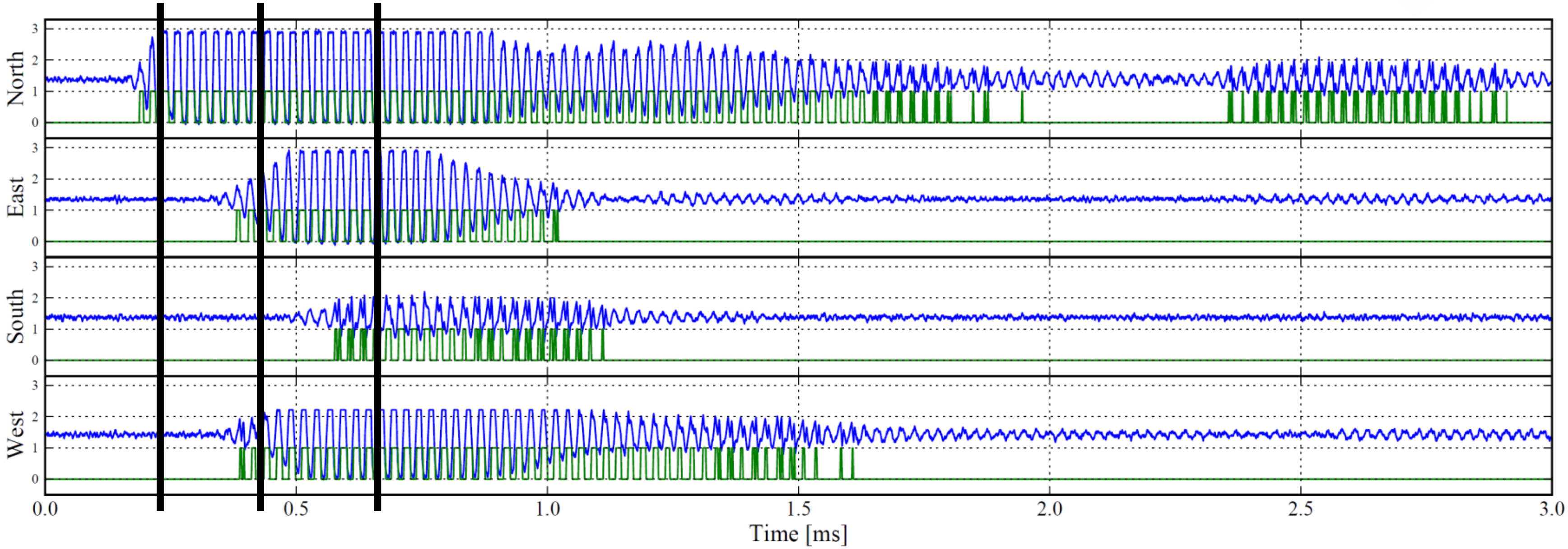
Angle-of-Arrival Measurements

Receiver

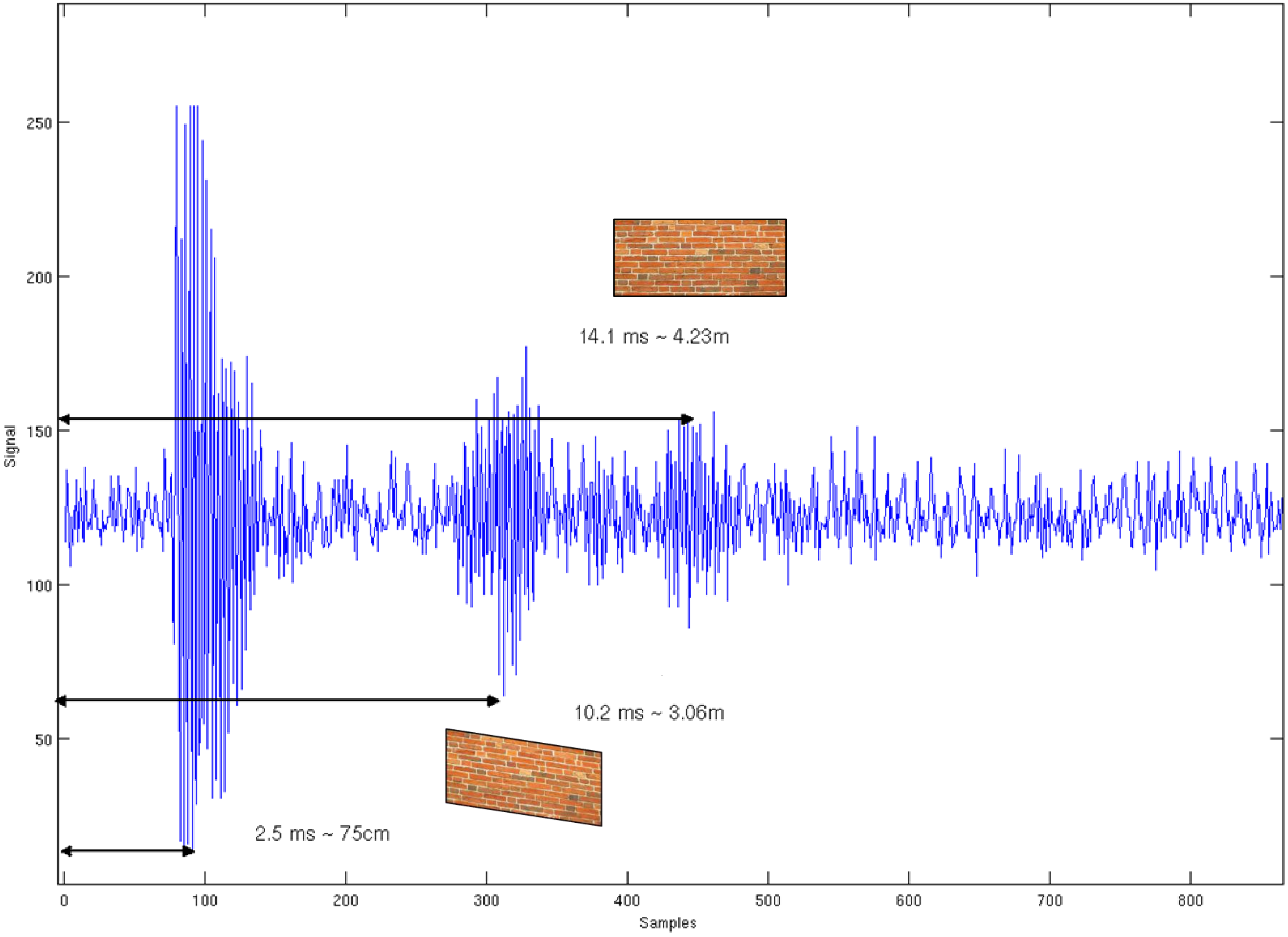


Sender

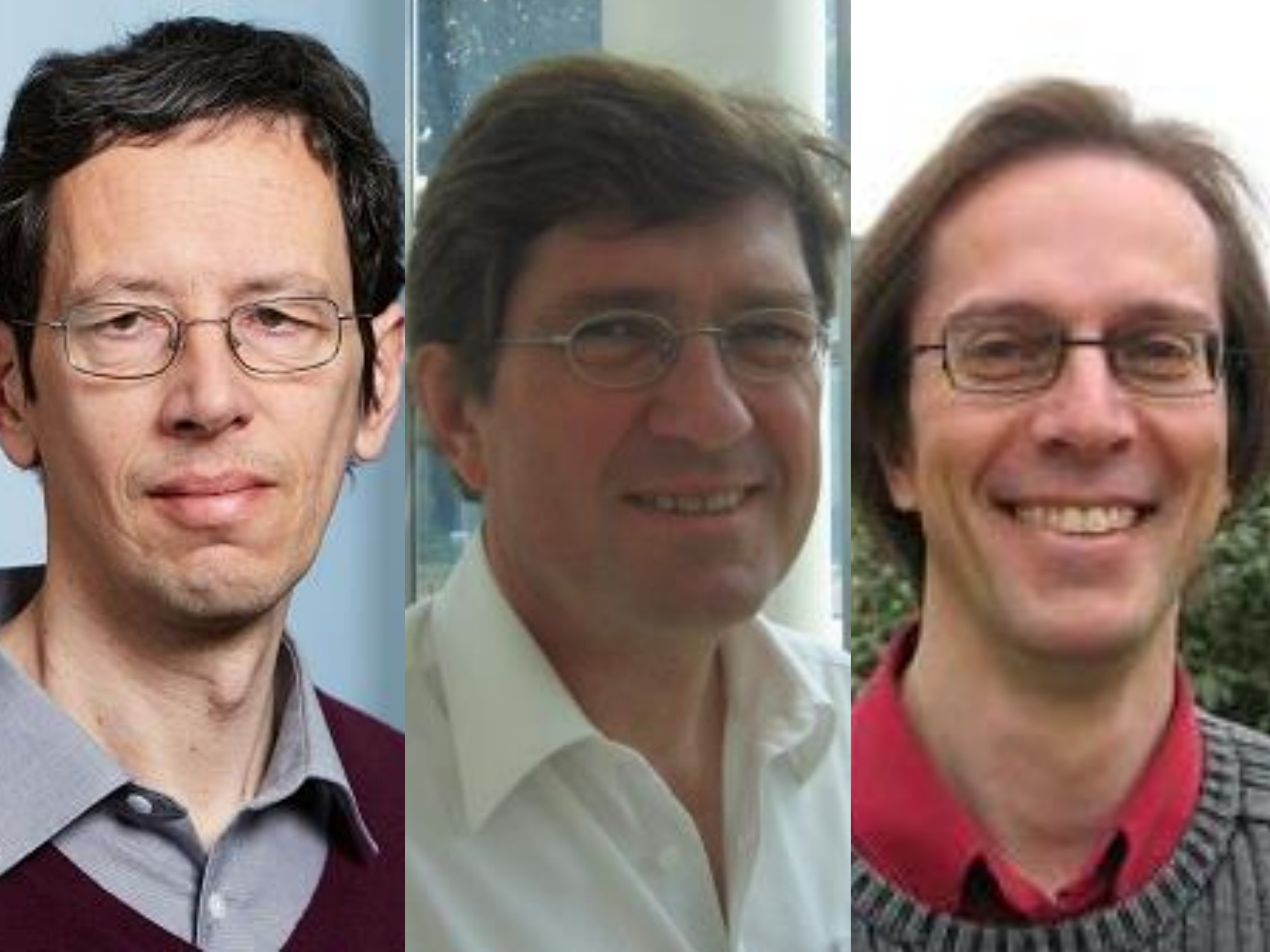




Learning Environment with SpiderBat?



SpiderBat:
Iterative Art Gallery Problem?



