Arguments for Cross-Layer Optimizations in Bluetooth Scatternets

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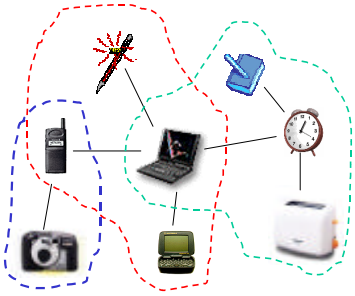
Background



Short-range RF
Low power
Point-to-point

Piconet: 1 Master, upto 7 slaves

Scatternet: many piconets

Outline

- Application scenarios
- Characteristics → Requirements
- Current approaches
- Arguments for cross-layer optimizations
- Quantitative evaluation
- Summary and Conclusions

Application Scenarios

- Lego-computing
  - Assemble your computing environment using wireless devices
- Communication among personal devices
  - Pager, cell-phone, laptop, watch, camera
- Laboratory environments
  - Labscape project (University of Washington)

Key Characteristics

1. Spontaneous network
2. Isolation
3. Simple devices
4. Small, multi-hop network
5. Connection-oriented, low-power link technology

- Compare with:
  - Internet
  - ATM LANs
  - Home RF, Ad-hoc networks

Requirements

- Link formation
  - Physical proximity does not mean connectivity
  - Active, sniff, hold, and park modes of operation
  - What links to form and when?
  - Master and slave nodes
- IP layer
  - Routing mechanism
- Service discovery
  - Protocol for information propagation and query/response
- Two possibilities:
  - **Layered** (independent solutions)
  - **Integrated** (lots of cross-layer optimizations)

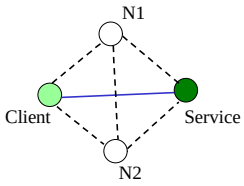
Current Approaches

- ATM LAN emulation
- IP routing in dynamic networks
  - AODV, DSR, DSDV, Associativity-based routing
- Service discovery protocols
  - SLP, SSDP, SDS
- Generic routing
  - INS
- Bluetooth SDP
  - Integrated with link-formation for point-to-point links

Case for an Integrated Approach: On-demand Operation

- Pattern of usage likely to be:
  - Long periods of inactivity interspersed with brief periods of activity
- There is link maintenance cost
  - Unlike in other link technologies: ATM or 802.11
- Inefficient to actively exchange information
  - On-demand operation
- Lower layers operate only on being triggered by a higher layer

Awareness of Higher-layer Requirements

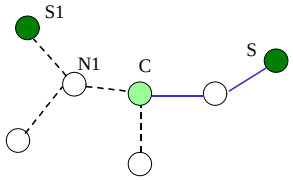


Applications look for services

Many nodes could be in physical proximity

Need to decide which of a set of links to form

When not to keep a link active



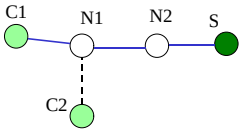
Scatternet inactive to begin with

Broadcast query, unicast reply

Service layer information can be used to decide which links to keep active

Such optimizations important when some nodes are accessed more frequently than others

Caching service descriptions



Service discovery and IP-routing: both require a level of indirection

In an integrated approach, service descriptions can be cached

IP-broadcasts can be minimized

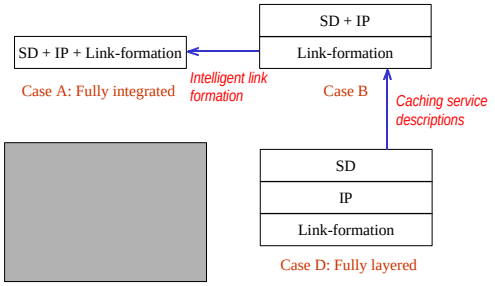
Scope of Operation

- In traditional networks
  - Different protocol layers have different scopes of operation
  - Link layer: subnet
  - IP layer: inter/intra AS
  - Service discovery: administrative scope or wider
- In Scatternets
  - All protocol layers have same scope of operation: the scatternet
- Single protocol layer is a natural optimization

Shortcomings of an Integrated Approach

- Layered ➔ modular design and implementation
  - Easy to build, verify correctness
  - Reuse of functionality
- But, in scatternets
  - Cross-layer optimizations highly beneficial

