Topology Control in Heterogeneous Wireless Ad-hoc Networks

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Distributed Computing Seminar
ETH Zurich, 30.11.2004

Overview of this Presentation

- Part 1:
  - Introduction
- Part 2:
  - Paper1: General Graphs
    - DRNG & DLMST
  - Paper2: Mutual Inclusion Graphs
    - $EYG_k(MG)$
- Part 3:
  - Proof for connectivity in DLMST
  - Conclusions

About the Papers

- Topology Control in Heterogeneous Wireless Networks: Problems and Solutions
  - Ning Li and Jennifer C. Hou
  - INFOCOM 2004
- Localized Topology Control for Heterogeneous Wireless Ad-hoc Networks
  - Xiang-Yang Li, Wen-Zhan Song, Yu Wang
  - MASS 2004

Part 1

Introduction

Why Topology Control?

- maintain network connectivity
  - every node can reach all others
  - reduce energy consumption
  - sending over near neighbours is more efficient than sending directly to a far target
  - do not send with maximal transmission power if not necessary
- improve network capacity

Related Work

- based on centralised algorithms
  - applicable for static networks
  - need global information
  - can achieve optimality
- based on unit disk graphs
  - homogeneous wireless nodes with uniform transmission ranges
  - every node sends with same transmission power
- based on fixed nodes
  - once a node has been initialised, it does not change its position

Why Heterogeneous Networks? (1)

- can easily add new devices without attention to the type of the device (mobility, dynamic)
  - we can use devices with non-uniform transmission ranges
- in practice there are many influences which affect the range of a device
  - obstacles like plants, walls, ... or other radio frequencies

Why Heterogeneous Networks? (2)

- there exist heterogeneous networks in which devices have dramatically different capabilities
  - Military: devices on soldiers vs. devices on vehicles
- even devices of the same type may have slightly different maximal transmission power

What we want

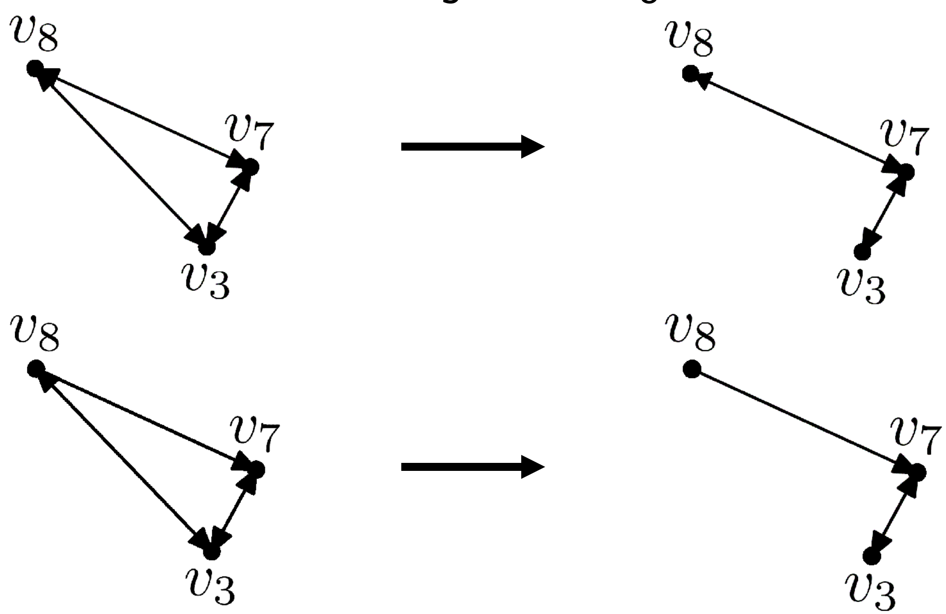
- each wireless node should locally
  - adjust its transmission power
  - select with which neighbours to communicate
- model should deal with dynamic changes in topology
  - addition of new nodes
  - removal or drop out of links (or nodes)

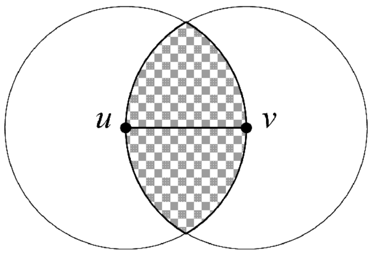
Simple adaptation doesn't work (1)

