DATAMAN
MOBILE COMPUTING LABORATORY

Trajectory Based Forwarding and Its Applications[1]

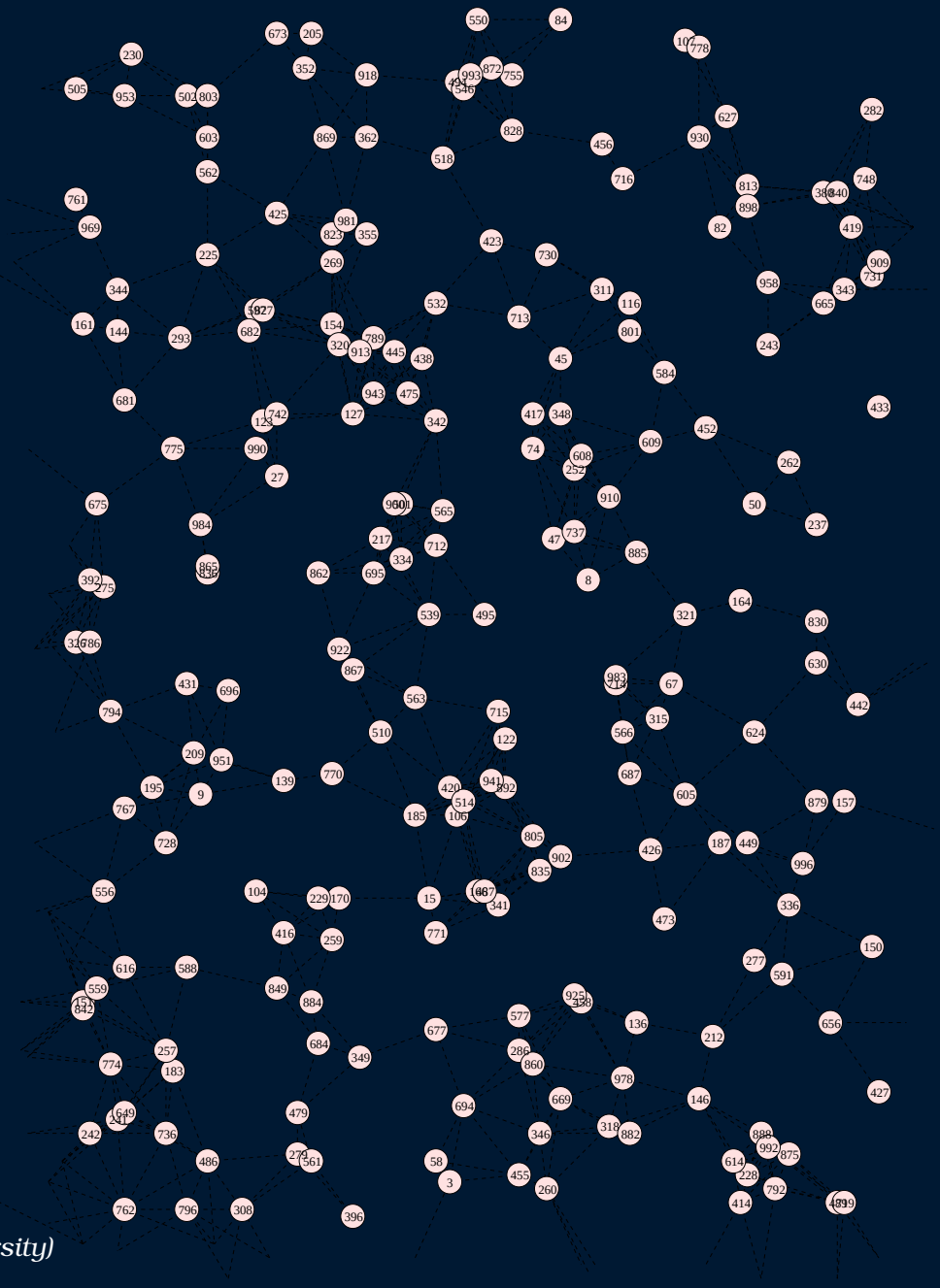
Dragoş Niculescu and Badri Nath
{dnicules,badri}@cs.rutgers.edu

RUTGERS University

[1]funded in part by NSF and DARPA

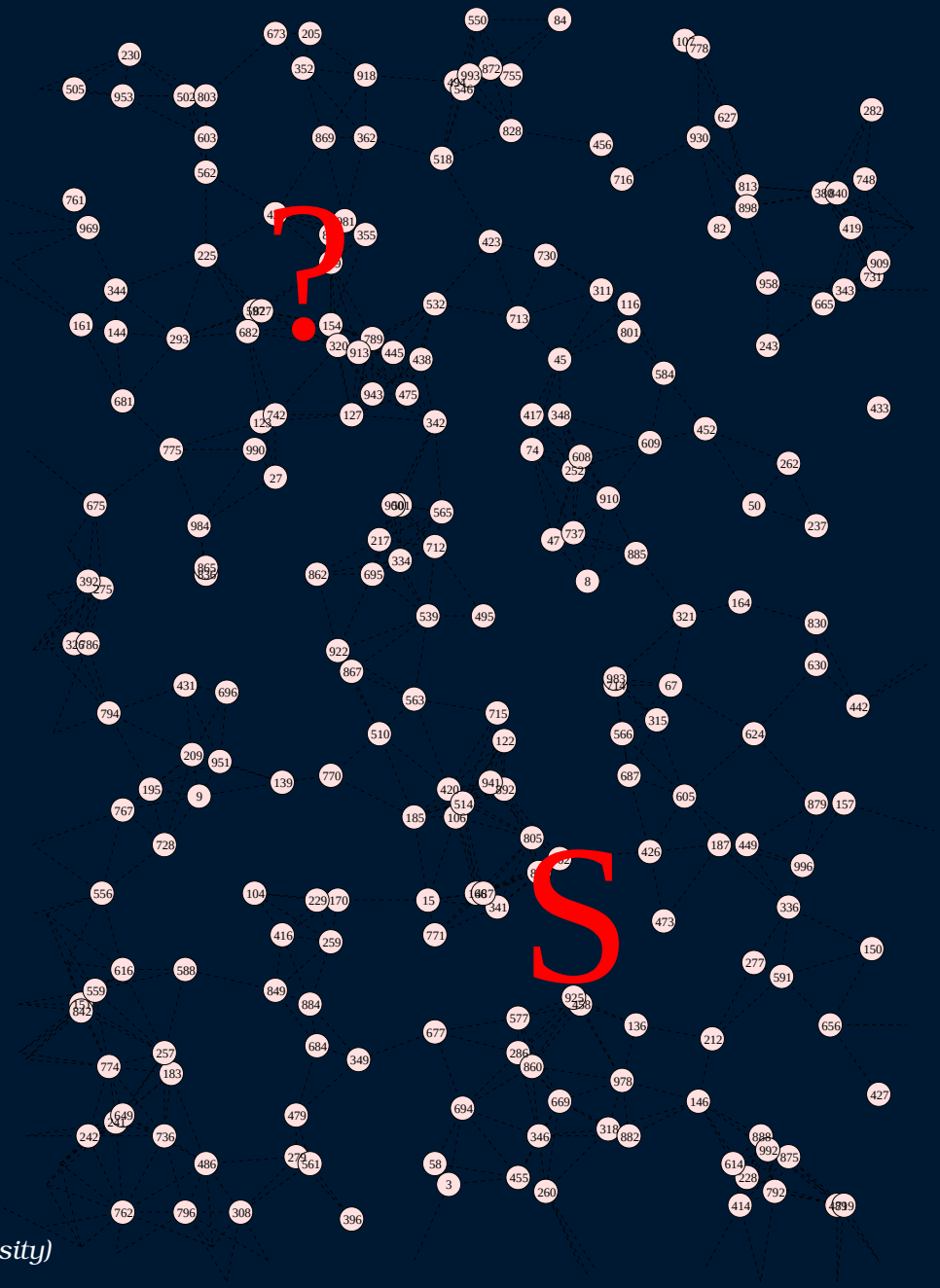
problems in ad hoc networks

- **discover**
- **route**
  - **multipath**
  - **mobile source**
  - **multicast**
- **scalability issues**
  - **routing tables**
  - **flooding**



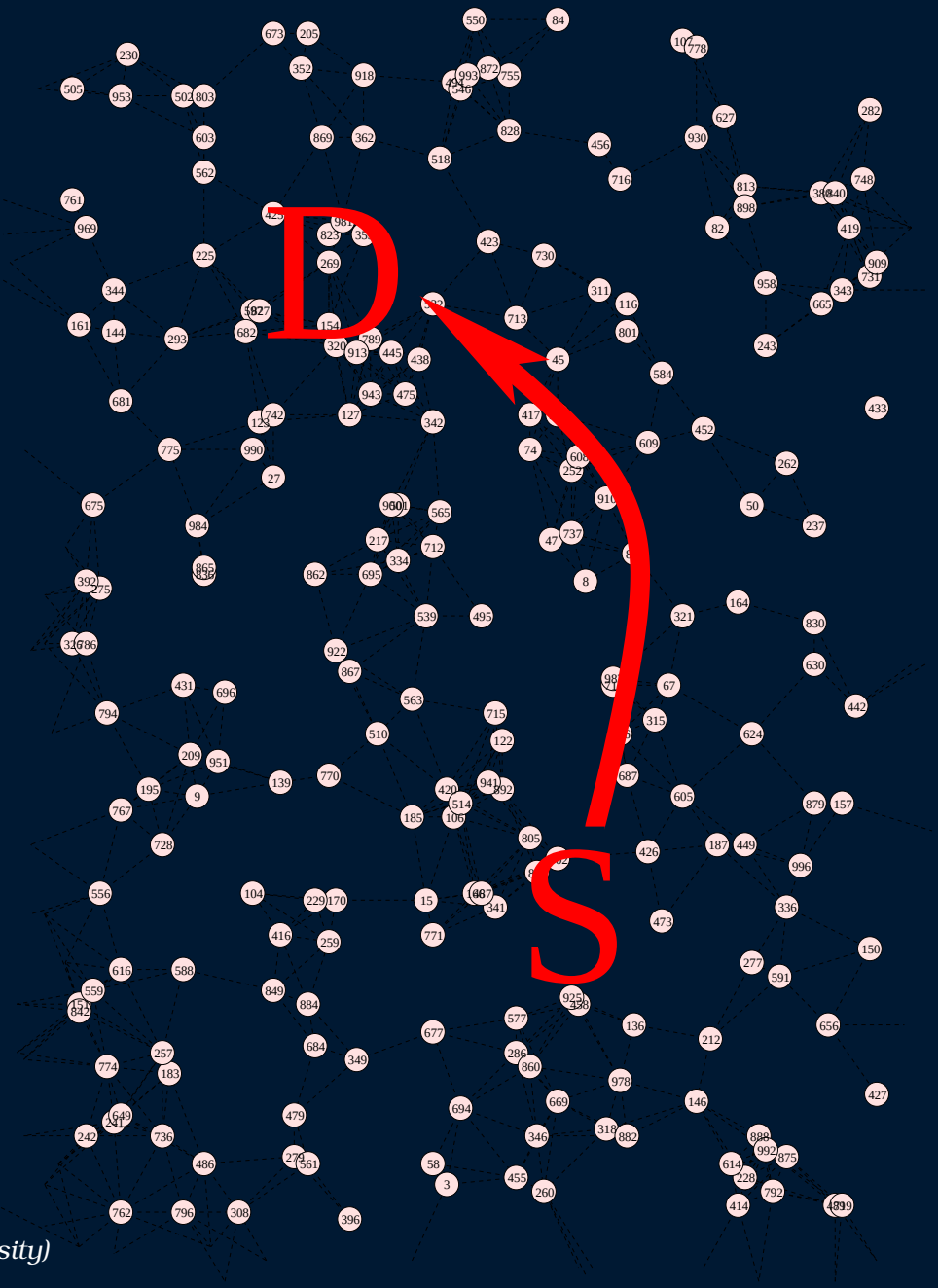
problems in ad hoc networks

- discover
- route
  - multipath
  - mobile source
  - multicast
- scalability issues
  - routing tables
  - flooding



