Energy-efficient Broadcast Routing and Topology Control in Wireless Ad Hoc Networks

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Outline

- Introduction
- Wireless Communication Model
- Energy-efficient Broadcast Routing
- Energy-efficient Topology Control
- Conclusion and Future Work

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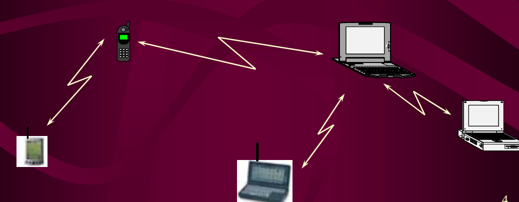
Introduction

Introduction --- Wireless networks

A wireless ad hoc network consists of a collection of mobile hosts dynamically forming a temporary network without the use of any existing network infrastructure.



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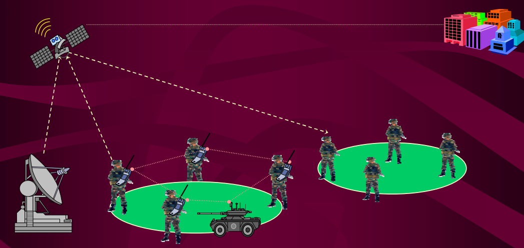
Introduction --- Wireless networks

Characteristics of Ad Hoc Networks

- Instantly deployable and re-configurable
- Node mobility
- Shared, scarce wireless channel
- Multihop routing
- Broadcast advantage
- Limited battery power

Introduction --- Wireless networks

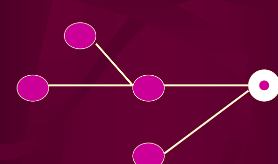


Introduction --- **Broadcast routing**

The broadcasting problem consists of finding a transmission radius for each node so that the source node can broadcast to all nodes either directly or indirectly through the relay nodes.

Introduction --- **Broadcast routing**

A broadcast tree is a spanning tree for the network in which the root is the source node and each path from the root to a node corresponds to the sequence of transmissions by which the source node communicates its message to that node.



Introduction --- **Broadcast routing**

Current research work

- Proved to be NP-hard.
- Exhaustive search of minimum energy broadcast tree.
- Broadcast least-unicast-cost algorithm.
- Broadcast incremental power algorithm.

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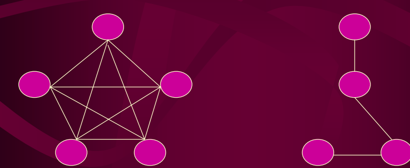
Introduction --- **Topology control**

A topology, consisting of a set of nodes and a set of communication links between node pairs, describes the connectivity information of a network.



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Introduction --- **Topology control**

Strongly Connected topology ---

If there is a communication path between any ordered pair of nodes, then the topology is strongly connected.

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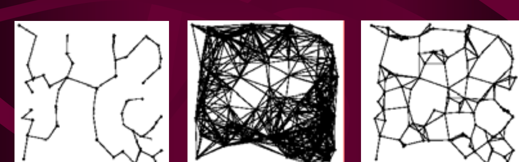
Introduction --- **Topology control**

Topology too sparse --- There is a danger of network partitioning and high end-to-end delays.

Topology too dense --- The limited spatial reuse reduces network capacity and cause more interference.



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Introduction --- **Topology control**

Current research work

The main purpose of topology control is to assign transmission powers to nodes so that the resulting graph satisfies some specified properties:

- Minimizing total energy consumption
- Connectivity or bi-connectivity
- Reducing interference
- Small diameter
- Increasing effective capacity

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Introduction

Considerations of the the energy-efficiency issue in broadcast routing and topology control:

- Minimize the total energy consumption of the whole network
- Balance the energy consumption at each node

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Wireless Communication Model

Wireless Communication Model

Network lifetime --- The earliest time that a node is depleted of energy

Goal --- To maximize the network lifetime and to balance the energy consumption at each node

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Wireless Communication Model

Assumptions:

- The nodes are static or they move slowly
- All nodes are located in the 2-dimensional plane
- $P_{ij} = Cr^{\alpha}$, r is the distance between *i* and *j*, $\alpha \in [2, 4]$, C =1
- Omni-directional antennas
- Each node can adjust its transmission power

