Maximizing transfer opportunities in Bluetooth DTNs

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Disruption Tolerant Networks

- Networking over intermittently connected nodes (no infrastructure)
Transfer opportunities

- When two nodes are in range of one another, there is an opportunity for data transfer (if the routing decides so and if the two nodes manage to detect each other).
Missed opportunity!

- If two nodes pass one another without a link-layer discovery, they miss their chance to transfer data!
- Discovery phase should be fast and shorter than typical values for connectivity durations. But ...
Problem: half-duplex discovery

- Wireless devices operate in half-duplex mode.
  - A device cannot listen while inquiring about other nodes.
  - A typical example is Bluetooth (used in the sequel as a reference).

- Due to half-duplex, inquiries could overlap and fail, and hence short duration opportunities could be missed. Some numbers:
  - In Bluetooth, it takes on average 3.5 seconds for an inquiry to succeed if no collision.
  - Add some seconds for time between inquiries. Result in tens of seconds.
  - Same order of magnitude of connectivity time of two pedestrians.

- Shortening the inquiry train is ineffective:
  - Not always possible in software
  - Fewer successful inquiries

- One could play with the time between inquiries (what is the optimal?).
Better solution: full-duplex discovery

- **Add a second radio** - a Bluetooth radio - to listen to other stations inquiries while inquiring.
  - A station can now transmit and listen at the same time.

- **Turn it off when not inquiring on primary.**

- **Low cost solution:**
  - Inexpensive (price of a radio < $5 / unit)
  - Low power (the other antenna only listens during inquiries)
  - Specification compliant
Remainder of the talk

- Maximizing single opportunities
- Dual radios performance in multinode scenarios
- Conclusion and future work
Maximizing an opportunity: Half-duplex transmission

- **Goal:** Shortening the discovery phase by setting optimally the time between inquiries.

- **A simple analytical model:**
  - Inquiries of fixed length \( D \).
  - Exponentially distributed time between inquiries of mean \( 1/\lambda \).
  - **Main result:** Closed form expression for average discovery time under the assumption that full inquiry \( D \) needed for success:

\[
T = \frac{D \lambda D (12 + 18\lambda D + 5(\lambda D)^2 + (\lambda D)^3)}{12} \frac{1}{(1 + \lambda D)^2}
+ e^{\lambda D} \frac{(1 + \lambda D)^2}{(2\lambda)}
\]

- Thus, the ideal mean inter-inquiry delay is \( 1/\lambda = 2.66D \)
Maximizing an opportunity: Dual radios

- **Same goal**: What is the optimal inter-inquiry time?
- **Same model**: Average discovery phase duration:

\[ T = \frac{3 + 6\lambda D - 6\lambda^2 D^2 + 2\lambda^3 D^3}{6\lambda(\lambda D + 1)^2} + D \]

which minimizes for \(1/\lambda = 0.435D\) (six times less than in the single radio case)

- Comparing both cases together in terms of discovery ...
Analytical results

Dual radio performance is roughly linear, clearly better than single radio case by several seconds.
Comparison in terms of energy and global performance: multinode simulations

- Second antenna consumes power but reduces collisions of inquiries!
- What about the global performance?
- Scenarios:
  - 1000 m x 1000 m area
  - All nodes follow predetermined paths
    - Paths built according to freeway model
    - Nodes follow paths (as pedestrians following walkways)
    - Nodes enter and leave scenarios
      - When one node leaves scenario, another enters at random path endpoint
  - Walking: Speed drawn from (1.0, 2.0) m/s, wireless range 10m.
  - Biking: Speed drawn from (2.0, 9.0) m/s, wireless range 10m.
Metrics

- Time until discovery
- Number of successful discoveries
- Transfer duration (time left for transmission)
- Energy cost per second of transfer
Mean discovery time

Calculated over successful transfer opportunities

12.5s for inter inquiry time
50 nodes

larger because nodes stay more in range

Seconds

Biking
Walking

Mean discovery time

Calculated over successful transfer opportunities

12.5s for inter inquiry time
50 nodes

larger because nodes stay more in range
Total number of opportunities

- A denser field results in more successful opportunities
- And dual antennas provide almost 200% more opportunities.
Time spent transmitting (data)

Dual radios consistently spend more time transmitting.

More nodes more time spent transmitting during the lifetime of a node.
Transmission costs

Transmission costs (millijoules/sec) (includes discovery costs)

Energy spent to transmit — walking

Nodes in simulation

- Single radios—6.25
- Single radios—12.5
- Dual radios—0.01
- Dual radios—6.25
- Dual radios—12.5

Dual radios use less power overall despite the energy spent by the second antenna

Power specifications the BlueCore3-ROM single chip Bluetooth Radio:

- 1.8V power supply
- Idle state draws 0.36mA
- Inquiries draw 0.66mA
- Data Tx/Rx draw 11.66mA

More nodes, less time to discover and more transfer opportunities, so better energy consumption
Related work

- **Salonidis2000, Peterson2004**
  Improve Bluetooth inquiry by protocol changes (not easy to deploy).

- **Busboom2002, Woodings2002**
  Detect nodes in range by other means than dual Bluetooth radios as for example infrared and RFID.

- **Shih2002, Bahl2004**
  Multiple tiers of radios to improve capacity in wireless mesh networks

- **Hui2005, Chaintreau2006, Chakaborty2006**
  Characterizing transfer opportunities in DTN like networks
Conclusion - Future Work

- Explicit expressions for the average discovery time.
- Dual Bluetooth
  - Almost doubles the number of successful opportunities.
  - Maximizes transfer opportunities
  - Lowers energy costs

Future Work

- Deploy and measure in a real system
- Mixed single/dual environments (incremental deployment)
- Multi-tiers of radios for DTNs