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Algorithms for Radio Networks

WSN: Data Aggregation I

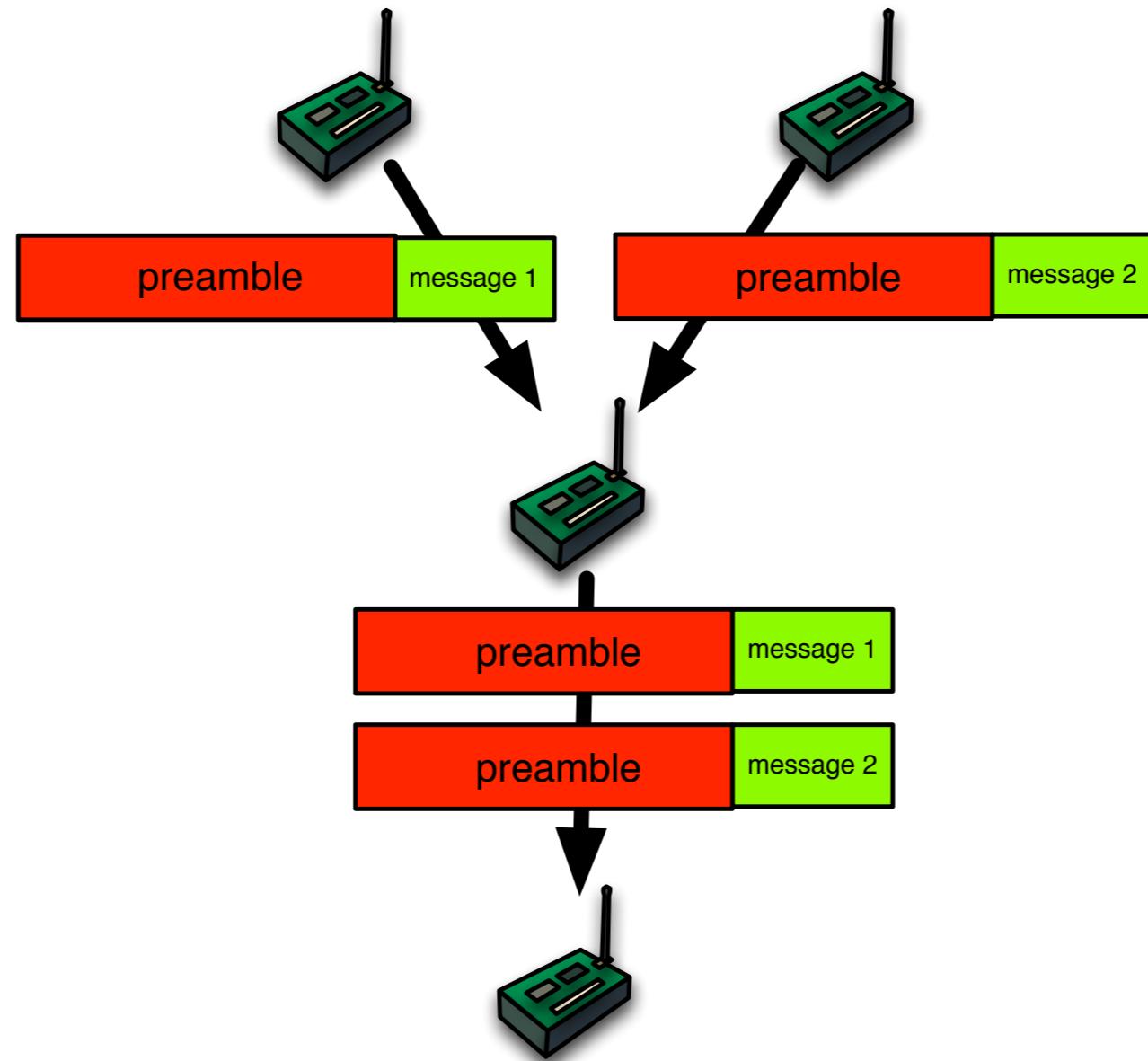
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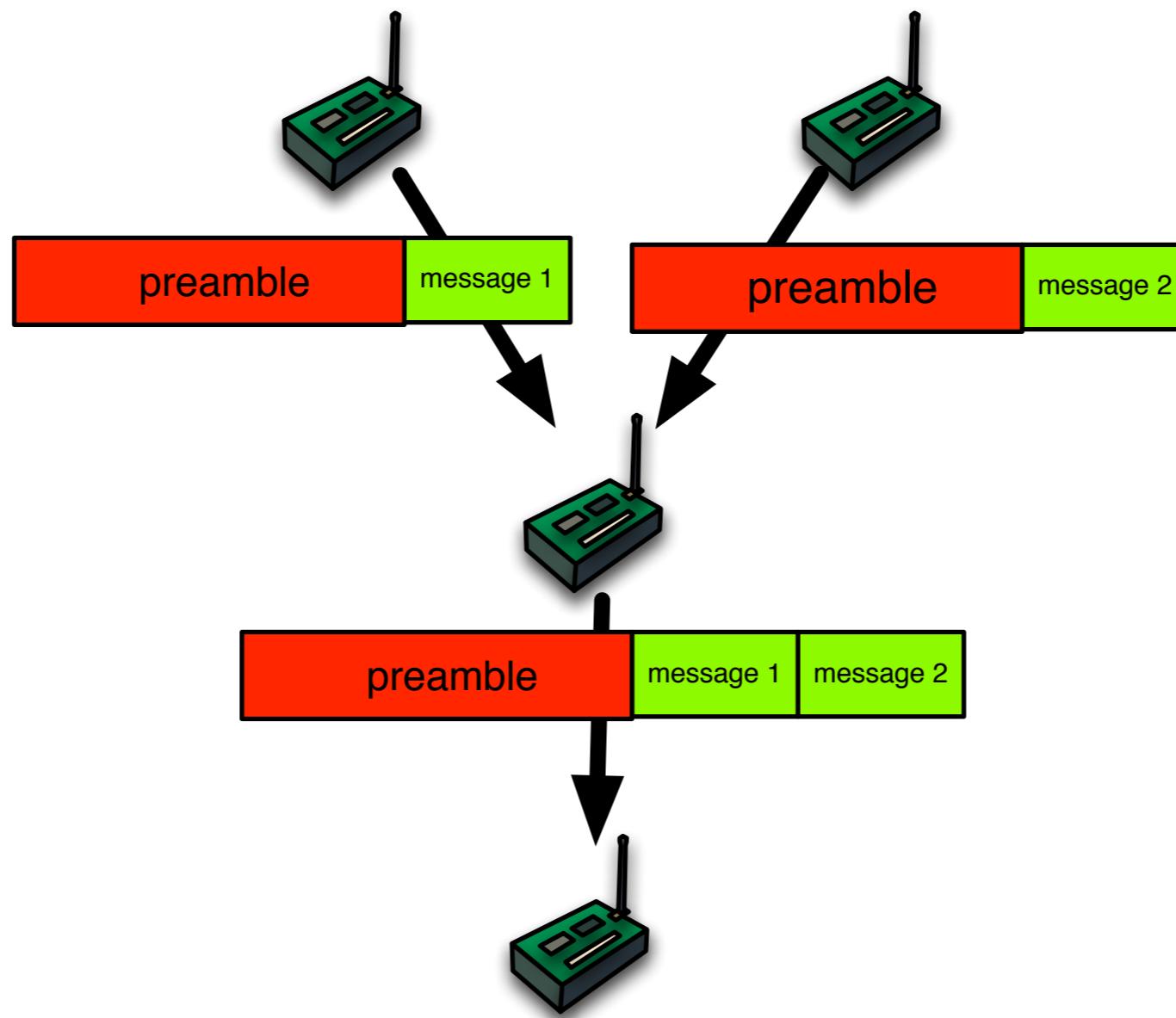
Data Aggregation