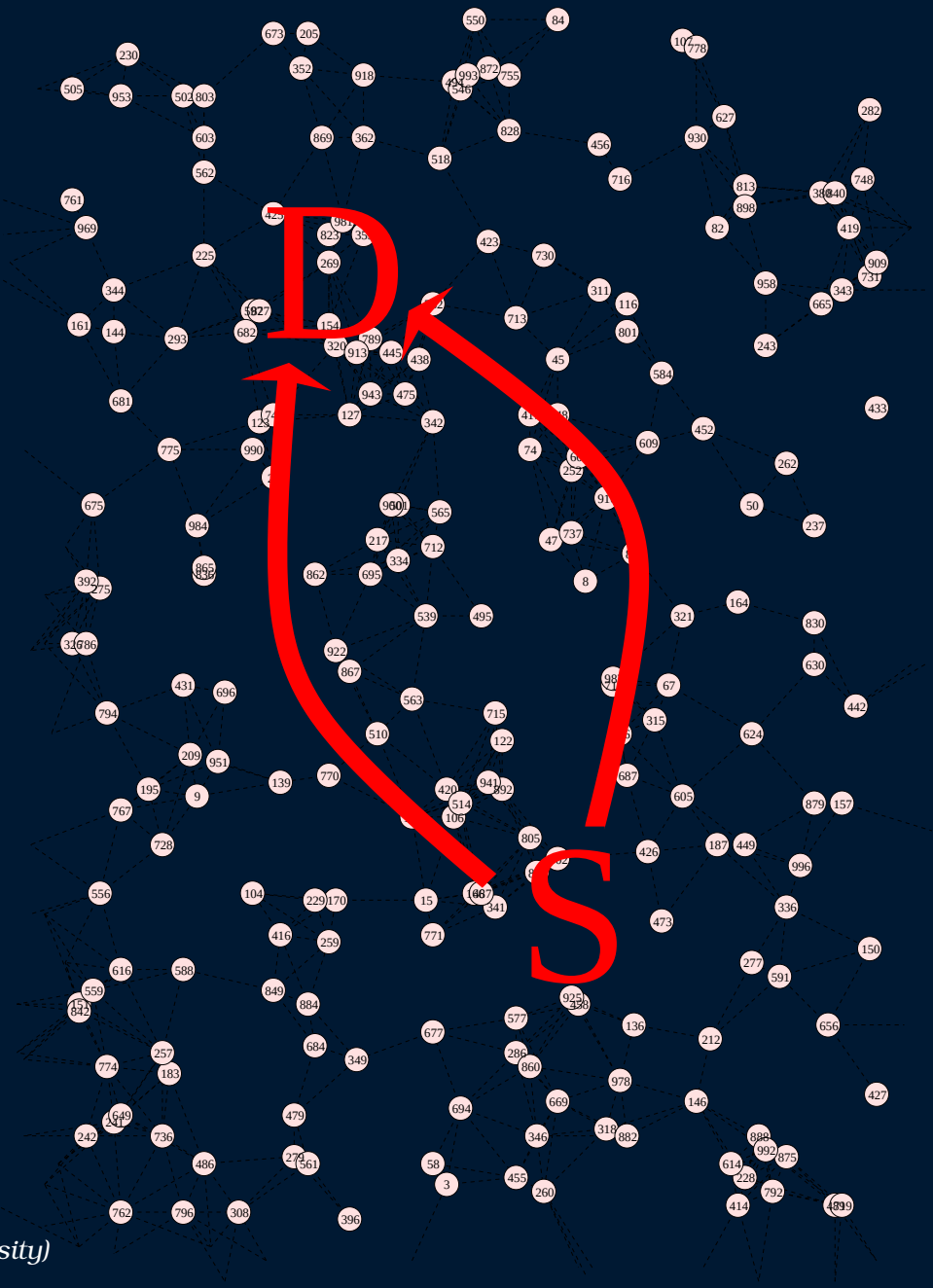
problems in ad hoc networks

- discover
- route
  - multipath
  - mobile source
  - multicast
- scalability issues
  - routing tables
  - flooding



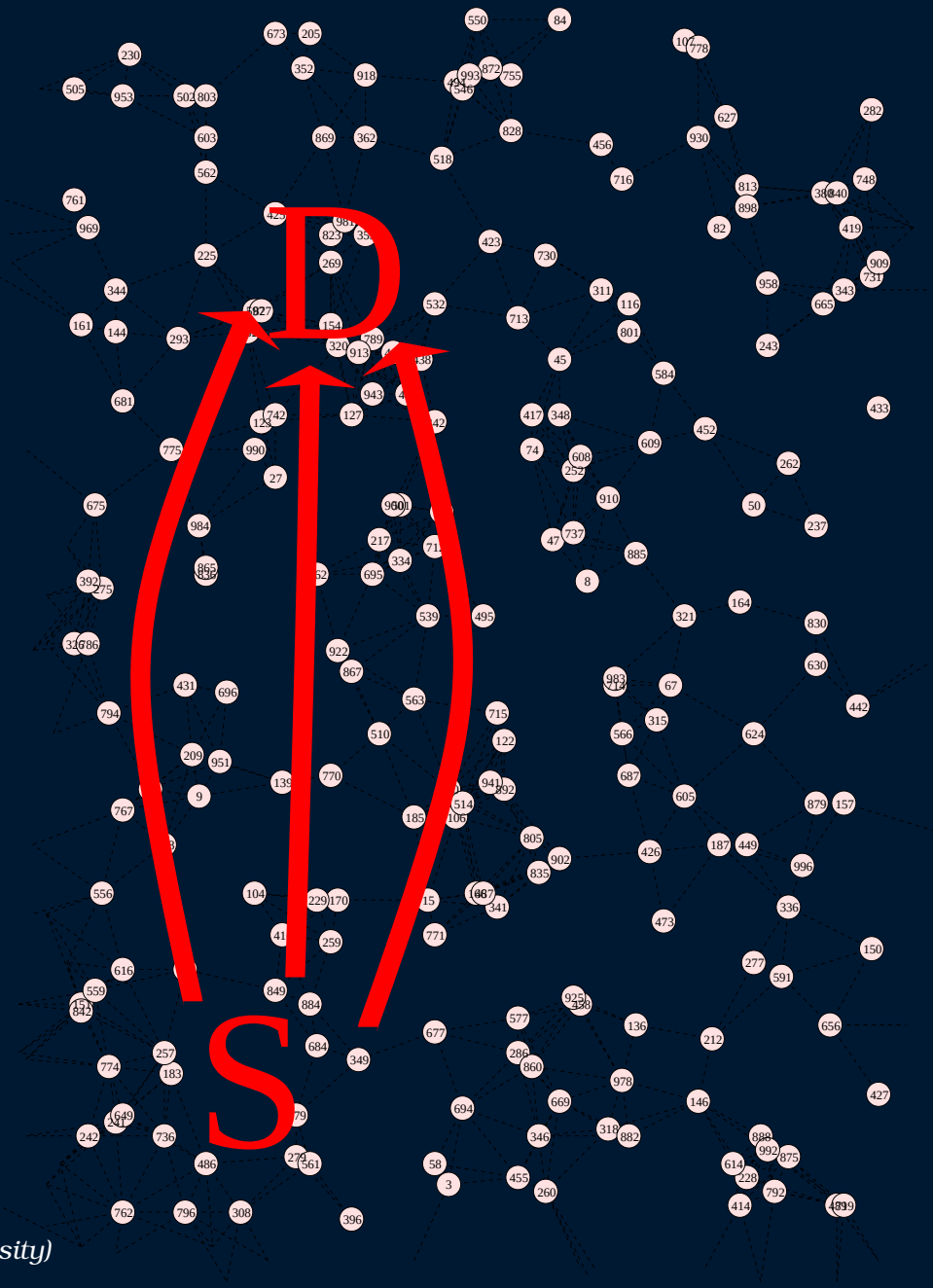
problems in ad hoc networks

- discover
- route
  - multipath
  - mobile source
  - multicast
- scalability issues
  - routing tables
  - flooding



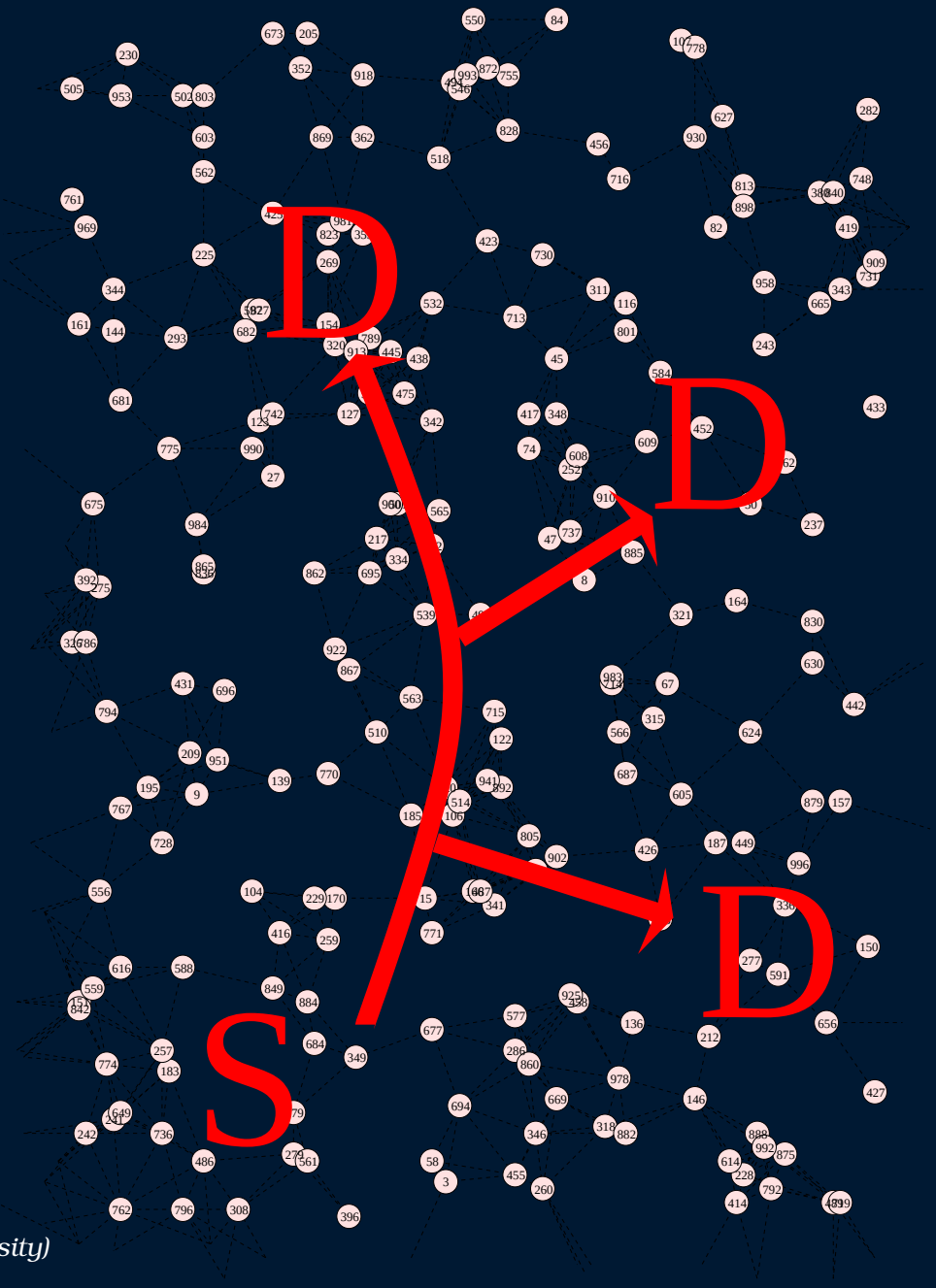
problems in ad hoc networks

- discover
- route
  - multipath
  - mobile source
  - multicast
- scalability issues
  - routing tables
  - flooding



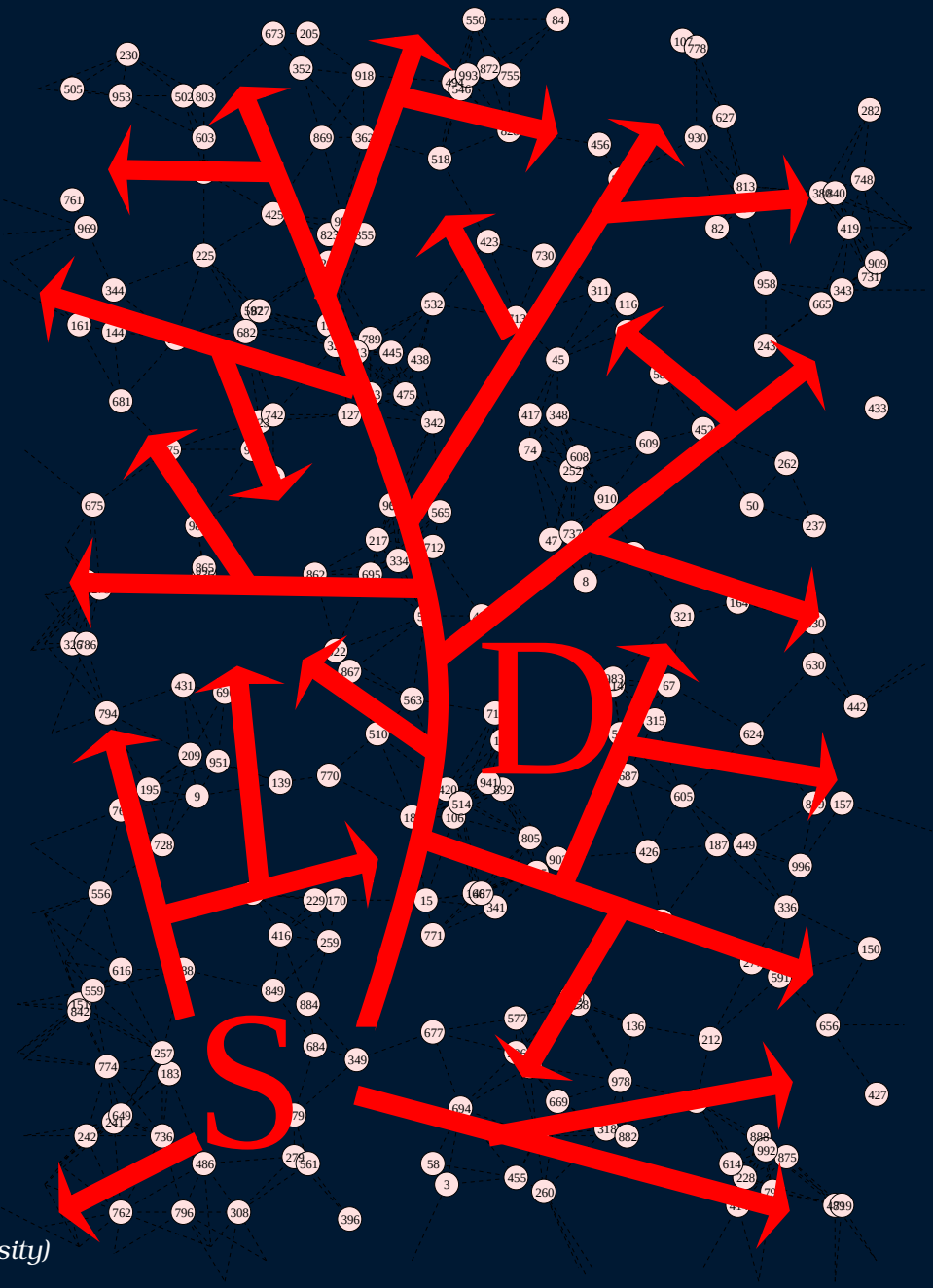
problems in ad hoc networks

- discover
- route
  - multipath
  - mobile source
  - multicast
- scalability issues
  - routing tables
  - flooding



