Maximizing transfer opportunities in Bluetooth DTNs

Marc Liberatore (UMASS)

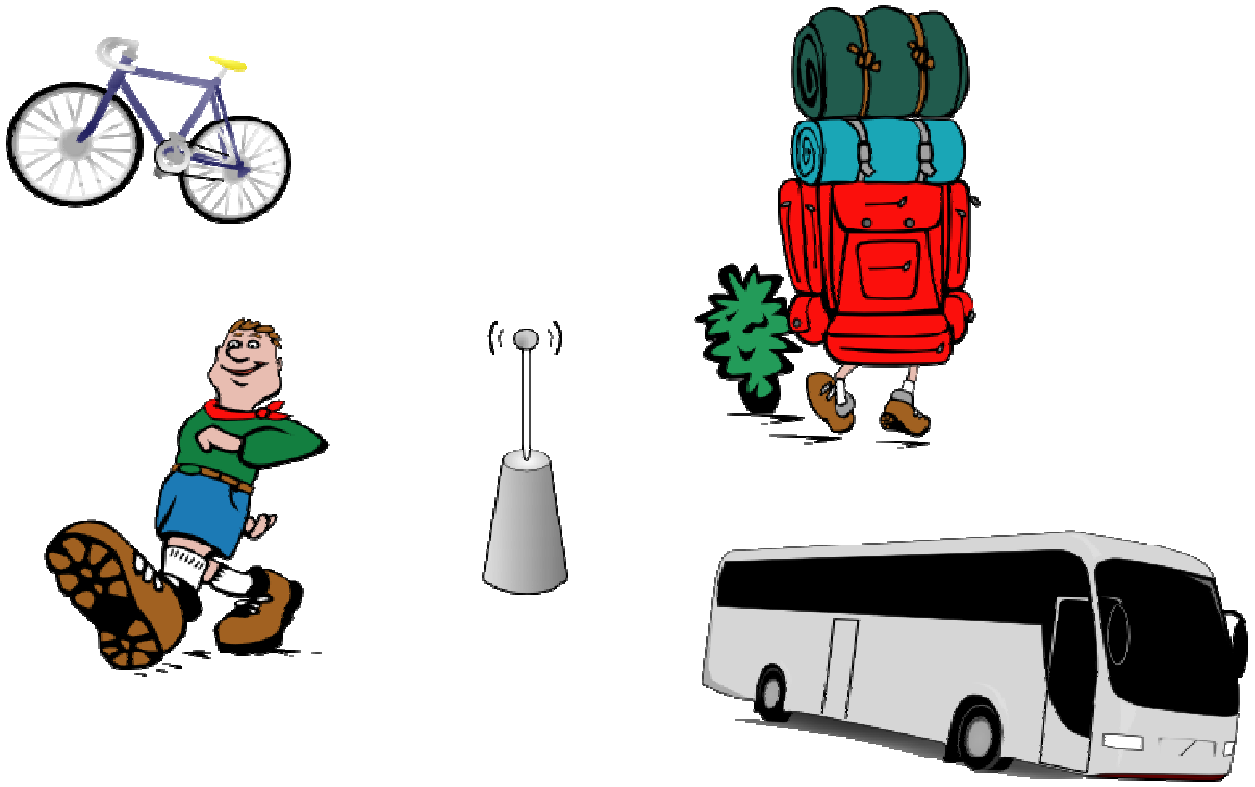
Brian Levine (UMASS)

Chadi Barakat (INRIA Sophia Antipolis)

CONEXT 2006 – Lisbon

Supported in part by Intel Research, the U.S. National Science Foundation under grants CNS-0519881, CNS-0133055, and ANI-0325868, and by DARPA under contract W15P7T-05-C-P213

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!