Audio → Radio

343 m/s

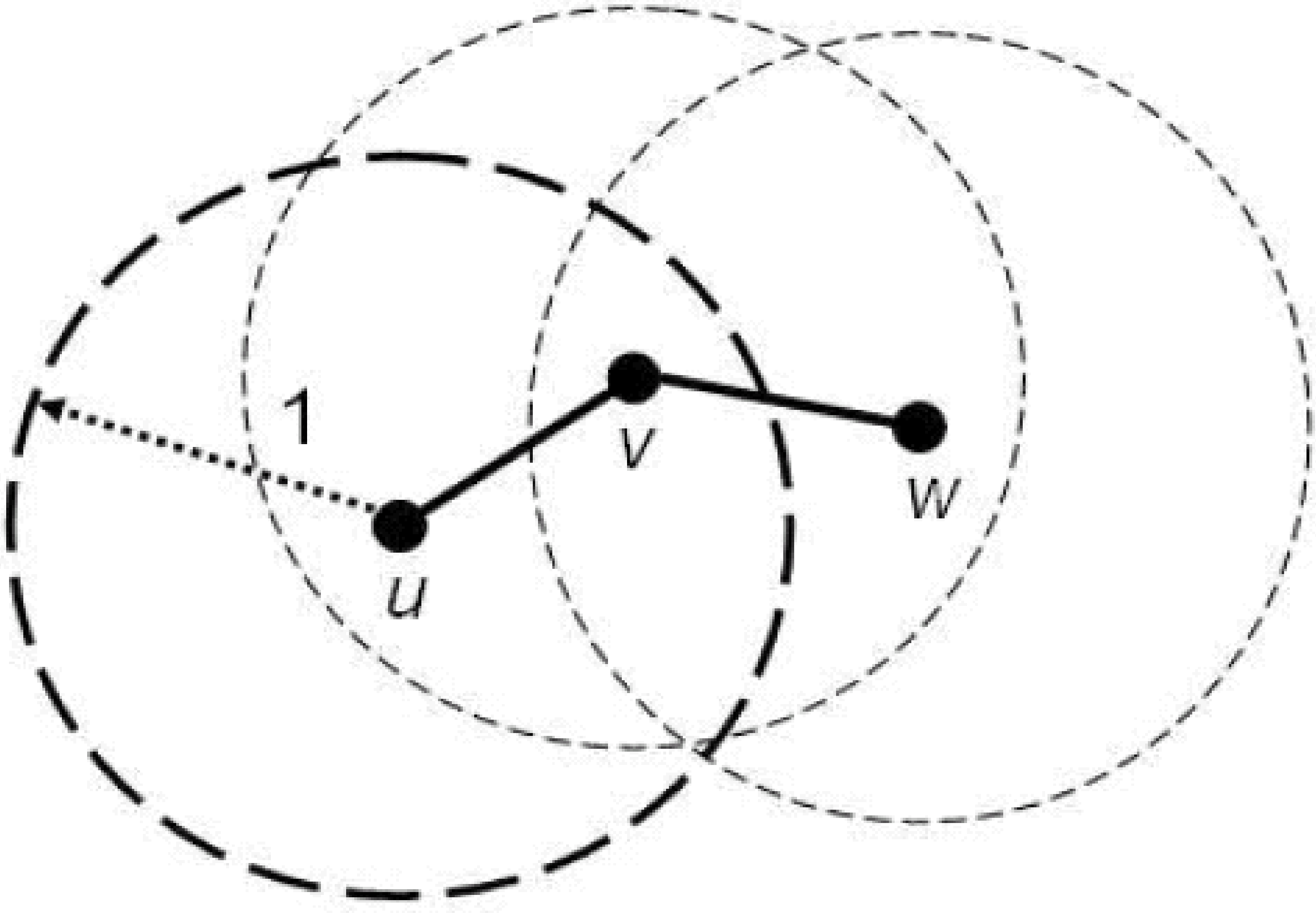
299 792 458 m/s

GPS

Theory?

Position only from Connectivity

Unit Disk Graph (UDG)



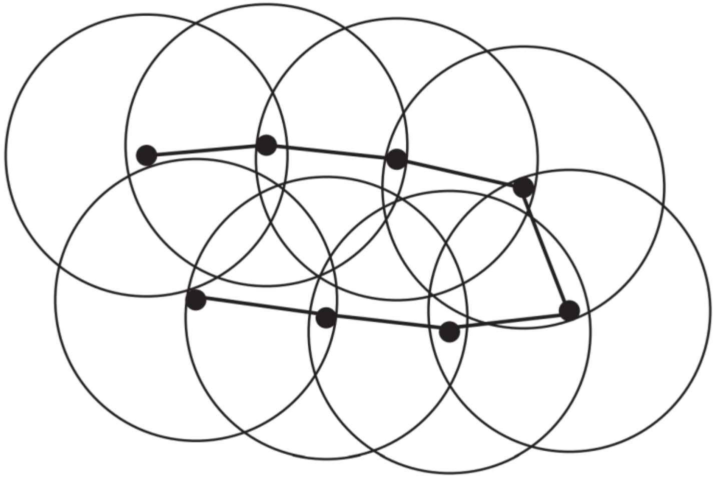
If you gave me $100 for each paper written with the unit disk assumption, I still could *not* buy a radio that is unit disk!

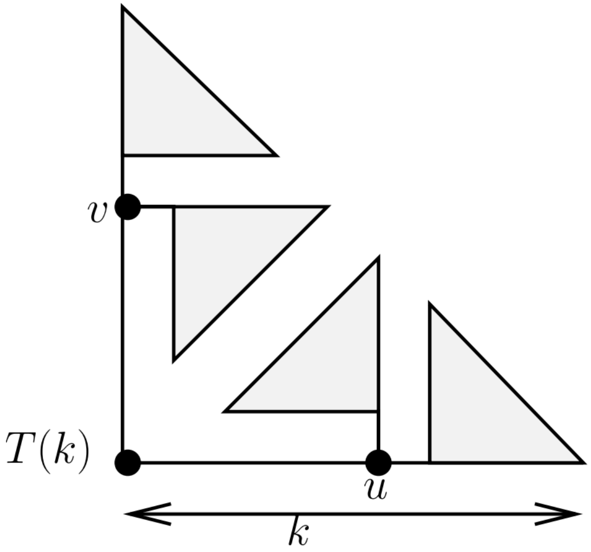
UDG Embedding

1D

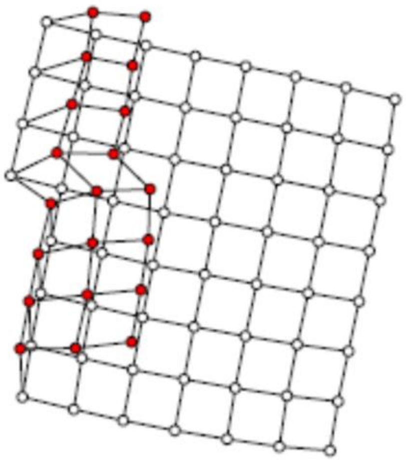
Easy greedy “Hop-Skip” algorithm [O’Dell et al., 2005]

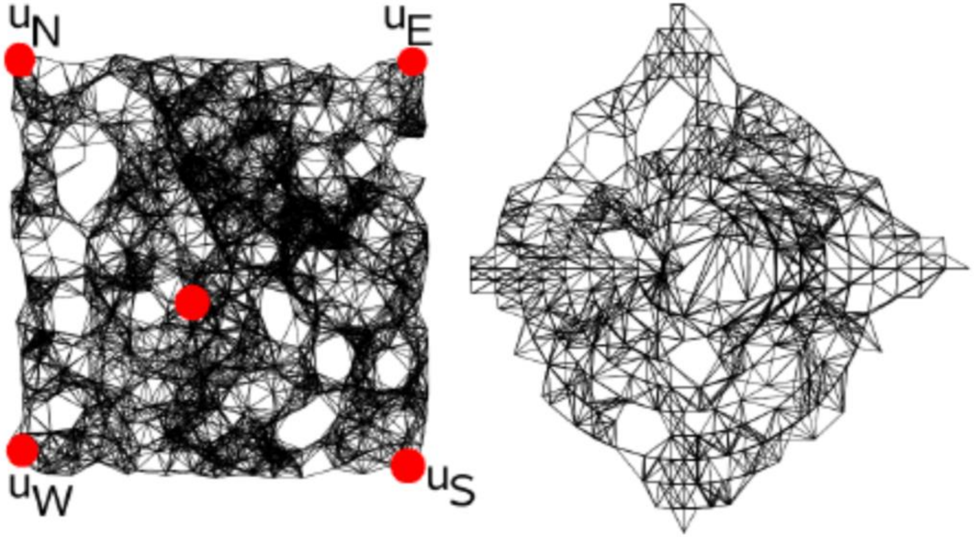
2D

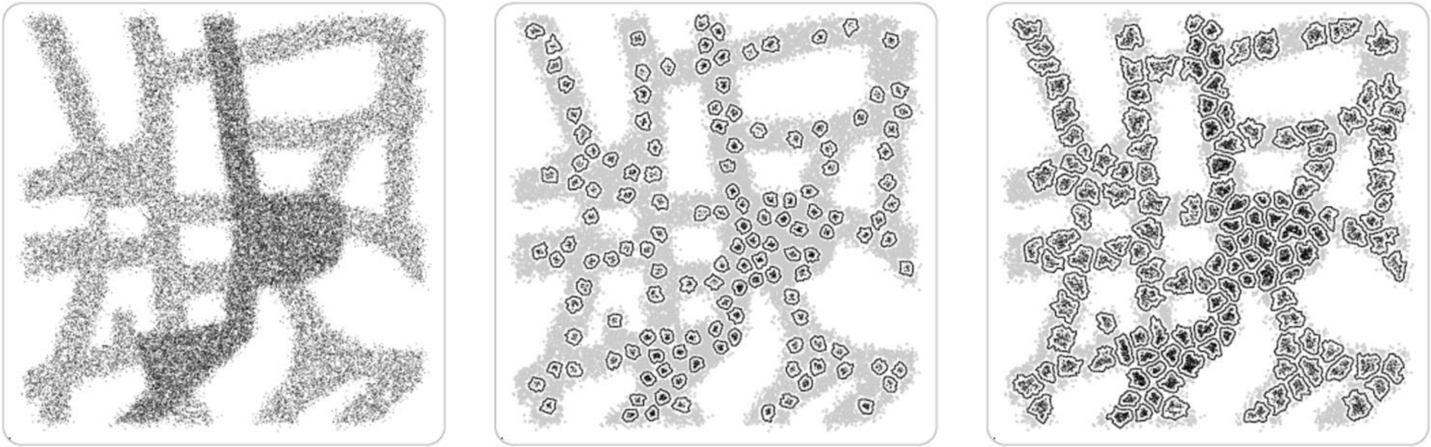




UDG Embedding 2D: Heuristics







e.g., [Priyanta et al., 2003], [Gotsman et al., 2004], [Bruck et al., 2005], [Kröller et al., 2006]

UDG Embedding 2D: Hard Results

2D

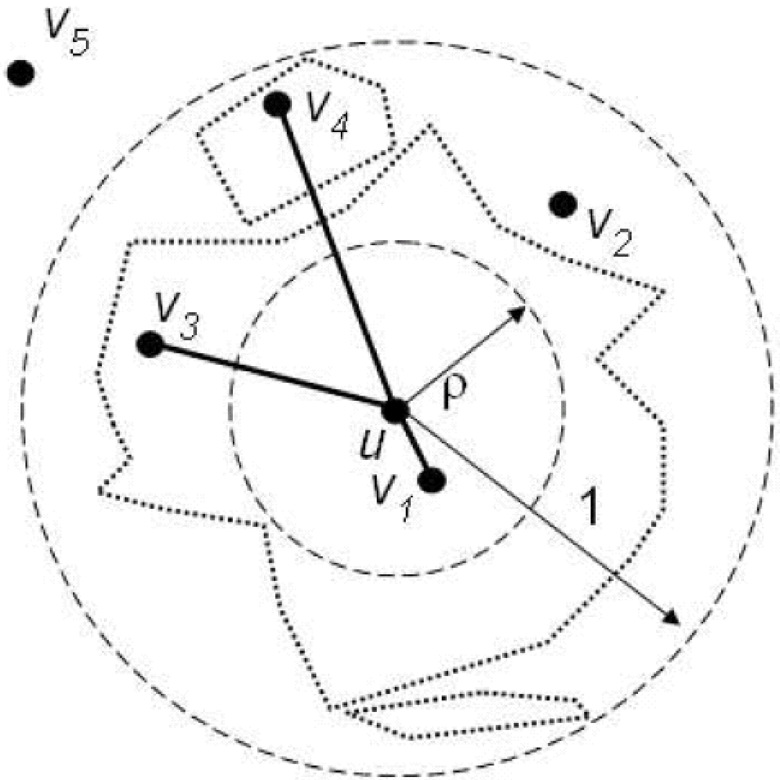
NP-hard, even with exact distance information [Breu, Kirkpatrick, 1998], or angle information [Aspnes et al., 2004] and [Bruck et al., 2004]. Also APX-hard: [Kuhn et al., 2004]

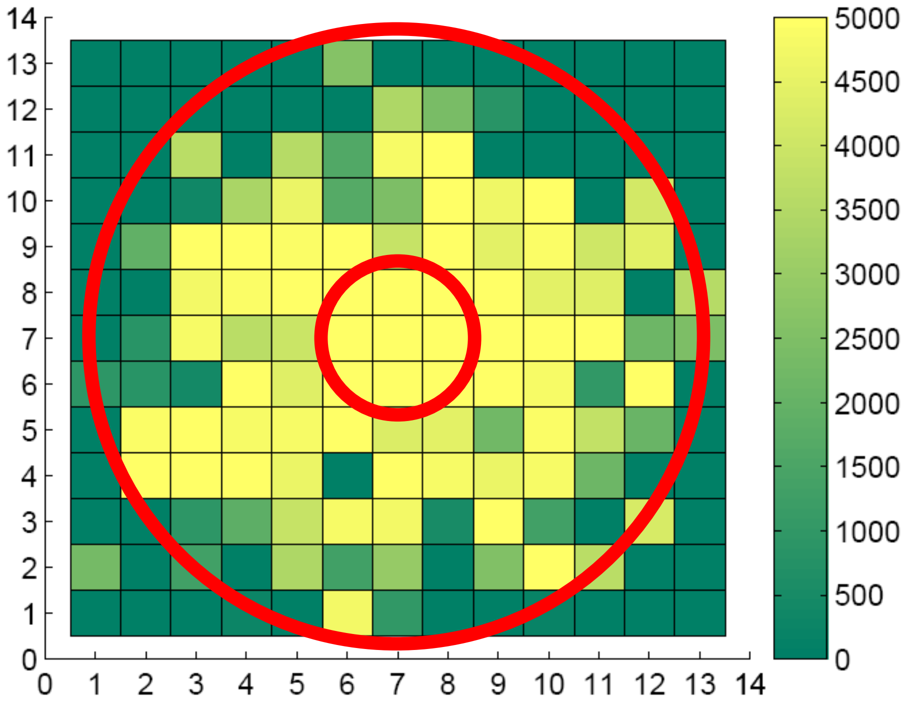
Approximation? $\max d_{\text{no edge}}$ with $d_{\text{edge}} \leq 1$

