Topology Control and Mobility Management in Mobile Ad Hoc Networks

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Mobile Ad Hoc Networks

- Infrastructure-less multi-hop wireless networks formed by mobile nodes
- Challenges
  - Frequent topology changes
  - Lack of central control
  - Limited network resources
    - Energy
    - Bandwidth
    - Computing power

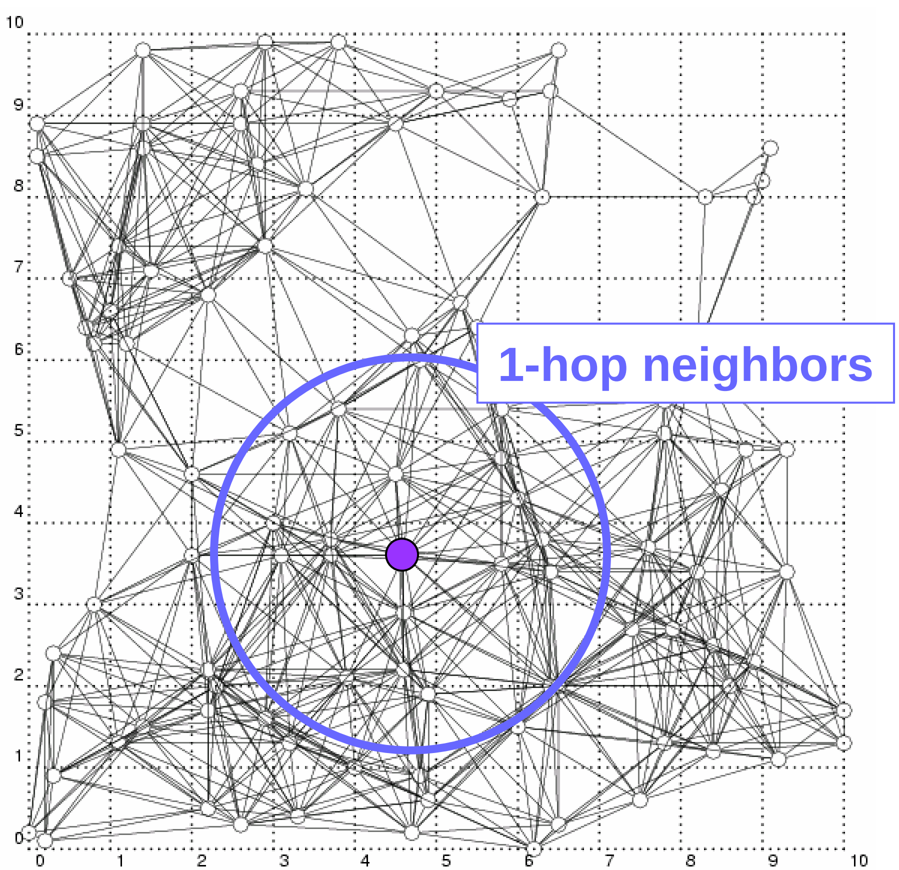
Topology Control (TC)

- Goal
  - Reduce transmission range (r) while maintaining network connectivity
- Motivation
  - Energy efficiency
    - $E_{Tx} \approx r^{\alpha}$ $(2 \leq \alpha \leq 4)$
    - r=10, single hop: $E_{Tx} \approx 1000$ $(\alpha=3)$
    - r=1, 10 hops: $E_{Tx} \approx 10$
  - Channel spatial reuse
    - Interference Area $\approx r^2$

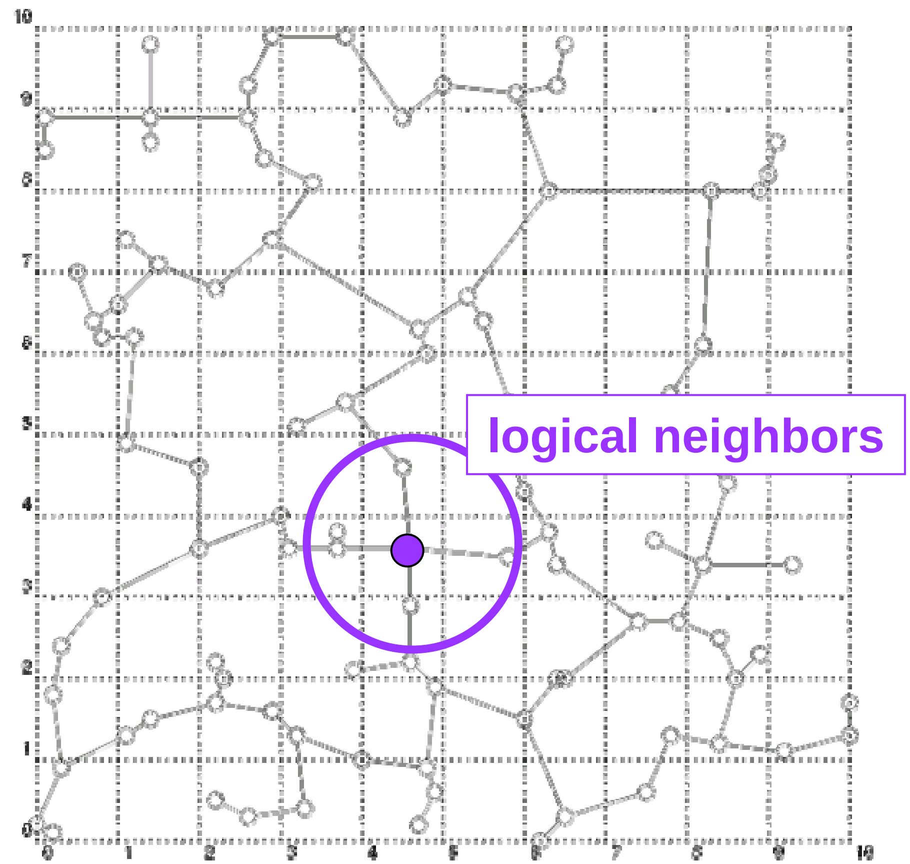
TC (Continued)

- Method
  - Each node collects information of 1-hop neighbors using “Hello” beacons
  - Select a few logical neighbors from 1-hop neighbors
  - Adjust transmission power to cover only logical neighbors
- Logical Topology
  - Virtual network formed by logical links (i.e., links between logical neighbors)

TC Example



Original topology



Logical topology

Existing TC Protocols

- Select logical neighbors using local info.
  - Relative neighborhood graph (RNG)
  - Minimal energy mobile wireless network and extensions (LSPT)
  - Local minimum spanning tree (LMST)
  - Yao graph
  - Cone-based topology control (CBTC)