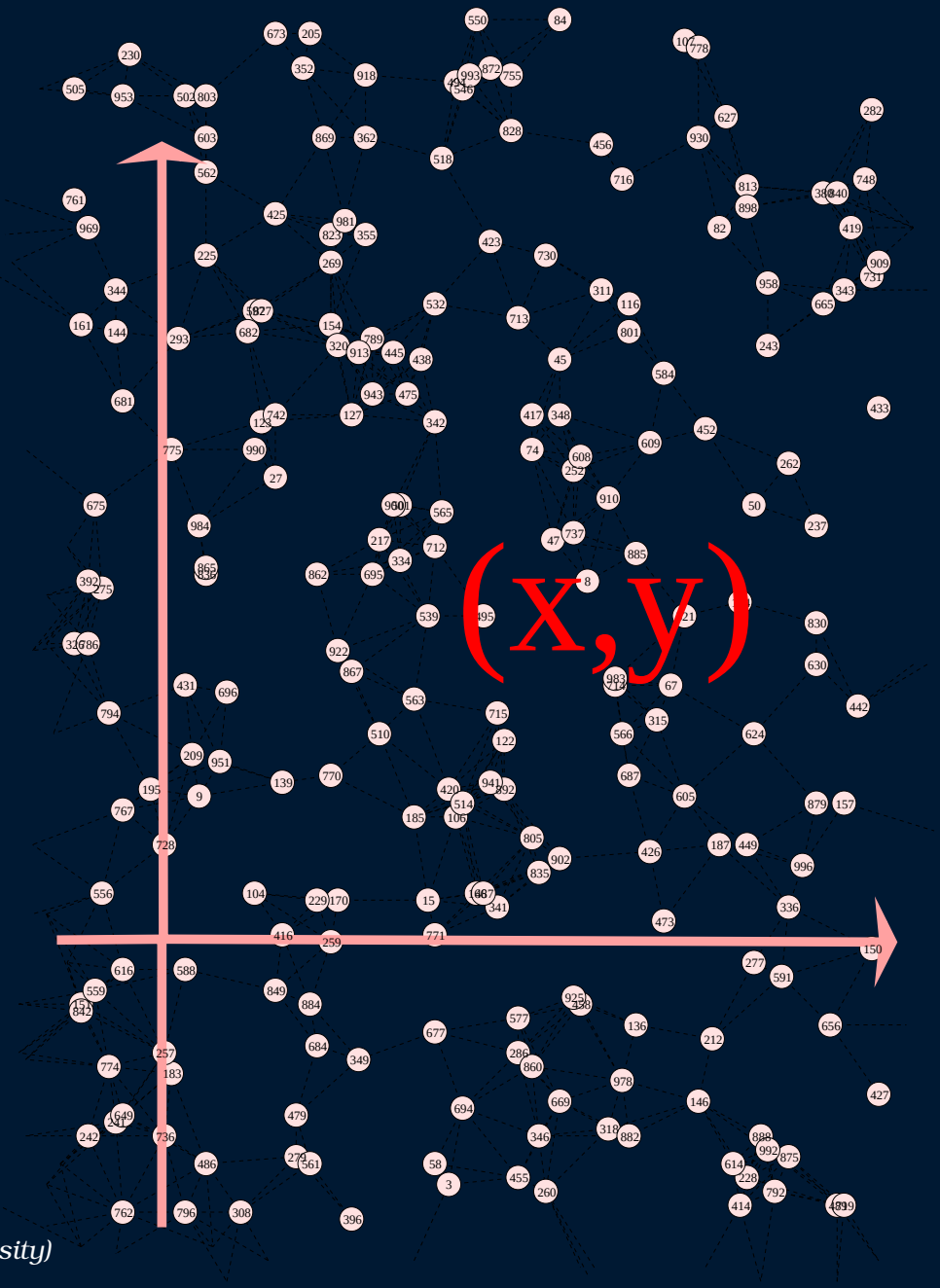
problems in ad hoc networks

- discover
- route
  - multipath
  - mobile source
  - multicast
- scalability issues
  - routing tables
  - flooding
  - mobility



problems in ad hoc networks

- discover
- route
  - multipath
  - mobile source
  - multicast
- scalability issues
  - routing tables
  - flooding
  - mobility

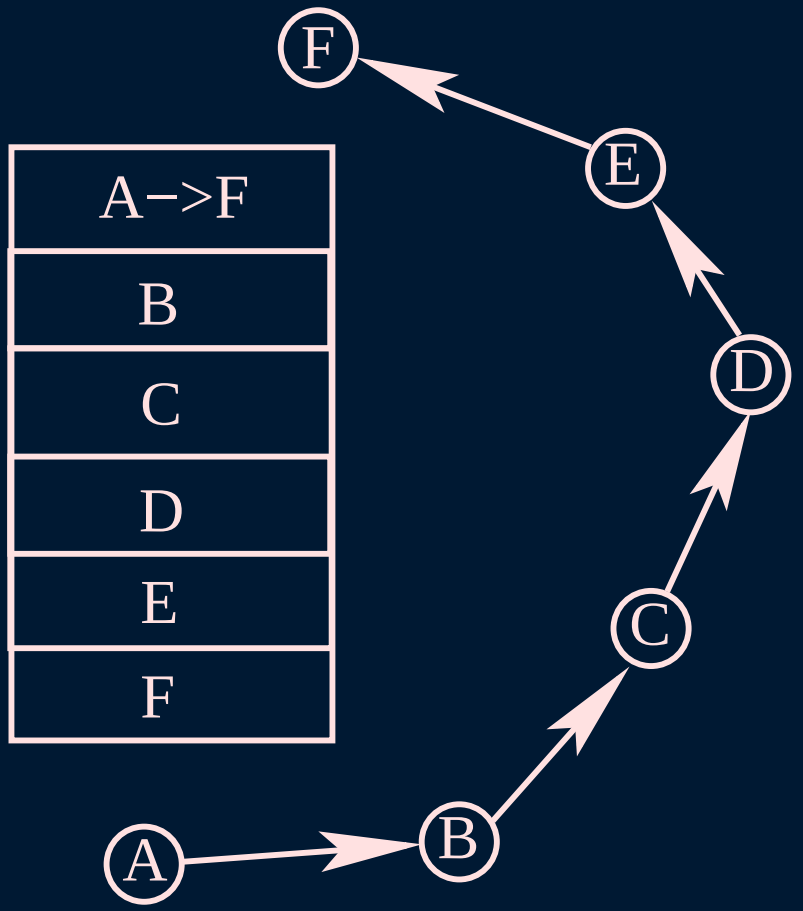


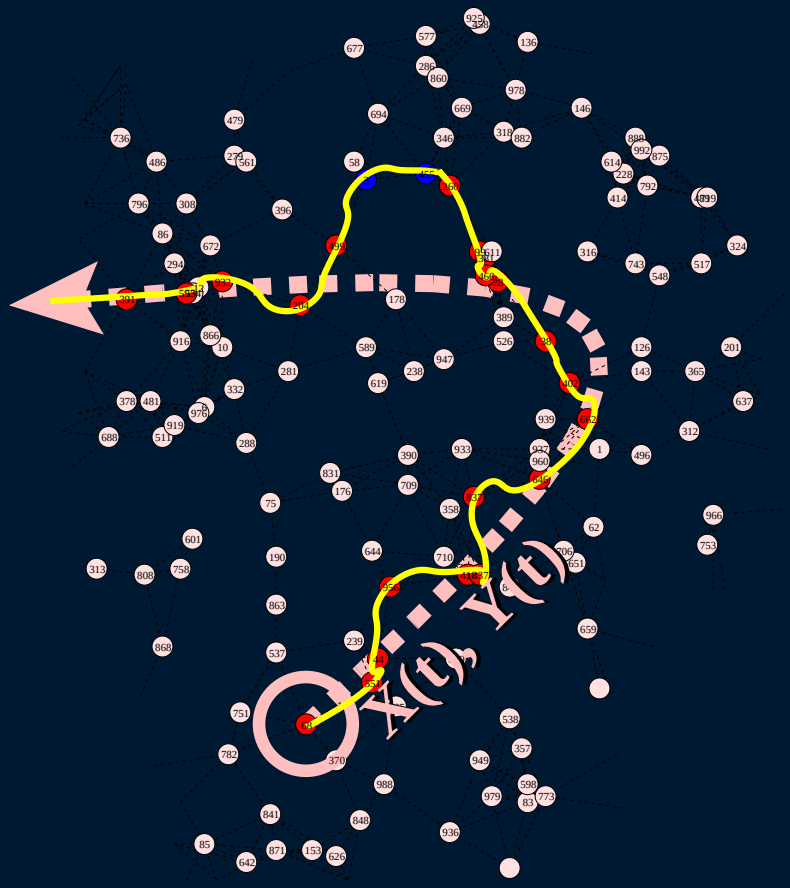
previous work

- **broadcasting** → **classical, probabilistic**[Haas00]
- **discovery** → **flooding, GLS**[Li00], **DREAM**[Basagni98]
- **routing**

1. **node centric** →**DSDV**[Perkins94], **DSR**[Johnson96], **AODV**[Perkins97], **ZRP**[Haas99]
   - **flooding**
   - **routing tables**
   - **multipath?**
2. **data centric** →**diffusion[Intanago00]**
3. **position centric**
   - **MFR**[Kleinrock76], **Cartesian**[Finn87],
   - **LAR**[Vaidya98], **DREAM**[Basagni98]
   - **Georoute**[Navas98]

TBF: fundamental idea





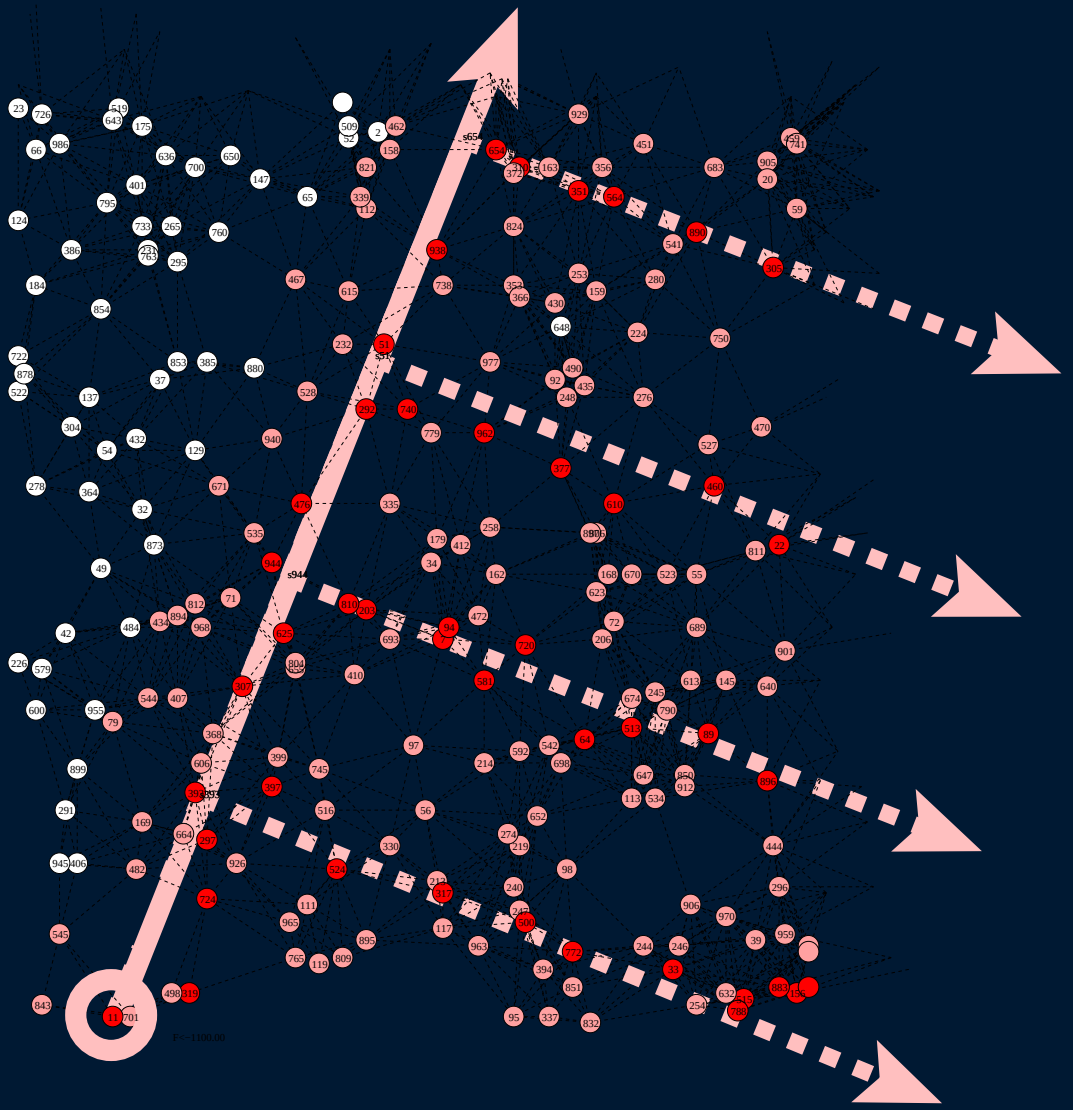
- **discrete paths**
- **overhead≃path length**
- **mobility→updates**