- ▶ **In multi-hop networks combining message can improve networking**
- ▶ **Concatenation) of messages**
 - overall number of headers is reduced
 - especially for Preamble Sampling
 - smaller costs for collision avoidance
- ▶ **Recalculation of contents**
 - e.g. If the minimum temperature is required, then it satisfies to forward the smallest value
 - For this purpose, collect the input over some time

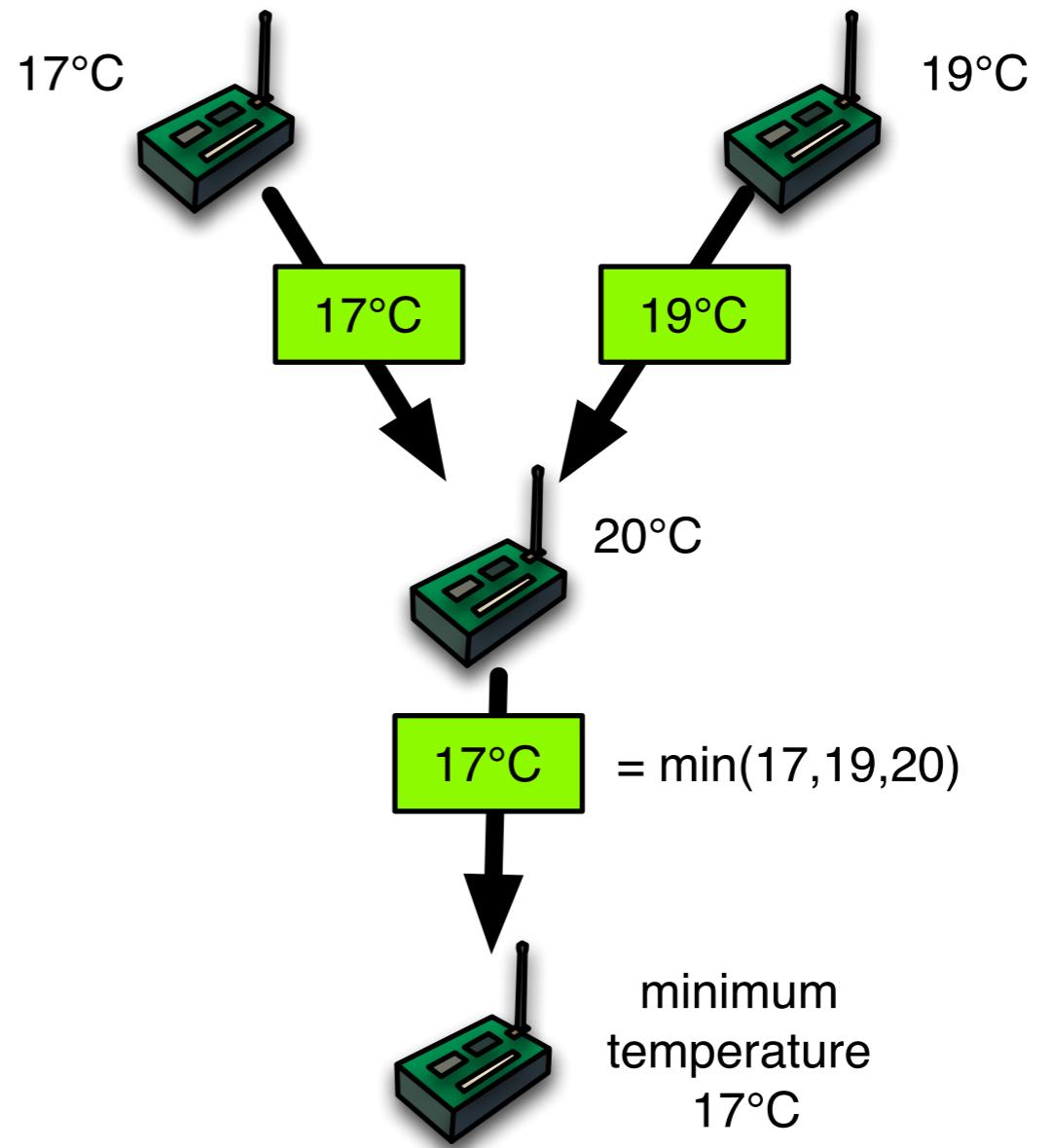
No Data Aggregation



Data Aggregation by Concatenation



Real Data Aggregation by Recalculation



Simple Functions for Data Aggregation

- ▶ **Minimum**
 - inner node computes the minimum of input values
- ▶ **Maximum**
 - like Minimum
- ▶ **Number of sources**
 - inner node adds input values
- ▶ **Sum**
 - addition at inner nodes

Aggregable Functions

▶ Mean

- compute the number of sensors: n
- compute the sum of sensor values: S
- mean = S/n

▶ Variance

- Berechne Durchschnitt und den Durchschnitt der Quadrate der Messwerte
- $V(X) = E(X^2) - E(X)^2$