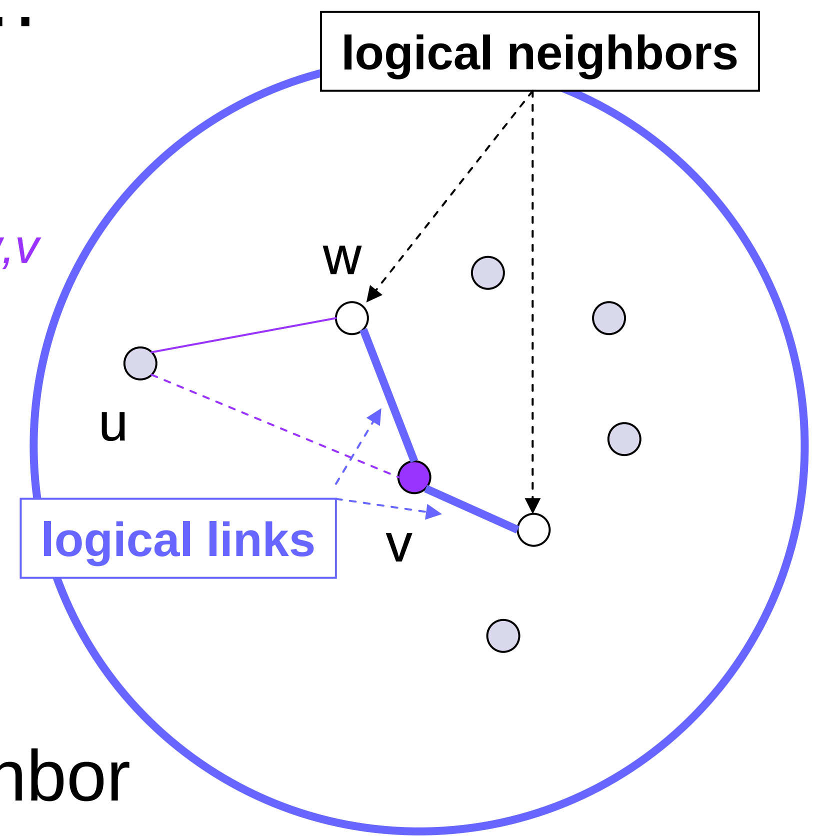
Relative Neighbor Graph (Toussaint, 1980)

- Remove link *(u,v)* if …
  - $\exists w$ s.t.

    $d_{u,v} > d_{u,w}$ and $d_{u,v} > d_{w,v}$
  - *where*

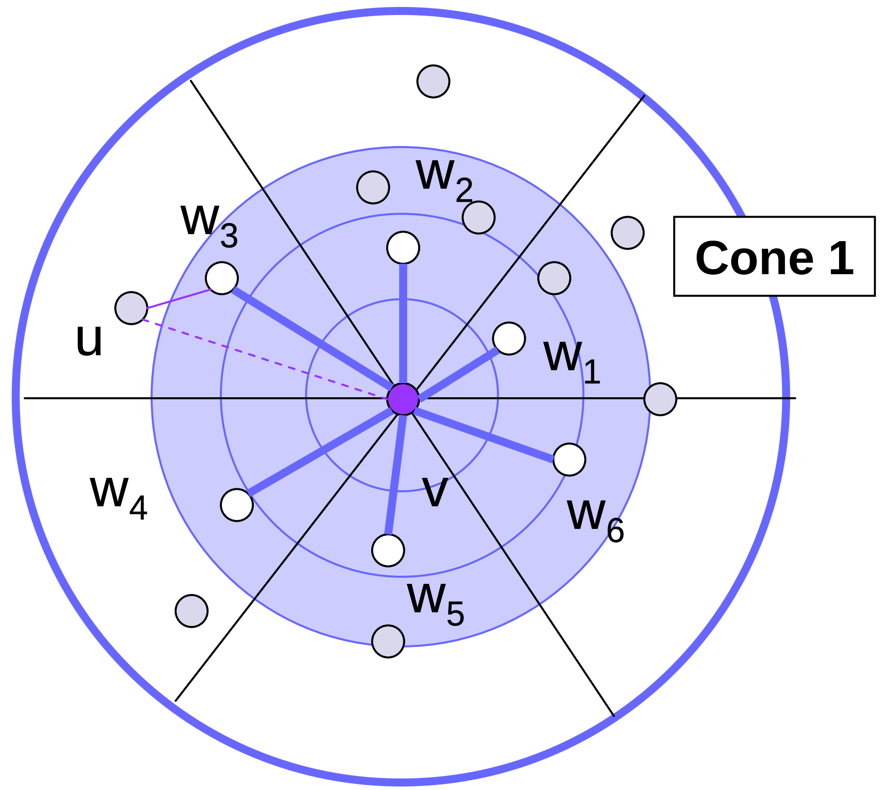
    $d_{u,v}$ = dist. from *u* to *v*

- From *v*'s view
  - *u* is a non-logical neighbor



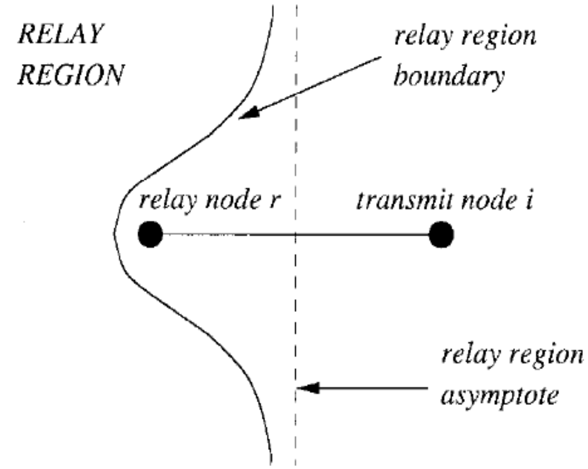
Yao Graph

- Divide neighborhood into 6 cones
- Select a nearest node from each cone as logical neighbor
- A special case of RNG
- Incremental search
  - Until one neighbor detected in each cone

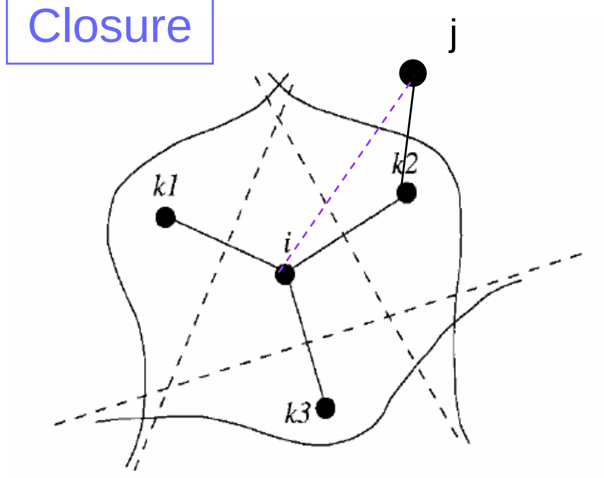


Minimal Energy Mobile Wireless Network (Rodoplu and Meng, 1999)