- **continuous paths**
- **fixed overhead**
- **no maintenance**

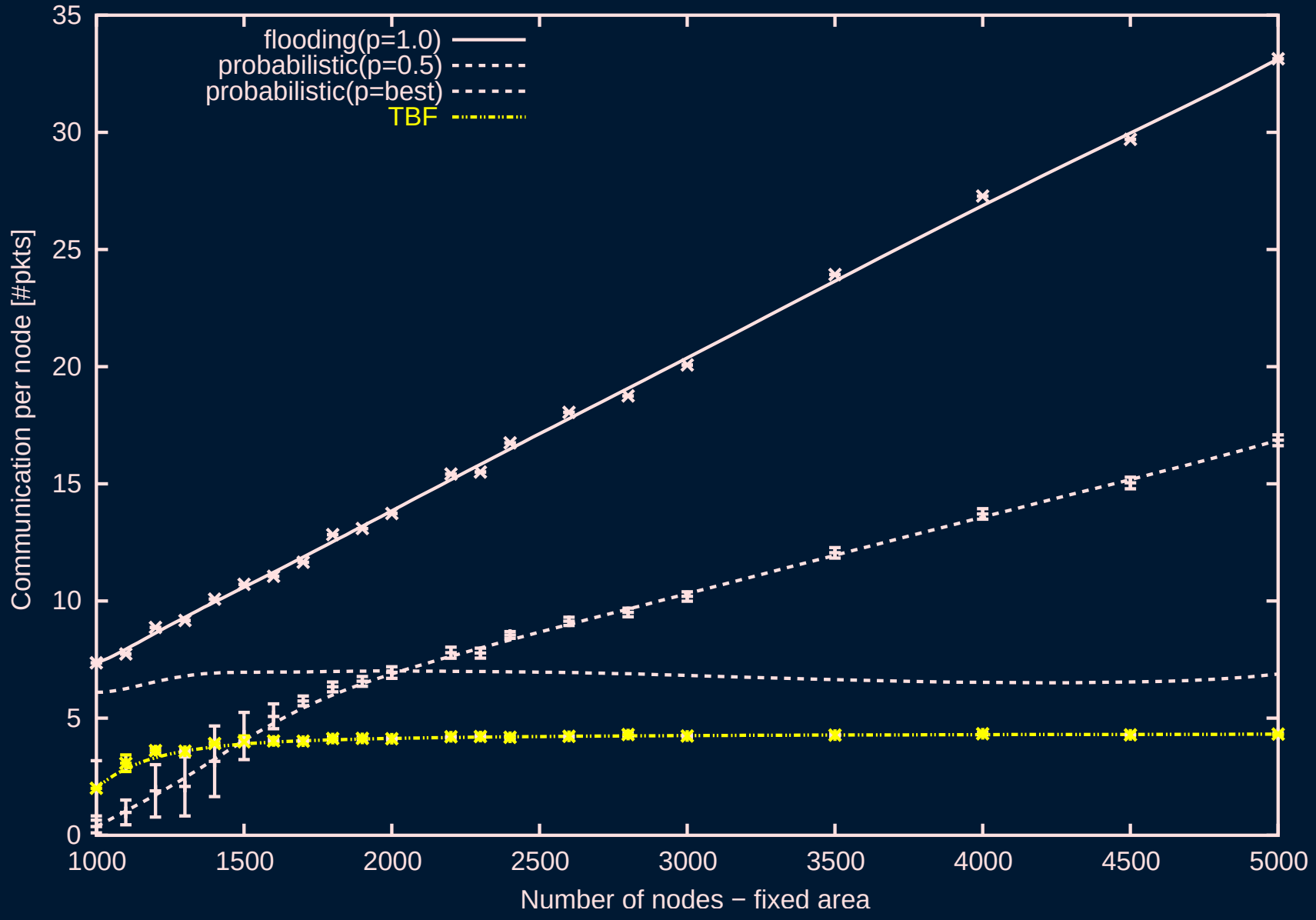
why is it good?

1. **cheap path diversity**
2. **decouples path name from actual path**
   - **no routing tables**
   - **fixed packet overhead**
   - **scalable for LARGE/DENSE networks**
3. **common framework**
   - **routing: unicast, multicast, multipath**
   - **discovery**
   - **broadcasting**
4. **simple to implement**

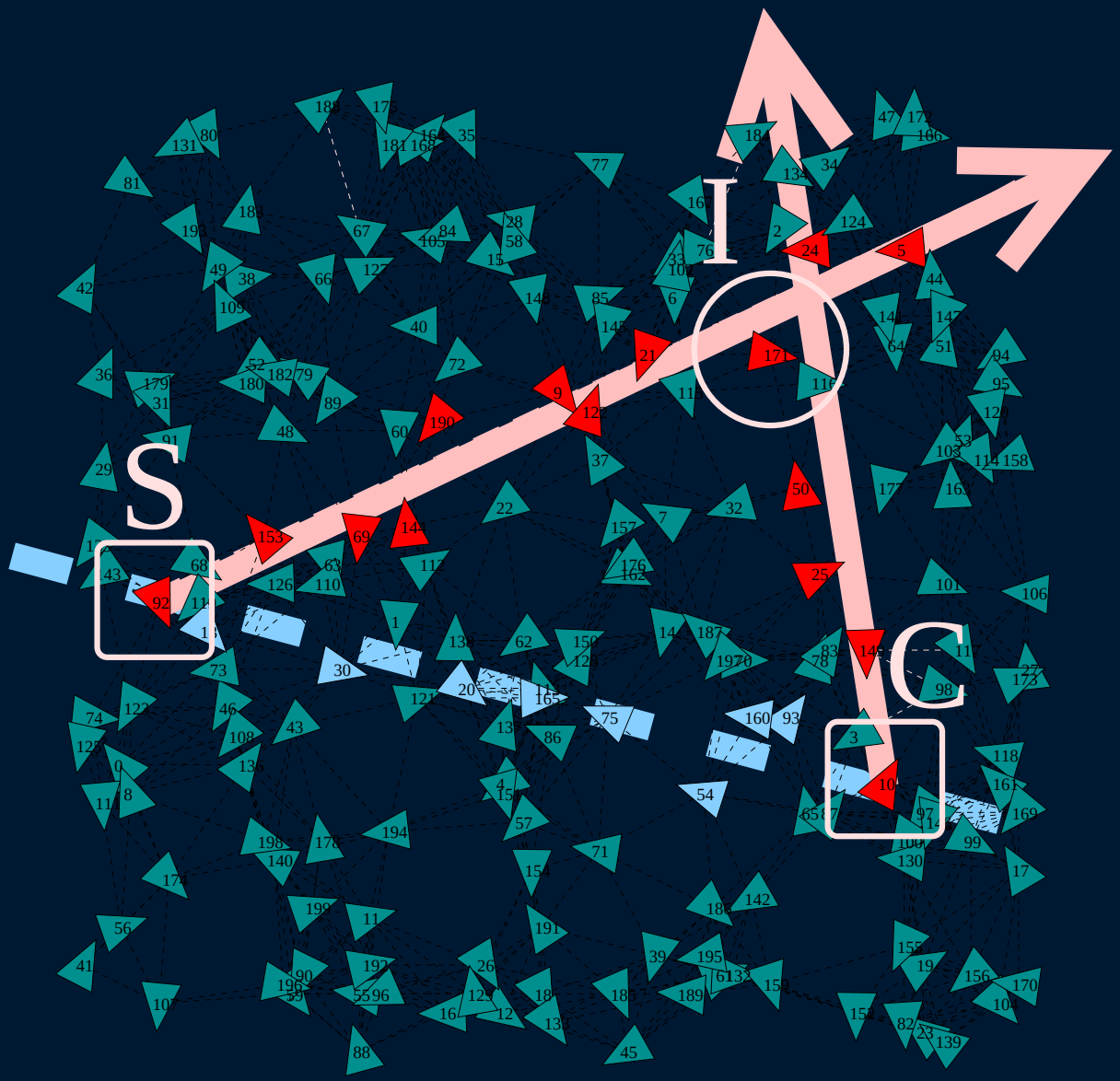
TBF based broadcasting

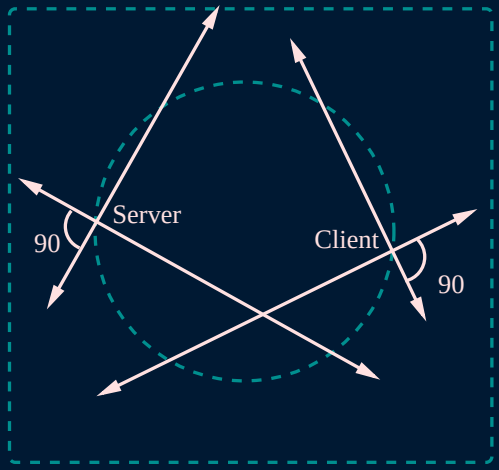


TBF based broadcasting



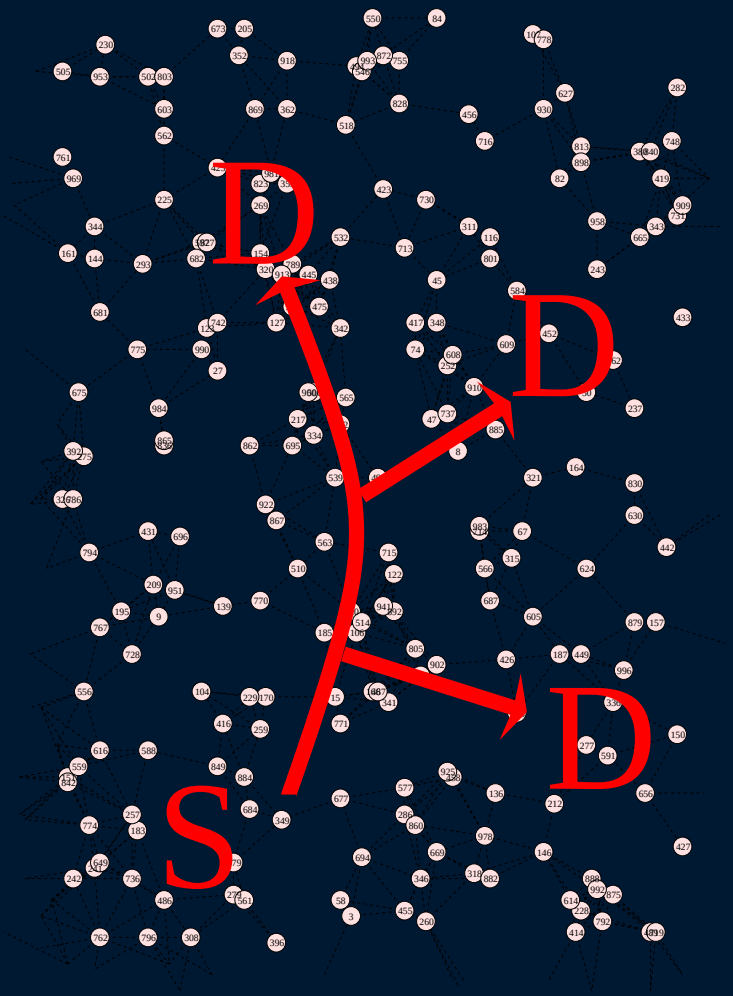
discovery



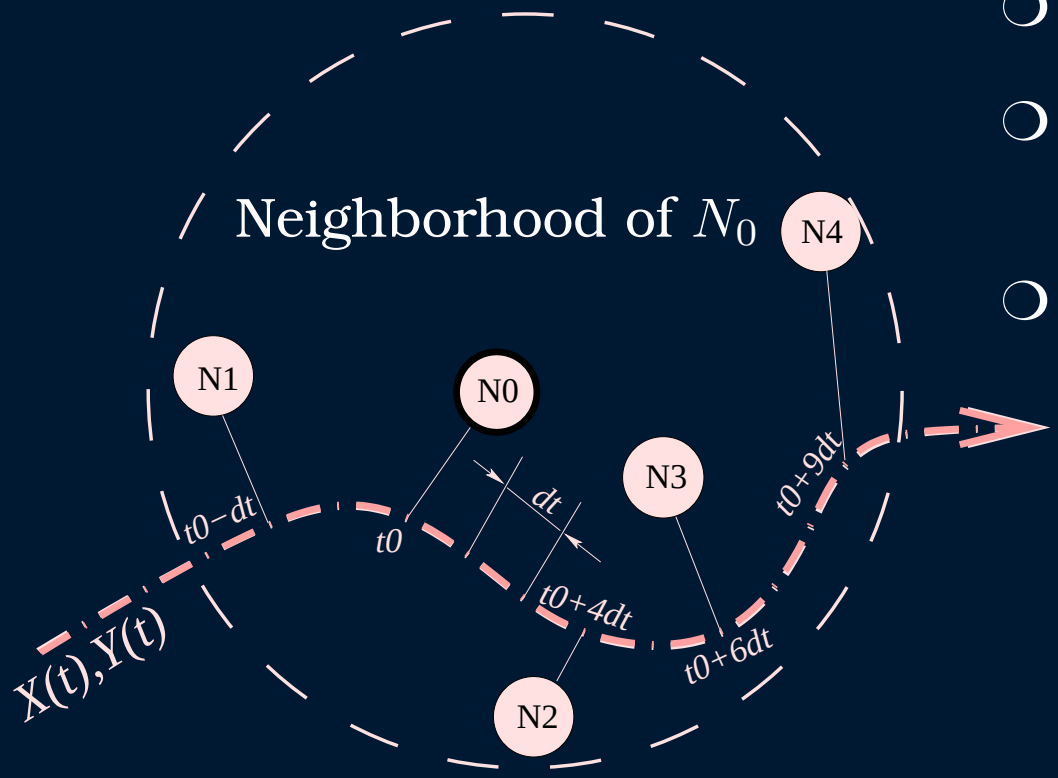


when is it best ?

