Multi-hop Scatternet Formation for Bluetooth Networks

Stefano Basagni

Northeastern University

Chiara Petrioli

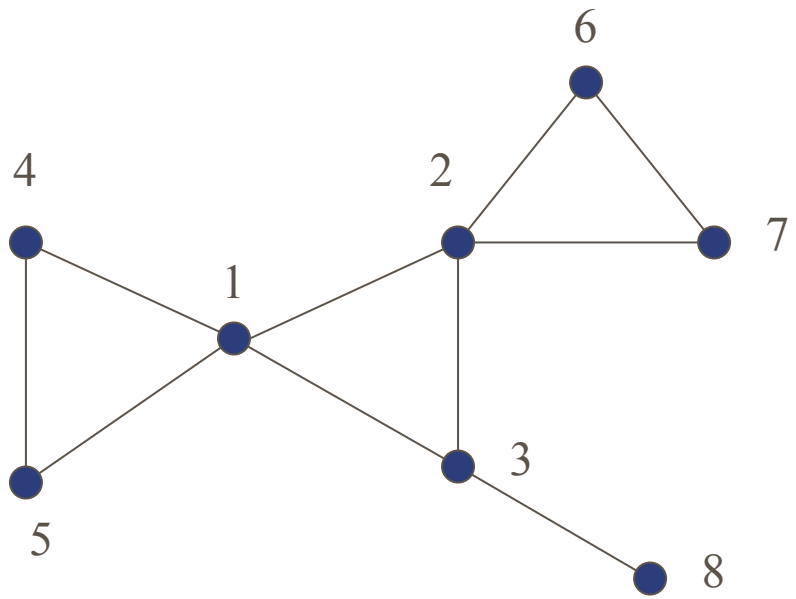
Univ. di Roma "La Sapienza"

Dagstuhl seminar 02441
October 29th 2002

Ad Hoc Networks

- Wireless networks with no fixed infrastructure (all nodes can move)
- Connection based on radio vicinity
- Each node is a switch
- Multi-hop communication