- can't guarantee network connectivity in heterogeneous case
  - no global information
  - assumptions about transmission power of counterparts don't hold anymore
- message overhead
  - energy
- unbounded out-degree
  - increase signal interference & overhead at a node

Simple adaptation doesn't work (2)

- a RNG structure in a homogeneous graph is connected since all links would be bi-directional
- edge (v_3,v_8) is discarded since v_7 lies in the shaded area between v_3 and v_8





Part 2

General Graphs

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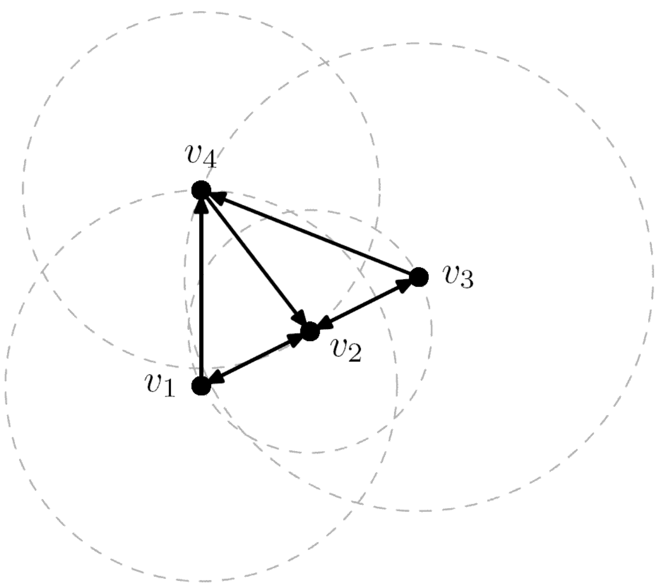
Mutual Inclusion Graphs

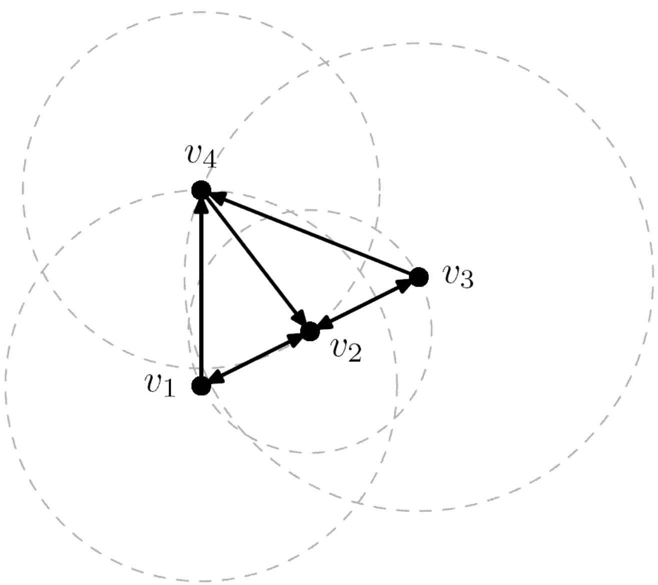
G: (General Graph)

- a node u connects to another node v iff the Euclidean distance between these two nodes is smaller than the transmission range of u
- this model has uni- and bi-directional connections



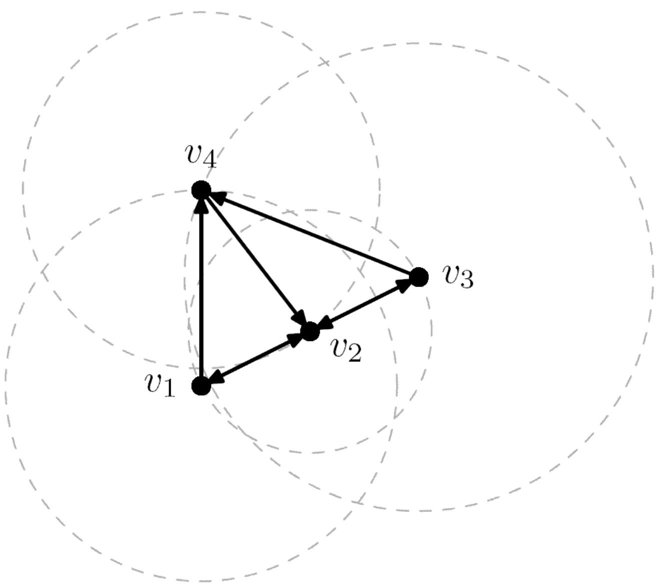
Reachable Neighbourhood (1)