- MEMWN
  - Logical neighbors forms a closure
  - ∀ outsider *j*, ∃ insider *k* s.t. $E_{i,j} > E_{i,k} + E_{k,j}$
- Extension (Li and Halpern, 2001)
  - Construct a shortest path from current node to each 1-hop neighbor w.r.t. Tx power
  - First hop relays are logical neighbors

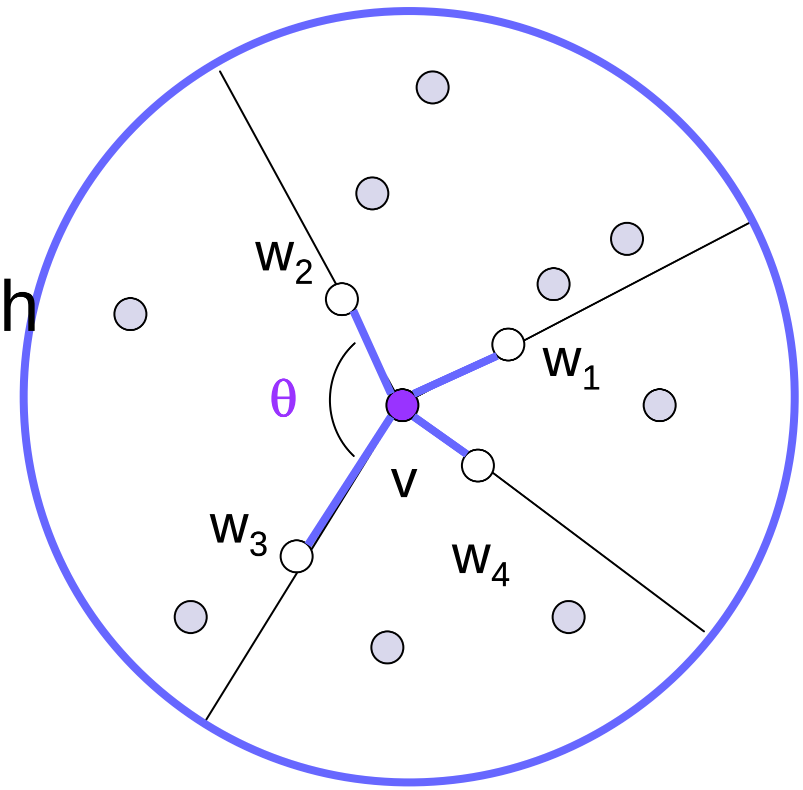


Closure



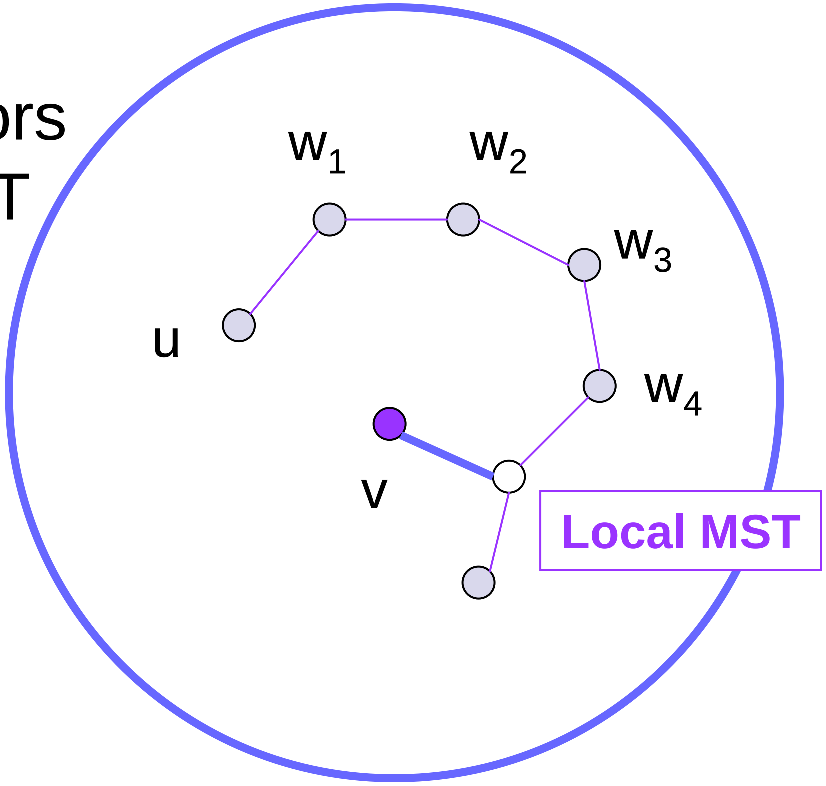
Cone-Based Topology Control (Li and Halpern, 2001)

- Find *k* logical neighbors that are
  - Nearest to the current node
  - The maximal cone width $\theta \leq 2\pi/3$
- Improve Yao graph
- Extension
  - $\theta \leq 4\pi/5$ with some additional constraint