Approximation algorithms: First [Moscibroda et al., 2004]

Still best: $O(\log^{2.5} n)$ approximation [Pemmaraju et al., 2006]

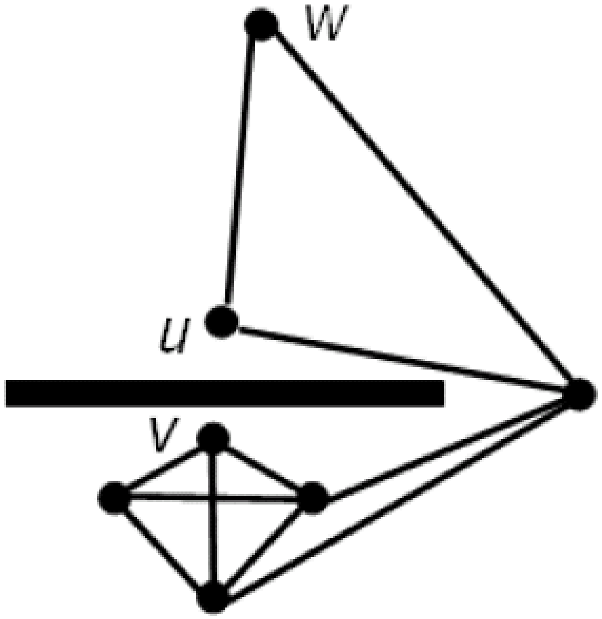
Quasi Unit Disk Graph (QUDG)

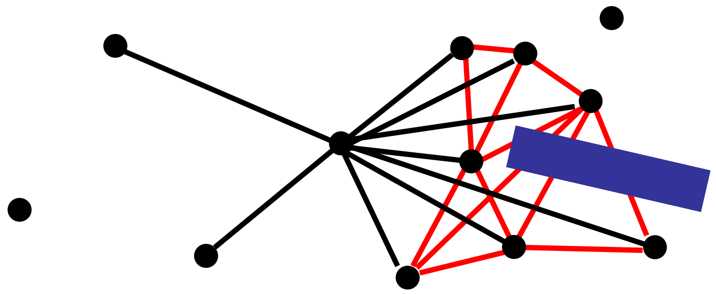





DON'T DISTURB MY CIRCLES.

Bounded Independence Graph (BIG)



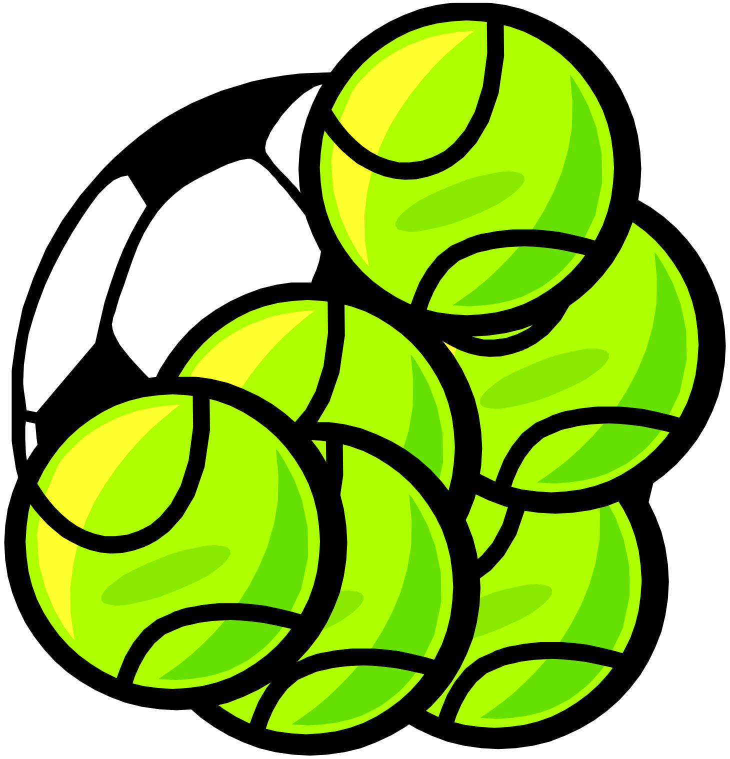


Size of any independent set grows polynomially with hop distance *r*

Unit Ball Graph (UBG)

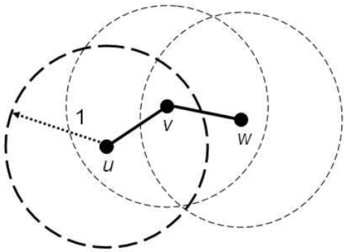
A *metric* with constant doubling dimension

you only need a constant number of balls of half the radius



Overview Wireless Connectivity Models

General Graph



UDG

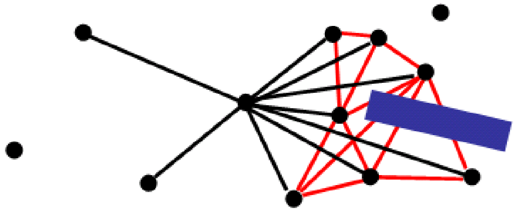
too pessimistic

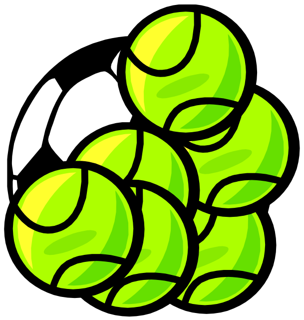
too optimistic

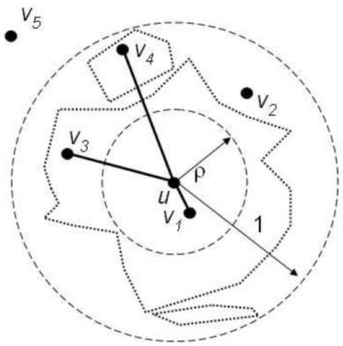
Bounded Independence

Unit Ball Graph

Quasi UDG



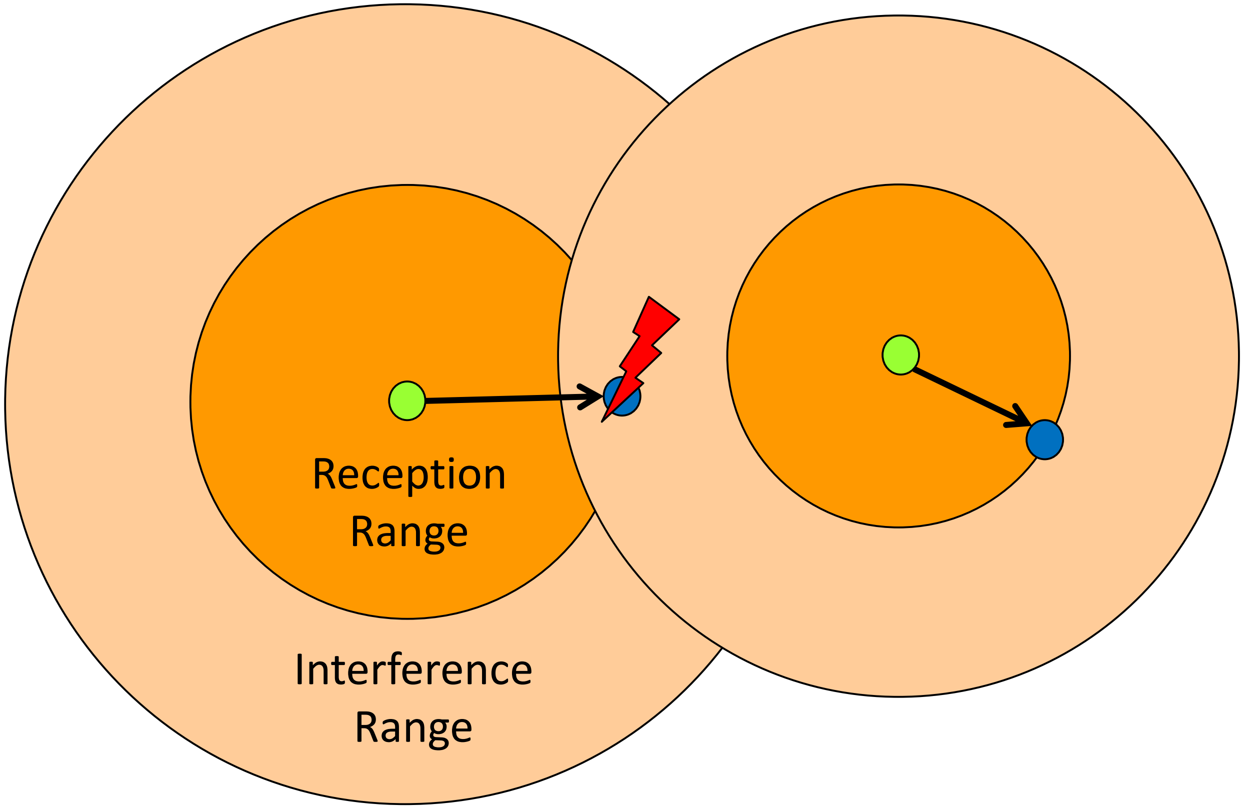




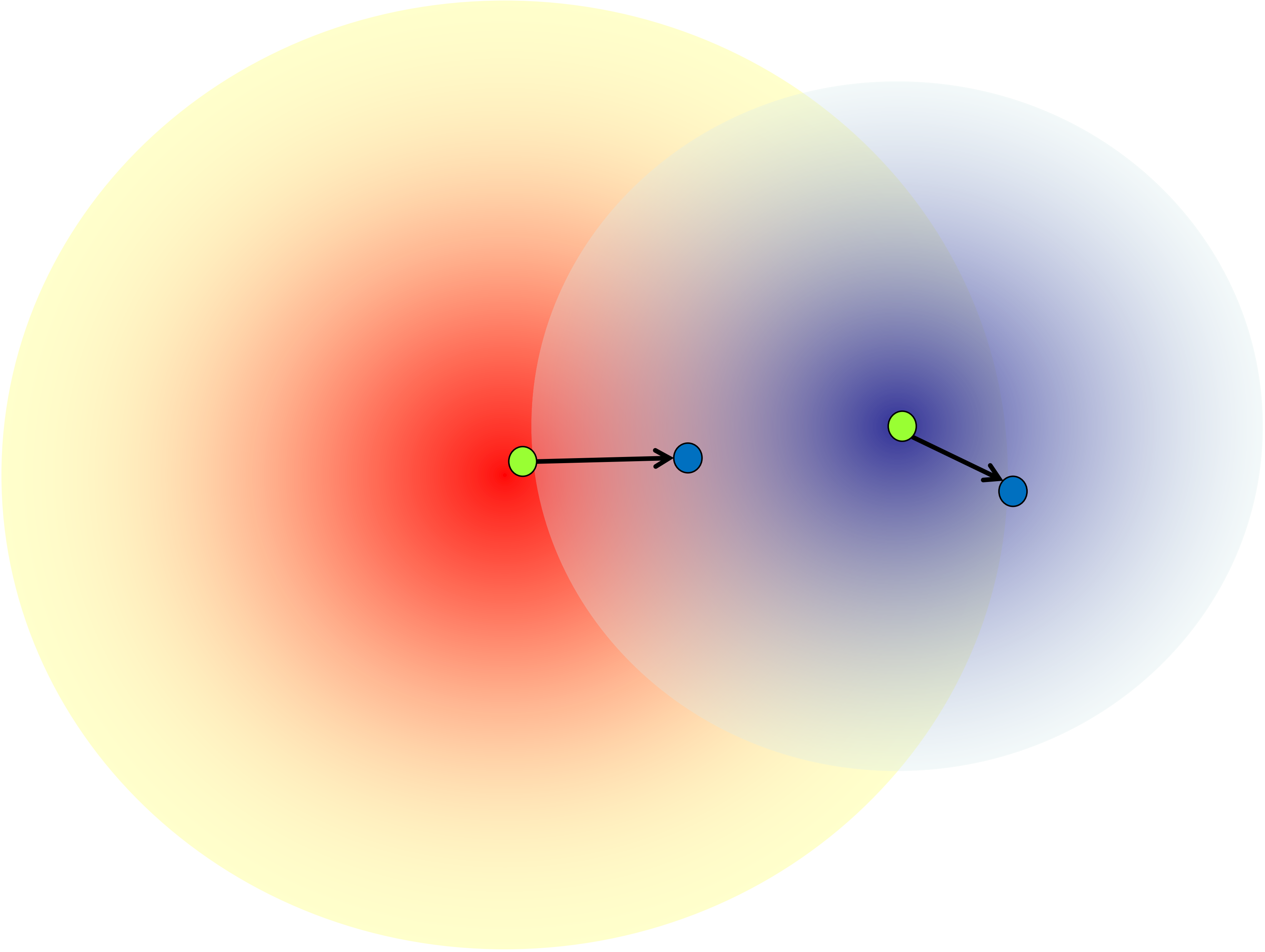
Wireless Networks are not only about Position…

