

G 364: Mobile and Wireless Networking

CLASS 16, Mon. Mar. 10 2004

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M-W, 11:40am-1:20pm, 109 Rob

Scatternet Formation

- ◆ The Bluetooth way for building multi-hop networks
- ◆ Usual approach:
 - Device discovery (inquiry/inquiry scan)
 - Piconet formation (page/page scan)
 - Piconet interconnection into a scatternet (gateway selection, scheduling, routing)

Scatternet Formation: Previous Solutions, 1

- ◆ Single-hop topologies (the radio vicinity of all nodes is required)
- ◆ Several solutions, pioneered by:
 - Salonidis et al.: works for up to 36 nodes
 - Law et al.: Creates a tree
 - Tan et al.: Creates a tree

Scatternet formation: Previous Solutions, 2

- ◆ Multi-hop topologies:
 - Zaruba et al.: BlueTrees, tree-like connected scatternet. Depends on a designated node
 - Haas et al.: BlueNets, mesh-like scatternet formation. Connectivity of the scatternet is not guaranteed.
 - Stojmenovic: mesh-like connected scatternet based on topology reduction techniques. Requires additional hardware (e.g., GPS receivers)

BTCP (Bluetooth Topology Construction Protocol)

- Proposed by Salonidis et al., INFOCOM 2001
- Distributed leader election (device discovery)
 - Based on number of nodes that “won” so far
 - Every confrontation requires the exchange of all the FHS of associated nodes
- Centralized (at the leader) scatternet formation
- Target: min. # piconets, piconet per gw, connected scatternet
- Limits: Single-hop, ≤ 36 nodes

Law, Siu Solution

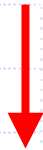
- MobiHoc, Globecom 2001
- Low # piconets, low.max degree, low network diameter
- Randomized protocol
 - Proceeds in rounds
 - In each round 'components' are merged
 - The leader of each component goes to inquiry/inquiry scan with a given probability
 - Components discovering each other merge

TSF (Tree Scatternet Formation)

- All nodes are originally free nodes
- Free nodes can aggregate in a tree with each other or connect to tree nodes
- Generated trees are made of 1 root node, 1 coordinator and several tree nodes
- Different trees discover each other through the coordinators and merge through the roots
- Target: self-healing
- Limits: single-hop, tree topology, no guarantee ≤ 7 slaves

Multi-Hop: BlueTrees

- Protocol initiated by a 'designated root' which becomes master and selects neighbors which do not belong to a piconet as slaves
- Slaves assume a master role and the procedure iterates
- Proposal of solutions to keep the number of slaves per piconet below 7 and do not need to rely on a designated node



Major limit: generates a tree

BlueNet

- Each node randomly enters either page or page scan. Master nodes selects up to N_{\max} of their neighbors as slaves.
- Isolated nodes become masters and selects up to N_{\max} neighbor as slaves.
- Piconet interconnection through common slaves.



Major limit: no guaranteed connectivity

“Stojmenovic Solution”

- IDEA: Graph topology sparsification so that nodes degree ≤ 7 and the nodes connectivity is maintained
- Every formation solution is applicable on the resulting topology (e.g., BleuStars)
- Generates a mesh topology
- Major limit: requires extra hardware (e.g., GPS)

State of Art in BT Scatternet Formation

	Multihop	Topology	Comments
Salonid, Tassiulas, Bhagwat	NO	Mesh	≤ 36 devices
Tan, Balakrishnan et al.	NO	Tree	Self-healing
Law, Siu	NO	Tree	Random algorithm
Zaruba, Basagni, Chlamtac	YES	Tree	Requires an initiator device
BlueStars BlueMesh	YES YES	Mesh Mesh	network connectivity Guaranteed <7 slaves,
Stojmenovic	YES	Mesh	Requires additional HW
Haas et al. 3/10/04	YES	Mesh	No guaranteed connectivity 11

BlueStars: Mesh-like Connected Scatternet

- ◆ Distributed solution: all nodes participate to the formation with minimal, local topology knowledge (one-hop neighbors)
- ◆ Multi-hop solution: nodes need not to be in each other communication range
- ◆ Mesh-like solution: multiple routes between pair of nodes
- ◆ No additional hardware is required
- ◆ Guaranteed connectivity