A Simple Ad Hoc Network

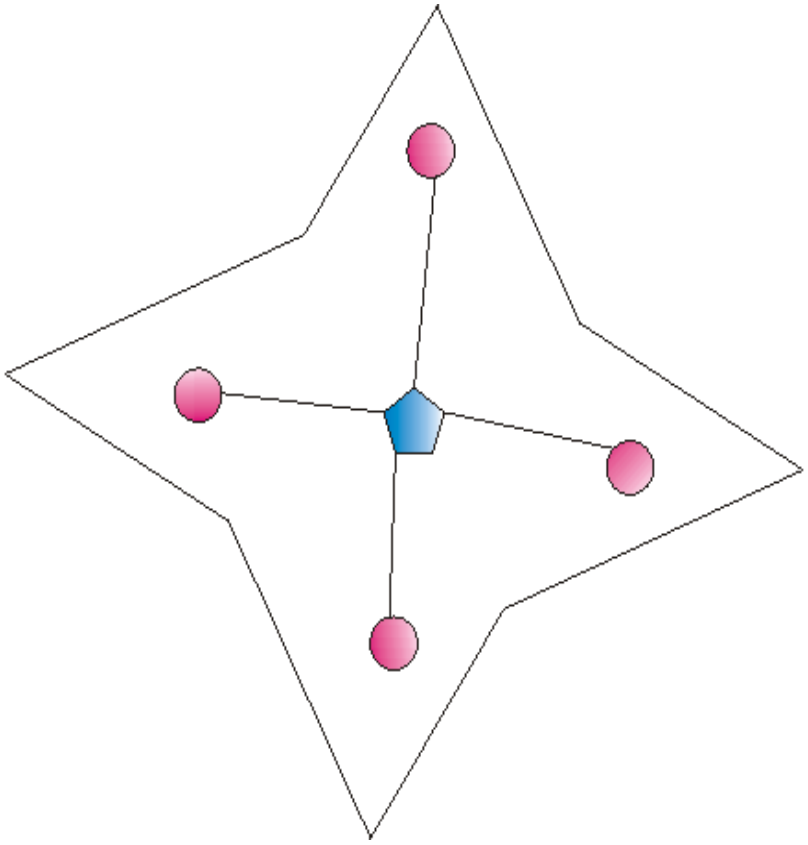


Bluetooth (BT): Enabling Ad Hoc Networks

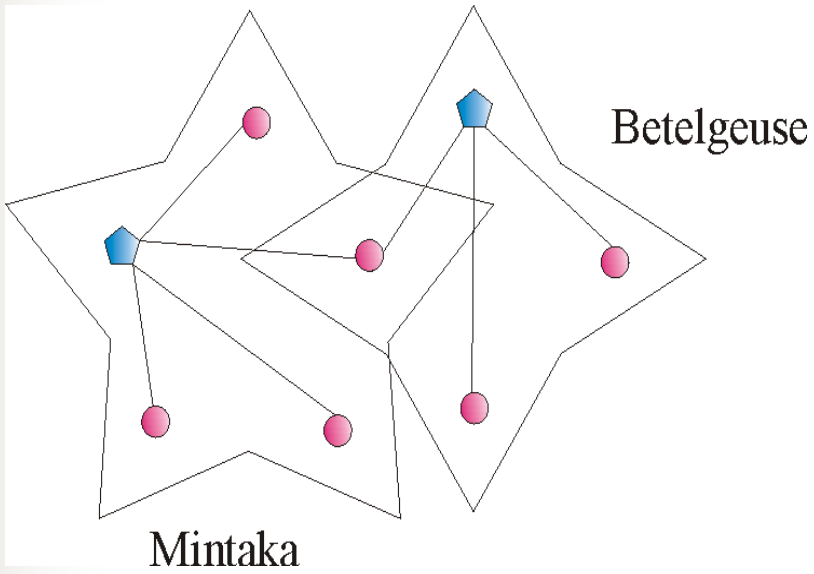
- Wireless technology in the ISM band (2.4GHz)
- Introduced for cable replacement
- Short range radio communication
- Frequency hopping spread-spectrum

Bluetooth: Piconets

- Master – Slave communication
- **Piconets** with one master and multiple slaves
- Synchronization based on master ID and clock