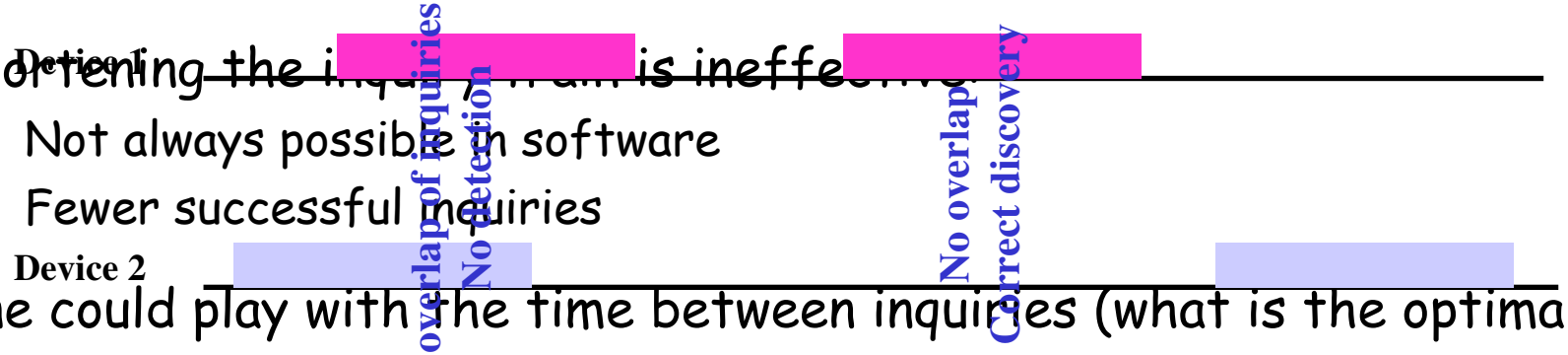
- If two nodes pass one another without a link-layer discovery, they miss their chance to transfer data!
- Discovery phase should be fast and shorter than typical values for connectivity durations. But …

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:

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

  - Thus, the ideal mean inter-inquiry delay is $1/\lambda = 2.66D$

Maximizing an opportunity: Dual radios

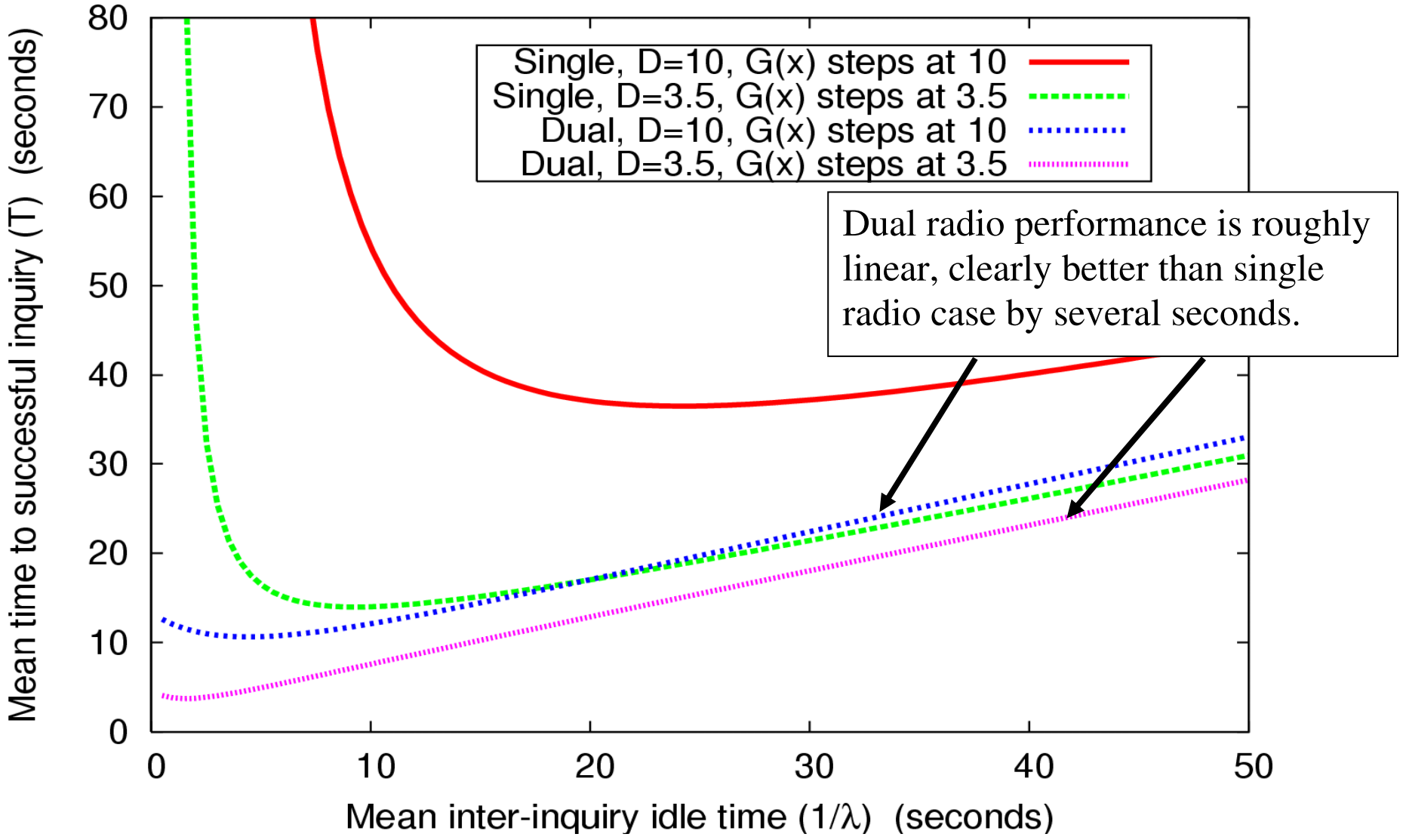
- Same goal: What is the optimal inter-inquiry time?
- Same model: Average discovery phase duration:

