Maximum Battery Life Routing to Support Ubiquitous Mobile Computing in Wireless Ad Hoc Networks

By

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Introduction to Wireless Ad Hoc Network

- There is a tremendous interest in wireless network
- Ad hoc wireless network is a collection of wireless mobile hosts (infrastructureless network)
- Most of the ad hoc mobile devices today operate on batteries

Characteristics of Ad Hoc Mobile Wireless Network

- Dynamic topology
- Bandwidth constraints and variable links
- Energy constrained nodes
- Multi-hop communications
- Limited security

Characteristics of Ad Hoc Mobile Wireless Network (contd)

- Determining/detecting changing network topology
- Maintaining network topology/connectivity
- Scheduling of packet transmission and channel assignment
- Routing

Characteristics of Ad Hoc Mobile Wireless Network (contd)

- Determination of Network Topology
- Maintaining Network Connectivity Under Changing Radio Conditions and Mobility
- Transmission Scheduling and Channel Assignment
- Packet Routing

Determination of Network Topology

- Must determine and monitor the dynamics of network topology over time
- The routing protocol need to ensure that link in the route has strong connection
- Must exist at least one path from any node to any other node
- Must aware of its surrounding and its neighboring nodes with which it can directly communicate

Maintaining Network Connectivity Under Changing Radio Conditions and Mobility

- Routing protocol must be able to update the status of its links and reconfigure itself in order to maintain a strong connectivity with others nodes in the network
- Centralized algorithm is vulnerable
- A fully distributed algorithm is reliable and robust

Transmission Scheduling and Channel Assignment

- An efficient transmission scheduling and channel assignment algorithm is needed to ensure that the new transmission will not conflict with an existing one
- Good Scheduling and Channel Assignment help reduce interference and improve bandwidth efficiency

Packet Routing

- Ad hoc networks require a highly dynamic, adaptive routing scheme to deal with the high rate of topology changes
  - Table-driven
  - On-demand
  - Hybrid

Importance Issues In Ad Hoc Wireless Network

- Power consumption rate need to evenly distribute among the nodes
- Efficient utilization of battery power is important
- Routing protocol for wire network can’t be use directly for wireless network

Outline

- Designed Properties of Ad Hoc Routing Protocols
- Power-Efficient Ad Hoc Mobile Networks
- Power-Efficient Ad Hoc Routing
- Performance of Different Routing Algorithms Considering Power Efficiency
- Simulation Results
- Conclusion

Desired Properties of Ad Hoc Routing Protocols

- Distributed Implementation
- Efficient Utilization of Bandwidth
- Efficient Utilization of Battery Capacity
- Optimization of Metrics
- Fast Route Convergence
- Freedom From Loops
- Unidirectional Link Support

Power-Efficient Ad Hoc Mobile Network

- Power required by each mobile host
  - Classified into two categories:
    - Communication-related power
    - Non-communication-related power
  - Communication-related power:
    - Processing power
    - Transceiver power

Power-Efficient Ad Hoc Mobile Network (contd)

- Physical Layer and Wireless Device
- Data Link Layer
- Network Layer

Physical Layer and Wireless Device

- Transmission power should be at a minimum level to maintain links
- Allow the ability to adapt to changes in transmission environment
- Excessive transmission power cause interference to other hosts

Data Link Layer

- Energy conservation can be achieved by using effective retransmission request schemes and sleep mode operation
- It is important to appropriately determine when and at what power level a mobile host should attempt retransmission
- Node’s transceiver should be powered off when not in use.

Network Layer

- In wireless network it is important that the routing algorithm select the best path from the viewpoint of power constraints as part of route stability
- Routing algorithm that can evenly distribute packet-relaying loads to each nodes to prevent nodes from being overused.

Power-Efficient Ad Hoc Routing

- Power-Efficient Routing Protocols
  - Minimum Total Transmission Power Routing (MTPR)
  - Minimum Battery Cost Routing (MBCR)
  - Min-Max Battery Cost Routing (MMBCR)
  - Conditional Max-Min Battery Capacity Routing (CMMBCR)

Minimum Total Transmission Power Routing (MTPR)

- $$SNR_j = \frac{P_i G_{i,j}}{\sum_{k \neq i} P_K G_{k,j} + \eta_j} \Psi_j(BER).$$
- $$P_l = \sum_{i=0}^{D-1} P(n_i, n_{n+1}) \quad \text{for all node } n_i \in \text{route}_l$$
- $$P_k = \min_{l \in A} P_l,$$

- Signal to Noise Formula
- Formula to calculate the total transmission power for route L
- The desired route k calculation
- Doesn't give the minimum number of hops