- in DRNG and DLMST each node has to know its reachable neighbourhood
  - set of nodes that a specific node can reach using its maximal transmission power (eg. for v_1 we get v_2 and v_4)



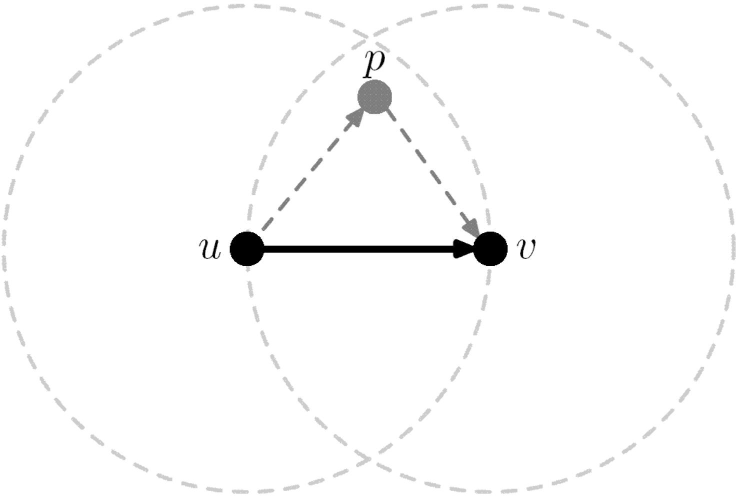
Reachable Neighbourhood (2)

- finding this reachable neighbourhood is difficult since v_4 can't reach v_1
  - unfortunately it is not described in the paper how they will manage this in the General Graph



Directed RNG (Relative Neighbourhood Graph)

- Algorithm:
  - collect reachable neighbourhood
  - build topology by selecting those nodes from the reachable neighbourhood for which there does not exist a node p that is closer to u and v than u to v and p can reach v.

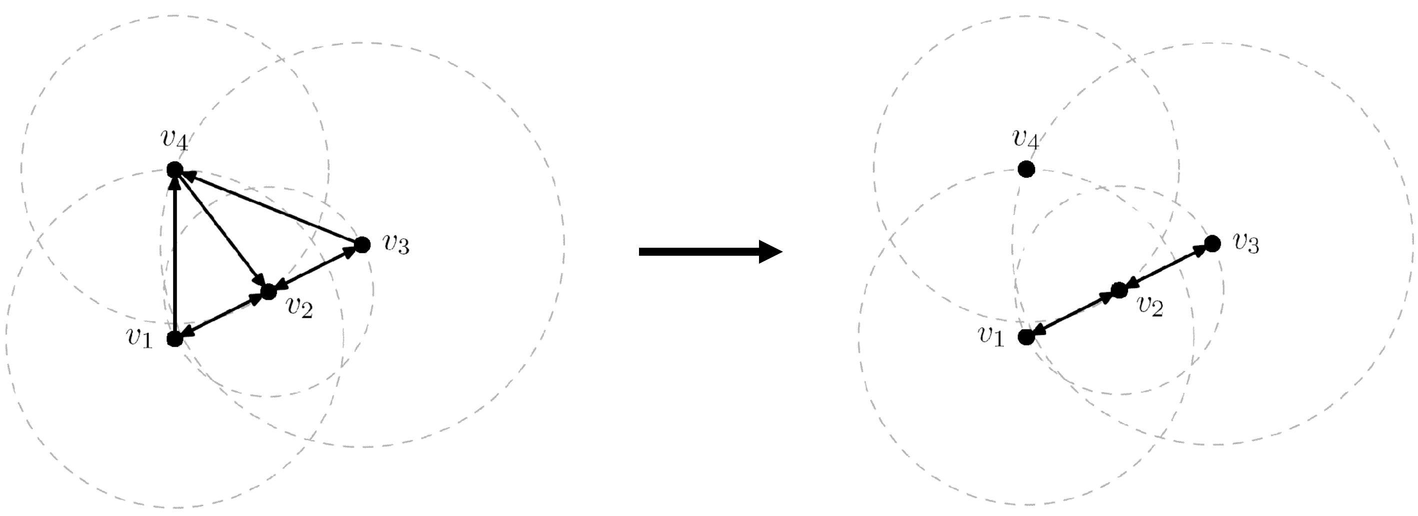


Directed Local MST (Minimum Spanning Tree)

- Algorithm:
  - collect reachable neighbourhood
  - build topology computing a directed MST for each node that spans the reachable neighbourhood of this node and takes on-tree nodes that are one hop away as its neighbours.