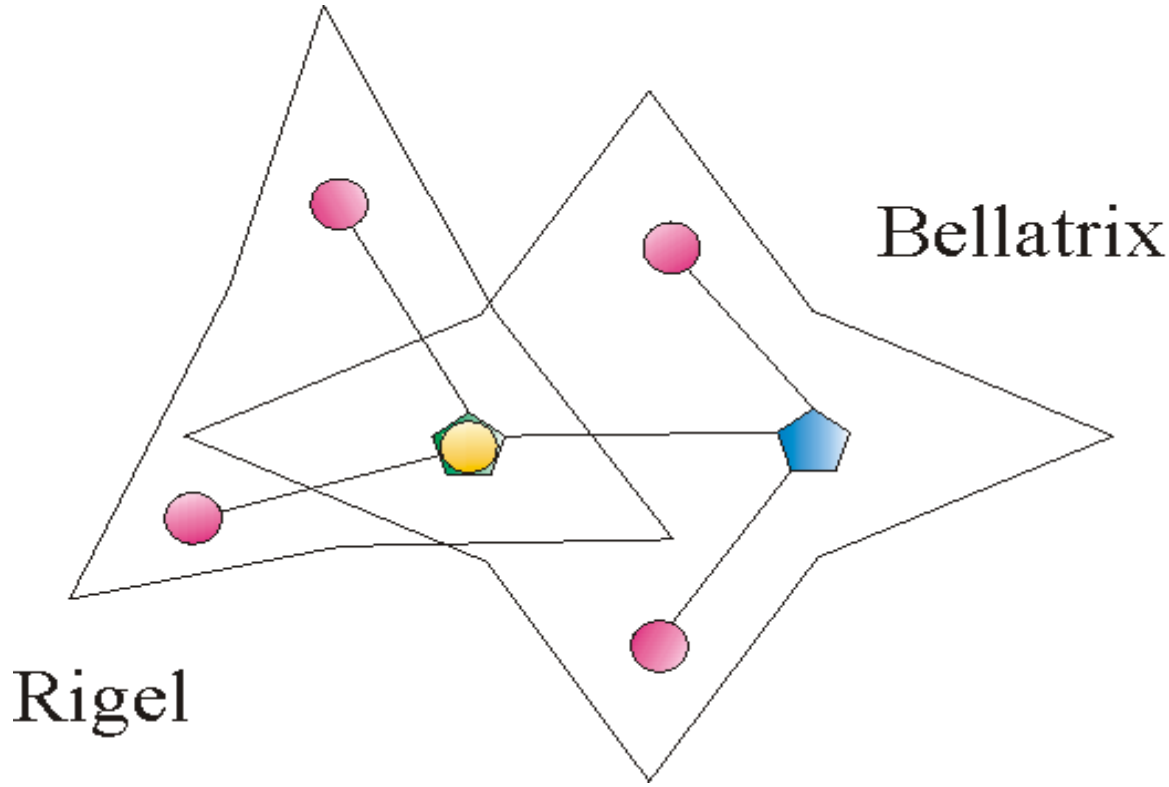


Bluetooth: Scatternets



- Nodes can have multiple roles
- Nodes with multiple roles timeshare between multiple piconets
- A **scatternet** enables multi-hop communication

Bluetooth: Scatternets



Scatternet Formation: The Problem

- Forming connected ad hoc networks of Bluetooth device
- Three major problems:
  - Device discovery
  - Piconet formation
  - Piconet interconnection

Scatternet Formation: Previous Solutions

- Single-hop topologies (the radio vicinity of all nodes is required):
  - 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

- 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)

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

BlueStars: Three-phase Protocol

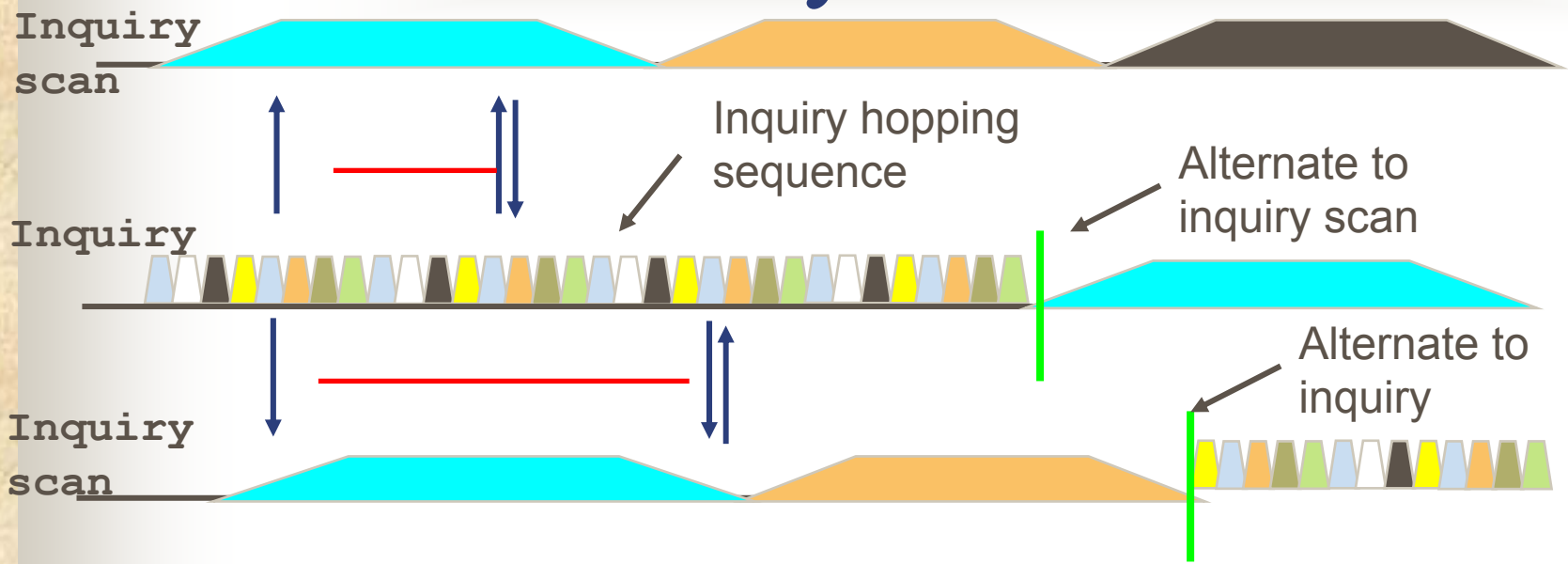
1. **Device discovery**: each nodes becomes aware of its one-hop neighbors and of their "weight" (symmetric knowledge)
    1. Node alternate between inquiry and inquiry scan
    2. Temporary piconets to exchange informations