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

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



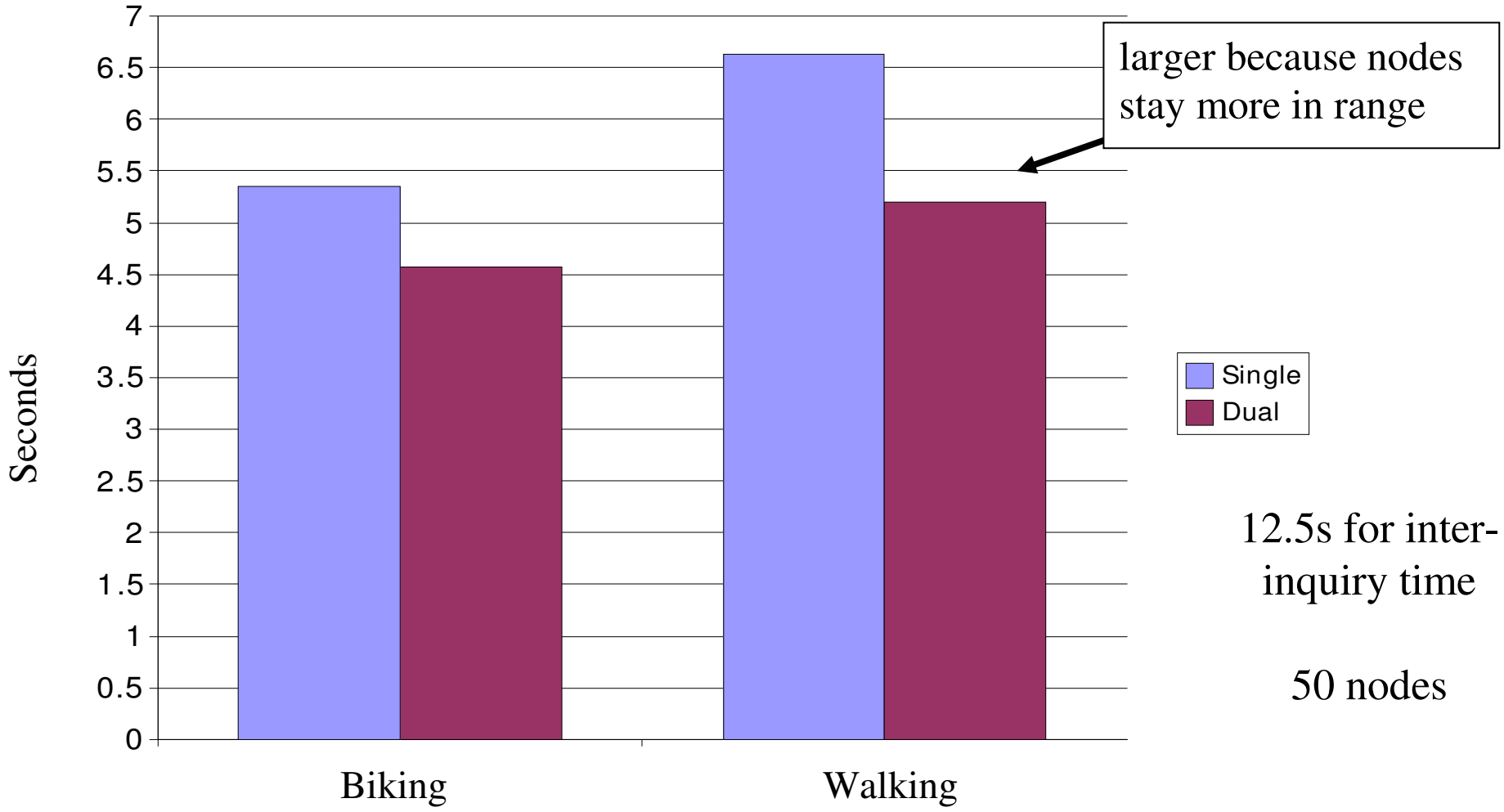
Comparison in terms of energy and global performance: multinode simulations