Communication

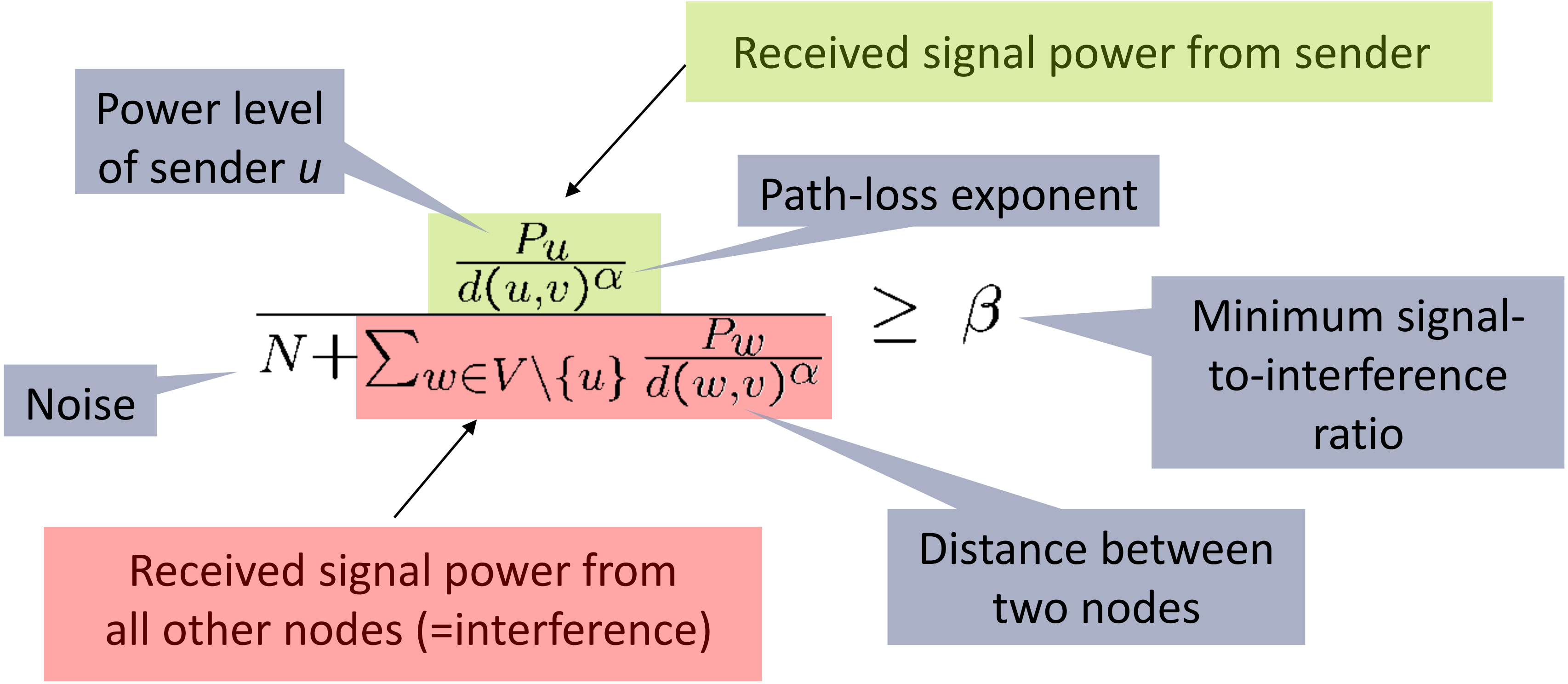
Protocol Model



Physical (SINR) Model



Signal-To-Interference-Plus-Noise Ratio (SINR)



$$\frac{\frac{P_u}{d(u,v)^\alpha}}{N+\sum_{w\in V\setminus\{u\}}\frac{P_w}{d(w,v)^\alpha}} \geq \beta$$

Power level of sender *u*

Received signal power from sender

Path-loss exponent

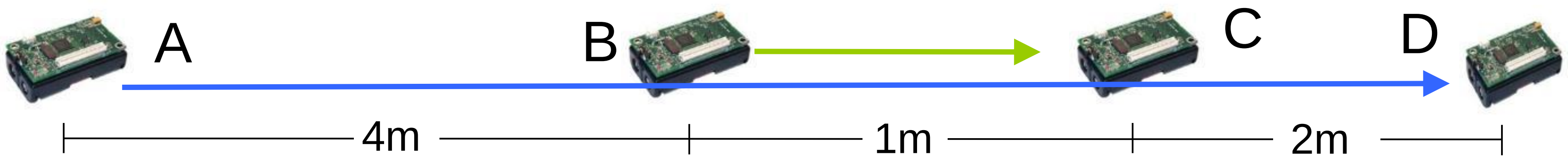
Noise

Minimum signal-to-interference ratio

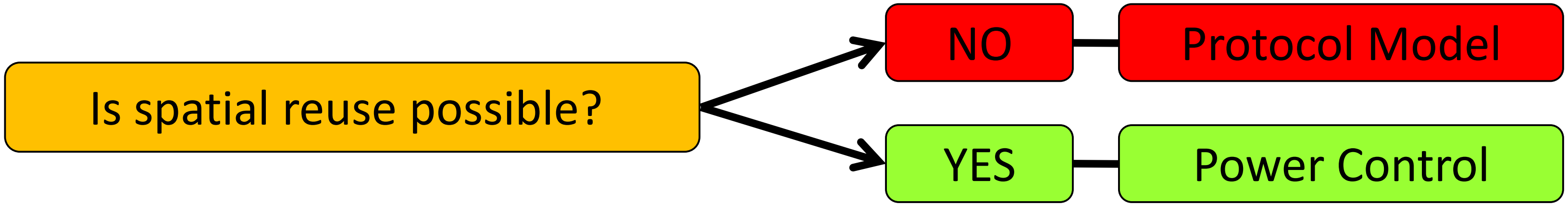
Received signal power from all other nodes (=interference)

Distance between two nodes

Example: Protocol vs. Physical Model



Assume a single frequency (and no fancy decoding techniques!)



Is spatial reuse possible?

NO – Protocol Model

YES – Power Control

Let α=3, β=3, and N=10nW

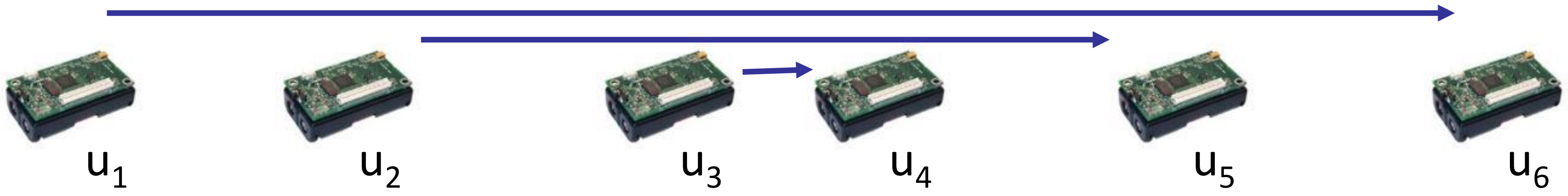
Transmission powers: P_B= -15 dBm and P_A= 1 dBm

SINR of A at D: $$\frac{1.26mW/(7m)^3}{0.01\mu W+31.6\mu W/(3m)^3} \approx 3.11 \geq \beta$$ 👍

SINR of B at C: $$\frac{31.6\mu W/(1m)^3}{0.01\mu W+1.26mW/(5m)^3} \approx 3.13 \geq \beta$$ 👍

This works in practice

… even with very simple hardware



Time for transmitting 20‘000 packets:

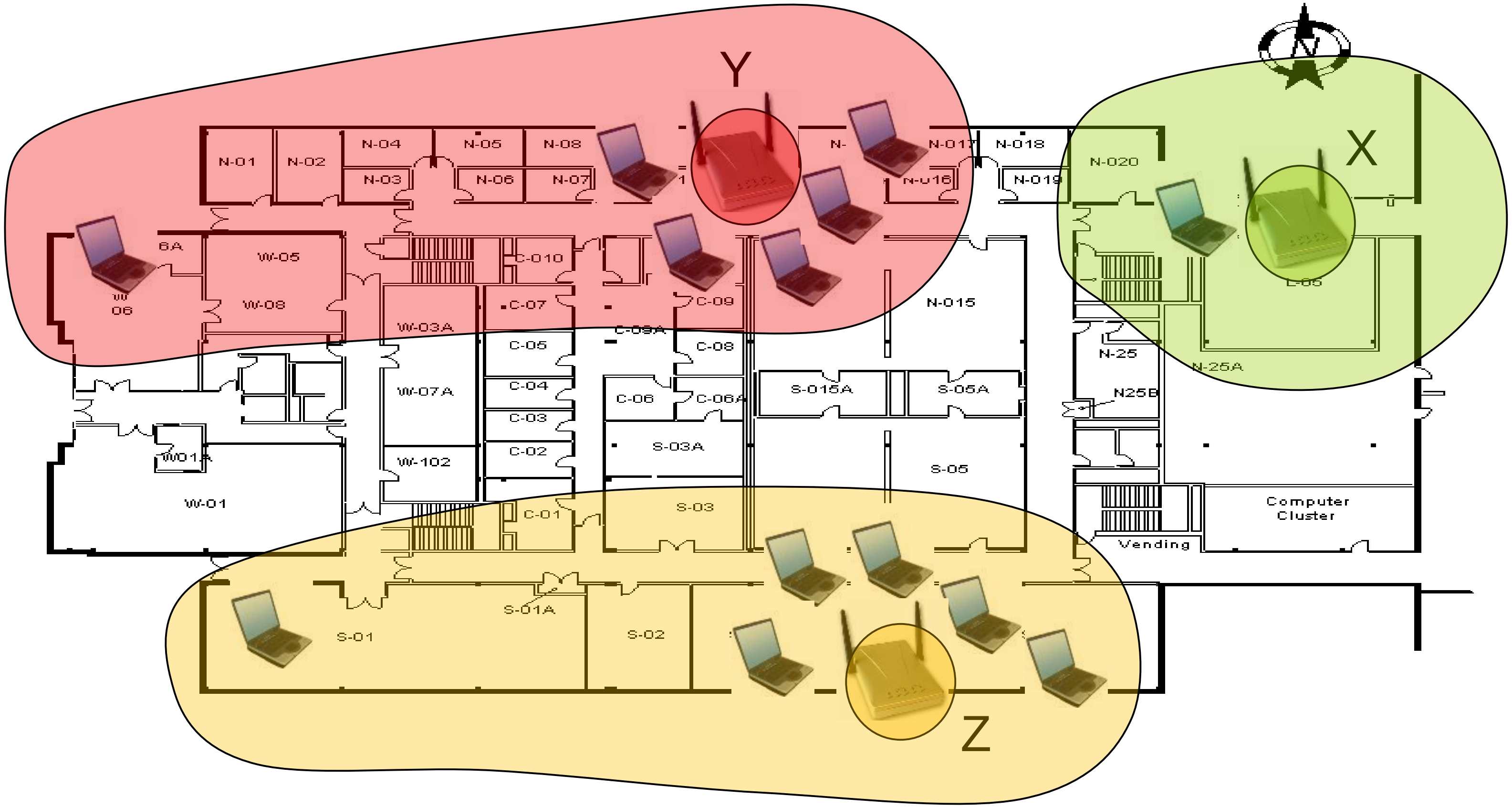
	Time required	
	standard MAC	“SINR-MAC”
Node u_1	$721s$	$267s$
Node u_2	$778s$	$268s$
Node u_3	$780s$	$270s$