BlueStars: Three-phase Protocol

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

Device Discovery: How It Works

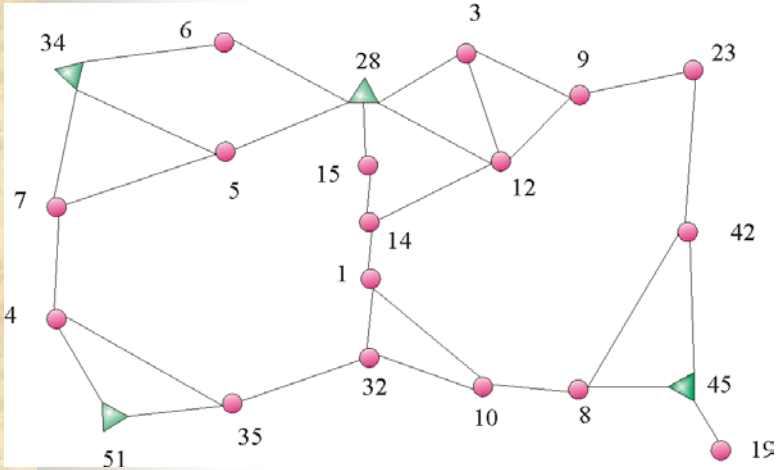


- **Need to alternate between inquiry and inquiry scan (only nodes in opposite modes can handshake)**
- **Long Back-off interval (2048 ticks)**
- **The ID packets sent by the inquirer do not identify the sender**

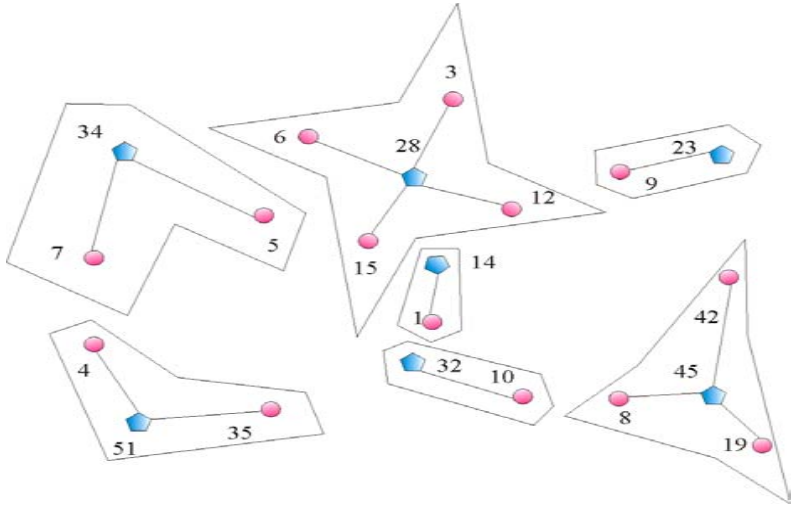
Discovering all neighbors in a multi-hop Bluetooth network can be extremely time consuming!