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Wireless Communication Model

Weights of nodes and edges

M = the maximum energy at each node
E_i = the remaining energy of node *i*
W_i = M / E_i (weight of node *i*)
P_{ij} = power needed to transmit from *i* to *j*
W_{ij} = P_{ij} * W_i (weight of edge (*i*, *j*))

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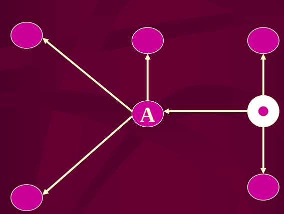
Wireless Communication Model



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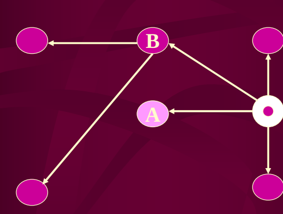
Wireless Communication Model



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Energy-efficient Broadcast Routing

Energy-efficient Broadcast Routing

Problem definition:

Given an edge-weighted complete directed graph *G* and a root node *r*, an arborescence is a tree with root *r* and paths from *r* to every other node of *G*. Find an arborescence rooted at *r* to minimize the weight of the heaviest edge.

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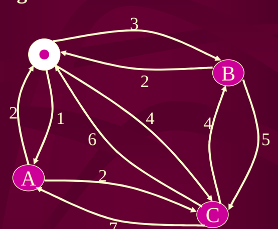
Energy-efficient Broadcast Routing

Minimum Weight Incremental Arborescence (MWIA)



Model the network as an edge-weighted directed graph

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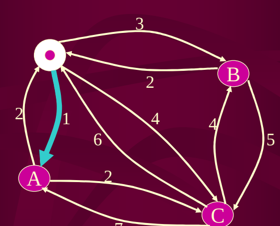
Energy-efficient Broadcast Routing



Grow an arborescence from the root *r*

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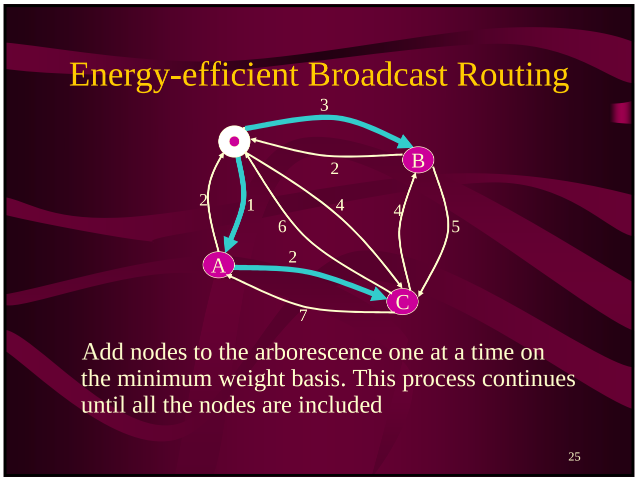
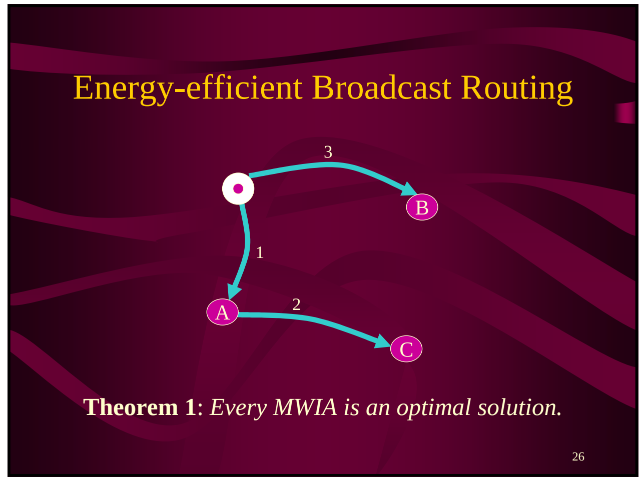

Energy-efficient Broadcast Routing
3
B
2
2
1
4
4
6
5
A
2
C
7
Add nodes to the arborescence one at a time on the minimum weight basis. This process continues until all the nodes are included
25