	Messages received	
	standard MAC	“SINR-MAC”
Node u_4	19999	19773
Node u_5	18784	18488
Node u_6	16519	19498

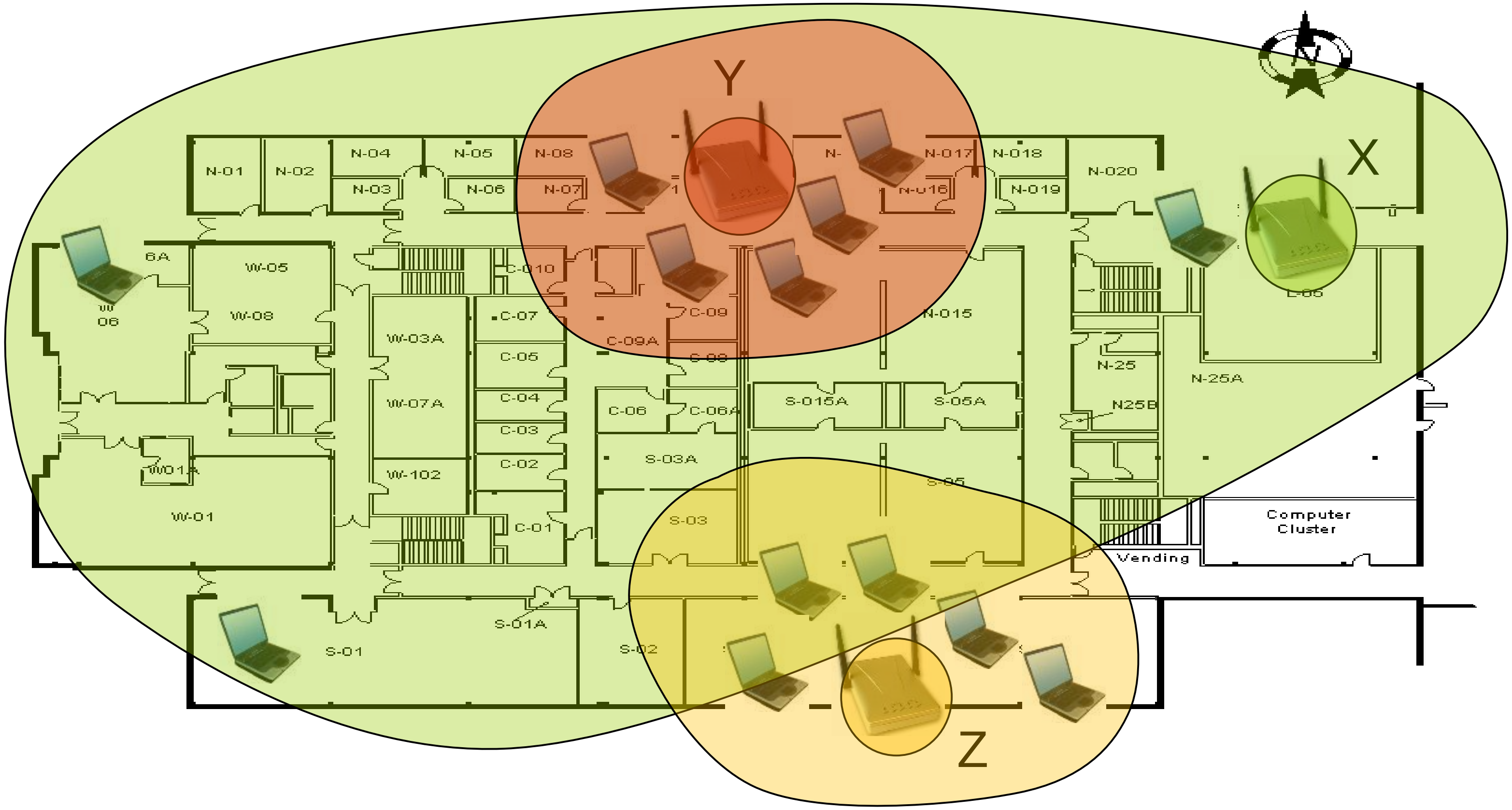
Speed-up is almost a factor 3

[Moscibroda et al., 2006]

Possible Application – Hotspots in WLAN



Possible Application – Hotspots in WLAN



The Capacity of a Network

Maximum concurrent wireless transmissions

Convergecast Capacity in Sensor Networks

[Moscibroda et al., 2006]

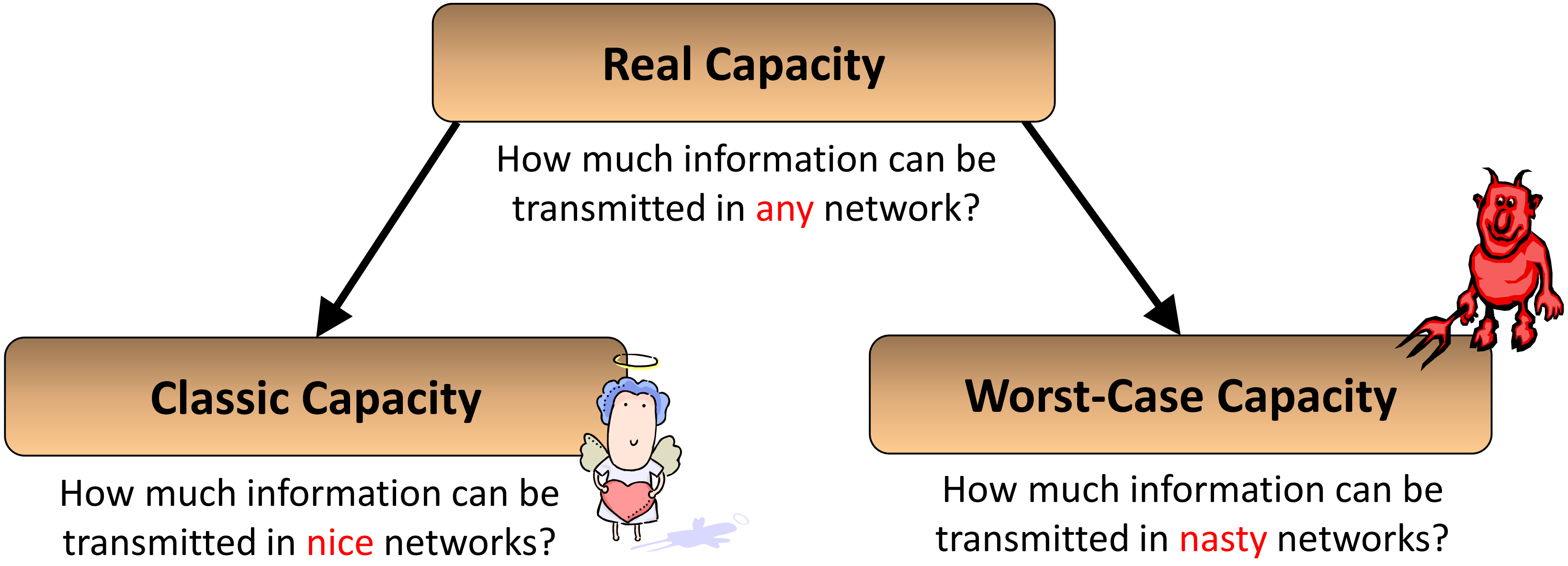
Worst-Case Capacity

[Giridhar, Kumar, 2005]

Classic Capacity

Topology Model/Power	Max. rate in arbitrary, worst-case deployment	Max. rate in random, uniform deployment
Protocol Model	$\Theta(1/n)$	$\Theta(1/\log n)$
Physical Model (power control)	$\Omega(1/\log^3 n)$	$\Omega(1/\log n)$

Capacity of a Network



Real Capacity

How much information can be transmitted in any network?

Classic Capacity

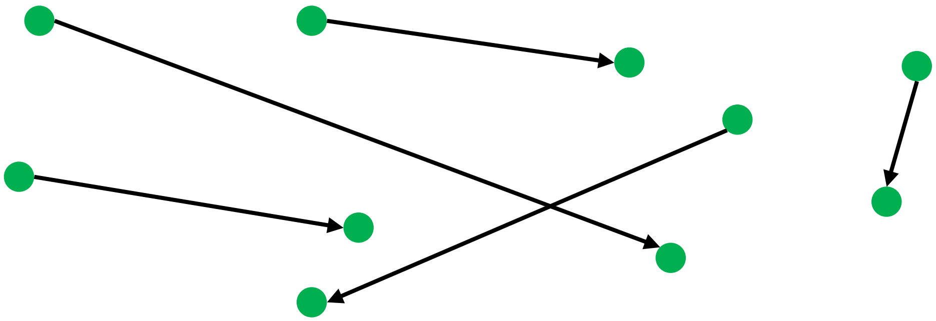
How much information can be transmitted in nice networks?

Worst-Case Capacity

How much information can be transmitted in nasty networks?

Core Capacity Problems

Given a set of arbitrary communication links



One-Shot Problem

Find the maximum size feasible subset of links

NP-hard [Goussevskaia et al., 2007]

O(1) approximations for uniform power [Goussevskaia et al., 2009 & 2014] as well as arbitrary power [Kesselheim, 2011]