1. **mobile network, static destination**
   - **(decouples path name from the actual path)**
2. **multipath, load balancing**
   - **(path diversity)**
3. **quick and dirty**
   - **multi-resolution discovery**
   - **point to multipoint**



how it forwards

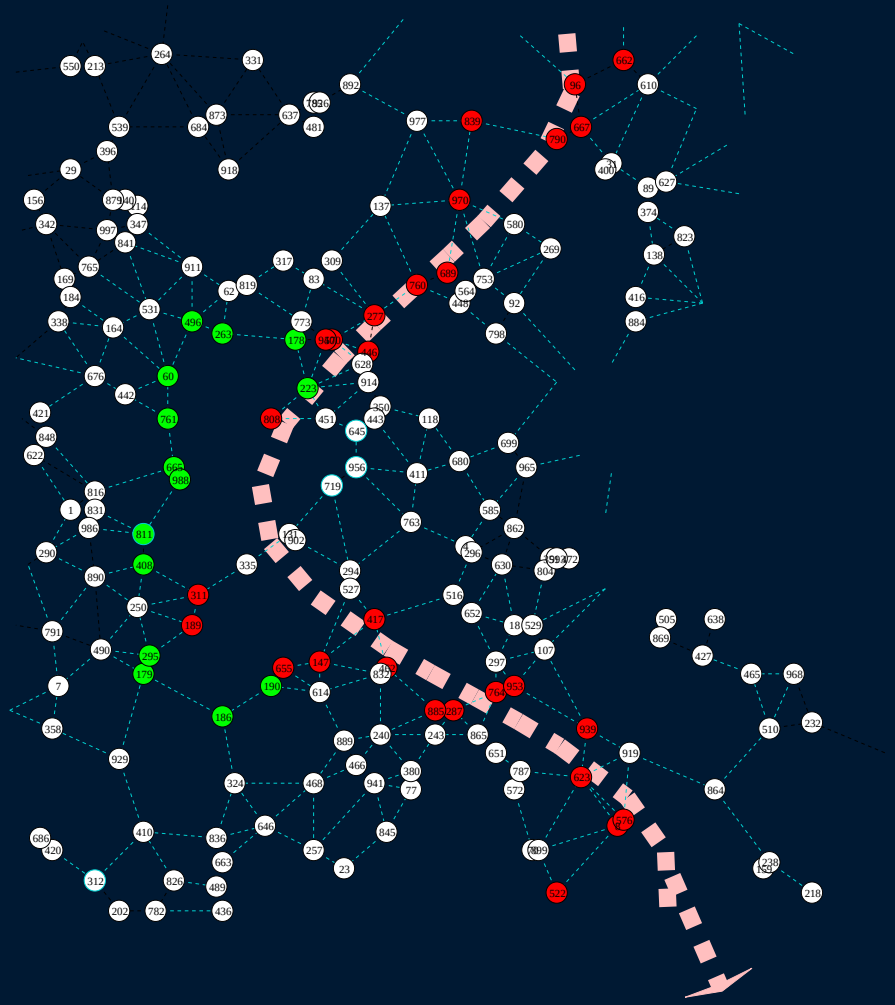


- **node N_0:**
- **receives $X(t), Y(t)$ - encoded curve**
- **chooses a next hop**
  - **closest to trajectory (N_2)**
  - **maximum advancement (N_4)**
  - **most battery left**

adverse conditions

sparse networks

- Greedy Face Greedy [BoseMorin99][Karp00]
- planarized graph
- right hand rule
- TBF: hard to guarantee delivery

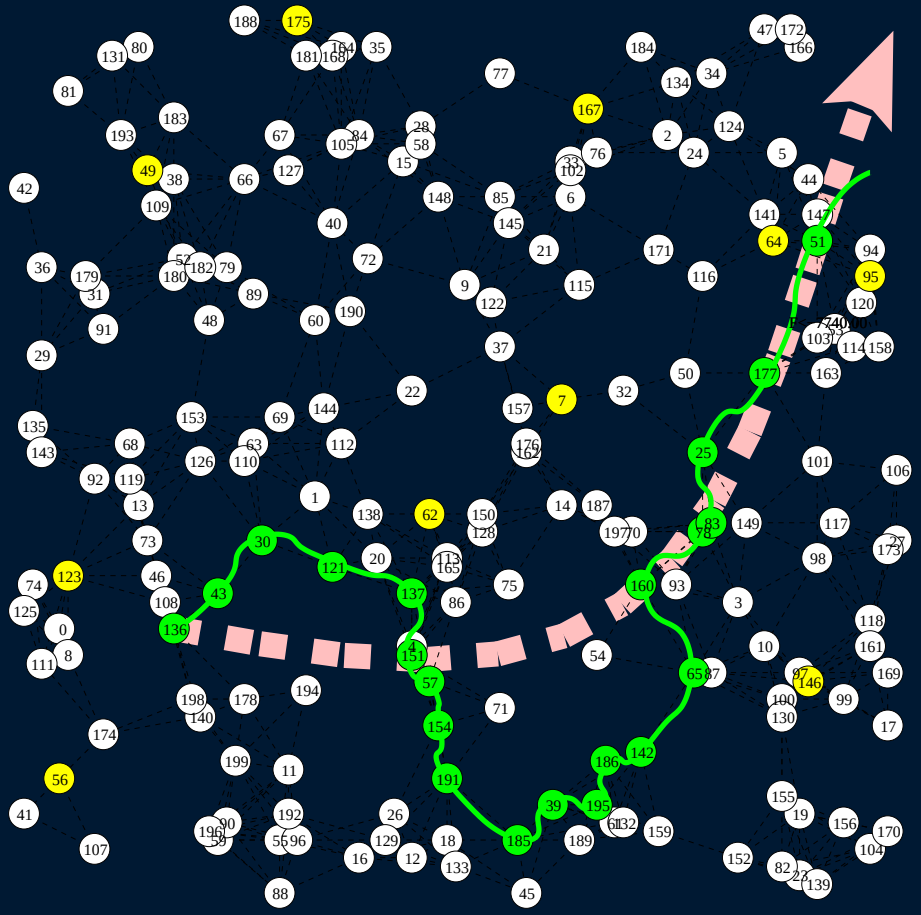


adverse conditions

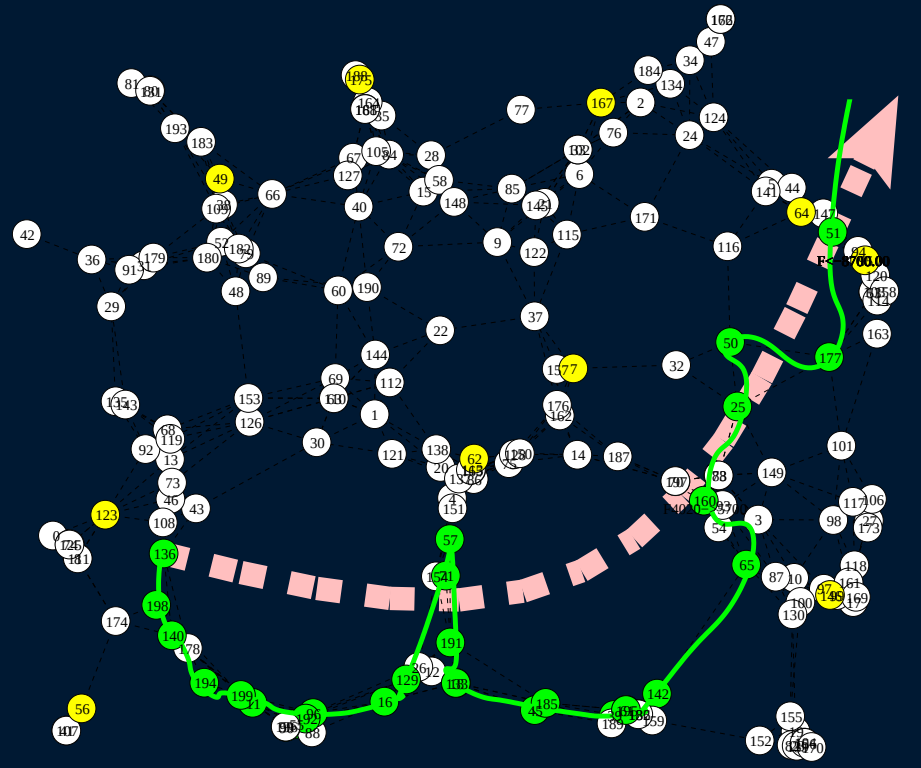
no positioning

- assume other capabilities
  - AoA, ranging, compass, accelerometer
- use localized schemes
  - **some landmarks**: APS, AhLOS, SPA
  - **no landmarks**: LPS (Local Positioning System)
- produce imprecise positions