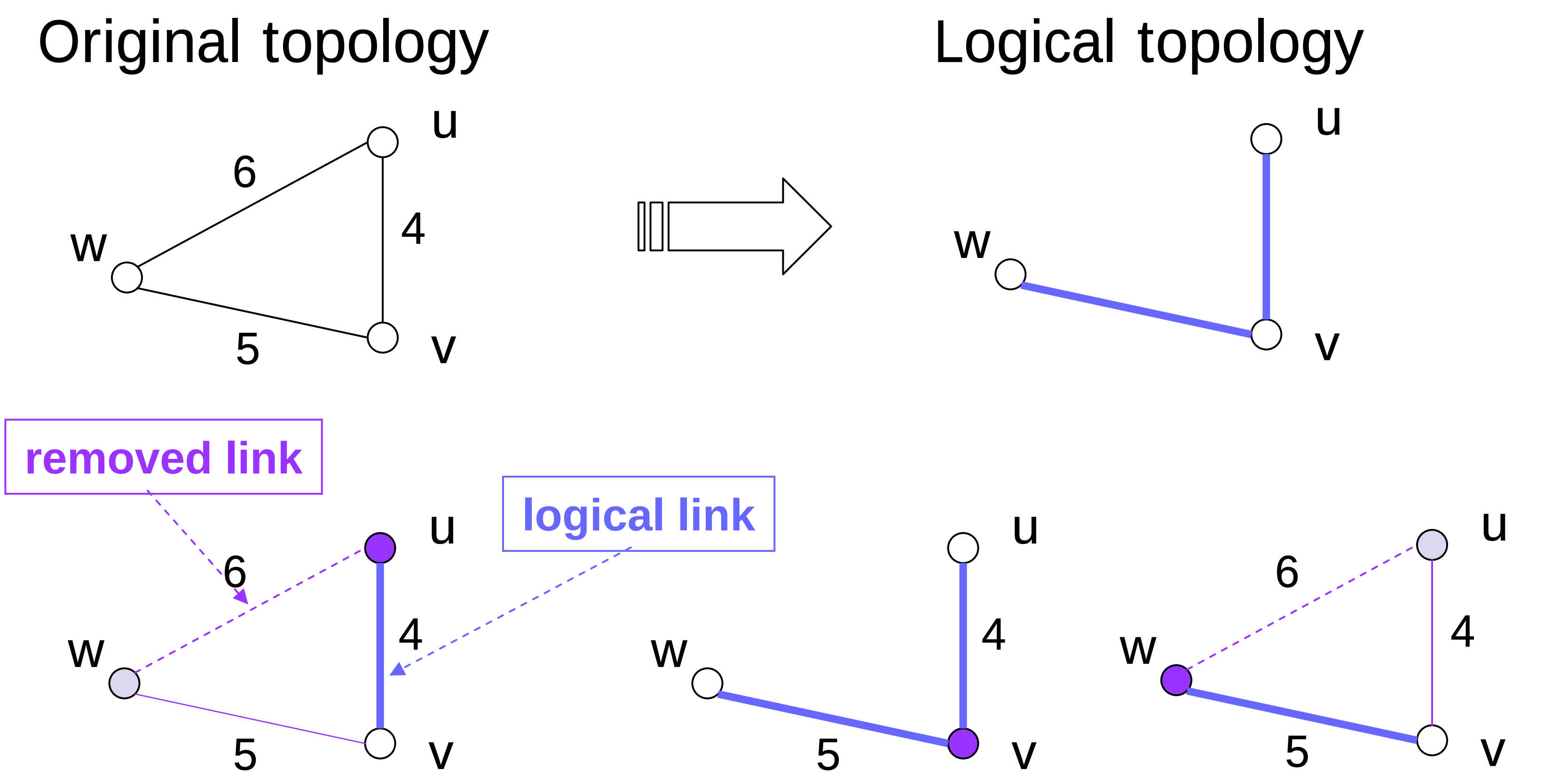


Local Minimal Spanning Tree (Li, Hou, and Sha, 2003)

- LMST
  - Formed by shortest links
  - Connect all 1-hop neighbors
  - Logical neighbors are MST neighbors
- In other words …
  - Remove link *(u,v)* if
    exist $w_1, w_2, \ldots, w_k$ s.t.
    - $d_{u,v} > d_{u,w1}$
    - $d_{u,v} > d_{w1,w2}$
    - ***…***
    - $d_{u,v} > d_{wk,v}$



LMST Example



Local MSTs at nodes *u*, *v*, and *w*

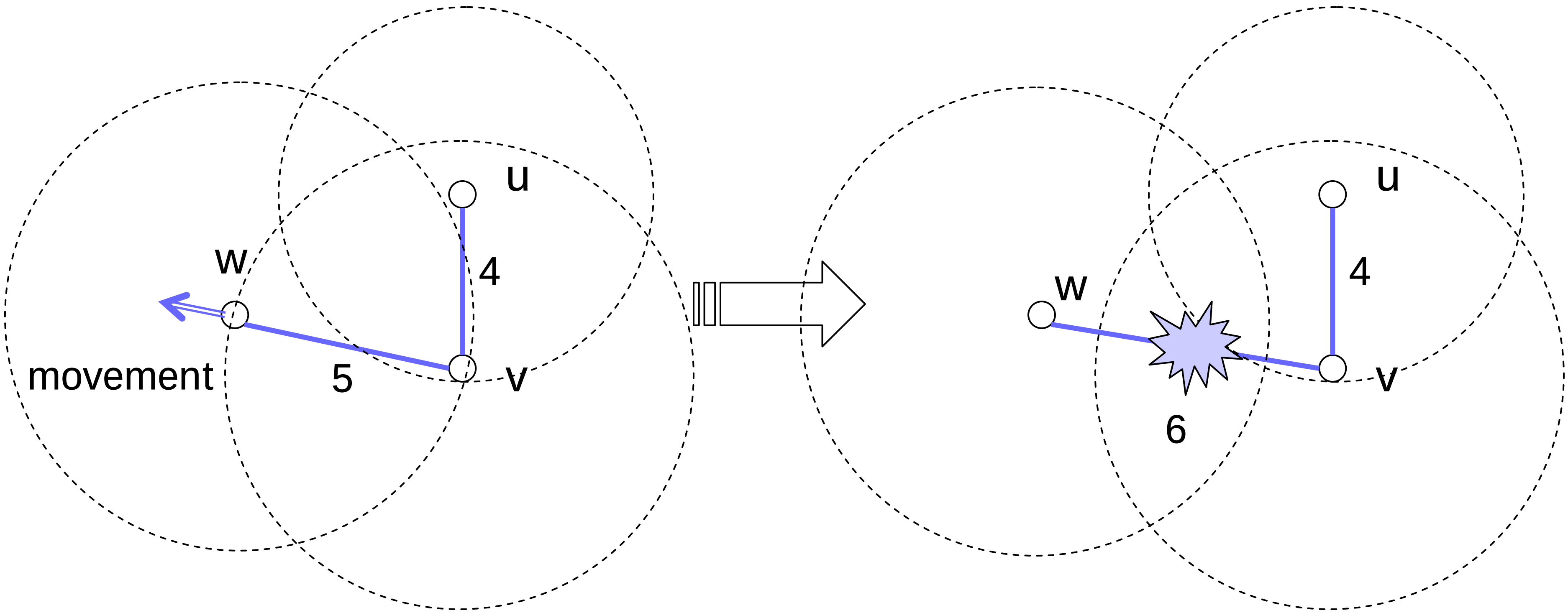
Summary: Link Removal Rule

- Detect loops ($u, w_1, w_2, \ldots, w_k, v$) within 1-hop neighborhood
- Break loop by removing a link (u,v) with the highest cost $C_{u,v}$
- Some criteria break more loops than the others
- Guarantees connectivity in static networks
- What if the network is not static?

TC in Mobile Networks

- Inaccurate position information
  - Actual transmission range may not cover all logical neighbors
  - Solution: slightly increase the actual transmission range (buffer zone)
- Inconsistent local view
  - Simultaneous removal => disconnection
  - Solution: enforce view consistency