BlueStars: Three-phase Protocol

- 1. Device discovery:** each nodes becomes aware of its one-hop neighbors and of their “weight” (symmetric knowledge)
- 2. Piconet formation:** nodes are partitioned into groups each with one master and possibly multiple slaves
- 3. Piconet interconnection:** piconets whose masters are at most three hops away are interconnected, so to form a connected scatternet

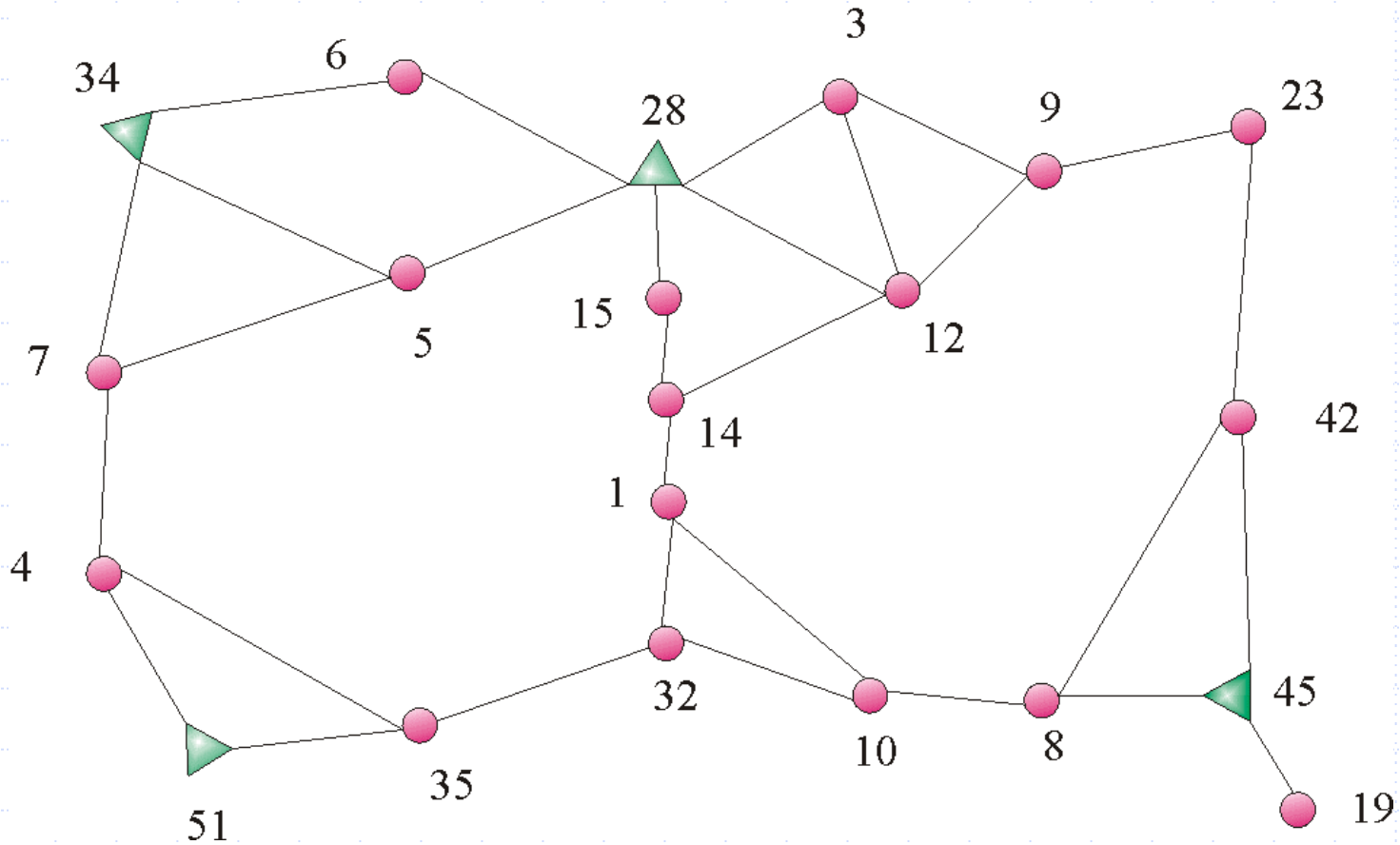
BlueStars: Device Discovery

- ◆ Uses the *inquiry* and *paging* procedures described in the BT specification [Salonidis+00]
- ◆ Each node alternates between *inquiry* and *inquiry scan* mode (random durations)
- ◆ In order to ensure symmetric neighbor knowledge temporary piconets are set up for data (ID, weight, etc.) exchange