Energy-efficient Broadcast Routing
3
B
1
A
2
C
Theorem 1: *Every MWIA is an optimal solution.*
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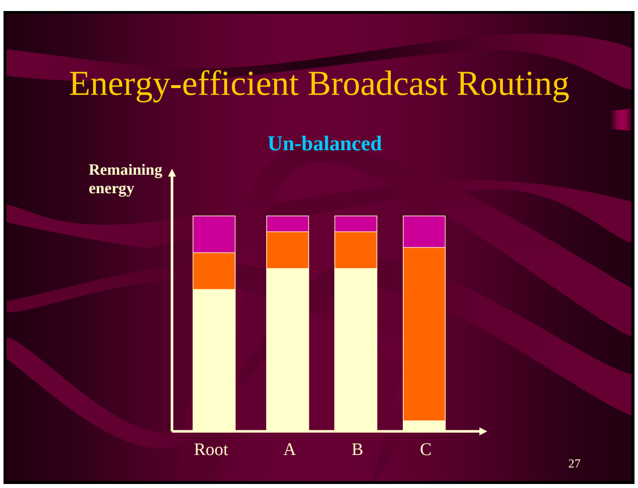
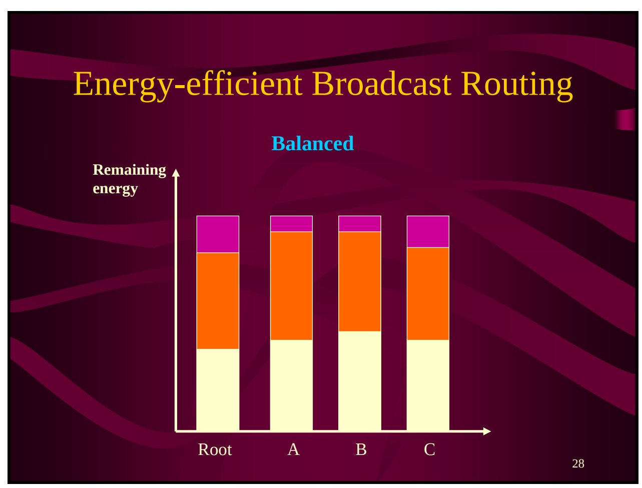

Energy-efficient Broadcast Routing
Un-balanced
Remaining energy
Root
A
B
C
27


Energy-efficient Broadcast Routing
Balanced
Remaining energy
Root
A
B
C
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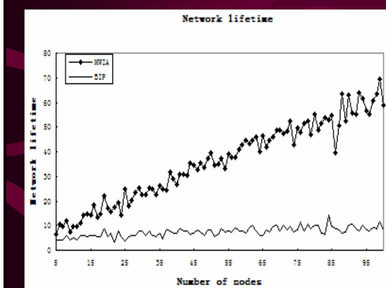
Energy-efficient Broadcast Routing

Simulation results

Compared with the Broadcast Incremental Power algorithm (BIP) by Wieselthier et al.

In BIP, node v is added to the tree by edge (u, v) if $P_{uv} = min_{i \in T, j \notin T} \{ P_{ij} - P_i \}$

Energy-efficient Broadcast Routing



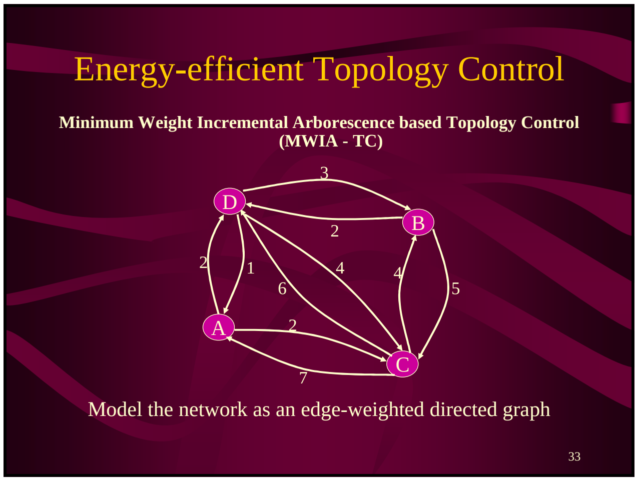
The lifetime of a network using MWIA algorithm is almost 3 times longer than that of the network using the BIP algorithm.