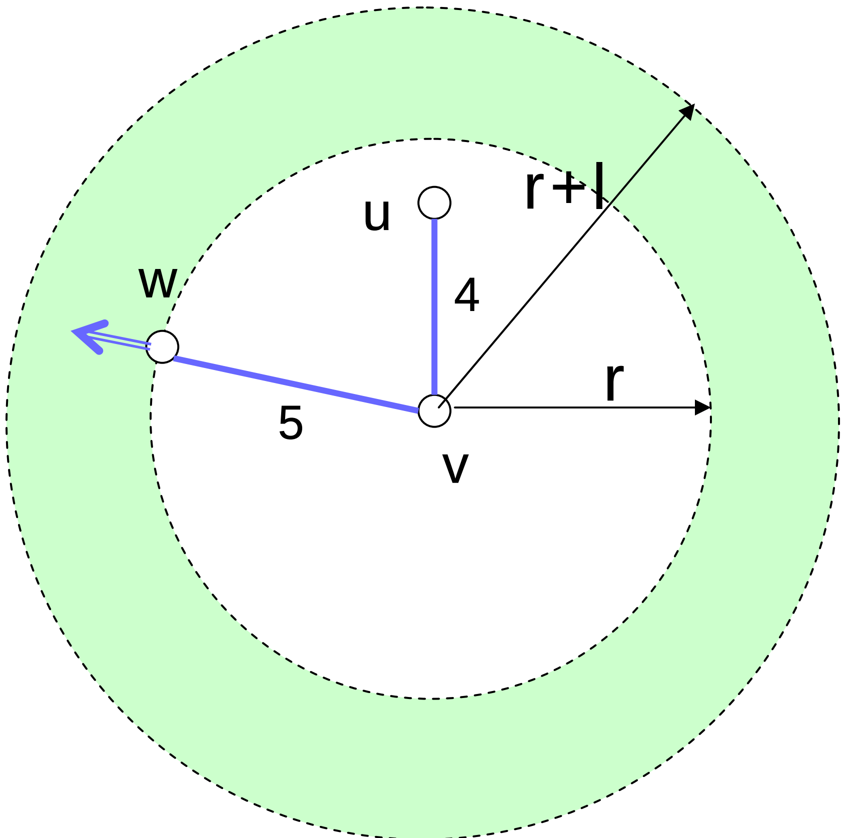
Outdated Information



- Link (v,w) is broken after w moves out of v's transmission range

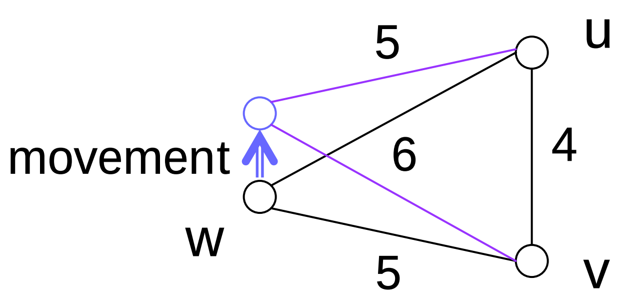
Solution: Buffer Zone

- Increase the actual transmission range r by l to create a buffer zone that tolerate node movement
- l=dt, where t is the maximal relative moving speed, and d is the maximal delay
- Using a l<dt is possible