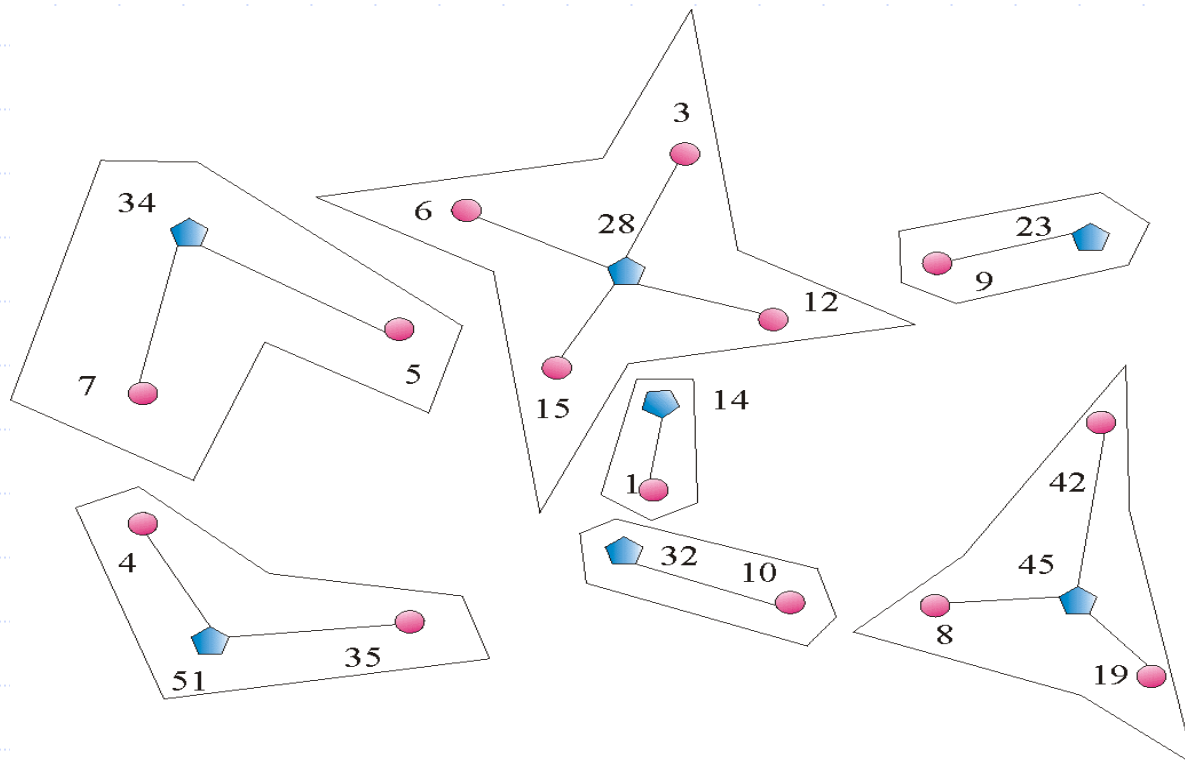
BlueStars: Piconet Formation

- ◆ Nodes with the biggest weight in their neighborhood (init nodes) start the process
- ◆ Init nodes go to page mode, non-init nodes go to page scan mode
- ◆ Every node decide whether to be a master or a slave depending on the role of “bigger nodes”
- ◆ Slaves join the first master that pages them