Non-Aggregable Functions

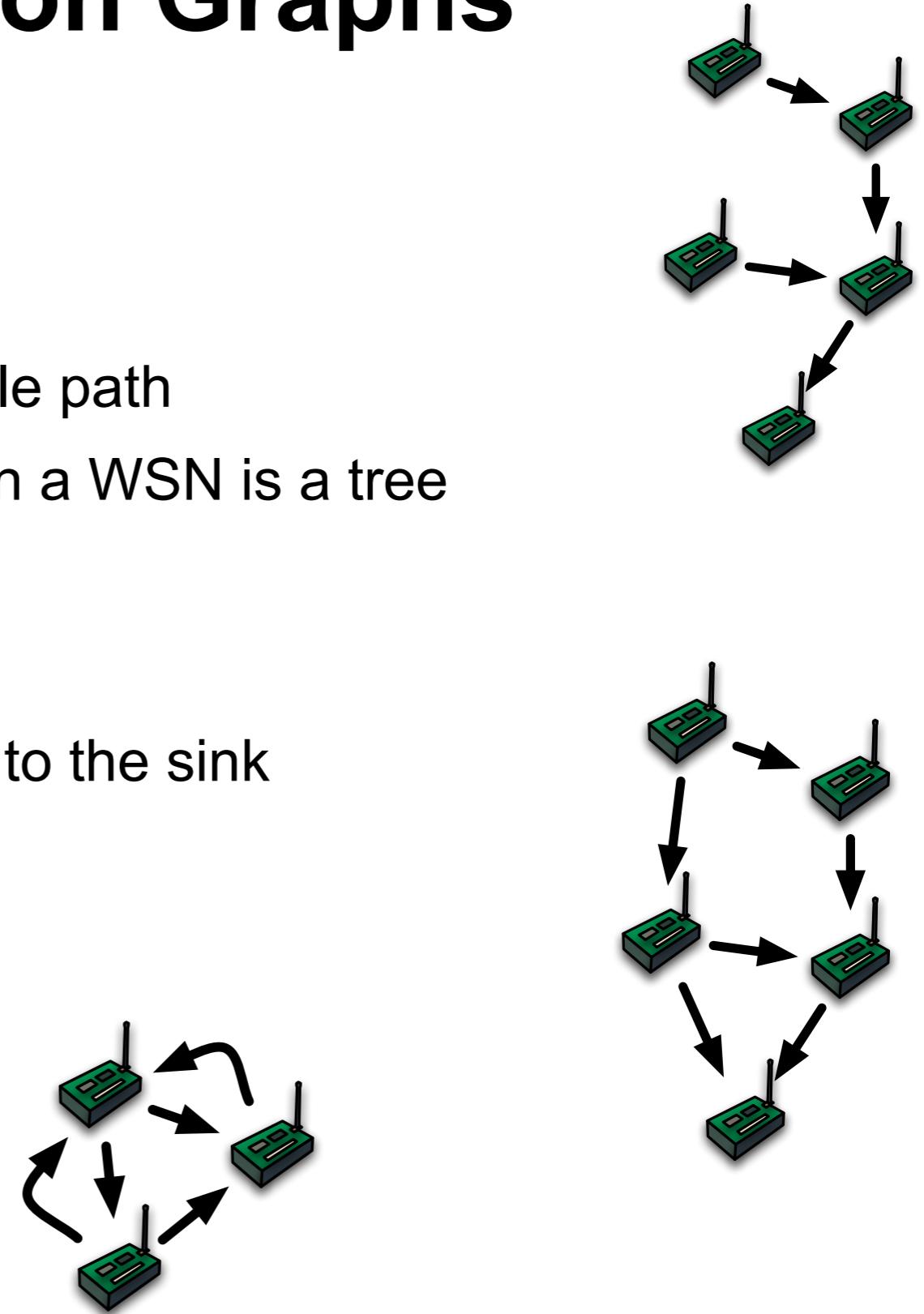
- ▶ **The following functions cannot be aggregated (or no solution is known so far)**
 - median
 - p-quantile
 - if p is not very small or large
 - number of different values
 - only for large data sets an approximation is possible

Routing Models for Data Aggregation

- ▶ **Address Centric Protocol**
 - each sensor sends independently towards the sink
 - not suitable for (real) aggregation
- ▶ **Data Centric Protocol**
 - Forwarding nodes can read and change messages

Communication Graphs

- ▶ **Tree Structure**
 - If there is only a single sink
 - and every source uses only a single path
 - then every communication graph in a WSN is a tree
- ▶ **DAG (directed acyclic graph)**
 - general case
 - caused by changing routing paths to the sink
 - may complicate data aggregation
 - e.g. sum
- ▶ **General graph**
 - Population protocols
 - are not used in WSNs