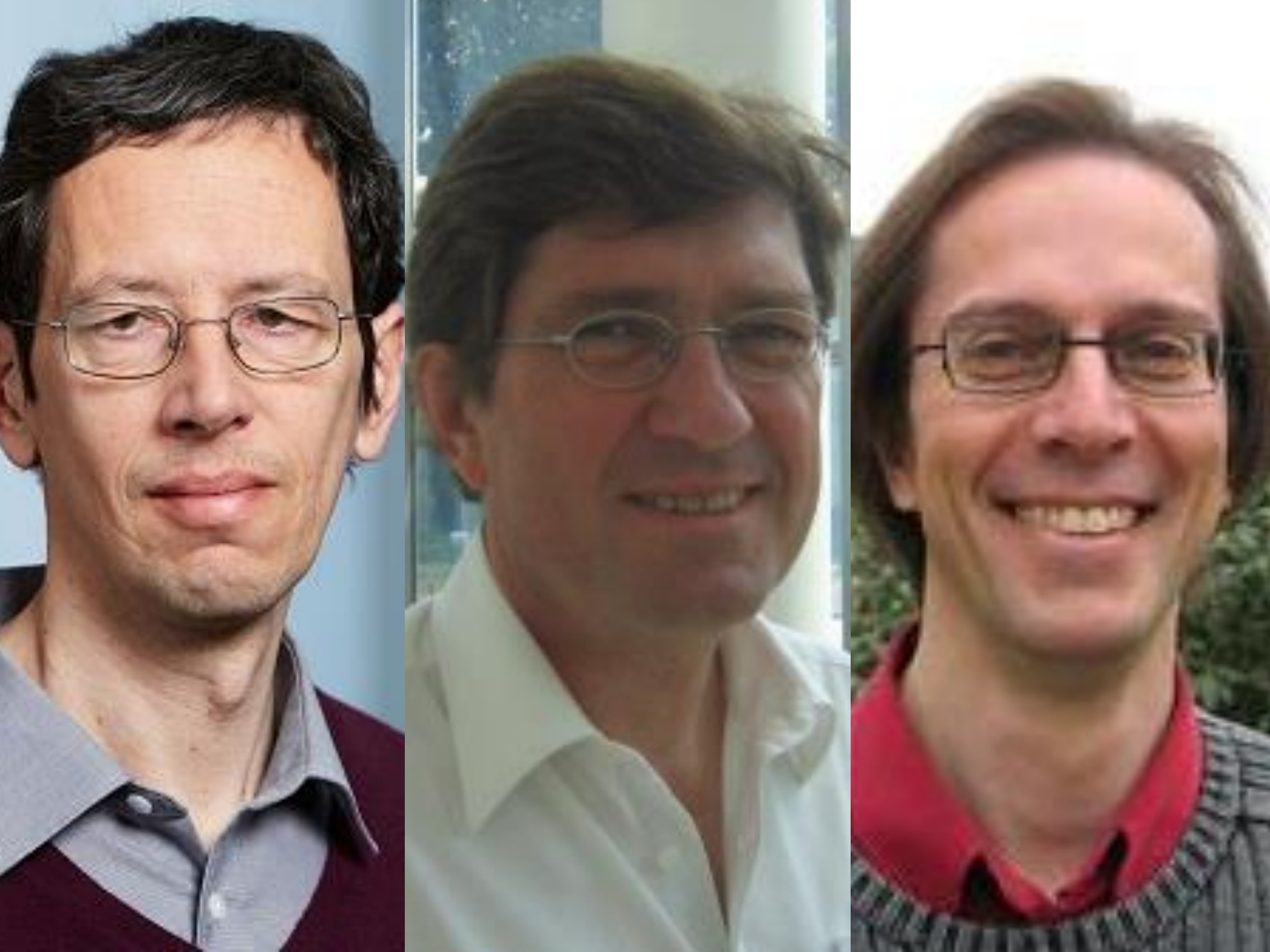
Scheduling Problem

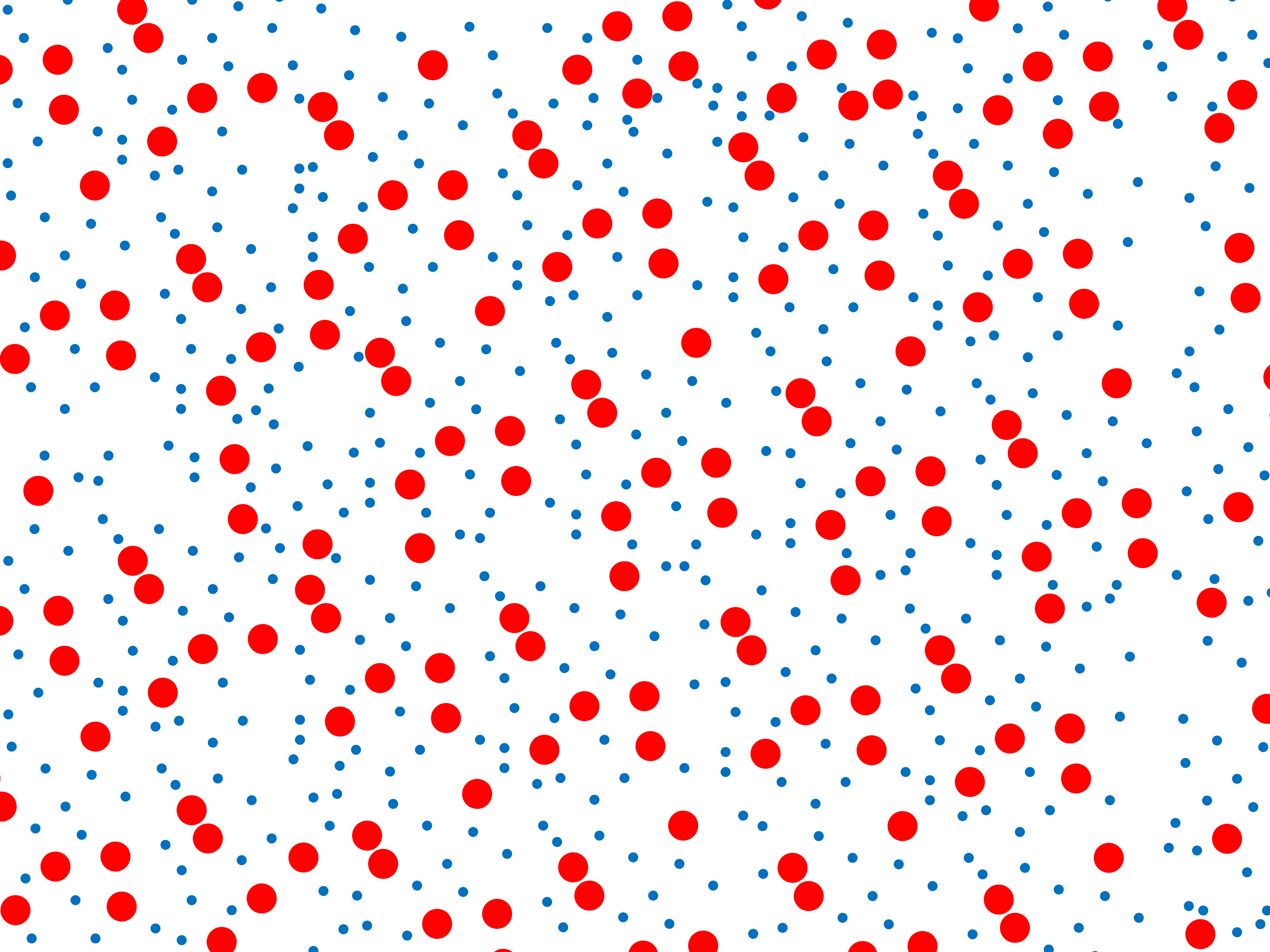
Partition the links into fewest possible slots, to minimize time

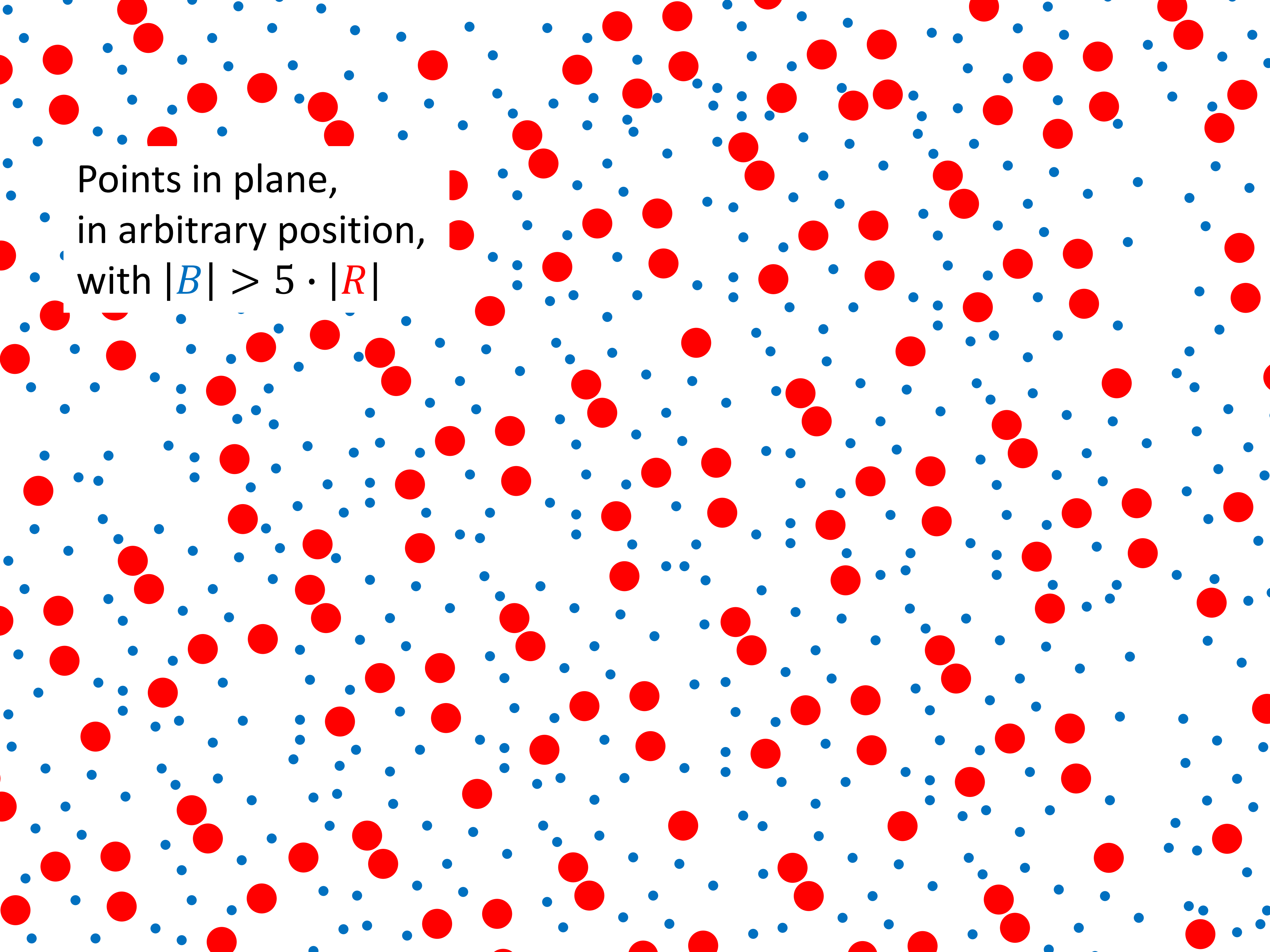
Open problem: Only $O(\log n)$ approximation using the one-shot subroutine*

*apart from $O(\log^* \Delta)$ approximation [Halldorsson & Tonoyan, 2015]

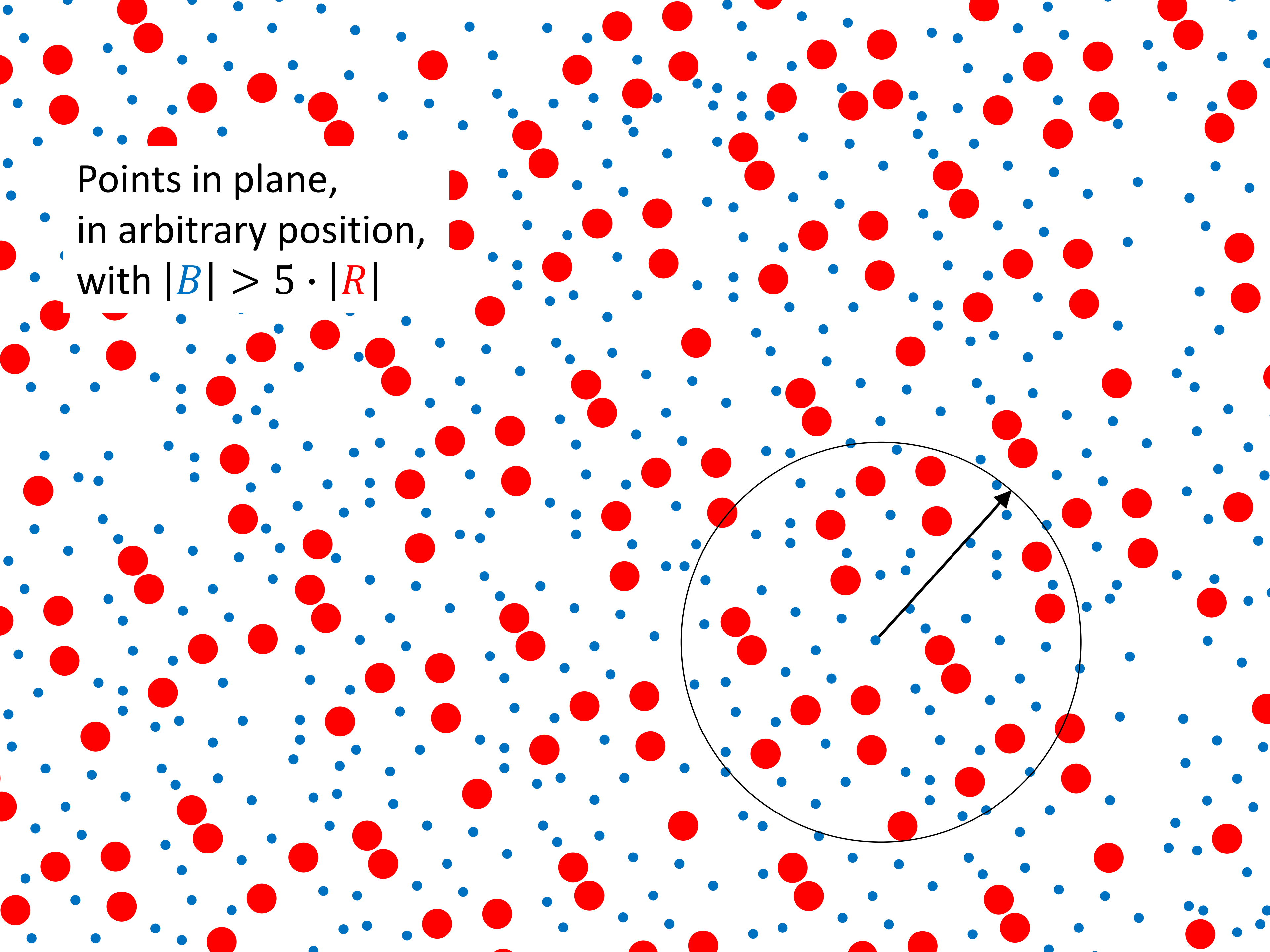
Let’s do some Geometry!