BlueStar: Piconet Formation



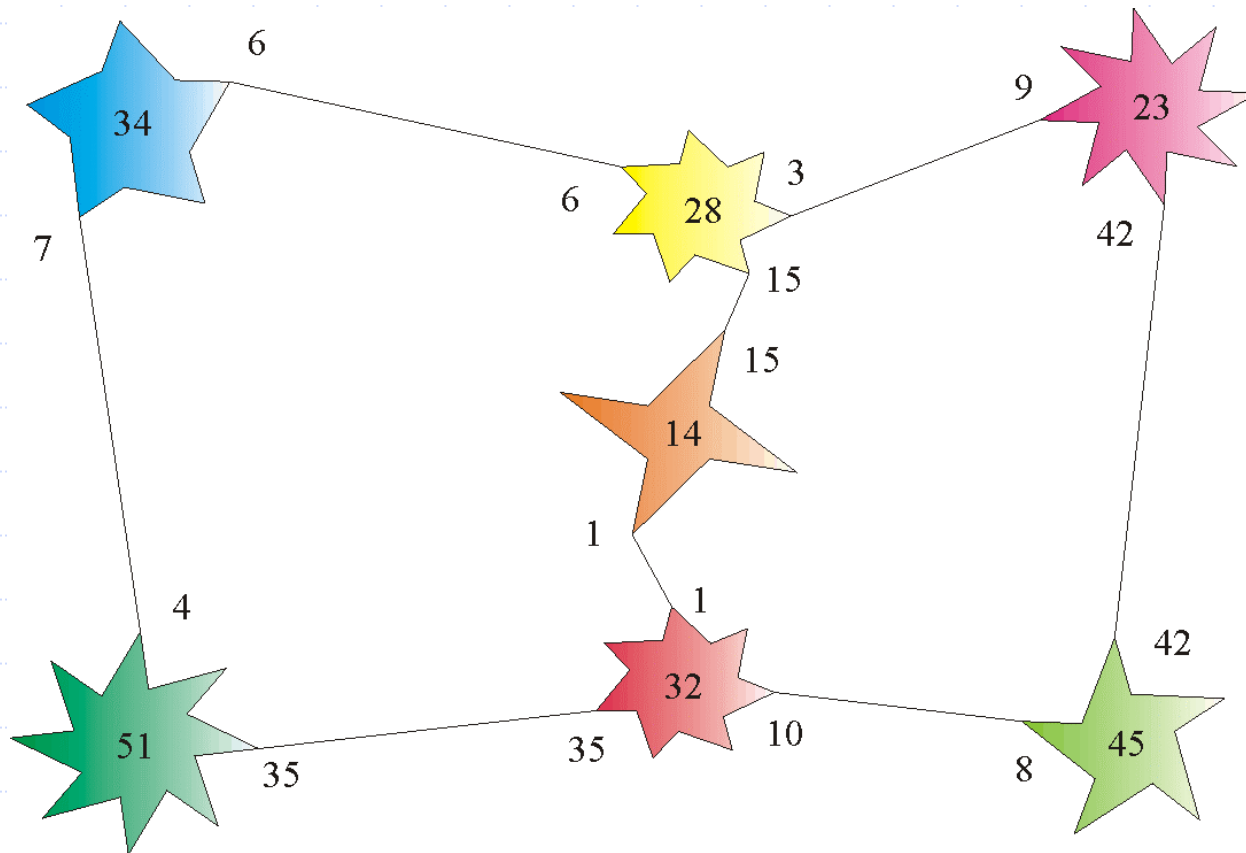
BlueStars: Piconet Formation



BlueStars: Piconet Interconnection

- ◆ Connectivity is guaranteed by finding routes between all masters at most three hops away [Chlamtac et al., 1999]
- ◆ Masters at most three hops apart are said M-neighbors
- ◆ “Init masters” start the process: common slaves and neighboring slaves are uniquely selected to interconnect M-neighbor

BlueStars: Piconet Interconnection



BlueStars: Limits

- Time needed for device discovery
 - discovery of **all** neighbors maybe time consuming when nodes degree is high BUT it is not needed! (Basagni, Bruno, Petrioli, Networking 2002)
- Piconets may have more than 7 slaves → potential need to park and unpark nodes for communication



BlueMesh

BlueMesh: The Idea

- Proceeds in **iterations**
- BT devices are divided into piconets, each piconet has at most 7 slaves
- Each master selects ≤ 7 slaves among its neighbors so that **through them all the other neighbors can be reached**
- Adjacent piconets are interconnected either through common **slaves**, or through neighbor **slaves**
- Only nodes involved in extra piconets for sake of scatternet connectivity survive to the next iteration