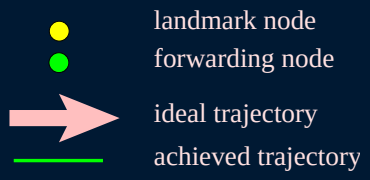
use of imprecise positions



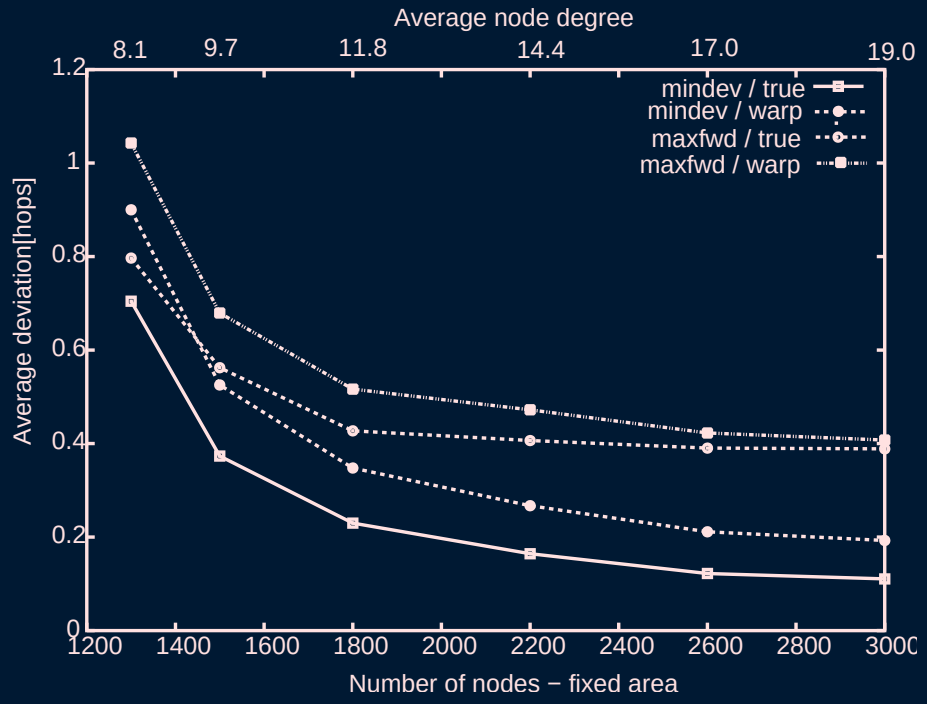
true space

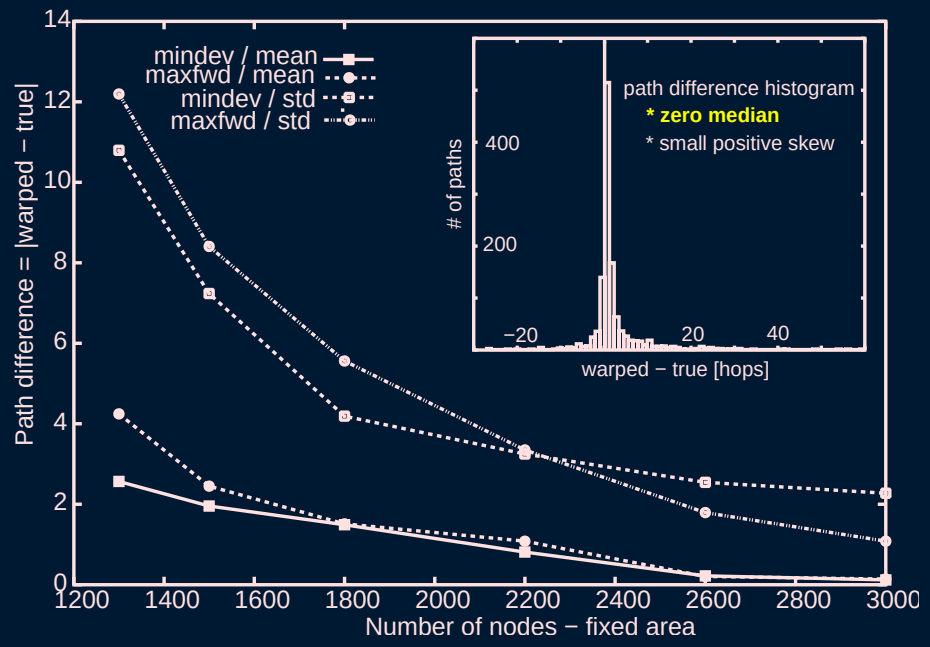


warped space

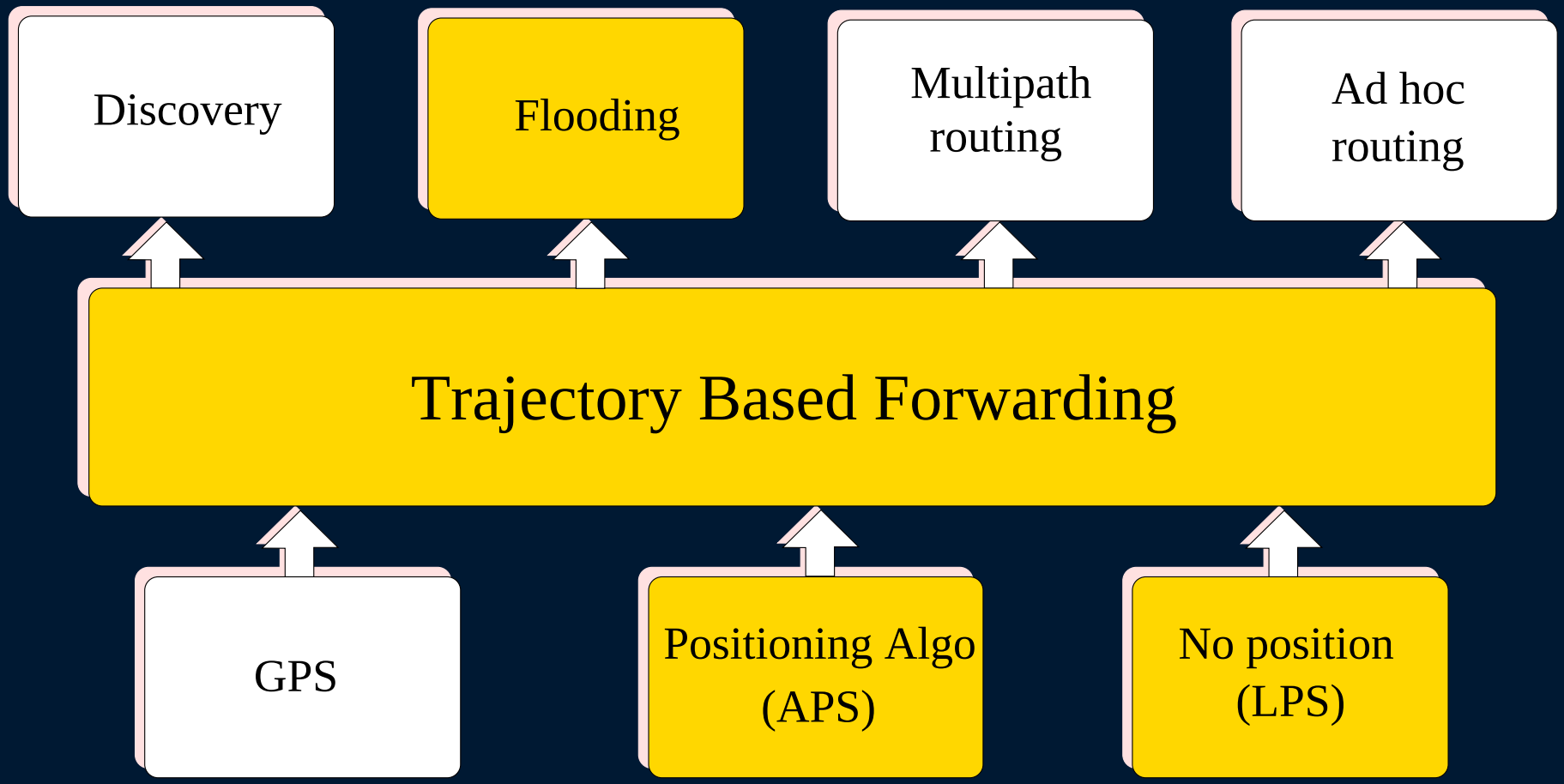


impact of imprecise positions





paths = 15..25 hops; degrees = 8..20; 200 random pairs;


Discovery
Flooding
Multipath routing
Ad hoc routing
Trajectory Based Forwarding
GPS
Positioning Algo (APS)
No position (LPS)

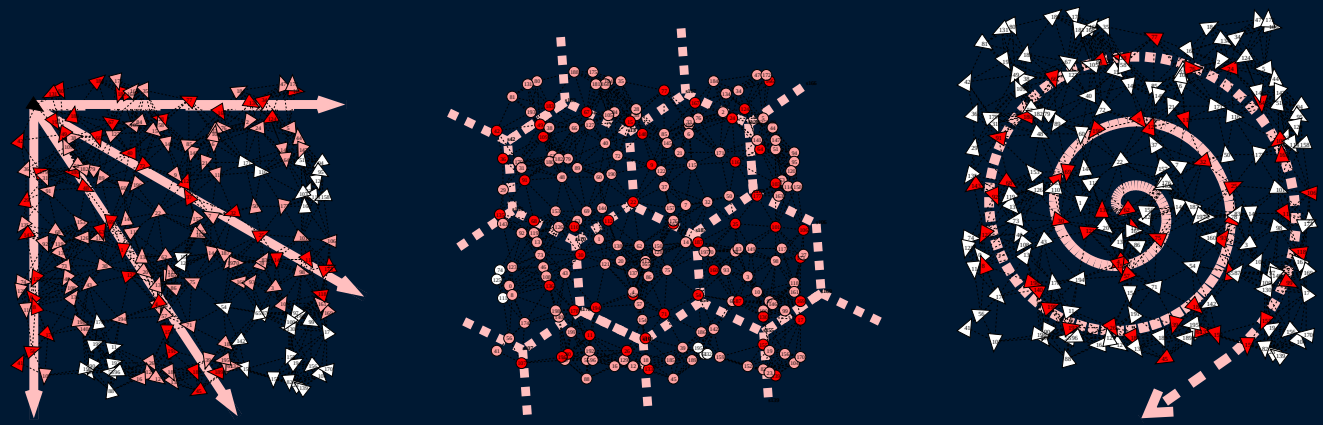
future/current work

- trajectory encoding
  - wavelets, polynomial
- determination:
  - mapping service
- modification and patching
- imprecise information
- multicast trees
- load balancing
- performance evaluation: mobility, TCP,...

TBF summary

- decouples path naming form the actual path
- provides cheap path diversity
- saves energy
- provides common framework for:
  - routing: unicast, multicast, multipath
  - flooding: stateless, stateful, multiresolution
  - discovery
- needs positioning $\rightarrow$ wide range of assumptions

http://www.cs.rutgers.edu/~dnicules/research/



trajectory based forwarding

- problems
- previous work
- TBF
- why is it good?
- broadcasting
- discovery
- when is it best?
- how it forwards
- adverse conditions
  - imprecise positions
- overhead
- LPS
- vision
- future work

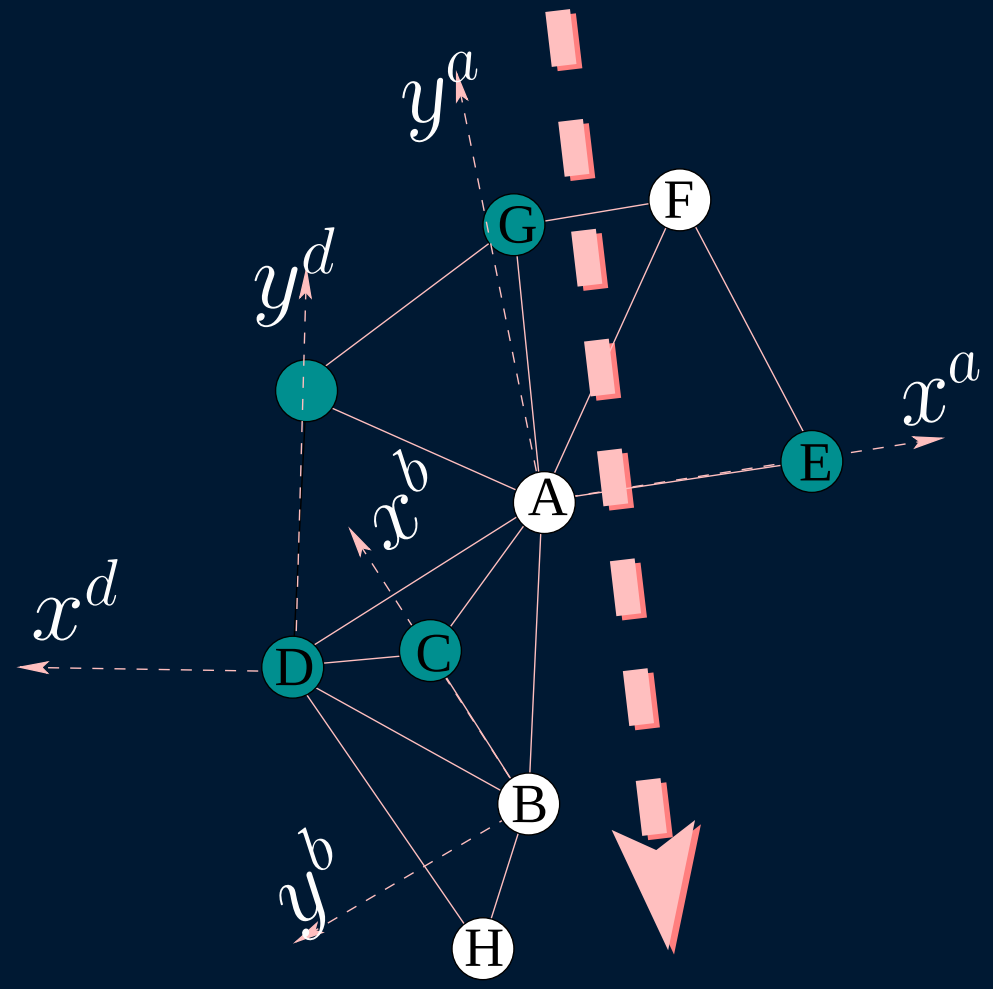
Localized Positioning System

$\Rightarrow$

- **no GPS in the network**
- **need certain capabilities**
  - **ranging**
  - **angle of arrival**
  - **compass, accelerometer**
- **positioning**
  - **only for nodes on the trajectory**
  - **in the coordinate system of the source**
- **forwarding, not routing**

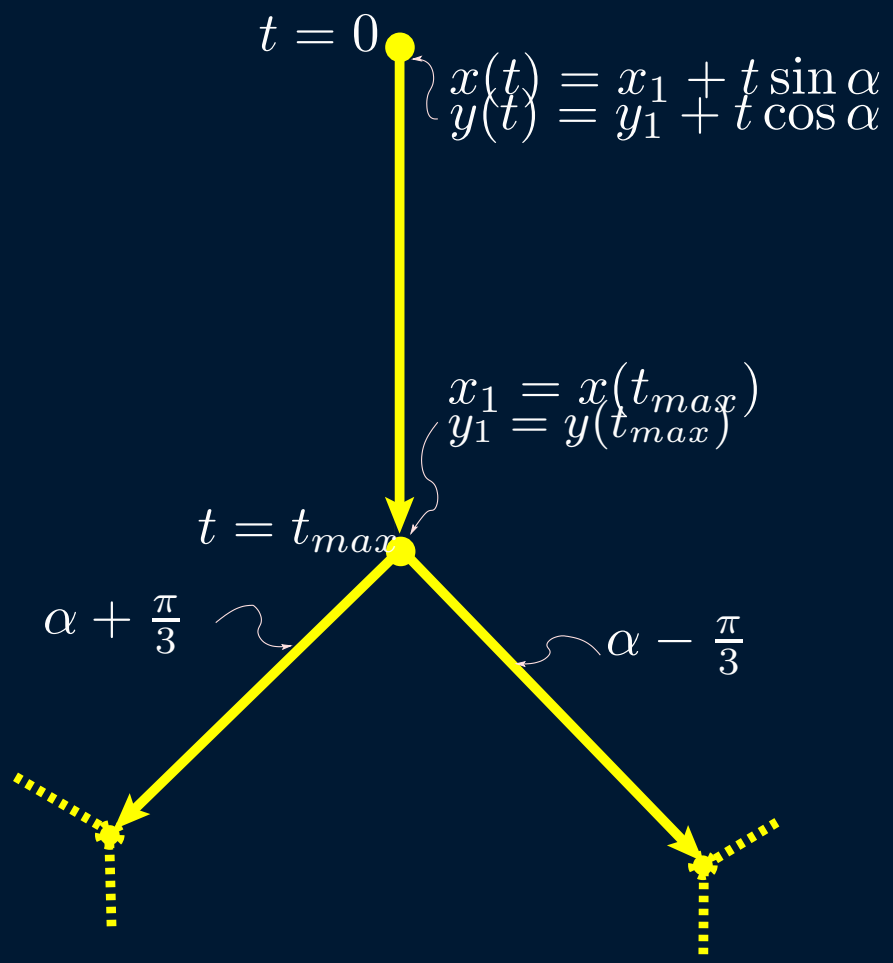
LPS

- nodes builds local coordinate systems
- trajectory is evaluated in the original coordinate system
- **registration:** align coordinate systems
- **optimization:** preregister with all neighbors