Energy Optimal Tree Structure

› **Given:**

- set of data sources and a sink
- communication graph G

› **Compute:**

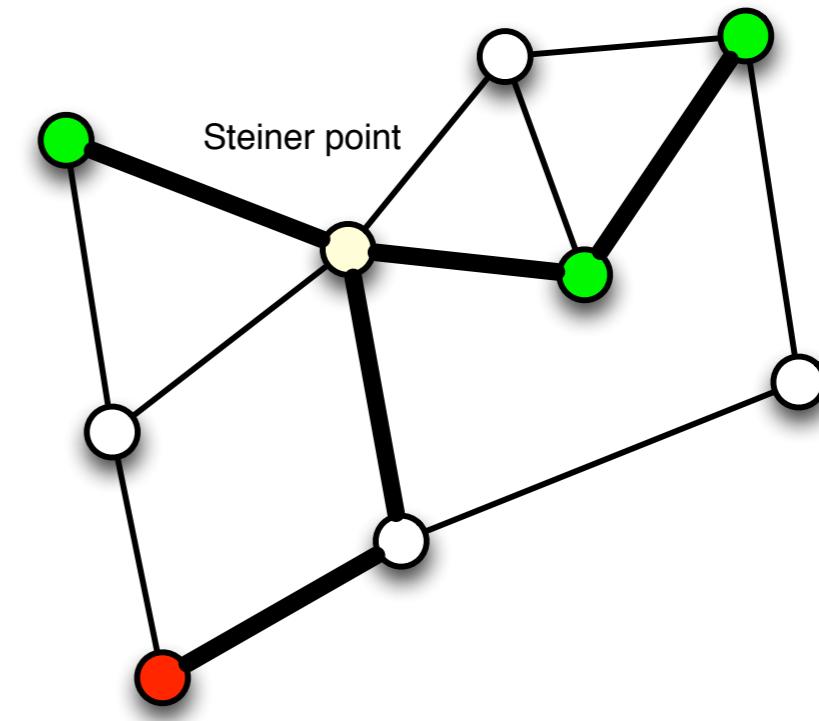
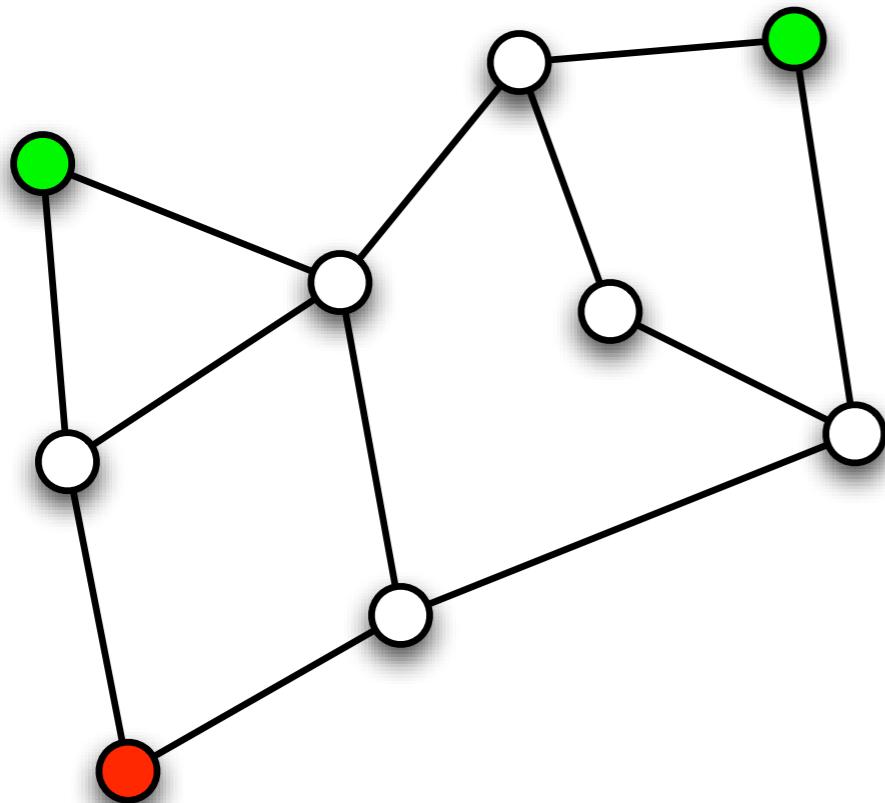
- Steiner tree T
 - sub-graph of G
 - connects all sources and sinks
 - number of edges is minimal