Performance Evaluation

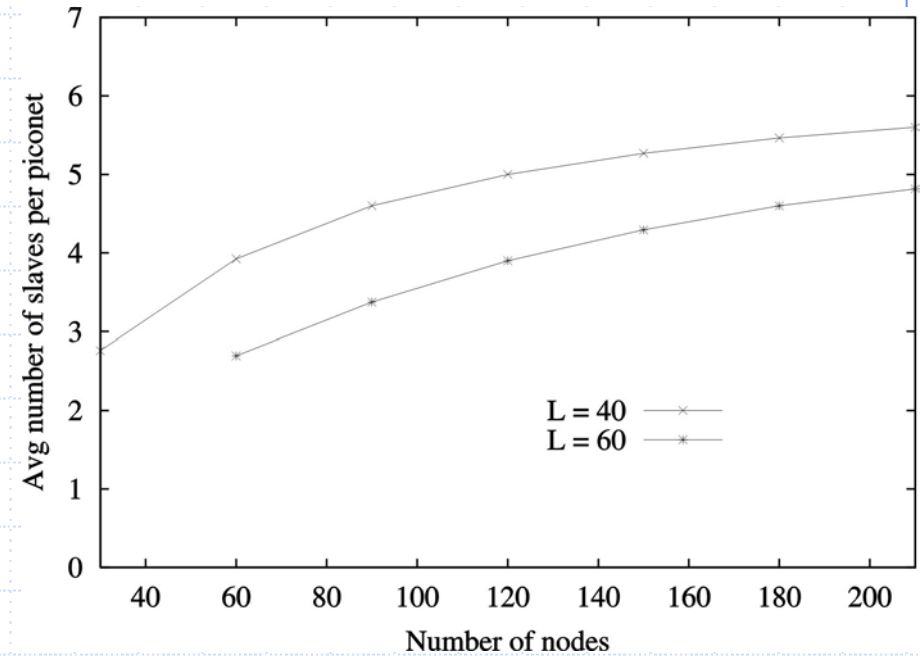
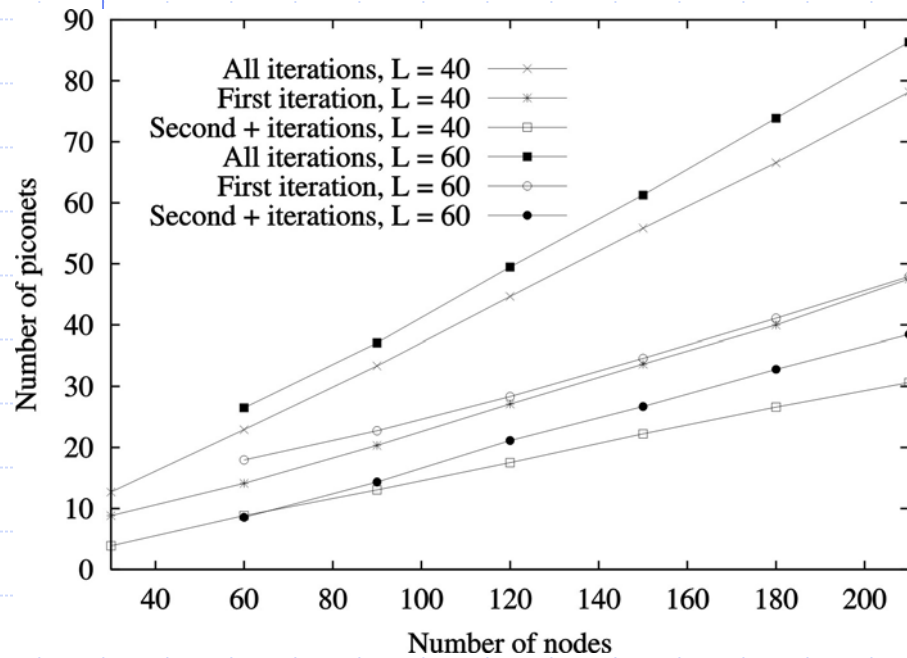
- ≤ 210 nodes, uniformly distributed in a square of side $L=40, 60$