Energy-efficient Topology Control

Energy-efficient Topology Control

Problem definition:

Given an edge-weighted complete directed graph G, find a sub-graph H with minimum largest edge-weight such that for every ordered pair of nodes (u, v) in G, H contains a path from u to v.


Energy-efficient Topology Control
Minimum Weight Incremental Arborescence based Topology Control
(MWIA - TC)
D
B
A
C
Model the network as an edge-weighted directed graph
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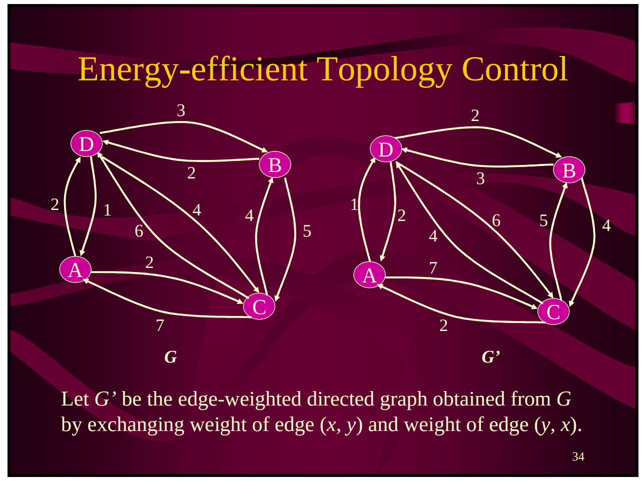
Energy-efficient Topology Control
D
B
A
C
G
G'
Let G' be the edge-weighted directed graph obtained from G
by exchanging weight of edge (x, y) and weight of edge (y, x).
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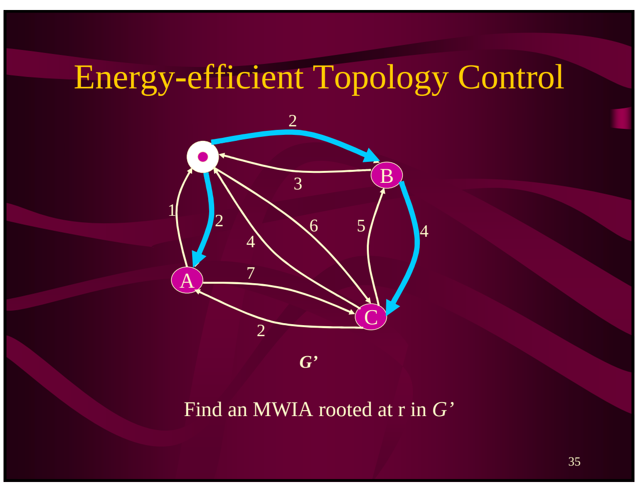
Energy-efficient Topology Control
B
A
C
G'
Find an MWIA rooted at r in G'
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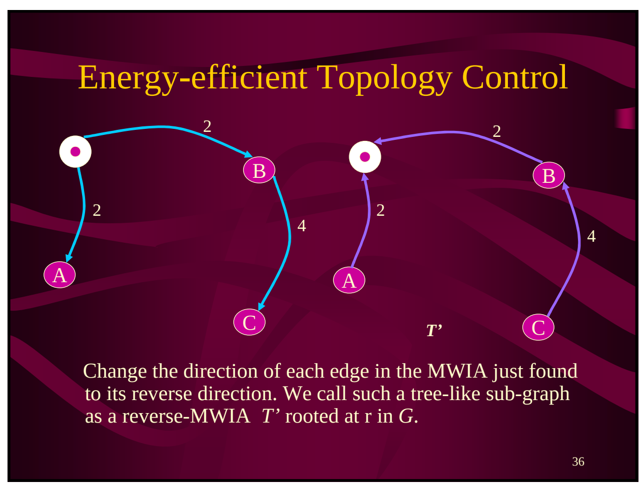
Energy-efficient Topology Control
B
A
C
T'
Change the direction of each edge in the MWIA just found
to its reverse direction. We call such a tree-like sub-graph
as a reverse-MWIA T' rooted at r in G.
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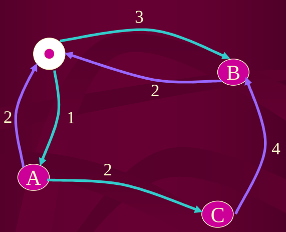
Energy-efficient Topology Control



Theorem 2: Find an MWIA ***T*** rooted at r and a reverse-MWIA ***T'*** rooted at r in ***G***. The union ***T*** ∪***T'*** is an optimal solution to the topology control problem.