› **Alternative:**

- edges have an (energy) weight
- minimize the sum of edge weights

Steiner Tree Problem

- ▶ **Observation:**
 - sources and sinks can be handled the same way



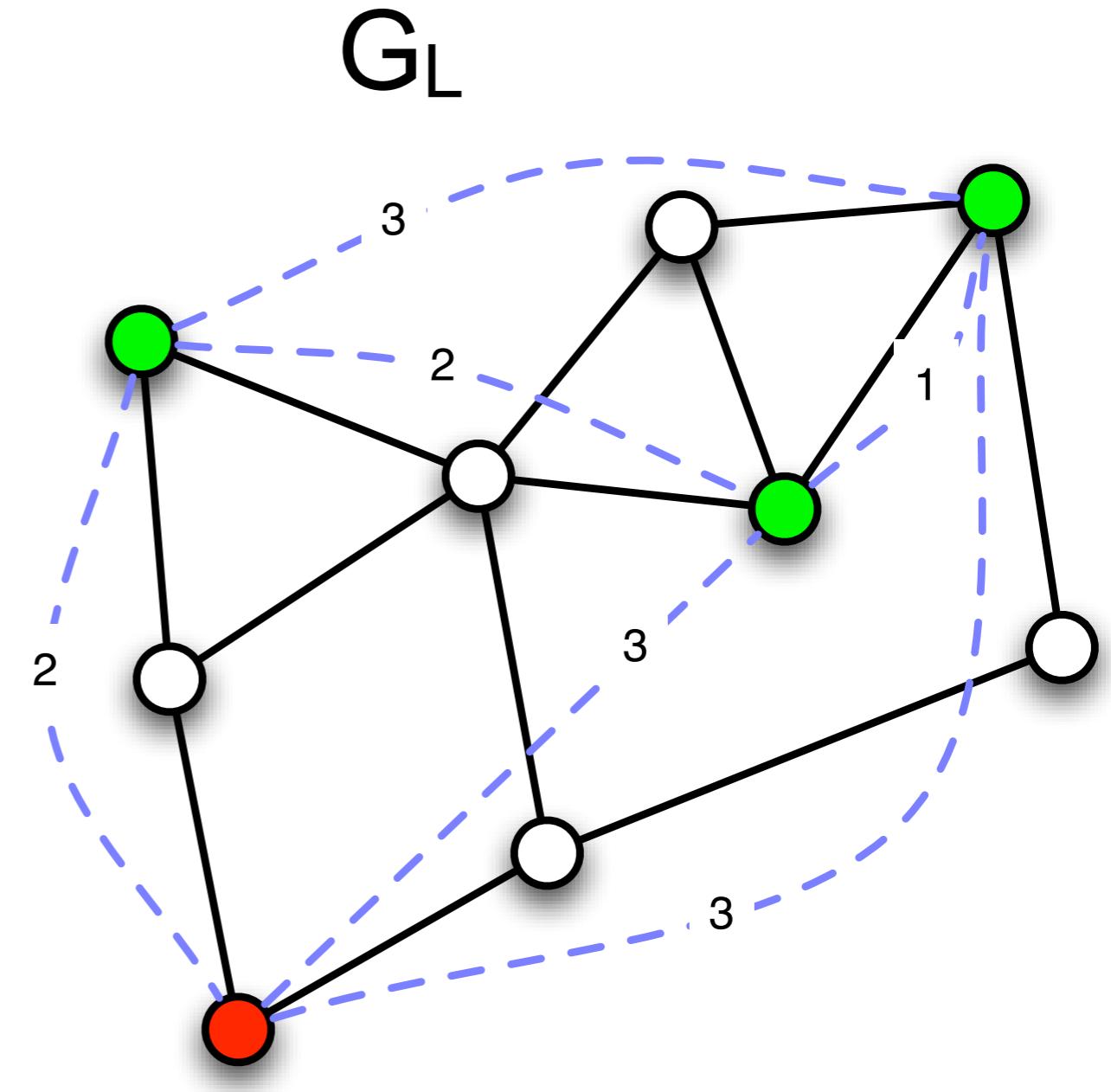
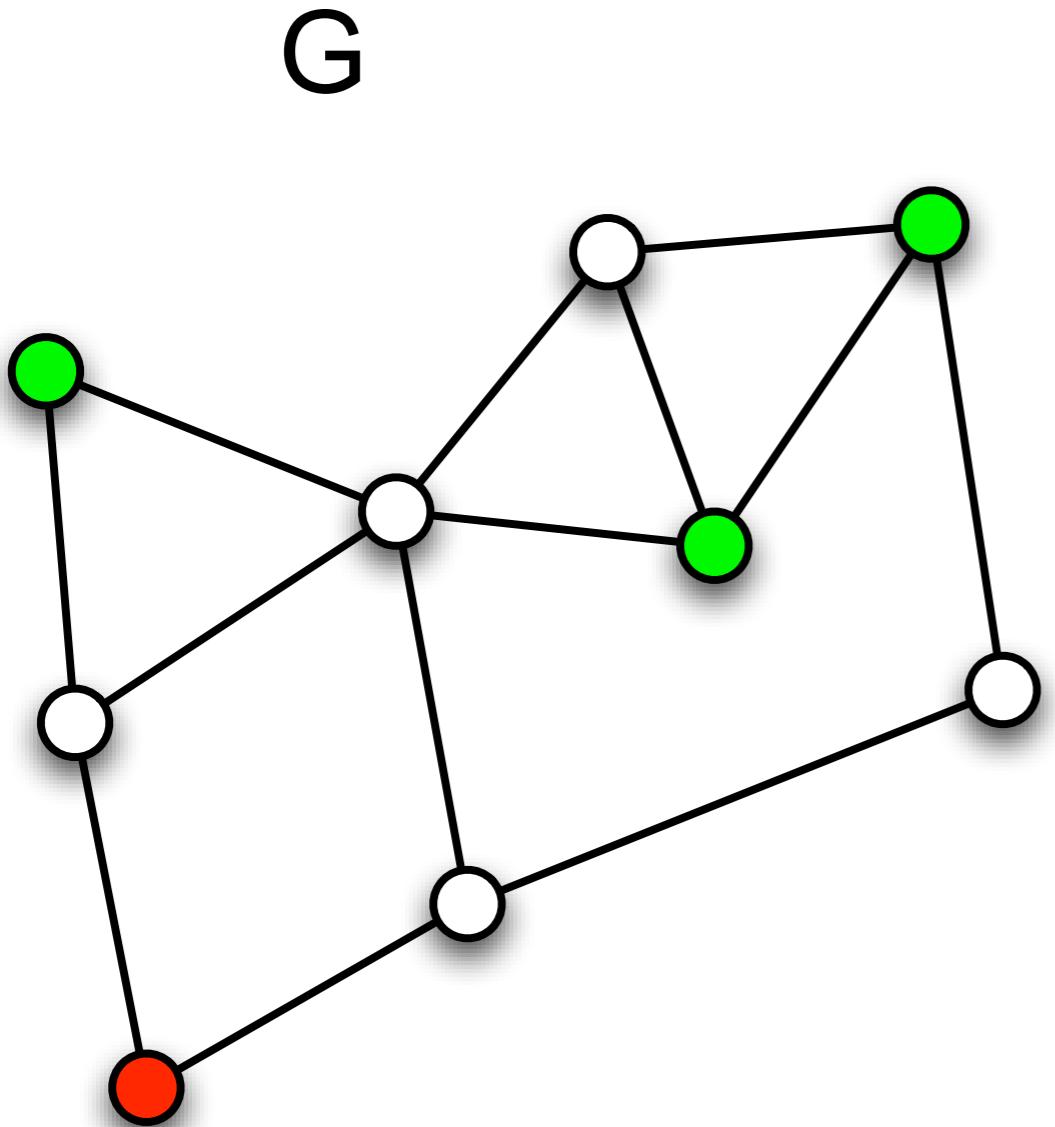
Optimal Choice of Data Aggregation