Points in plane,
in arbitrary position,
with $|B| > 5 \cdot |R|$

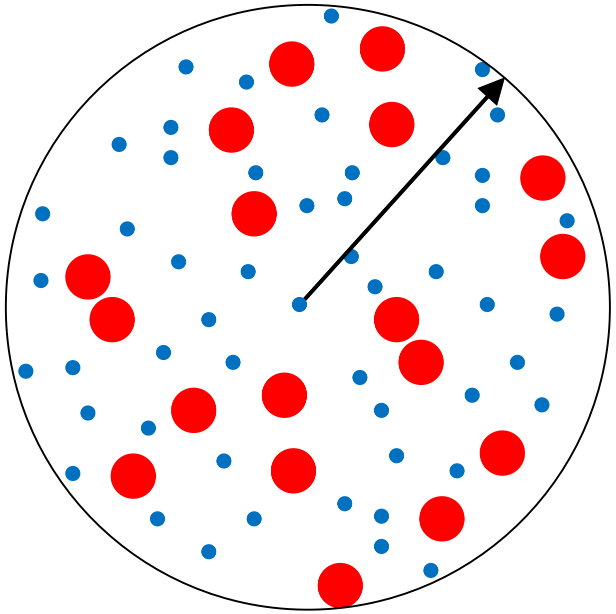


Points in plane,
in arbitrary position,
with $|B| > 5 \cdot |R|$

Points in plane,
in arbitrary position,
with $|B| > 5 \cdot |R|$

There is a $b \in B$,
in any radius r,
$|B| > |R|$

Likewise, if $|B| > 5c \cdot |R|$,
we get $|B| > c \cdot |R|$

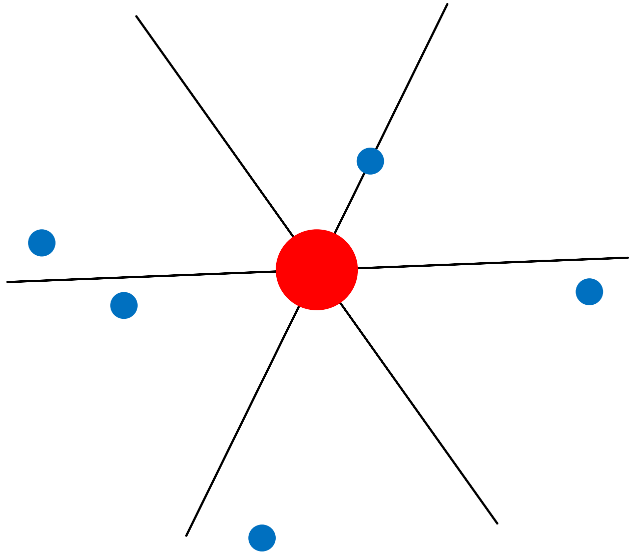


Guarding Nodes

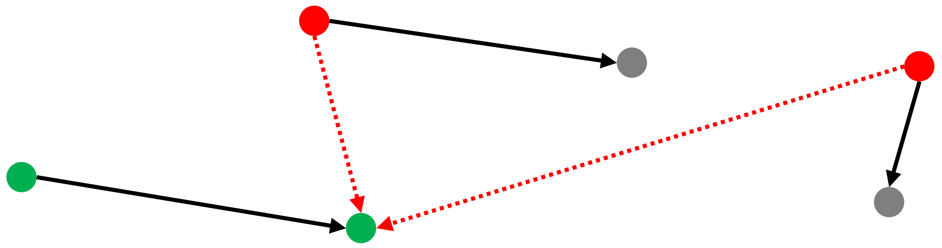
Process red nodes R in arbitrary order

- Each red node r gets 5 blue guardians:
  - The closest blue node b
  - Place star centered at r, through b
  - Closest blue node in 4 other sectors
  - Remove all these nodes

All other blue nodes (at least one) are *guarded* (from red nodes)



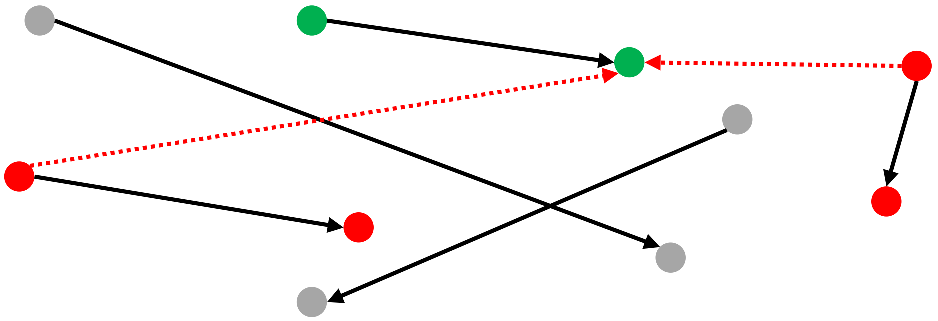
Definition: Affectance



How much does set of interfering senders affect receiver, according to SINR definition, relative to sender strength.

If affectance is not more than 1, receiver can still receive data.

Greedy Algorithm for One-Shot, Constant Power

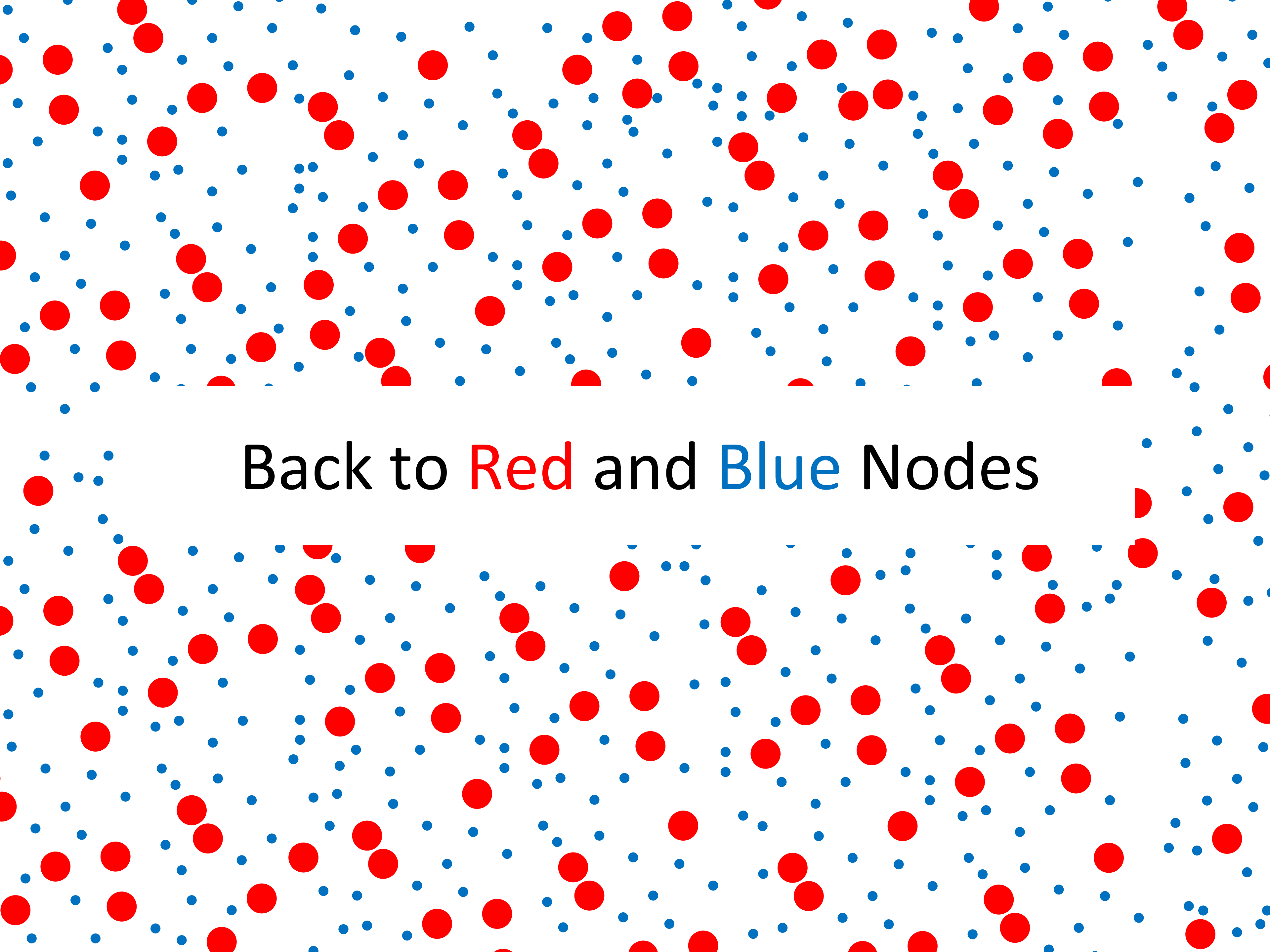


```
Set $S$ = {}
Process all links with increasing length
    If link affectance of set $S$ on link $l$ is less than constant $c < 1$
        Add link $l$ to set $S$
```

Set S is correct because also longer links will not increase affectance beyond 1 (proof omitted)

Why is it a constant approximation?

Back to Red and Blue Nodes



Points in plane,
in arbitrary position,
with $|B| > 5 \cdot |R|$

There is a $b \in B$,
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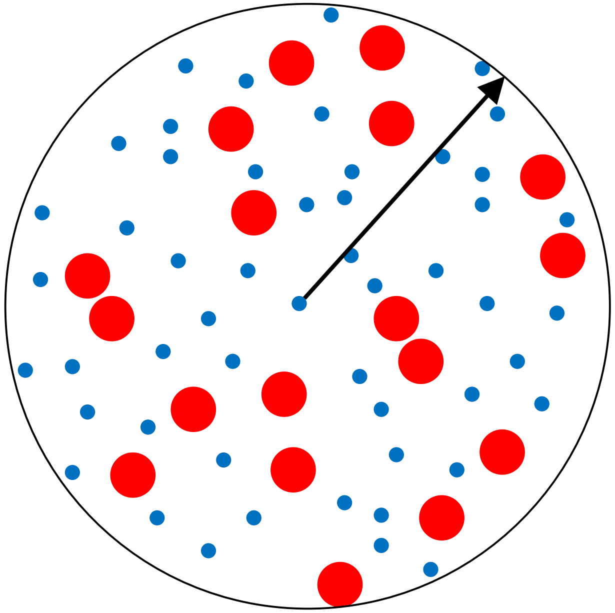


Proof Sketch

Red nodes: Senders of our algorithm, but not optimal

Blue nodes: Senders of optimal algorithm, but not ours

Contradiction:

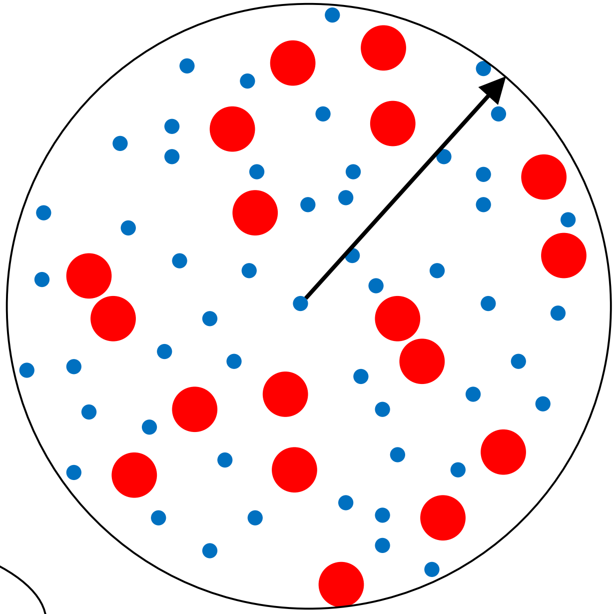
Our algorithm would had

chosen guarded blue nodes

In any radius r, $|B| > c \cdot |R|$

affectance OK
for optimal

affectance too
high for us



SINR Discussion

\+ In contrast to Protocol Model, SINR allows for interference that does sum up.

– Competing transmissions may cancel themselves, and produce less interference. Hence, SINR is pessimistic.