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Energy-efficient Topology Control

Simulation results

Compared with Minimum Incremental Power algorithm (MIP) by Cheng et. al.

$$P_{uv} = min_{i \in T,\, j \notin T} \{ P_{ij} - P_i + P_{ji} \}$$

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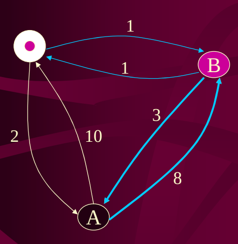
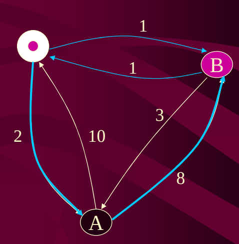
Energy-efficient Topology Control



MIP



MWIA-TC

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Energy-efficient Topology Control

Simulation 1 --- Evaluate the effect of MWIA-TC on the energy consumption of a network when nodes have different remaining energy.

$W_{ij} = P_{ij} \cdot (M / E_i) = K \cdot r^{\alpha}$, $\alpha = 2$, $K \in [1, 10]$

Mean power consumption of MWIA-TC is 10.1% lower

Maximum power consumption is 14.9% lower

Standard deviation is 15.6% smaller than that of MIP.

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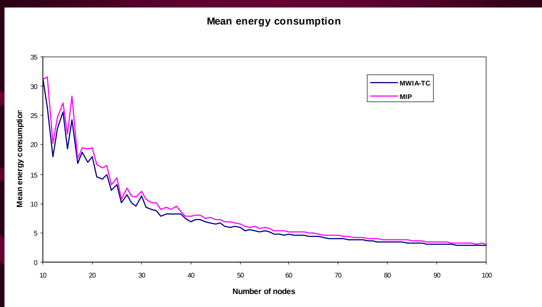
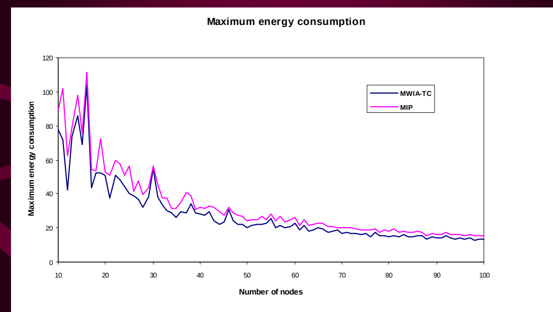
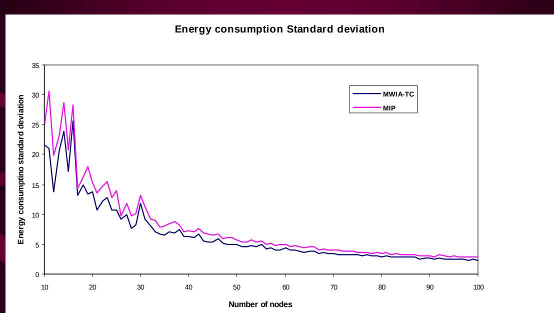
Energy-efficient Topology Control



Energy-efficient Topology Control



Energy-efficient Topology Control



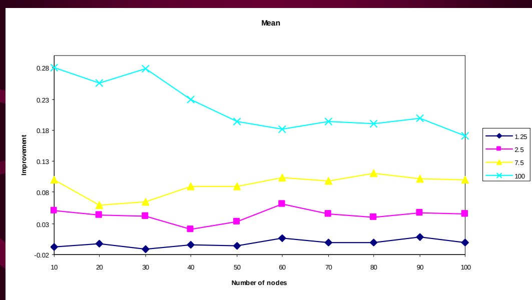
Energy-efficient Topology Control

Simulation 2 --- Evaluate the effect of MWIA-TC on the energy consumption of a network when nodes have different variances of remaining power .

$W_{ij} = P_{ij} \cdot (M / E_i) = K \cdot r^{\alpha}$, $K \in [1, \ max\_K]$

As *max*_K increases, the improvement of MWIA-TC over MIP is also increased.