BlueStars Operations: An Example

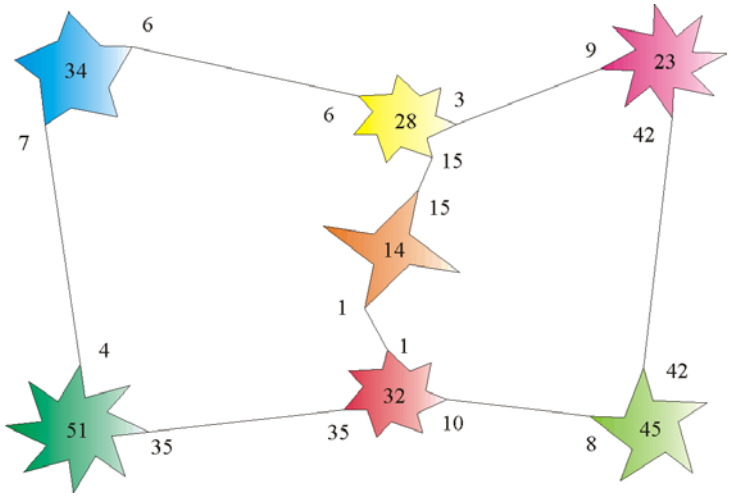
a) Original topology



b) BlueStars (piconet) formation



c) Piconet interconnection into a scatternet



BlueStars Simulations, 1

- **Extension of the VINT ns2 simulator that**
  - Implements all the details of the protocol stack
  - Implements the device discovery phase
  - Implements BlueStars
- **Simulation scenarios**
  - 30, 50, 70, 90, 110 Power Class 3 BT devices uniformly spread over a square area of side 30
  - Connected visibility graphs
  - Avg.degree ranging from 7.4 (30 nodes) to 27.9 (110)
  - Results obtained over 300 topologies

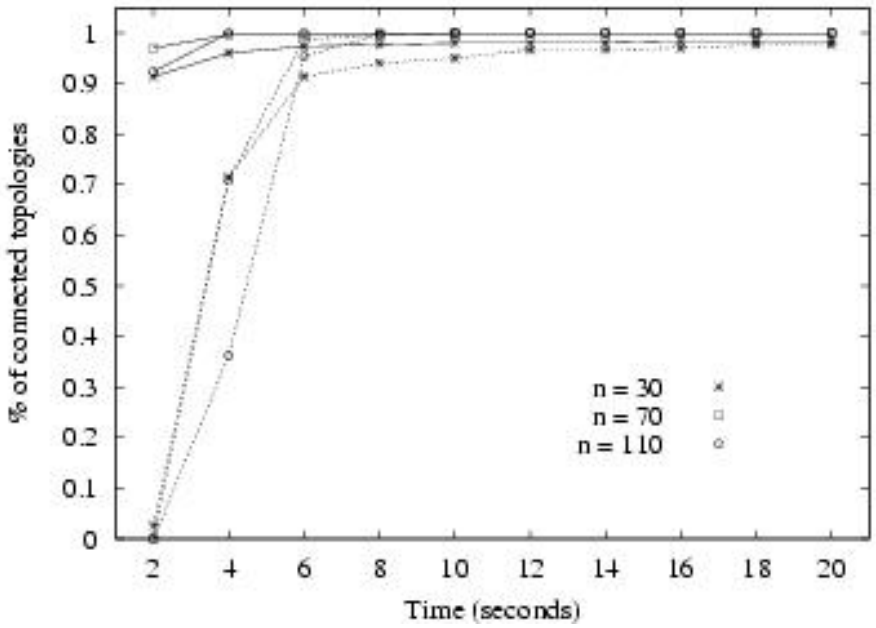
BlueStars Simulations, 2

- **Methodology and metrics:**
  - Effect of device discovery parameters on the discovered topologies
  - Effect of device discovery length on BlueStars performance:
    - Avg. Number of piconet
    - Avg. Number of roles per node
    - Avg. Number of slaves per piconet
    - Avg. Length of routes

Device Discovery Performance

- 20s are needed to discover more than 90% of neighbors, BUT
- Neighbors discovered after 8-10s guarantee connected topologies
- Average degree is halved (closer to 7)
- Average route length increases 35%

Device Discovery (Modified Inquiry)



- Smaller back-off interval and transmission of inquirer address dramatically improves performance
- Setting the back-off interval to 25% of the standard value, 4-6s are enough to guarantee connected topologies

BlueStars Performance

- Phase II and III last at most 2s (most of the times, less than 1s)
- Each node assumes at a most an average of 2.4 roles
- Half of the piconets are due to phase III
- Device discovery can be used as a “tuning knob” for reducing the number of piconets and of slaves per piconets

Something "To Go"

- Protocols for scatternet formation in the **ad hoc** setting, **connectivity** and with no additional **HW**.
- ns2-based performance evaluation:
  - Identify importance of device discovery on overall performance
  - Identify parameters and standard features that have a dramatic impact on performance
  - Assess BlueStars ability to rapidly and locally generate a connected scatternet with 'good properties'

"IMPROVEMENTS:" **BLUEMESH**

basagni@ece.neu.edu