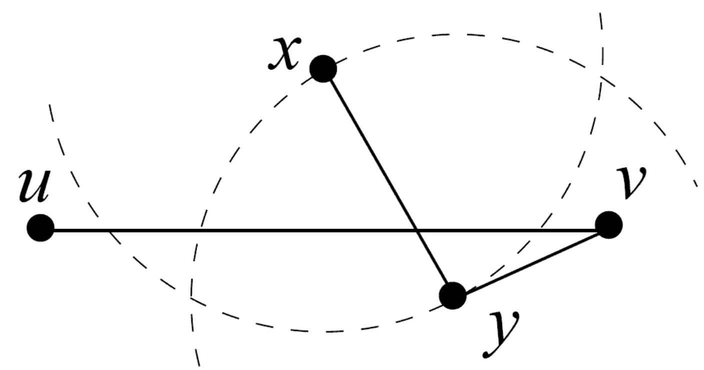
MG: (Mutual Inclusion Graph)

- two nodes are connected iff they are within the maximum transmission range of each other
- there are only bi-directional links



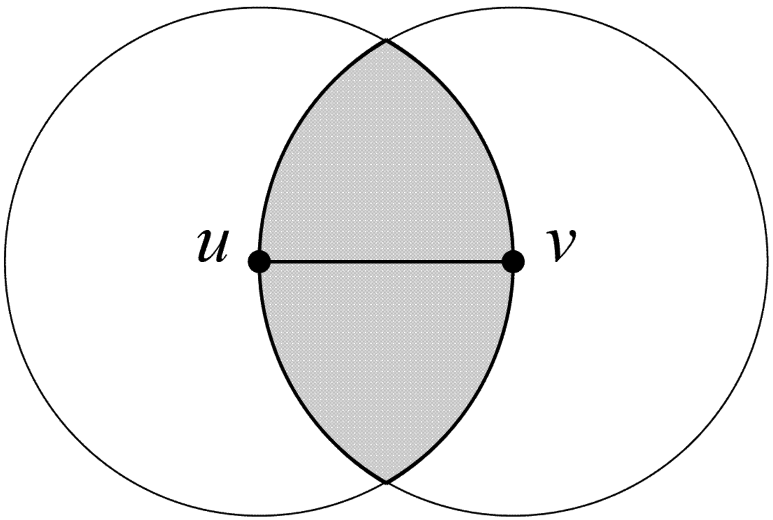
Planar Topology

- for any topology control method it is not always possible to create a planar topology while keeping the communication graph connected
  - u is out of the transmission range of x and y, while v is in the transmission range of y and out of the range of x
  - according to MG, there are only xy, vy and uv in the graph



Sparse Structure

- based on RNG they found an extension that has bounded number of links → sparse structure
- unfortunately that's not what we want
- we are looking for bounded out-degree

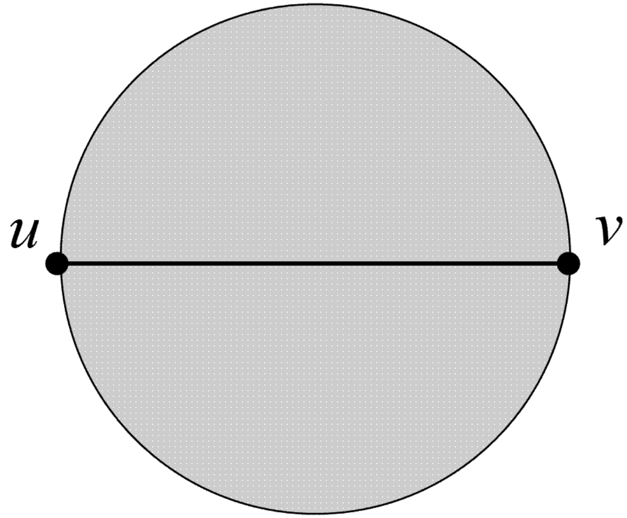


Idea of Spanners

- Given a graph G and a subgraph H of G.
- H is a t-Length Spanner of G if for any two nodes u,v $\in$ V(H) the shortest path between u and v is at most a constant factor t longer than the shortest path of these two nodes in G.
- if the weighting function is not the length but the power than we have with the same argumentation a Power Spanner instead of a Length Spanner