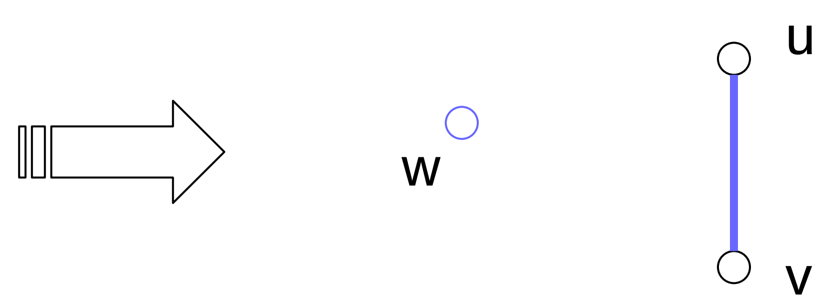


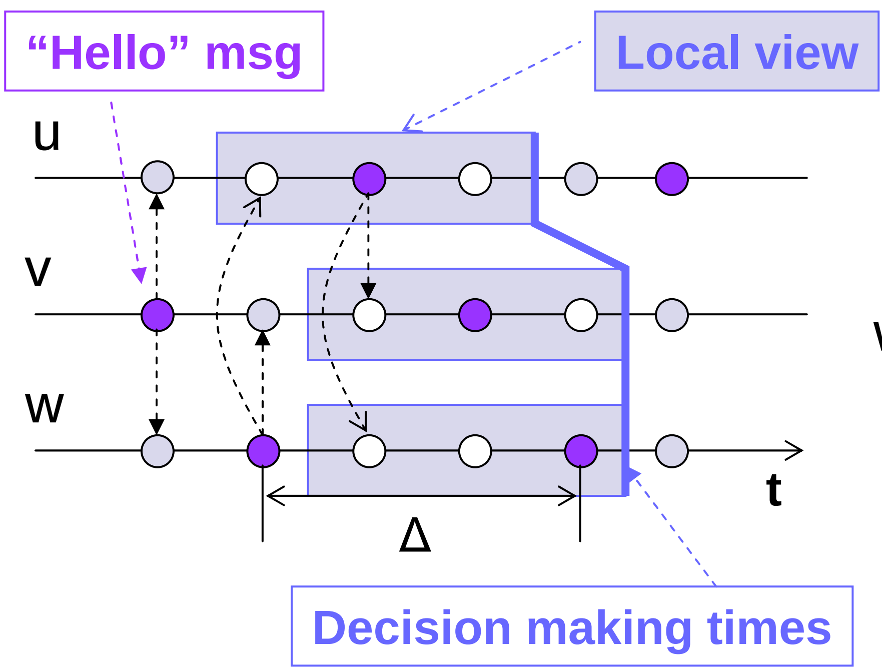
Inconsistent Local Views

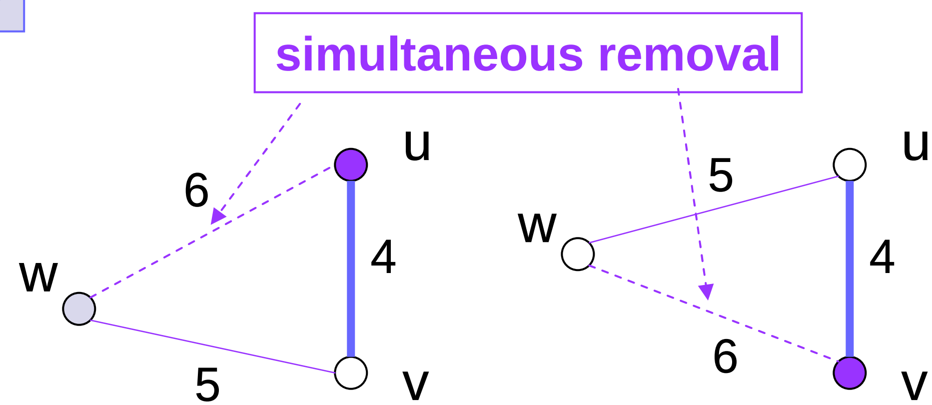
Original topology



Logical topology



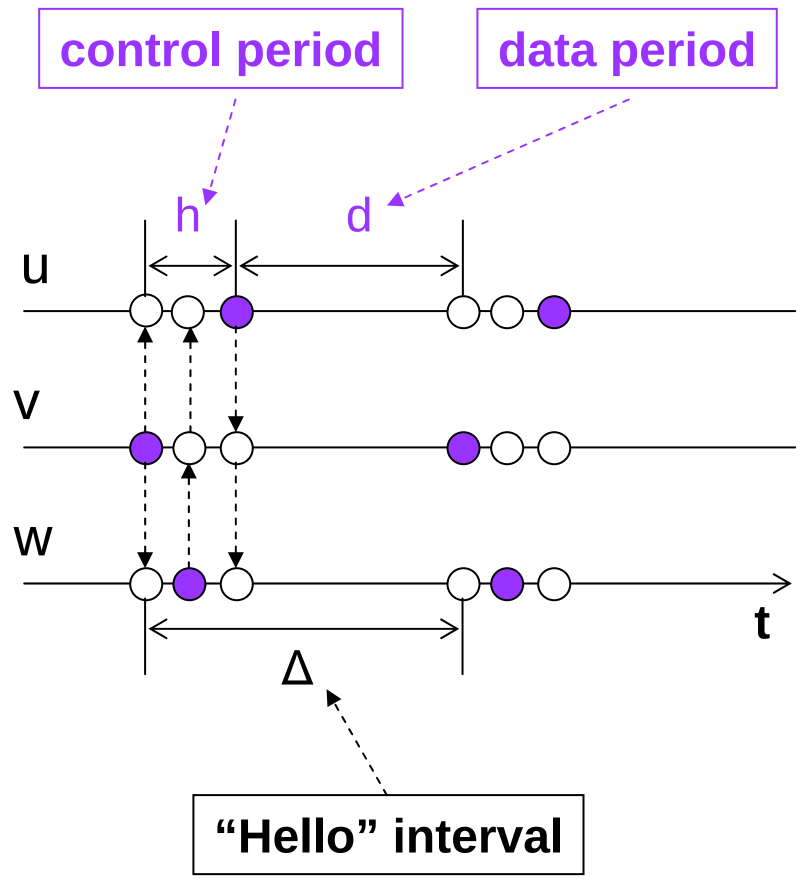




Local MSTs at nodes *u* and *v*

Strong View Consistency (Wu and Dai, 2004)

- Solution
  - All nodes exchange "hello" messages at control period (h)
  - Decisions are made at the beginning of each data period (d)
- Problems
  - "Hello" message collision
  - Require synchronous clocks

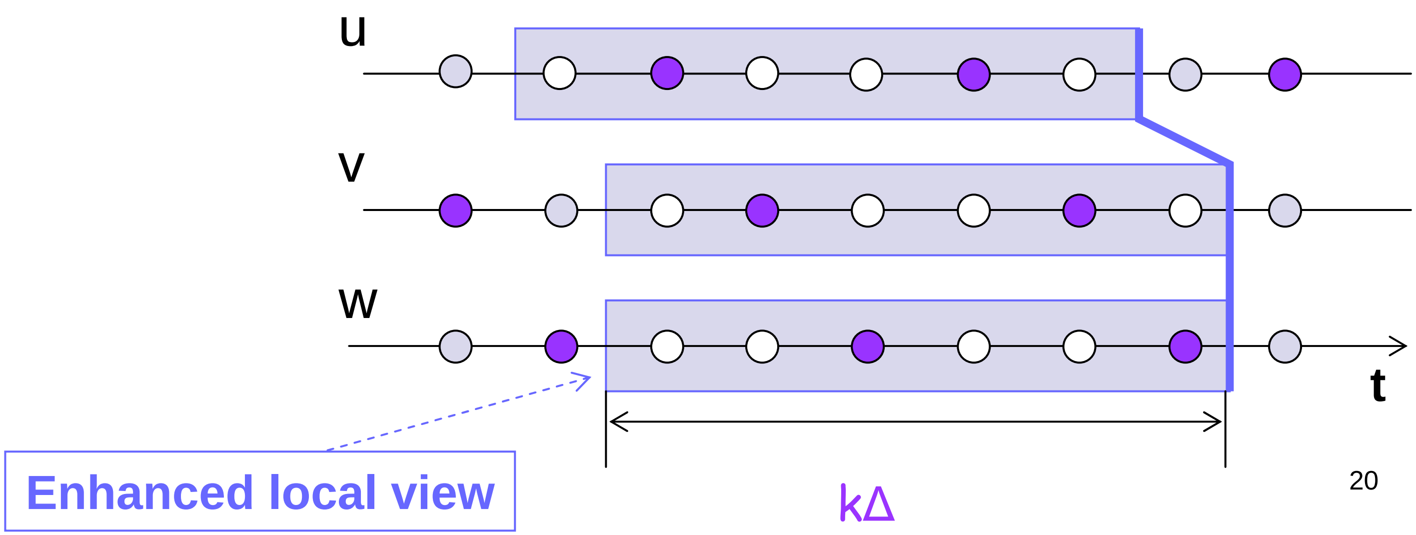


Asynchronous Solution (Dai and Wu, 2005)

- Enhanced local view
  - Use history information
- Enhanced link removal rule
  - Make conservative decisions
- Weak view consistency
  - Guarantee connectivity in spite of mobility and asynchronous decision making

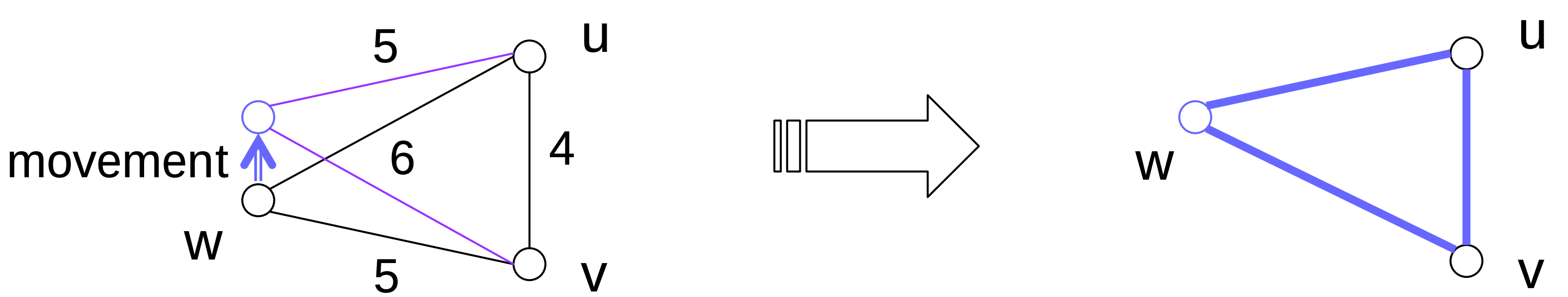
Enhanced Local View

- Contain *k* recent "Hello" messages
- Up to k^2 cost values for each link *(u,v)*
  - $Max(C_{u,v})$: maximum cost in current local view
  - $Min(C_{u,v})$: minimum cost in current local view
  - $MinMax(C_{u,v})$: minimum $Max(C_{u,v})$ in all local views
  - $MaxMin(C_{u,v})$: maximum $Min(C_{u,v})$ in all local views



Enhanced Link Removal Rule

- A link *(u,v)* can be removed, if
  - a loop ($u, w_1, w_2, \ldots, w_k, v$) exist, and
  - $Min(C_{u,v}) > Max(C_{u,wi}), Max(C_{w1,w2}), \ldots, Max(C_{wk,v})$
- Previous example reconsidered
  - Cannot remove *(u,w)*: $Min(C_{u,w}) < Max(C_{v,w})$
  - Cannot remove *(v,w)*: $Min(C_{v,w}) < Max(C_{u,w})$



Weak View Consistency

- Local views are weakly consistent, if
  - $MinMax(C_{u,v}) >= MaxMin(C_{u,v})$ for all (u,v)

Theorem: Applying enhanced link removal rule using weakly consistent local views guarantees connectivity

Theorem: Enhanced local views containing two recent "Hello" messages are weakly consistent.