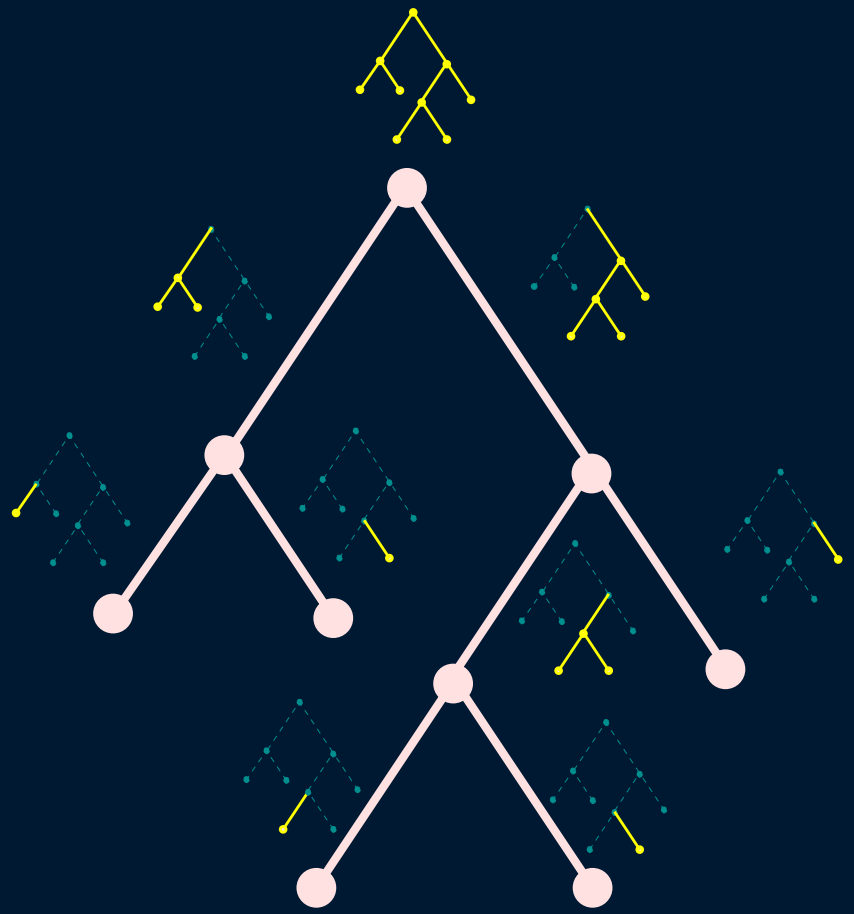


how it splits

REGULAR TREE



ARBITRARY TREE



overhead

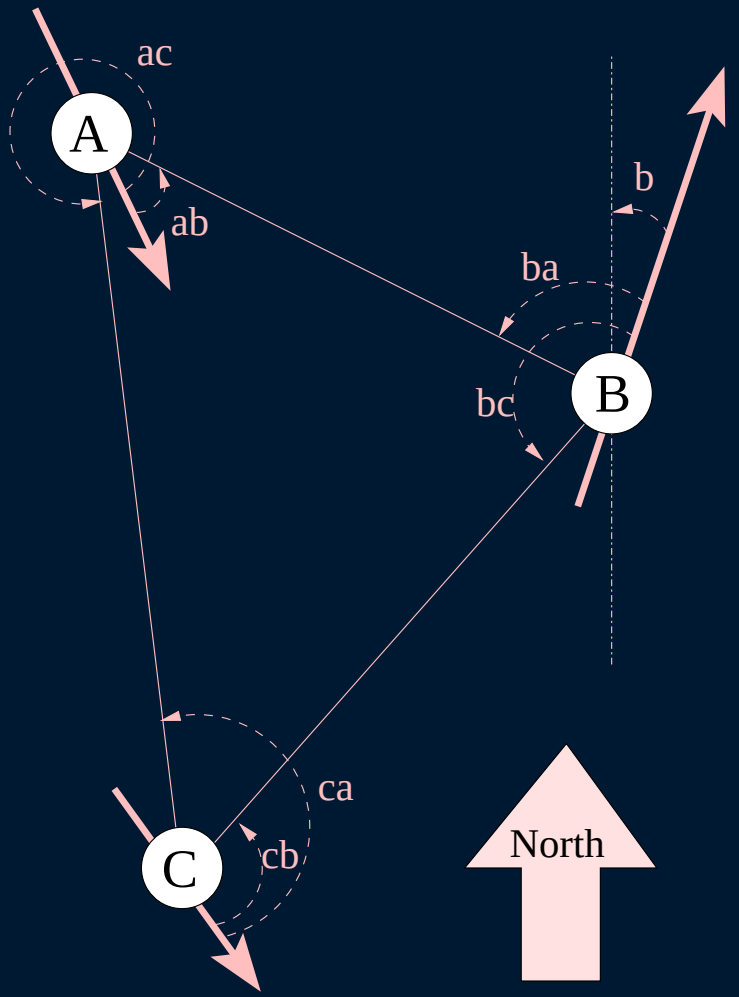
packet overhead

- independent on
  - density
  - path length
- depends on representation
- polish notation (RPN)
  - best flexibility
- function tables
  - parameters in packet
  - most compact

CPU overhead

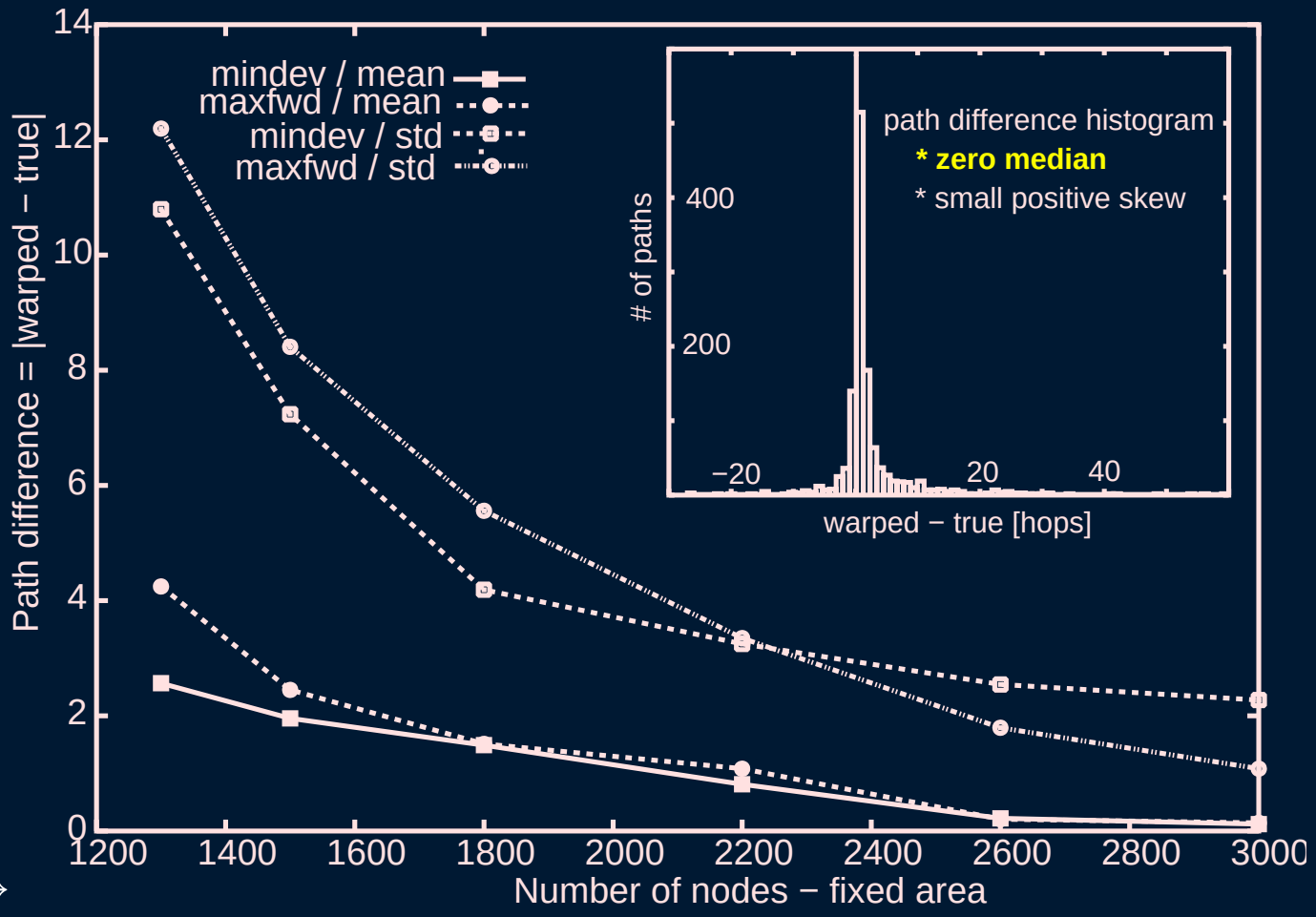
- dependent on
  - density
  - path length
- curve discretization
- positioning