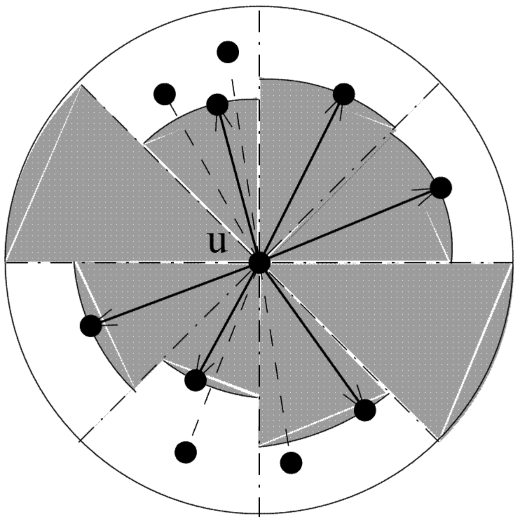
Power Spanner

- based on GG (Gabriel Graph) they found a graph which contains the minimum power consumption path for any two nodes in MG
- we are still looking for bounded out degree



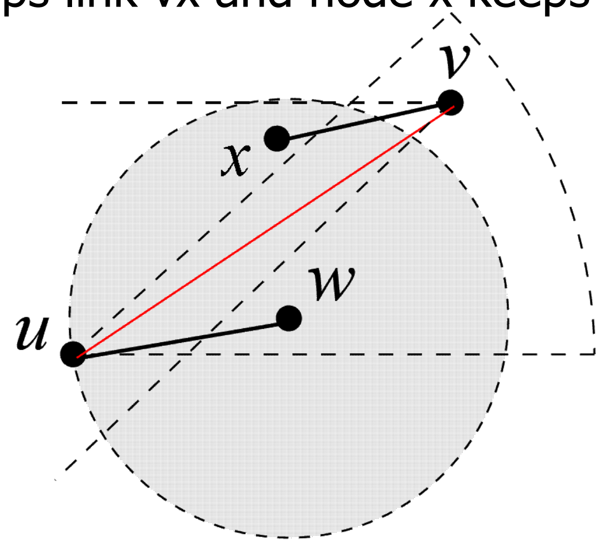
Degree-Bounded Spanner (1)

- based on Yao Graph
- at each node u, partition space into k equal subspaces (= cones) and connect to the nearest node in each cone if there is any



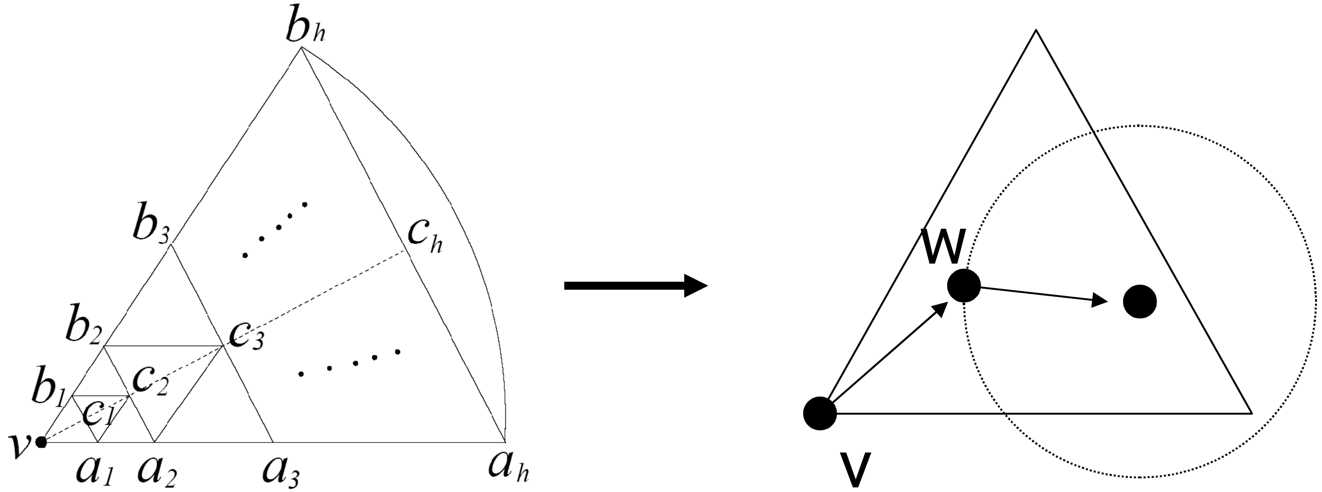
Degree-Bounded Spanner (2)

- in a MG model simply selecting the closest incoming neighbour does not guarantee connectivity
  - v, w are in same cone of u ; x , u are in same cone of v
  - node u keeps link uw and node w keeps link uw
  - node v keeps link vx and node x keeps link xv.