- 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



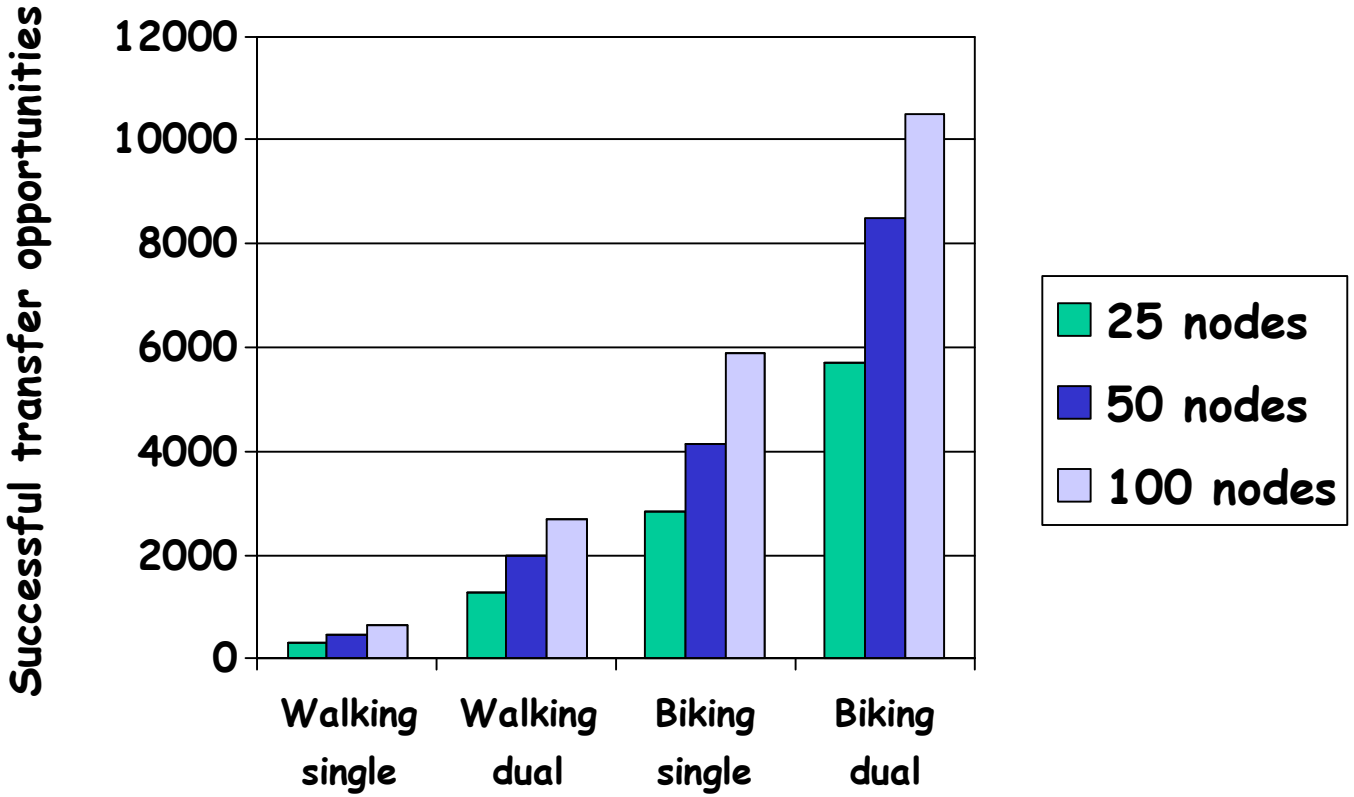
12.5s for inter-inquiry time