- Put together
  - Two "Hello" messages from each neighbor are enough to guarantees connectivity

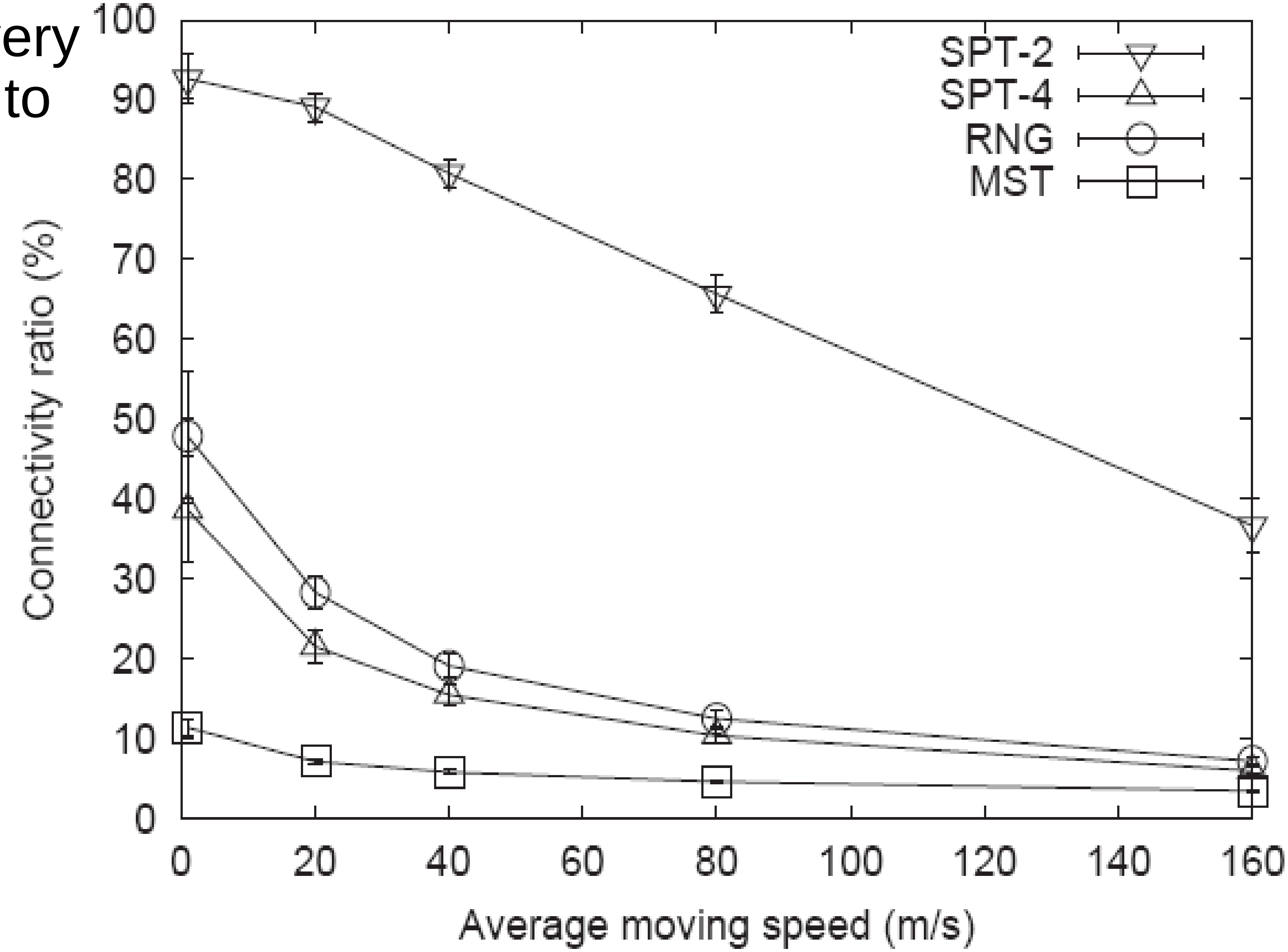
Simulation

- Simulator: ns2
- Simulated algorithms
  - MST: local minimal spanning tree
  - RNG: relative neighborhood graph
  - SPT: local shortest spanning tree with link cost d^2 (a=2) and d^4 (a=4), where d is distance.
- Mobility model
  - Random waypoint, avg. speed 1-160m/s
- Ideal MAC layer without collision/contention
- Connectivity ratio:

  (pairs of connected nodes) / (total node pairs)