Novel Space Partition

- partition space into k equal subspaces (= cones)
- divide each cone into constant number of subsets and connect v to the nearest node w in each subset
- the algorithm guarantees that all nodes in a subset are connected to node w in this subset



$EYG_k(MG)$: (Extended Yao Graph)

- has bounded out-degree in $O(\log_2 q)$
- is a Length- and a Power-Spanner to MG
- is connected if MG is connected
- is bi-directional
- they reach almost optimum since any connected graph will have degree at least $O(\log_2 q)$
- $q = \max_{v,w} r_v/r_w$ with $v \in V(MG)$ and $wv \in EYG_k(MG)$

Part 3

Proof

&

Conclusions

Proof for connectivity in G_{DLMST} (1)

- Lemma 1:

  For any edge (u, v) which is only in G but not in G_{DLMST}, there must be a unique path on T_u from u to v in G_{DLMST}. Let p be the last node on this path before v than we have $w(p, v) < w(u, v)$.

  w(u, v): gives any edge in a graph a unique weight

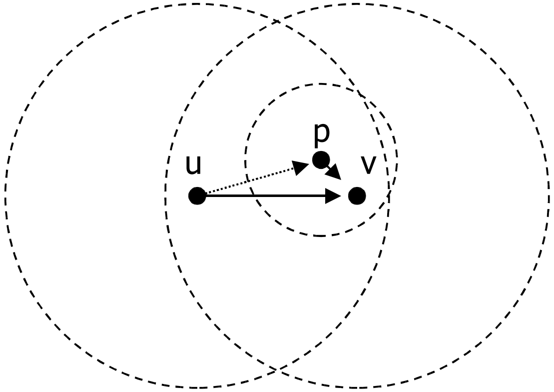
  T_u: local MST rooted at node u containing all reachable nodes of u

  G: General Graph

Proof for connectivity in G_{DLMST} (2)

- Proof (by contradiction):

Suppose w(p, v) > w(u, v), we can construct another directed spanning tree T'_u rooted at u with lower weight, by replacing edge (p, v) with (u, v) and keeping all the other edges in T_u unchanged. This contradicts the assumption that T_u is the local directed MST.



Proof for connectivity in G_{DLMST} (1)

- Lemma 2:

  Let T be the global directed MST of G rooted at any node w $\in$ V (G), than E(T) $\subseteq$ E(G_{DLMST}).

- Proof (by contradiction):

  For any edge (u, v) $\in$ E(T) suppose (u, v) $\notin$ E(G_{DLMST}). Since v is on the directed local MST T_u , there exists a unique path from u to v with p as the last node on this path before v.

  We have w(p, v) < w(u, v) by Lemma 1. By replacing edge (u, v) with (p, v) and keeping all the other edges in T unchanged, we can construct another global directed spanning tree T rooted at w that has lower weight than T. This contradicts the assumption that T is the global MST rooted at w.

Proof for connectivity in G_{DLMST} (4)

- Theorem 1 (Connectivity of G_{DLMST}):

  If G is strongly connected, than G_{DLMST} is also strongly connected.

- Proof (by contradiction):

  For any two nodes u, v $\in$ V (G), there exists a unique global MST T rooted at u since G is strongly connected. Since E(T) $\subseteq$ E(G_{DLMST}) by Lemma 2, there is a path from u to v in G_{DLMST}.

Conclusions: Paper 1 (1)

- for a General Graph there are two localized topology control algorithms, DLMST and DRNG, which preserve connectivity
- DLMST and DRNG preserve bi-directionality if they are based on a Mutual Inclusion Graph and Addition & Remove operations are applied

Conclusions: Paper 1 (2)

- DLMST has a bounded out-degree while DRNG may be unbounded
- there is no description of how exactly they find the reachable neighbourhood
  - it is more like a theoretical and mathematical work showing the general possibility for building such topologies based on a General Graph

Conclusions: Paper 2

- EYG_k(MG) has a stricter bound on the out-degree than DLMST and guarantees better characteristics
- Length- and Power-Spanner to MG
- they reach almost optimum since any connected graph will have degree at least $O(\log_2 q)$

Questions?