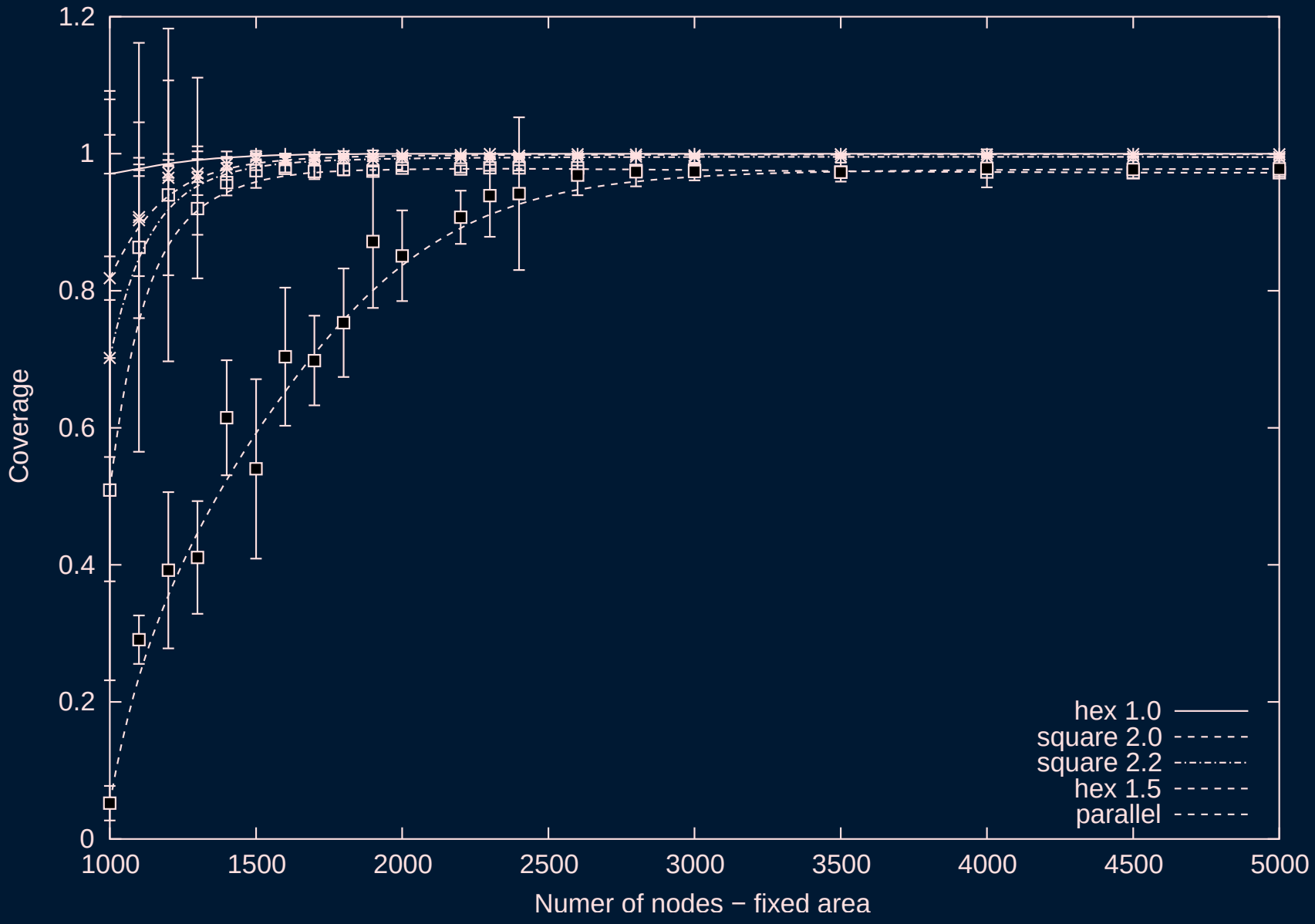
node capabilities

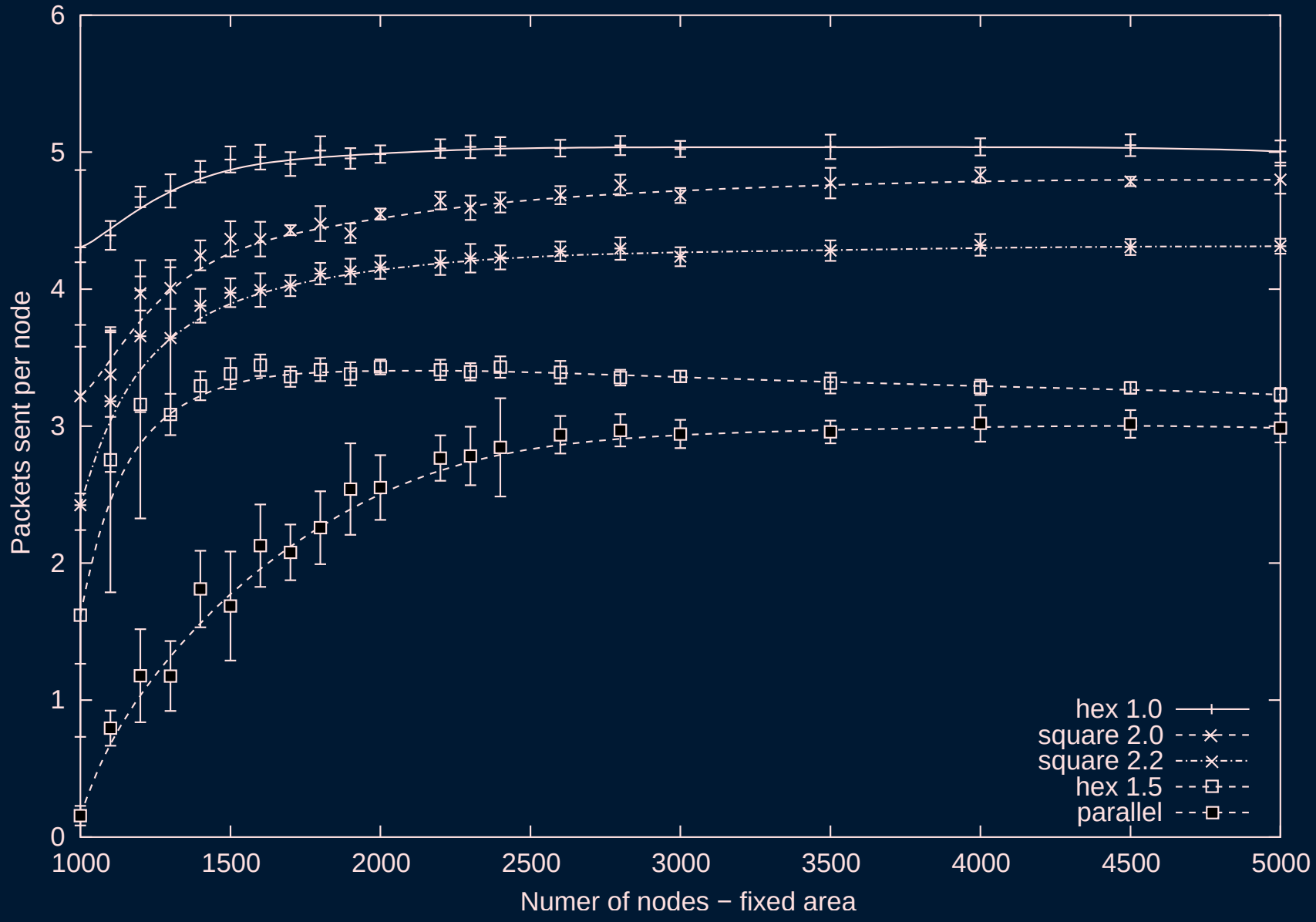


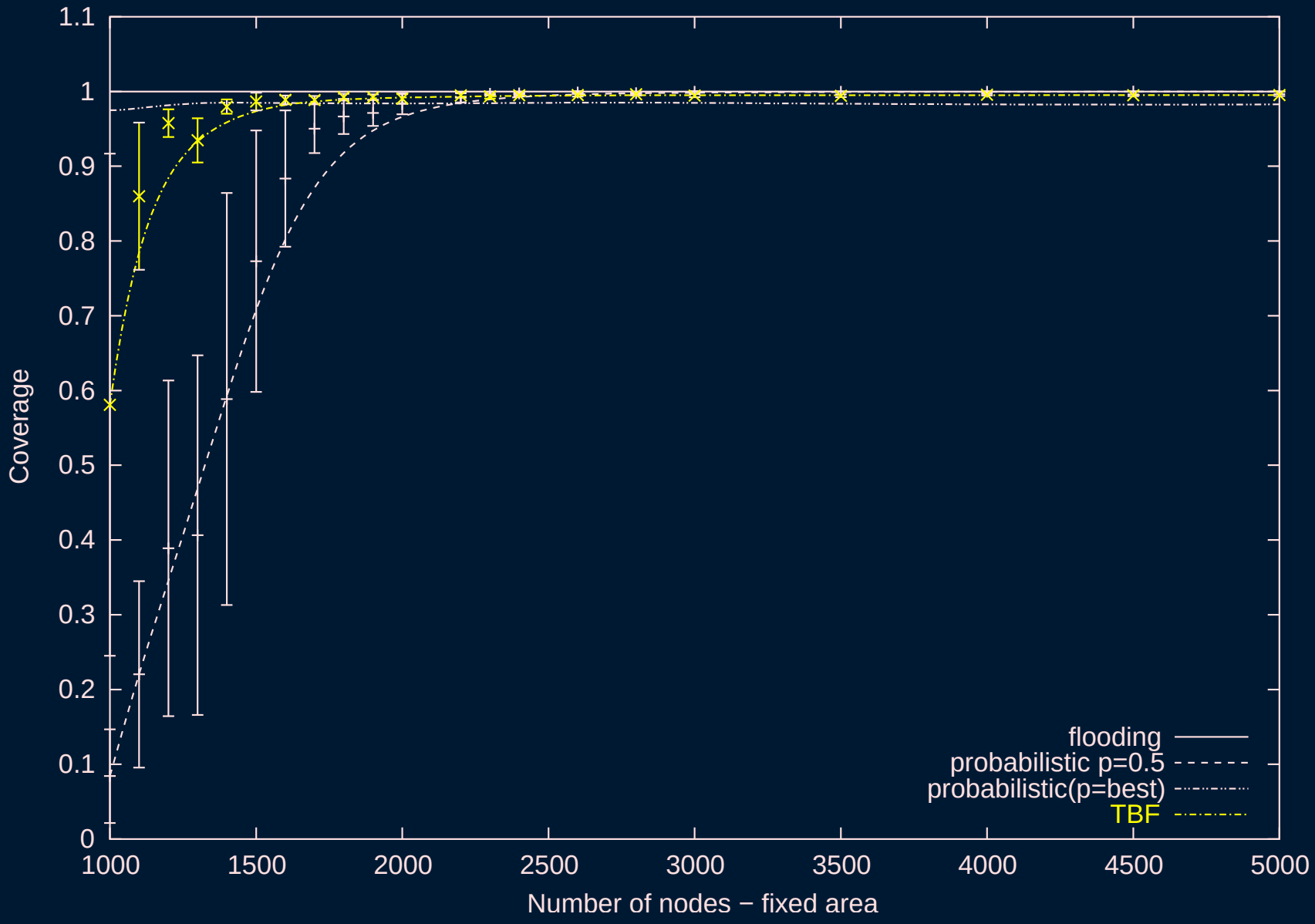
impact of imprecise positions

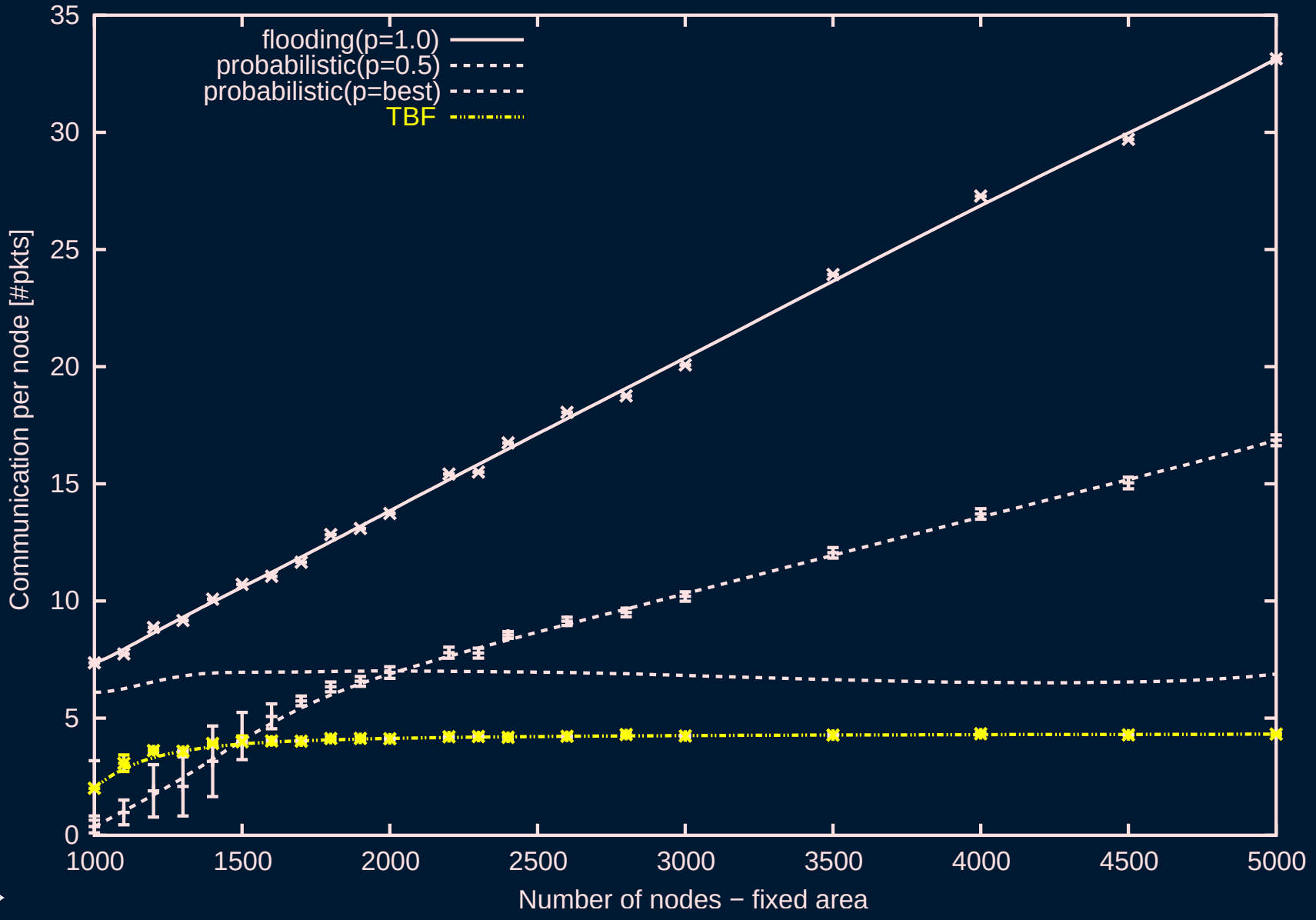
- low impact on path length
- low deviation from ideal trajectory




1.2
1
0.8
0.6
0.4
0.2
0
Coverage
1000
1500
2000
2500
3000
3500
4000
4500
5000
Numer of nodes − fixed area
hex 1.0
square 2.0
square 2.2
hex 1.5
parallel

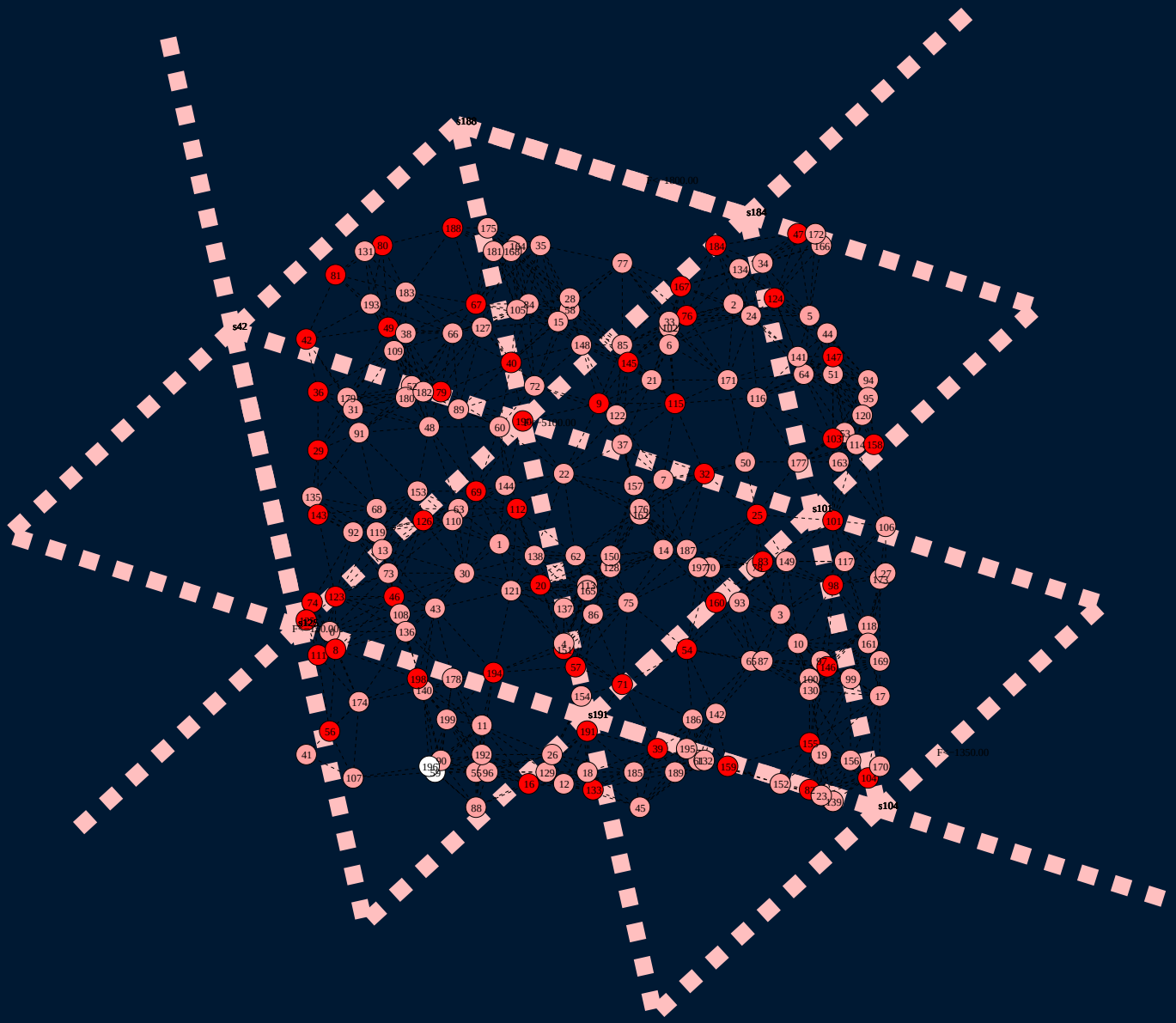

Packets sent per node
Numer of nodes − fixed area
0
1
2
3
4
5
6
1000
1500
2000
2500
3000
3500
4000
4500
5000
hex 1.0
square 2.0
square 2.2
hex 1.5
parallel


1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Coverage
1000
1500
2000
2500
3000
3500
4000
4500
5000
Number of nodes − fixed area
flooding
probabilistic p=0.5
probabilistic(p=best)
TBF


flooding(p=1.0)
probabilistic(p=0.5)
probabilistic(p=best)
TBF
Communication per node [#pkts]
Number of nodes − fixed area
0
5
10
15
20
25
30
35
1000
1500
2000
2500
3000
3500
4000
4500
5000

→

stateful flooding



references

- **http://www.cs.rutgers.edu/~dnicules/research/**
- **"*Ad Hoc Positioning System (APS) using AoA*" - INFOCOM 2003, Elsevier journal of Ad Hoc Networks**
- **"*Localized Positioning in Ah Hoc Networks*" - SNPA 2003, Elsevier journal of Ad Hoc Networks**
- **"*Routing on a Curve*" - ACM HOTNETS, 2002**
- **"*Ad Hoc Positioning System (APS)*" - GLOBECOM 2001, Kluwer journal of Telecommunications Systems**