- ▶ **Steiner tree**
 - minimal tree connecting all sources and sinks
- ▶ **Computation of the Steiner tree is NP-hard**
- ▶ **Approximation**
 - the Steiner tree problem can be approximated with factor 2
 - if the underlying graph is metric
 - best known approximation factor for algorithms in polynomial time: 1.55
 - Zelikovsky, Robins 2006

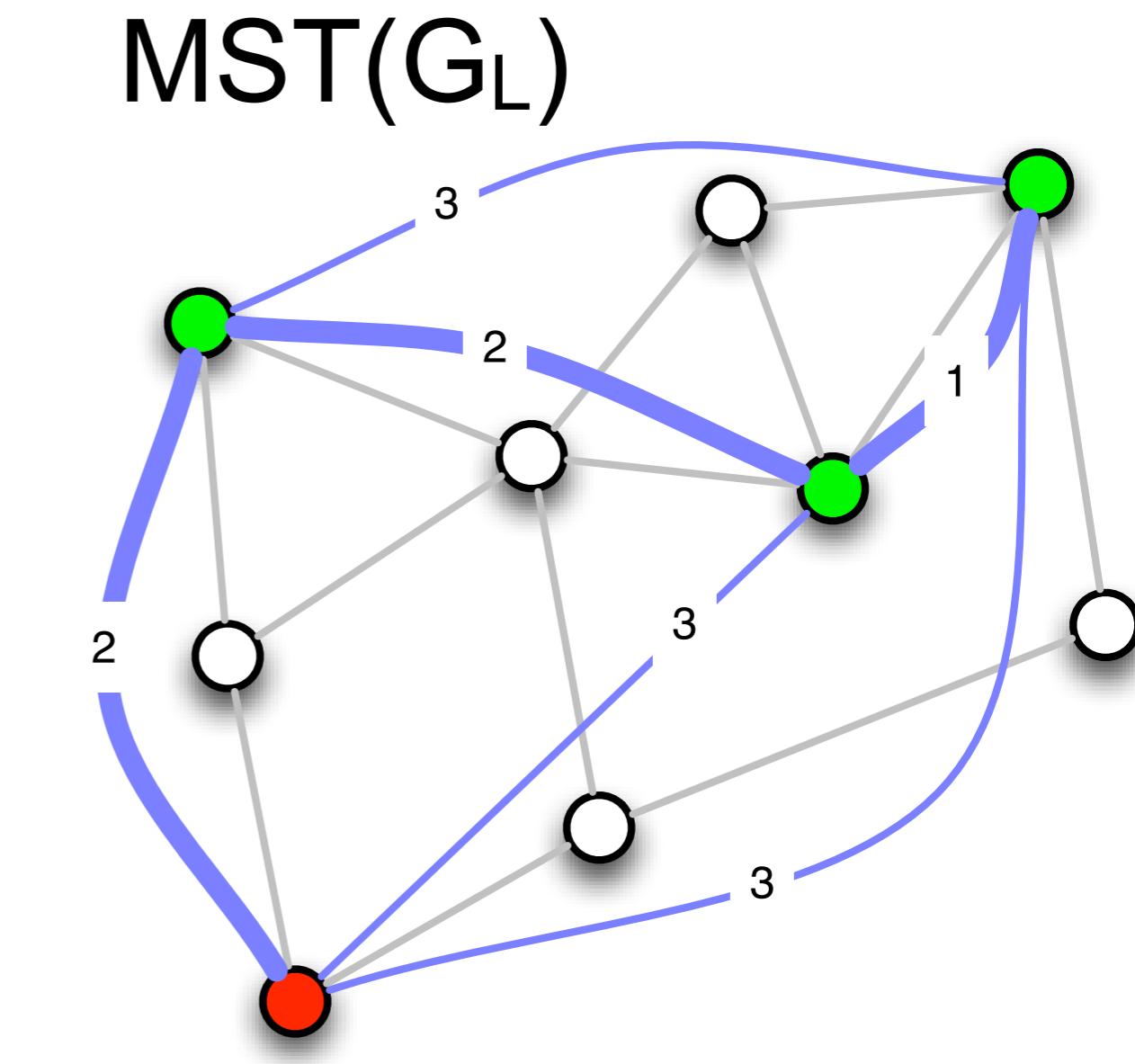
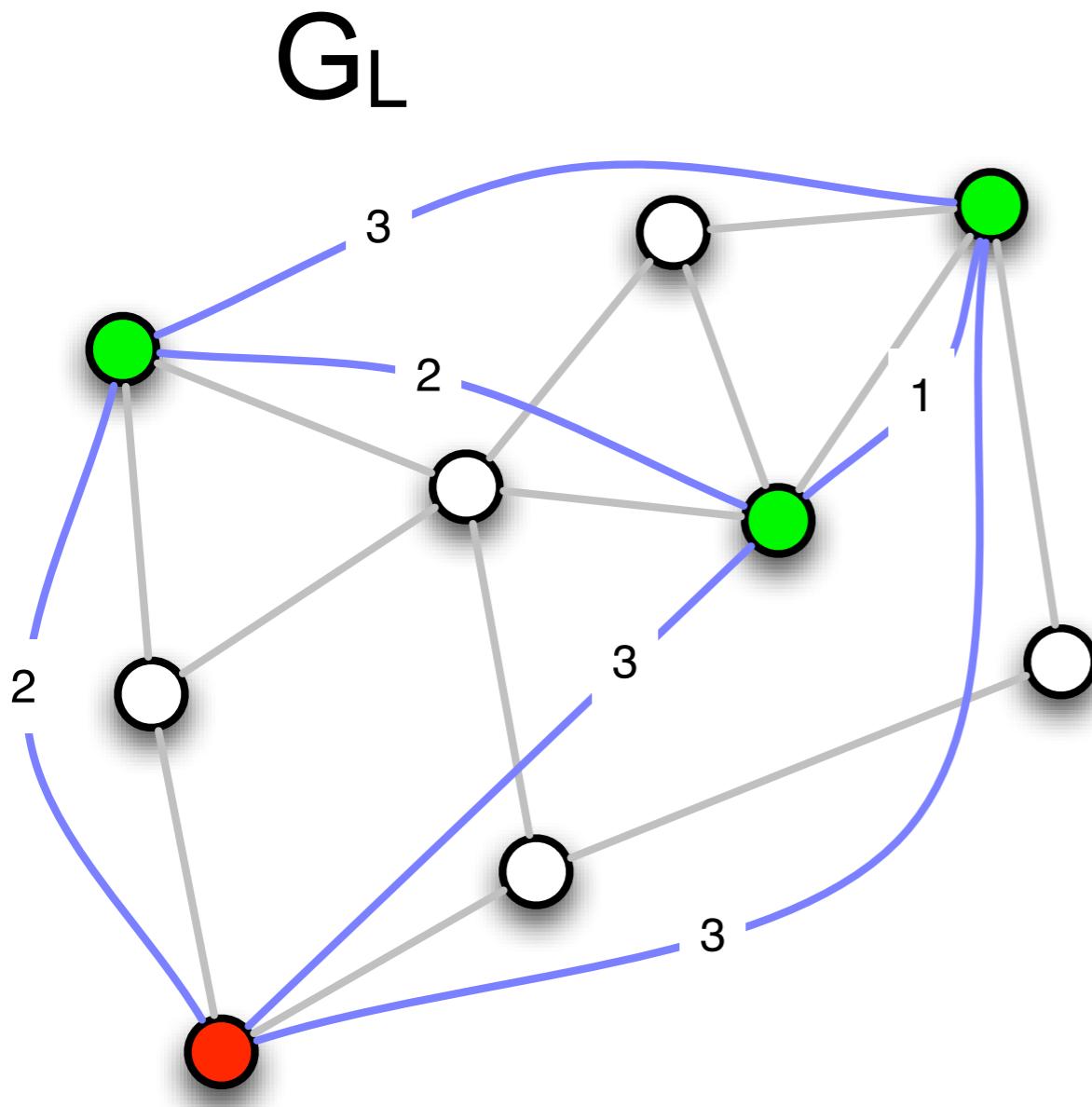
Approximation with the Help of MST

- ▶ Source:
 - Information Processing Letters, 27 (1988), 125-128, Kurt Mehlhorn, *A Faster Approximation of the Steiner Tree Problem*
- ▶ Compute the distance the terminal nodes in the graph G
 - Compute the complete graph G_L with terminal nodes V_T and edge weight according to the distance in G
- ▶ Compute **minimum spanning tree** in G_L
- ▶ Initialize tree T with empty set
- ▶ For each edge $e=(u,v)$ of the **MST**
 - Find shortest path P from u to v in G
 - If less than two nodes of P are in T then
 - Insert P into T
 - Else
 - Let p and q be the first and last node of P in T
 - Insert sub-path (u,p) and sub-path (q,v) of P into T
- ▶ **Output: Steiner tree approximation T**