Avg. degree

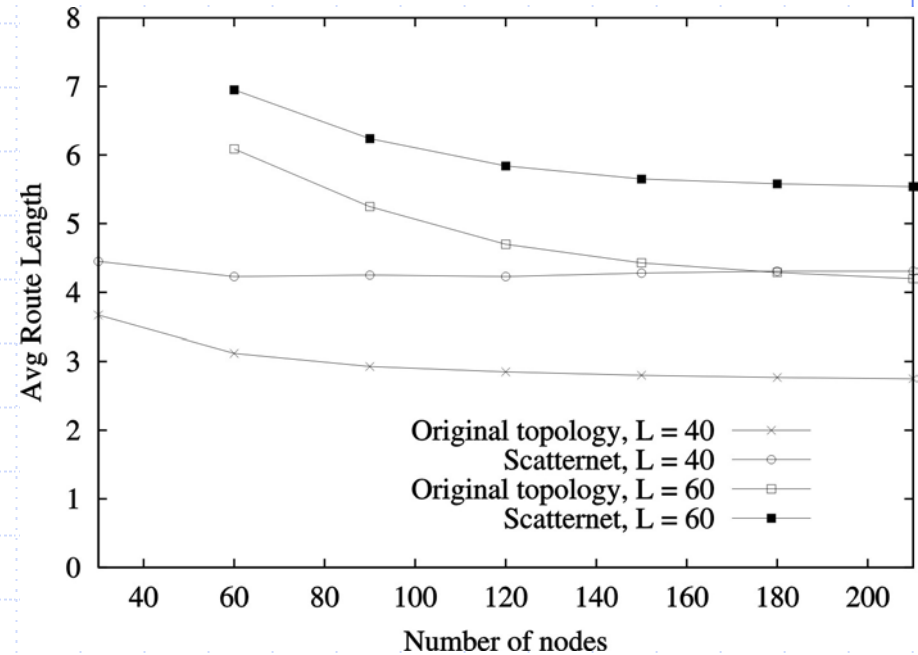
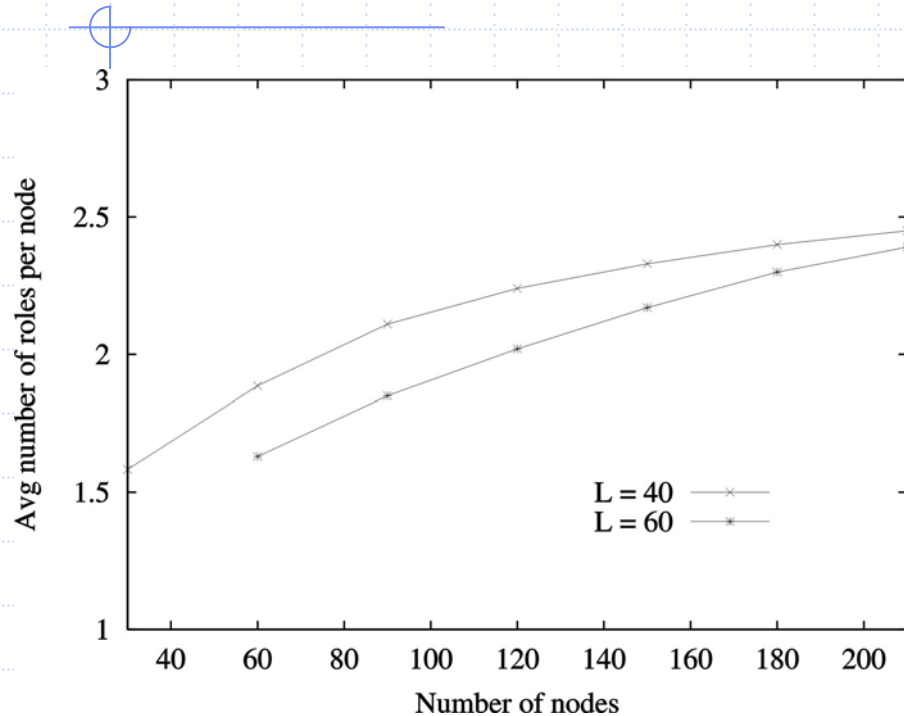
<u># nodi</u>	<u>30</u>	<u>60</u>	<u>90</u>	<u>120</u>	<u>150</u>	<u>180</u>	<u>210</u>
L=40	4.6	9.2	13.9	18.6	23.3	28	32.8
L=60		4.4	6.6	8.9	11.2	13.5	15.8

- Transmission range: 10 m
- Topology = unit disc graph
- Results refer to connected topologies
- Metrics: set-up time, # of piconets, # of roles per node, # of slaves per piconet, route length

BlueMesh: Results, 1



BlueMesh: Results, 2



Bluetooth: Summary

- ◆ Bluetooth devices form piconets composed of one master and one or more slaves
- ◆ Multiple piconets form a scatternet
- ◆ BlueStars/BlueMesh are distributed protocol for scatternet formation over multi-hop networks
- ◆ BT nodes do not need to be in radio vicinity
- ◆ The resulting scatternet is connected
- ◆ There are multiple routes between pairs of nodes
- ◆ No additional hardware is necessary
- ◆ BlueMesh: no more than 7 slaves per piconet

Assignments

- ◆ Read the chapter on scatternet formation
- ◆ Updated information on the class web page:
www.ece.neu.edu/courses/eceg364/2004sp