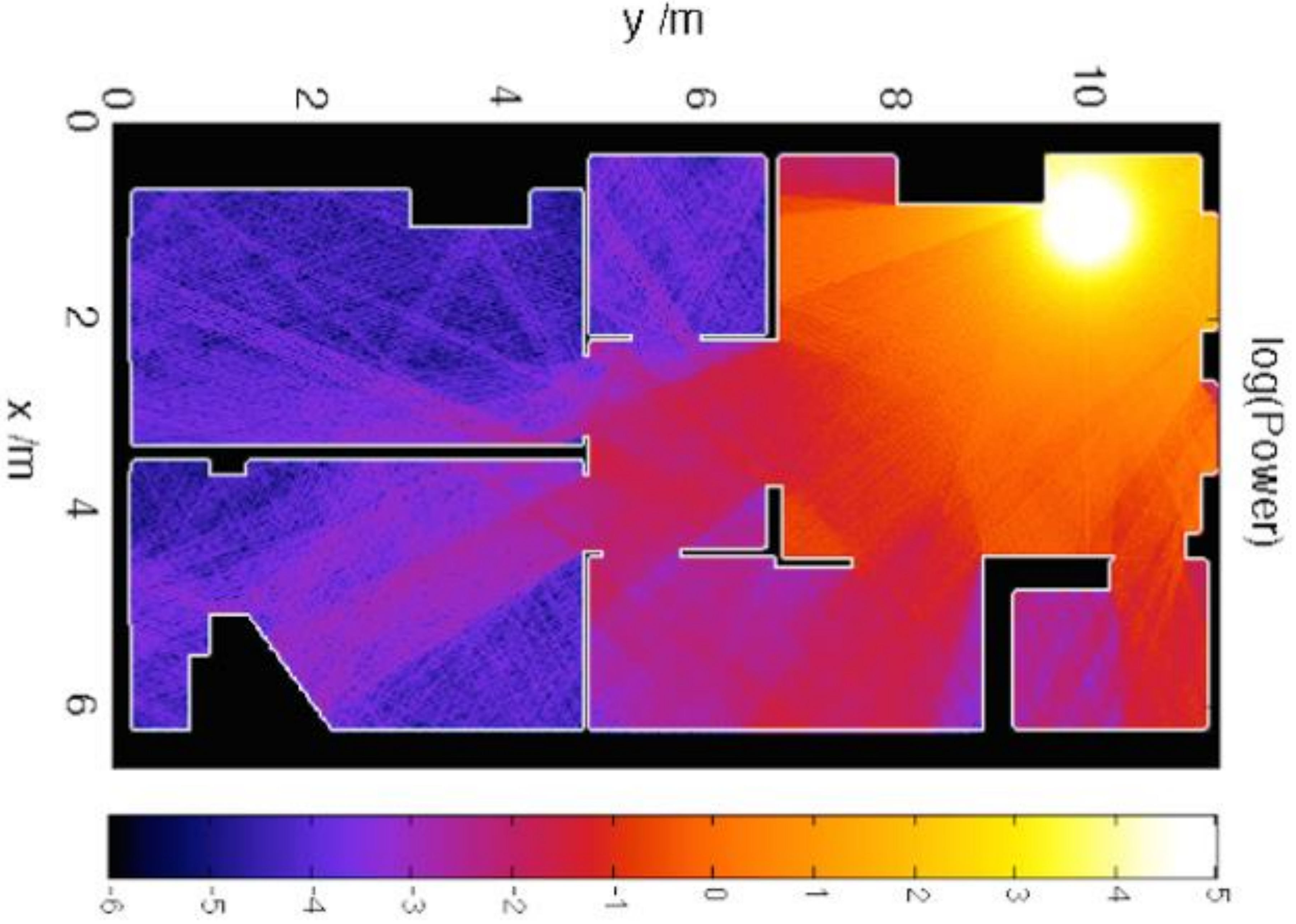
– Signals fluctuate over time. Some of these issues are captured by more complicated fading channel models.

– SINR is “complicated”, hard to analyze.

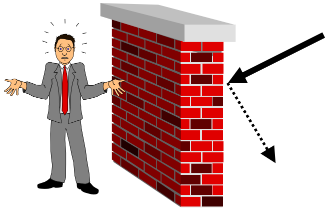
SINR Discussion

- Often, a higher S/N ratio allows for more advanced modulation and coding techniques, allowing for higher throughput.
- One may be able to “subtract” a stronger known part of a summed up signal, in order to get a better understanding of the remaining weaker signal.

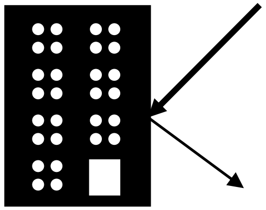
What about walls and other obstructions?


y /m
0
2
4
6
8
10
x /m
0
2
4
6
log(Power)
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5

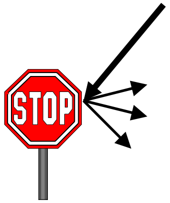
Reality



shadowing

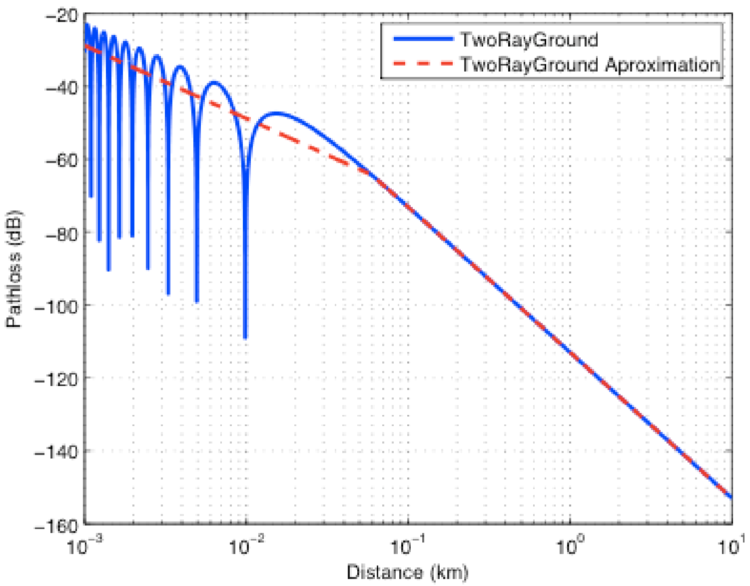


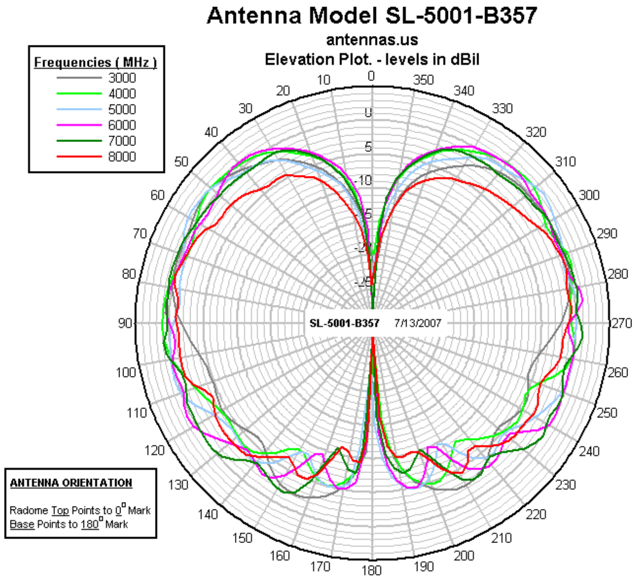
reflection



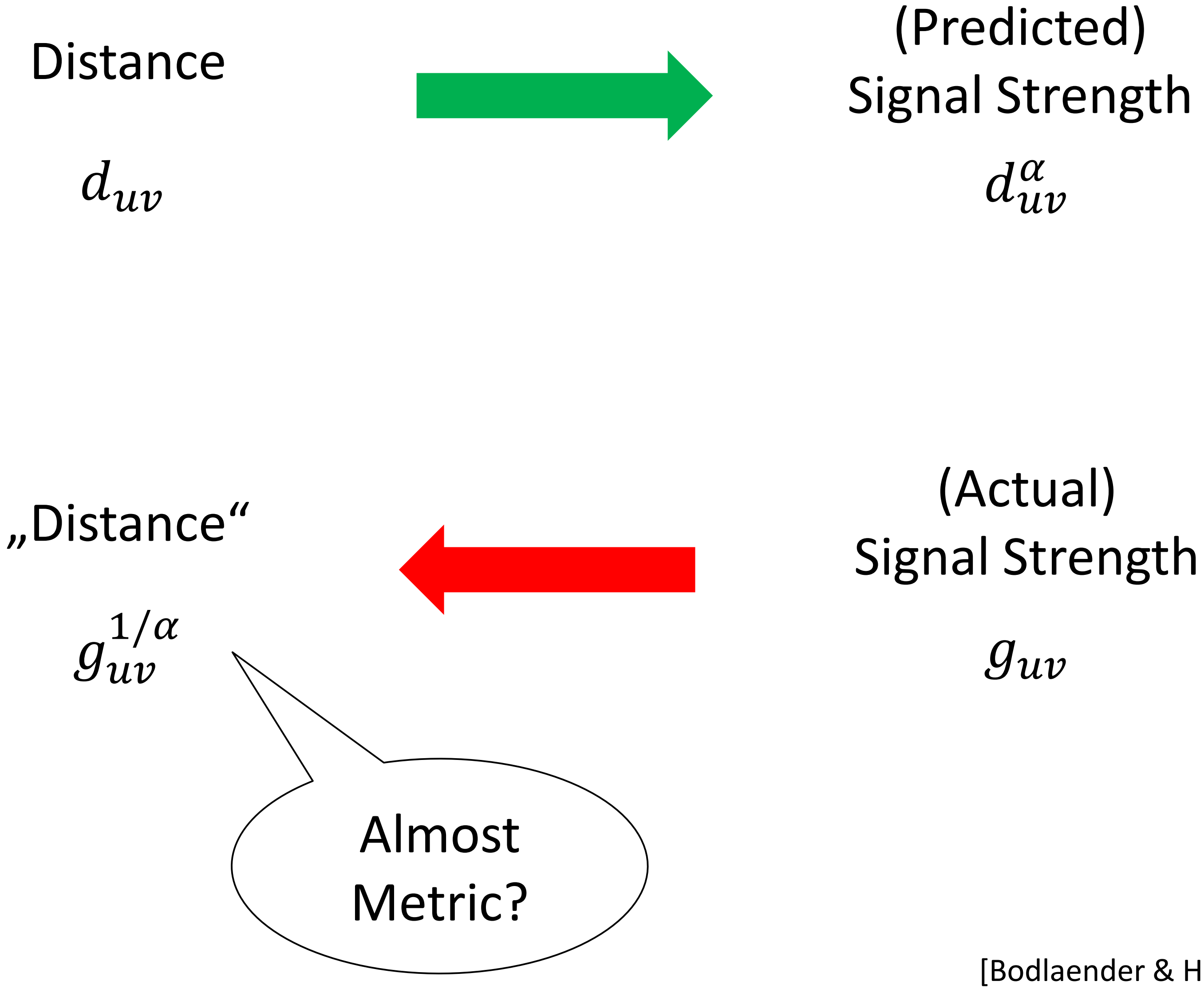
scattering

diffraction





SINR without Geometry?



Distance

d_{uv}

(Predicted)
Signal Strength

d_{uv}^{α}

„Distance“

$g_{uv}^{1/\alpha}$

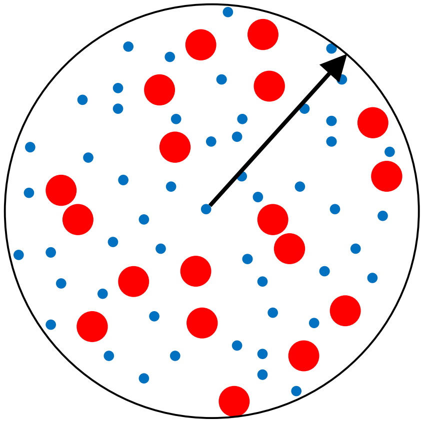
(Actual)
Signal Strength

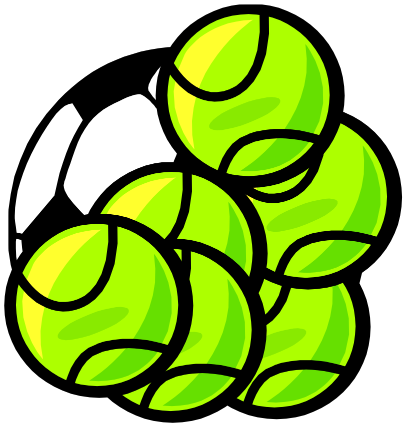
g_{uv}

Almost
Metric?

[Bodlaender & Halldorsson, 2014]

Summary





Thank You!

Questions & Comments?

Thanks to my co-authors, mostly
Pascal Bissig
Olga Goussevskaia
Magnus Halldorsson
Thomas Moscibroda
Philipp Sommer

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