Quantitative comparisons

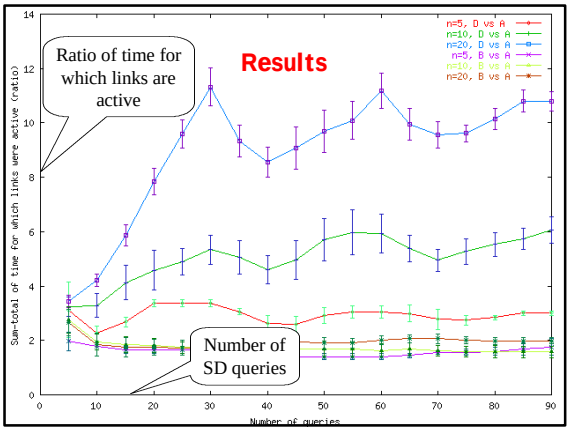


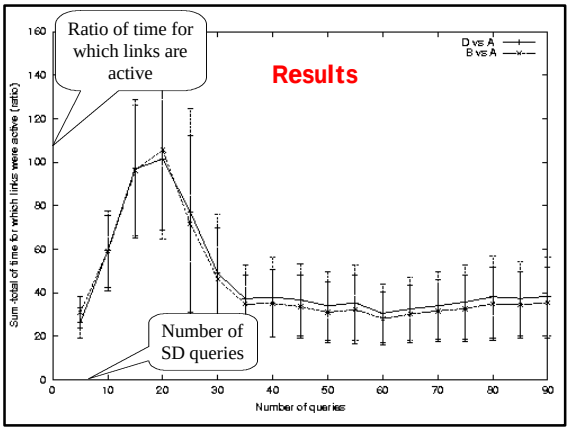
Simulation setup

- Emulated scatternet
- SD, IP: AODV algorithm
- Links formed on demand
  - Timed out on inactivity (layered)
  - Kept active only on seeing service reply (integrated)
- Scenario: collection of nodes look for services in the network
- No node mobility during simulation runs
- SD/IP information timed out periodically
- Series of queries for services from random nodes

Parameters and Metrics

- Parameters
  - *n* – number of nodes in the scatternet
  - *M* – number of links that can be formed
  - *S* – number of services accessed
  - *nQ* – the number of SD queries
- Metrics
  - Time for which links are kept active
  - Total number of messages in the network
  - *Both are measures of power consumption*





What do the results mean?

- Power consumption in Bluetooth chip-sets
  - Cambridge Silicon Radio chip-sets (www.cambridgesiliconradio.com)
  - 40mA@2.8V in active mode
  - 120microA@2.8V in park mode
  - 3 orders of magnitude difference
- Very important to intelligently manage transitions between the two modes

Summary

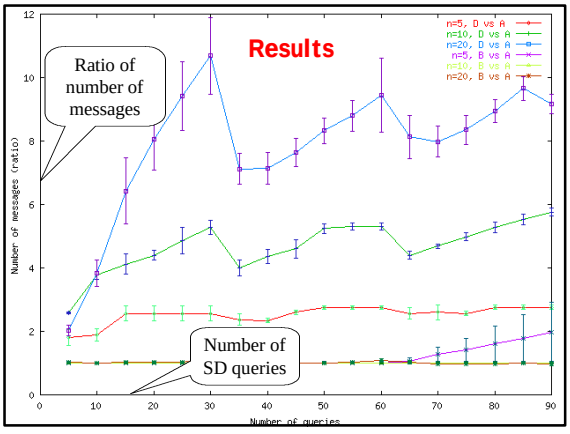
- Bluetooth scatternets are different from networks considered so far
  - Connection-oriented, low-power link technology
- Cross-layer optimizations are crucial
  - Intelligent decisions on when to make/break links
  - Single level of indirection for flooding: SD & IP layers – benefits of caching service discovery queries
  - Others possible…
- An integrated approach is also natural

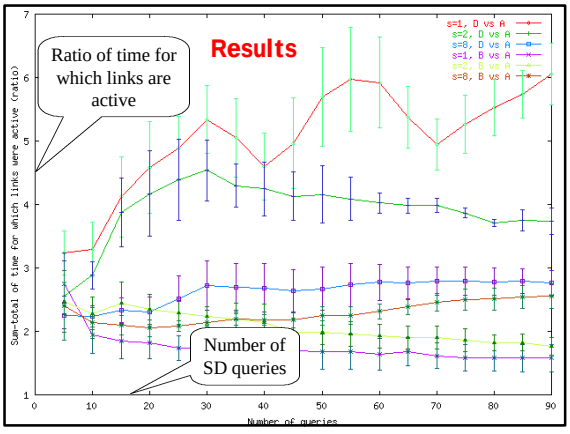
Conclusions

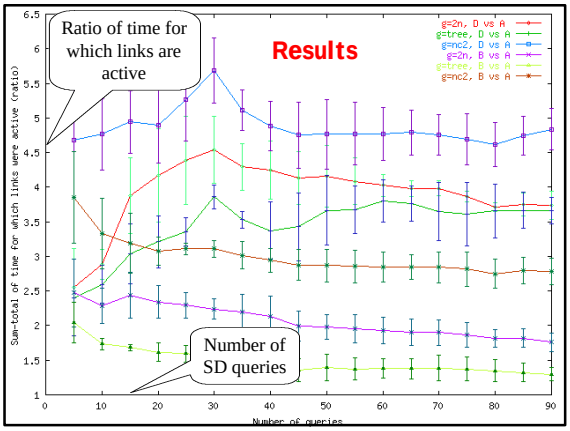
- IP over Bluetooth imminent
- Service discovery solutions and IP-routing solutions exist for similar small-scale ad-hoc networks
  - Do not gel well in a layered system
  - Important to preserve idleness
- Optimizations can be extended to application layer – but will not be generic
- Cross-layer techniques will probably be important for other similar link technologies in the future

http://www.cs.berkeley.edu/~bhaskar

(Presentation running under VMWare under Linux)






Ratio of time for which links are active
Results
Number of SD queries
g=2n, D vs A
g=tree, D vs A
g=nc2, D vs A
g=2n, B vs A
g=tree, B vs A
g=nc2, B vs A
Sum-total of time for which links were active (ratio)
Number of queries