50 nodes

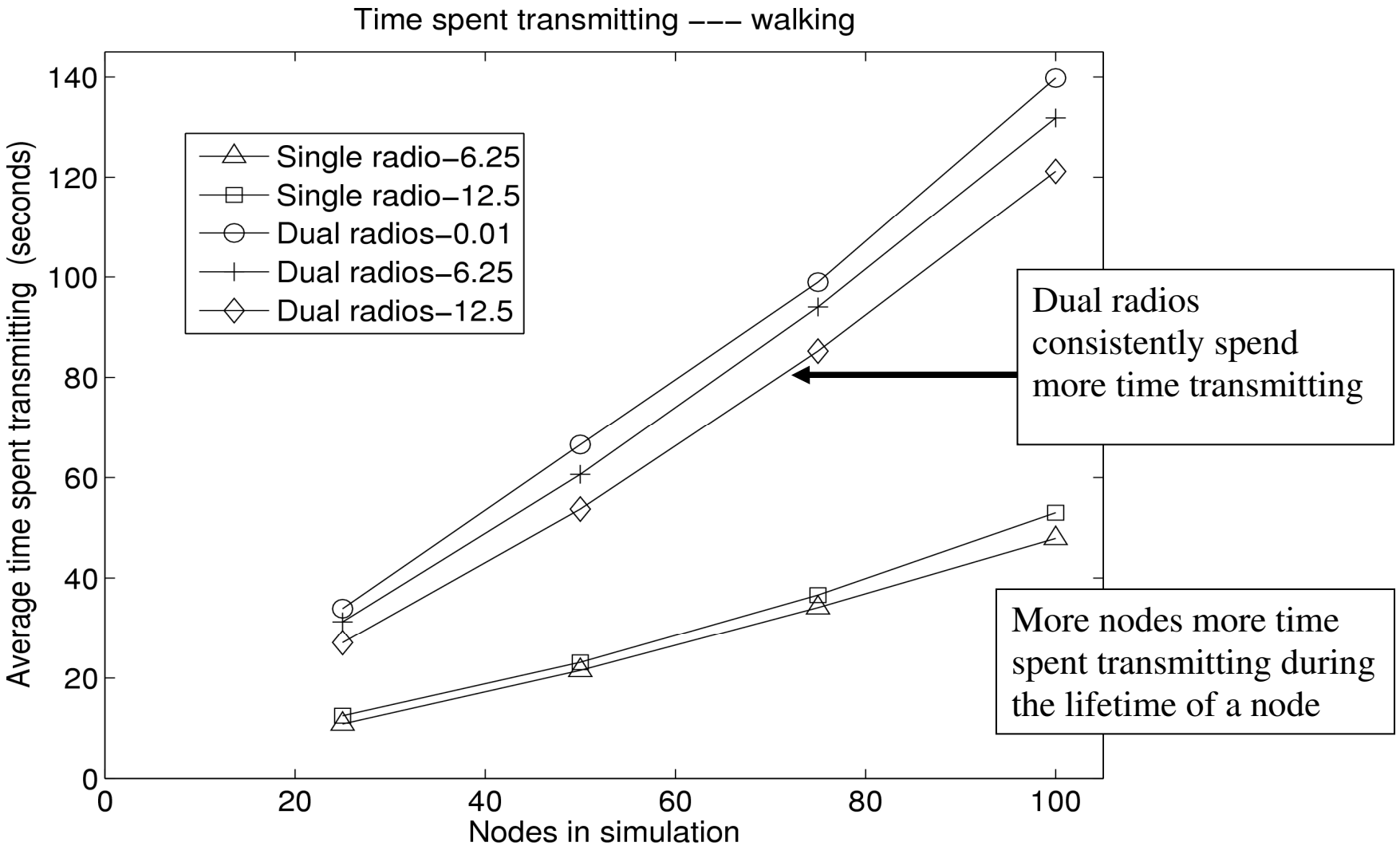
Calculated over successful transfer opportunities