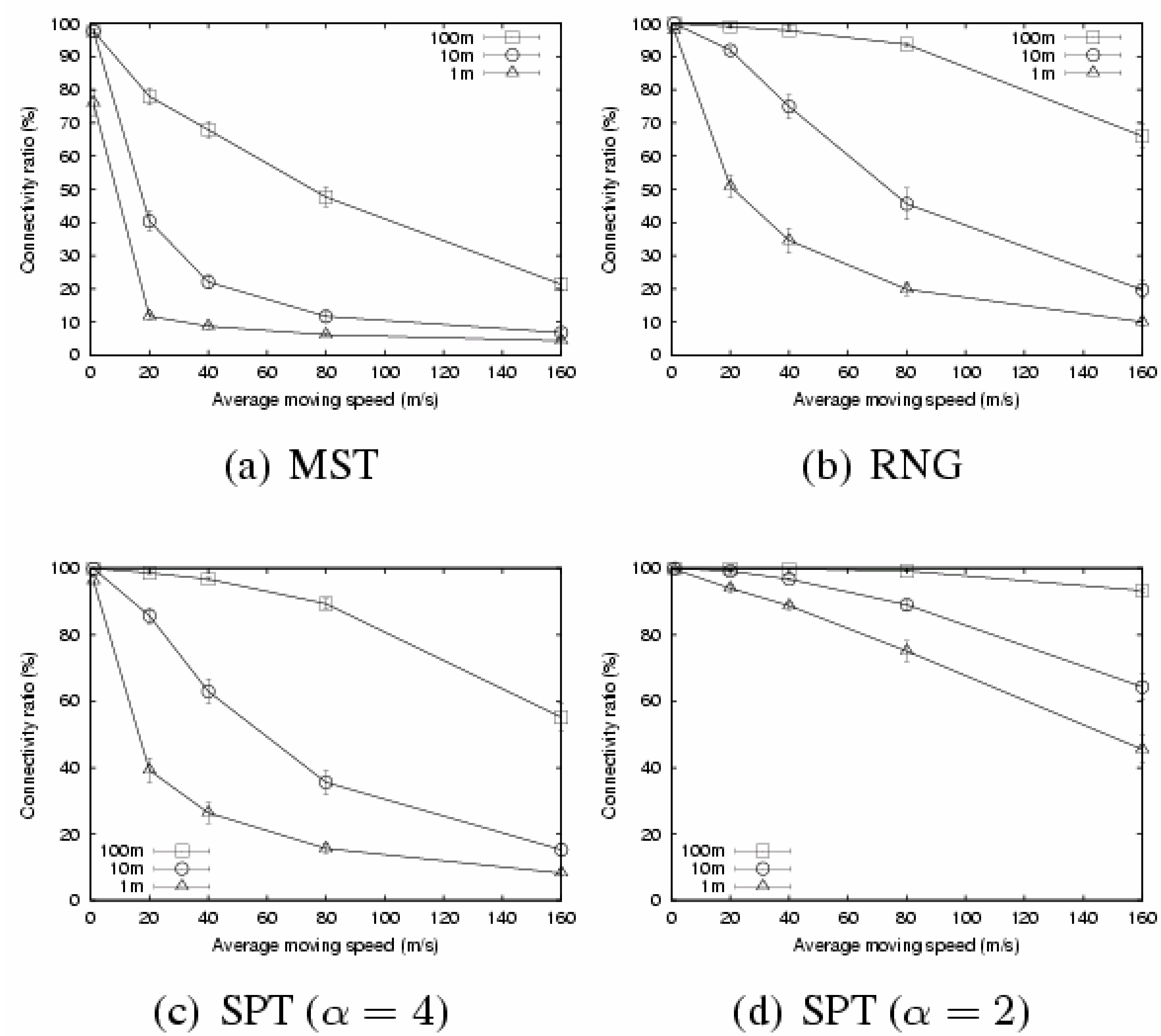
TC Protocols Under Mobile Environment

- Fragile: very sensitive to mobility



Buffer Zone Width

- Connectivity ratio increased as buffer zone width increases
- Buffer zone alone does not guarantee connectivity



(a) MST

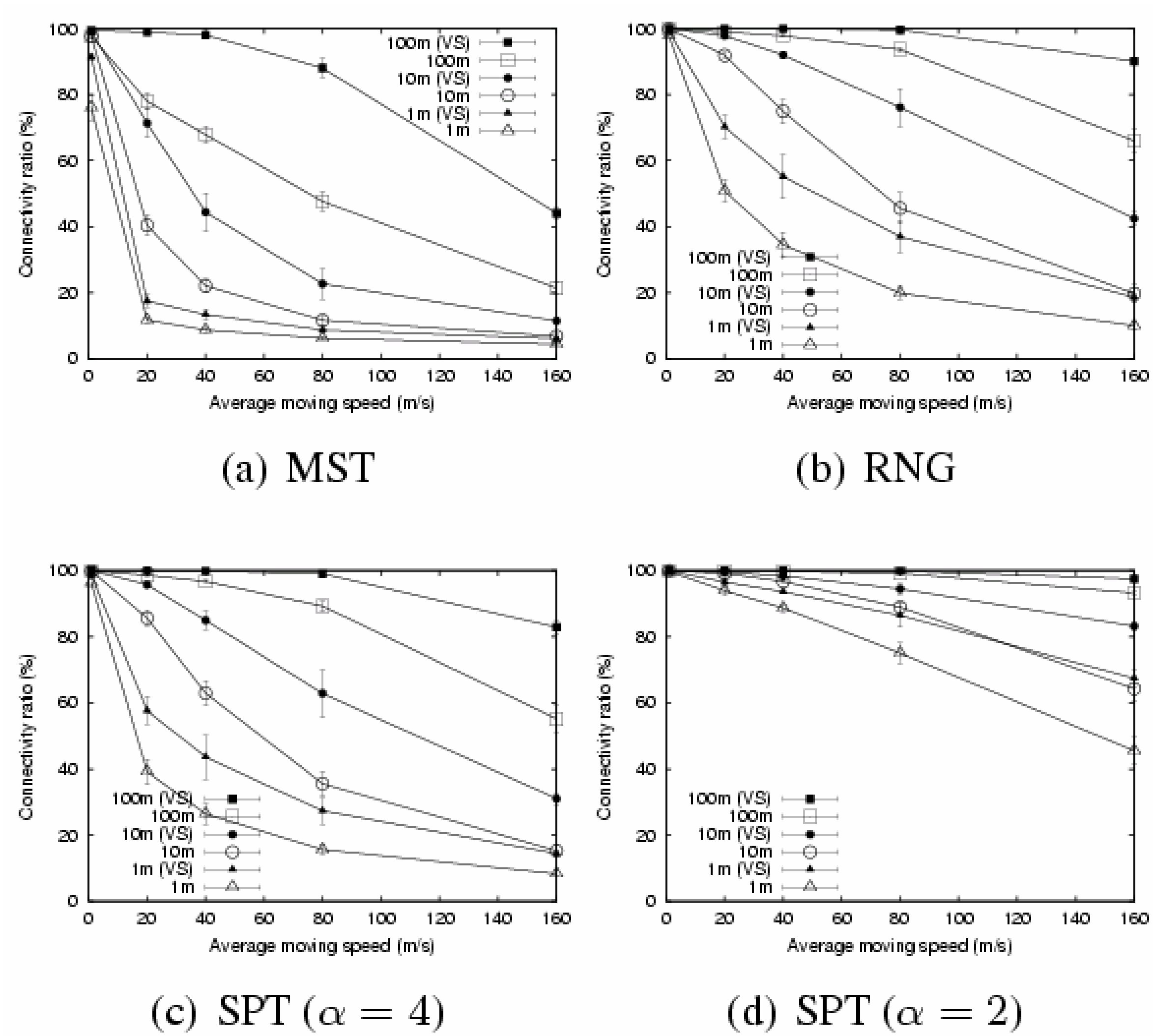
(b) RNG

(c) SPT ($\alpha = 4$)

(d) SPT ($\alpha = 2$)

Consistent Views

- Using consistent views improves connectivity ratio significantly



(a) MST (b) RNG

(c) SPT ($\alpha = 4$) (d) SPT ($\alpha = 2$)

Conclusion

- In MANETs, TC may cause
  - Insufficient actual transmission power
  - Disconnected logical topology
- Weak consistency scheme
  - Guarantee connectivity using 2 recent “Hello” messages
  - No synchronization overhead
  - Slightly increase the number of logical links
  - Enhance many existing TC protocols
- Future directions
  - Fault tolerance against collision