MST Steiner Tree Approximation Example

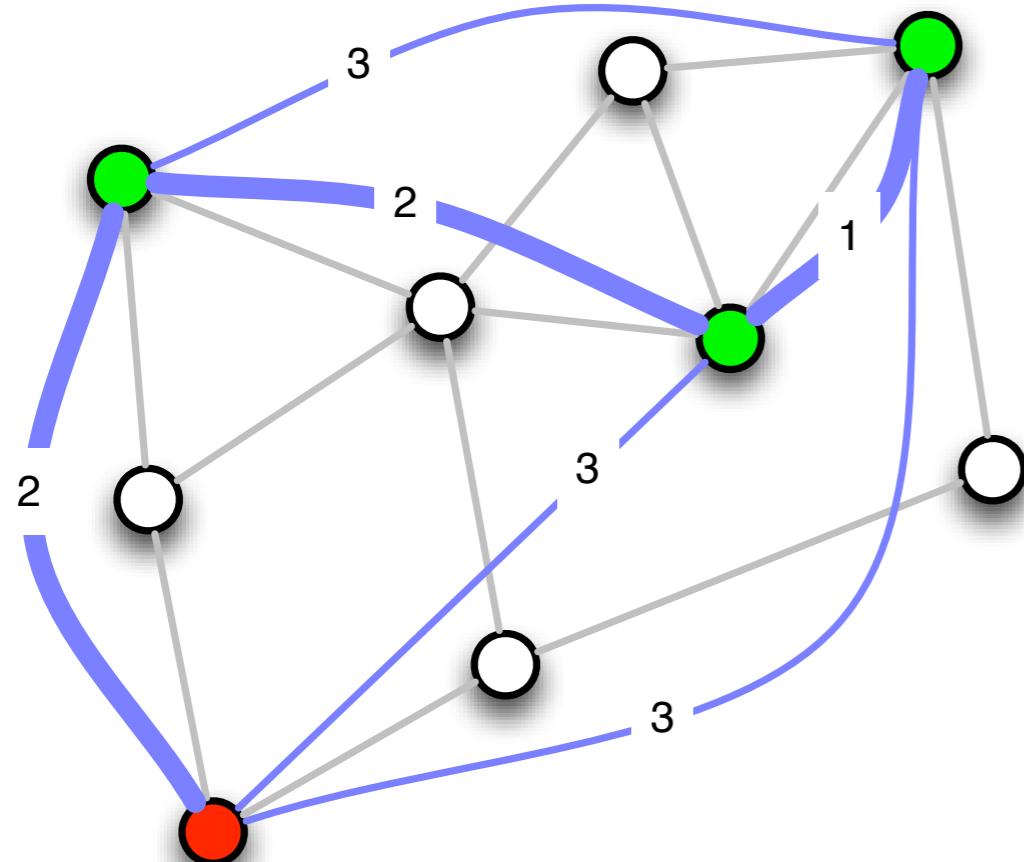


MST Steiner Tree Approximation Example

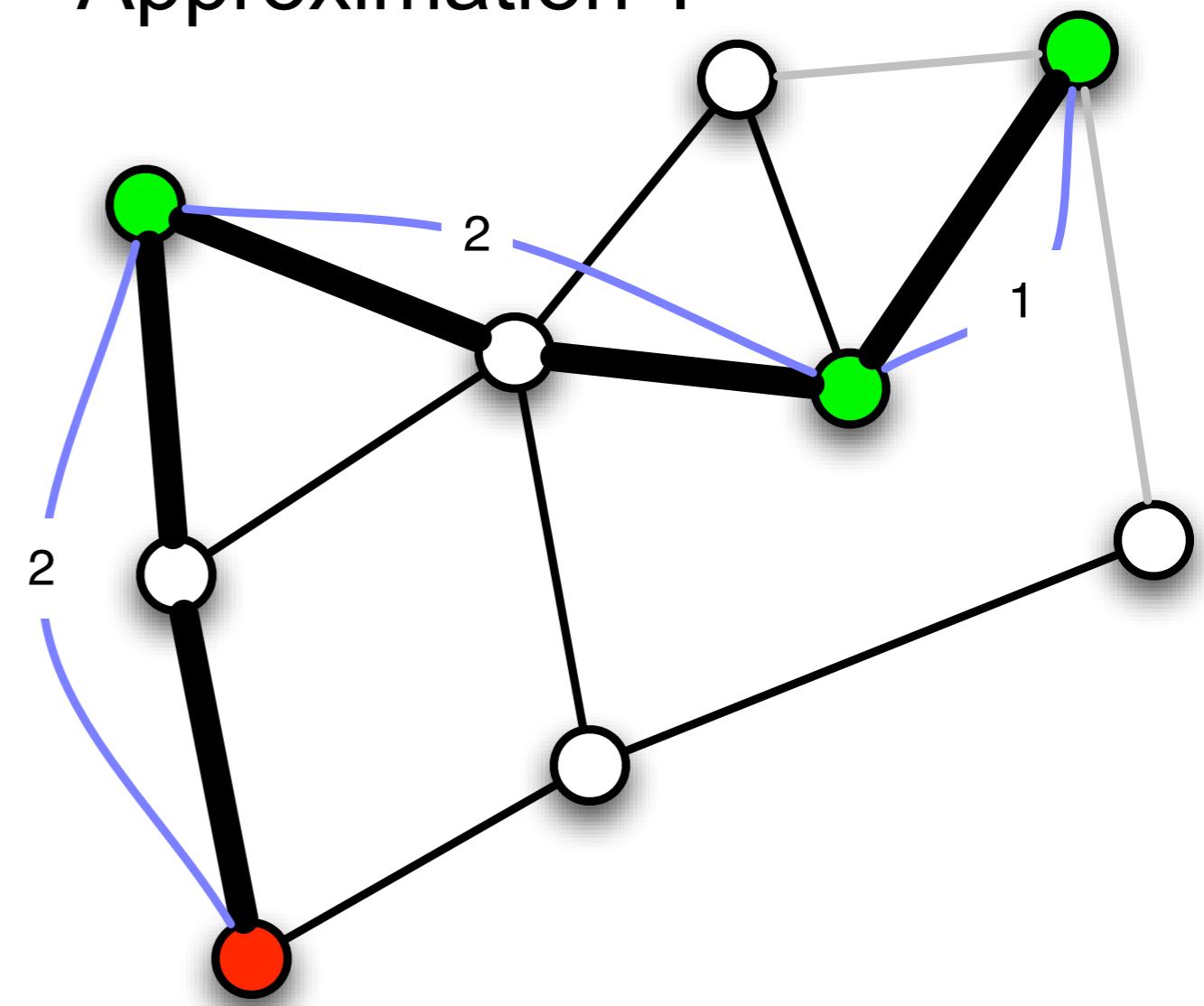


MST Steiner Tree Approximation Example

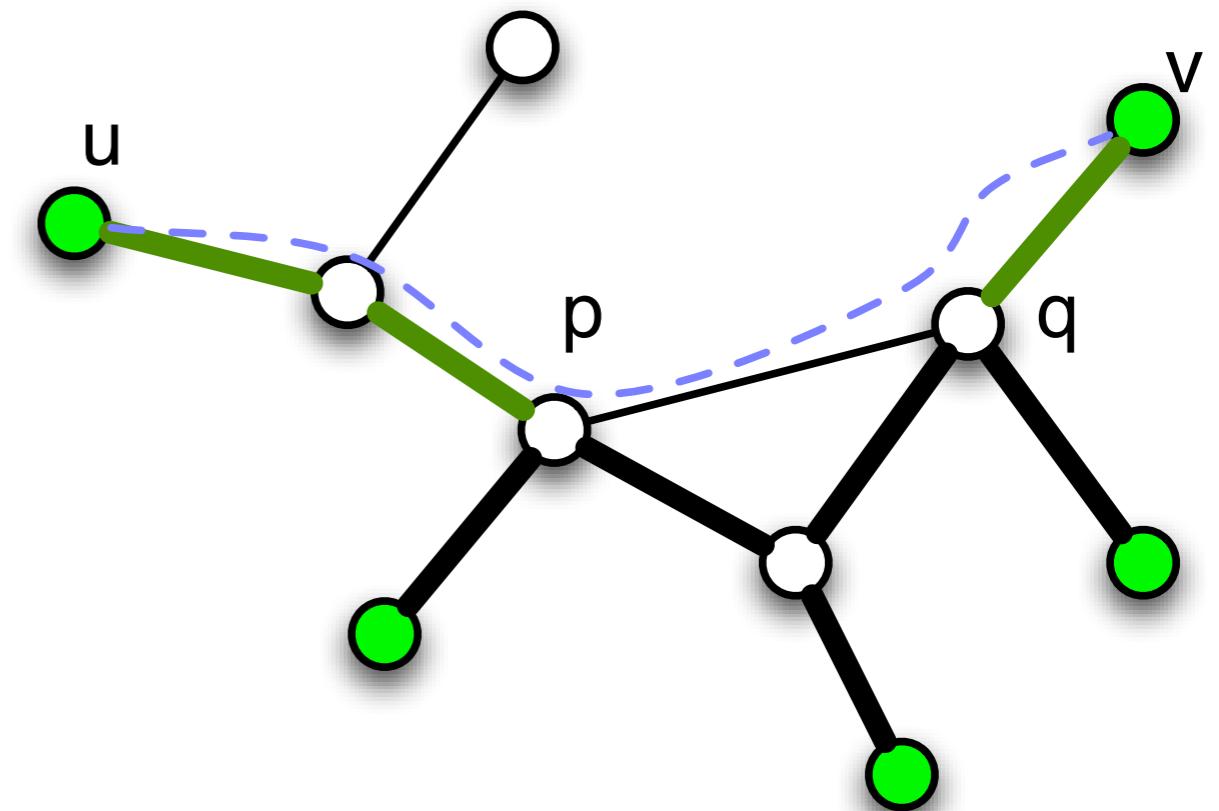
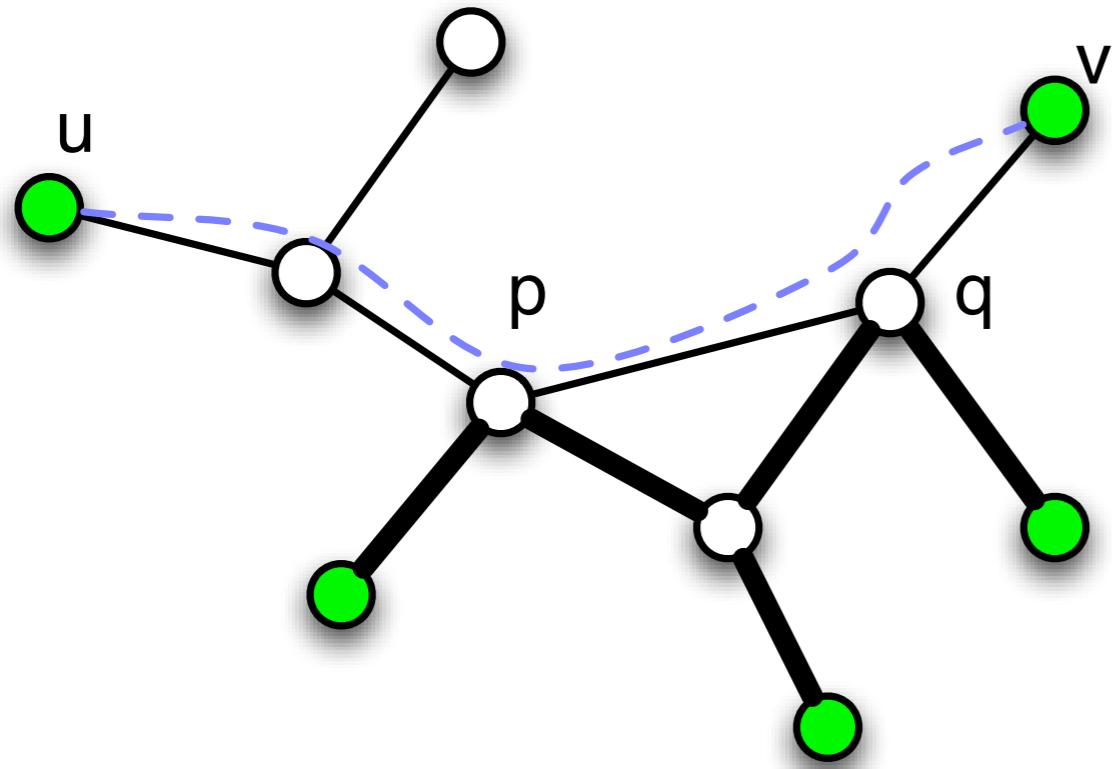
MST(G_L)



Steiner Tree
Approximation T



Preventing Cycles



Quality of the MST- Approximation

► Theorem

- The MST-Approximation constructs a tree in polynomial time. The edge sum of this tree is at most twice as large as those of the Steiner tree.

► Proof sketch

- A Steiner Tree without Steiner points without Steiner points is a factor 2 approximation of the Steiner tree
- The minimum spanning tree of G_L is the Steiner Tree without Steiner points of G
- This results in approximation algorithm with factor 2



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