Energy-efficient Topology Control



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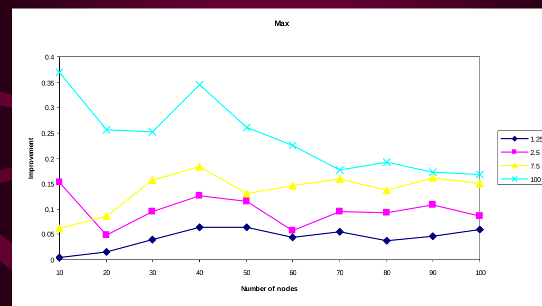
Energy-efficient Topology Control



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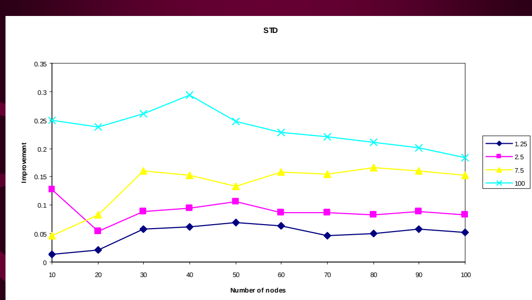
Energy-efficient Topology Control



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Energy-efficient Topology Control

Simulation 3 --- Evaluate the effect of MWIA-TC on the network lifetime.

Network lifetime = $min_{i \in V}$ {remaining energy of node ***i*** / transmission power of node ***i***}

X = maximum energy reserve / minimum energy reserve

The lifetime improvement by use of MWIA-TC increases when the variance of the remaining energy increases.

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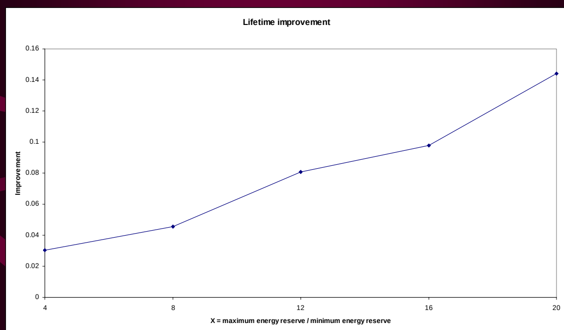
Energy-efficient Topology Control



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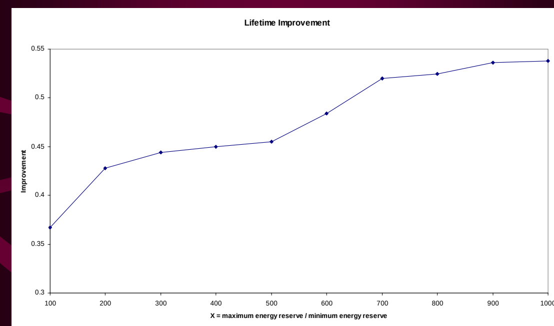
Energy-efficient Topology Control



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Conclusion and Future Work

Broadcast routing and topology control

- How frequently to update the broadcast tree and the topology.
- Evaluate the performance of the proposed solutions in terms of the throughput, message complexity, transmission delay and etc.
- Study the problem in mobile environment where node mobility is highly concerned.
- Develop distributed algorithms.

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Conclusions and Future Work

Minimum connected dominating set (MCDS)

A dominating set of a graph is a subset of all the nodes such that each node is either in the dominating set or adjacent to some node in the dominating set. A connected dominating set of a graph is a dominating set and the subgraph induced is connected.

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Conclusions and Future Work

Sensor networks

- Sensors are densely deployed in large numbers
- Sensor networks' topology changes very frequently
- Sensors are very limited in power, computational capacities and memory
- Sensors are very prone to failures
- Sensors may not have global identification (ID) because of the large amount of overhead
- Building an intelligent data collecting system

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Conclusions and Future Work

Data communication in mobile ad-hoc network

Current research issues:

- Client power consumption
- Connectivity of the network
- Reachability of mobile clients from a server
- Power consumption and mobility of the servers

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Conclusions and Future Work

Data communication in mobile ad-hoc network

Future research issues:

Ways in which data communication may take place

a). Data broadcast (data push)

b) Data-on-demand (data pull)

c). Peer-to-peer communication

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