Total number of opportunities

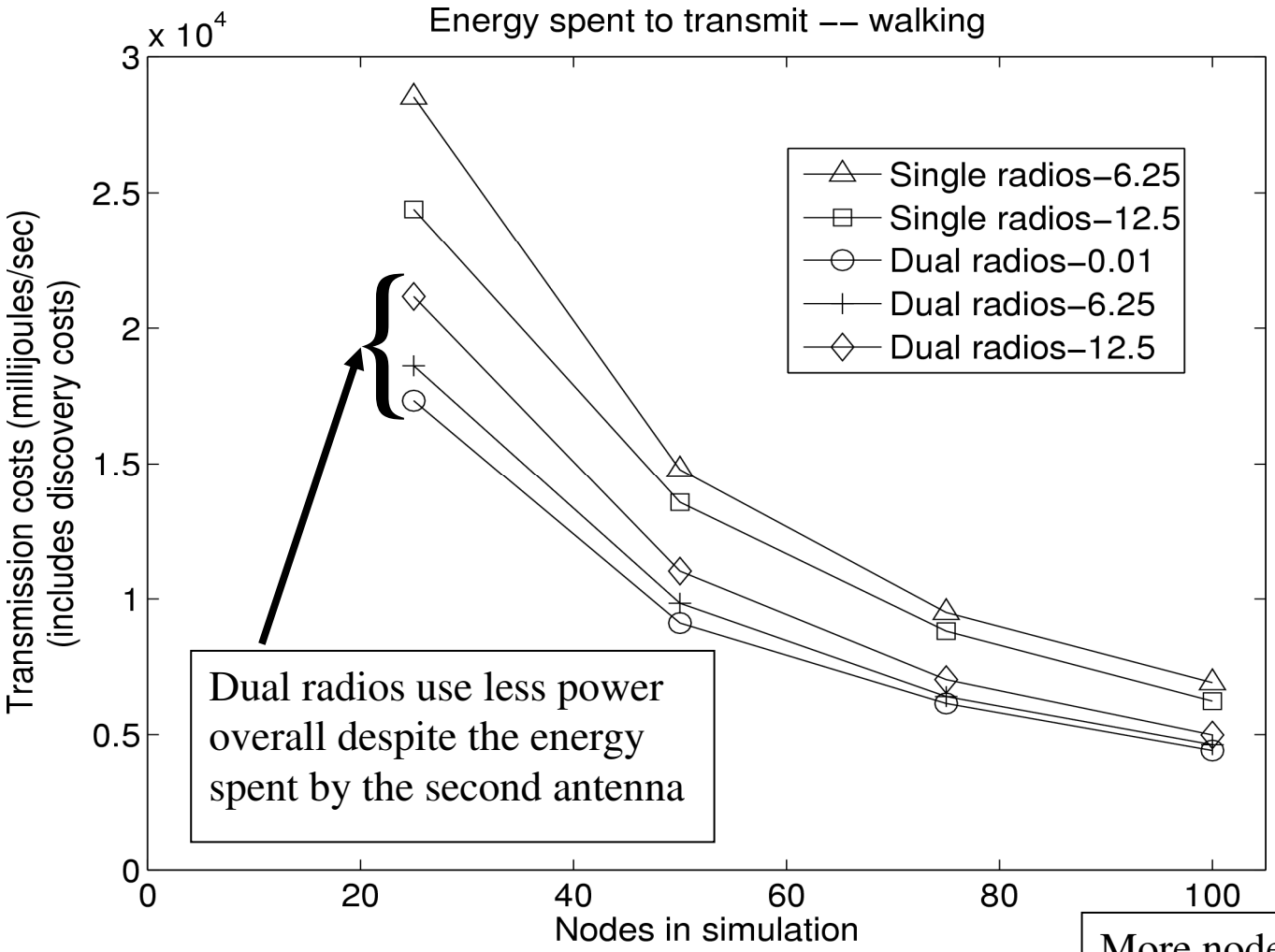
- A denser field results in more successful opportunities
- And dual antennas provide almost 200% more opportunities.



Time spent transmitting (data)



Transmission costs



Power specifications of 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