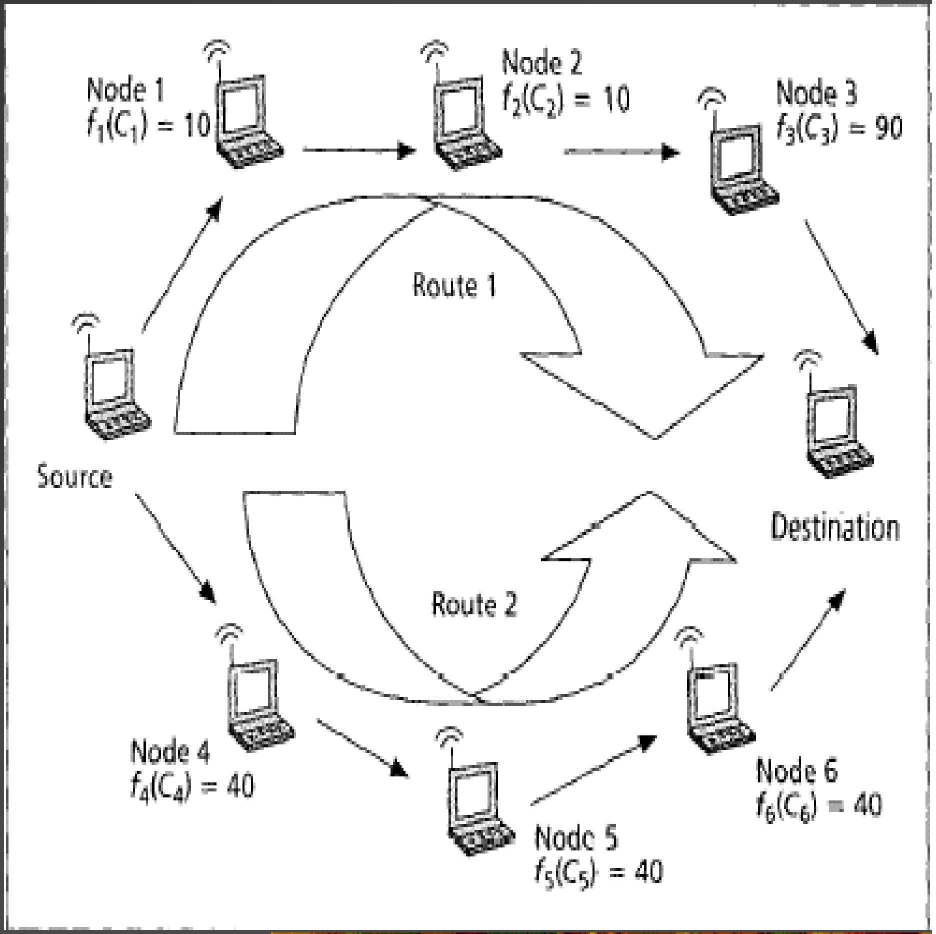
Minimum Battery Cost Routing (MBCR)

- $$f_i(c_i^t) = \frac{1}{c_i^t}.$$
- $$R_j = \sum_{i=0}^{D_j - 1} f_i(c_i^t).$$
- $$R_i = \min\{R_j \mid j \in A\}.$$

- The remaining battery capacity of each host is a more accurate metric to describe the life time of each host
- Battery cost function of a host
- Battery cost Rj for route I
- To find the maximum remaining battery capacity, we select route I that has the minimum battery cost.

Minimum Battery Cost Routing (MBCR)

- If all nodes have similar battery capacity, this metric will select a shorter-hop route
- Only consider the summation of values of battery cost; therefore can overuse any single node



Min-Max Battery Cost Routing (MMBCR)

- $$R_j = \max_{i \in route\_j} f_i(c_i^t).$$
- $$R_i = \min\{R_j \mid j \in A\}.$$

- The power of each host is being used more fairly in this scheme than previous schemes.
- No guarantee of minimum total transmission power path under all circumstances
- Consume more power to transmit mean reduce the lifetime of all nodes

Conditional Max-Min Battery Capacity Routing(CMMBCR)

- $$R_j^c = \min_{i \in route\_j} c_i^t.$$
- $$R_j^c \geq \gamma, \text{ for any route } j \in A.$$

- Using previous scheme, maximize the life time of each node and use the battery fairly can't be achieve simultaneously
- Use battery capacity instead of cost function
- Choose route with minimum total transmission power among routes that have nodes with sufficient remaining battery capacity

Performance of Different Routing Algorithms Considering Power Efficiency

- The Structure of the Simulator
  - Ad hoc Mobile Network Formation
  - Mobile Host Migration Engine
  - Route Requests Event Generator
  - Routing Protocols Implementation
  - Power Consumption Computation

Ad Hoc Mobile Network Formation

- Confined space of 100m x 100m
- Each mobile host has a wireless cell size of 25 m radius

Mobile Host Migration Engine

- At the start of each simulation time slot, each node chooses randomly a new direction and moves a distance equal to the product of its speed and the length of a time slot
- If it hit a boundary of the confined space, it bounces back
- It move at a speed of 2 m/s

Route Requests Event Generator

- Use Poisson process for calculation of the route request
- If a route request occur, then choose two nodes are randomly pick as source and destination
- Request arrival rate is proportional to the number of nodes that power up
- Duration of each call is also exponentially distributed

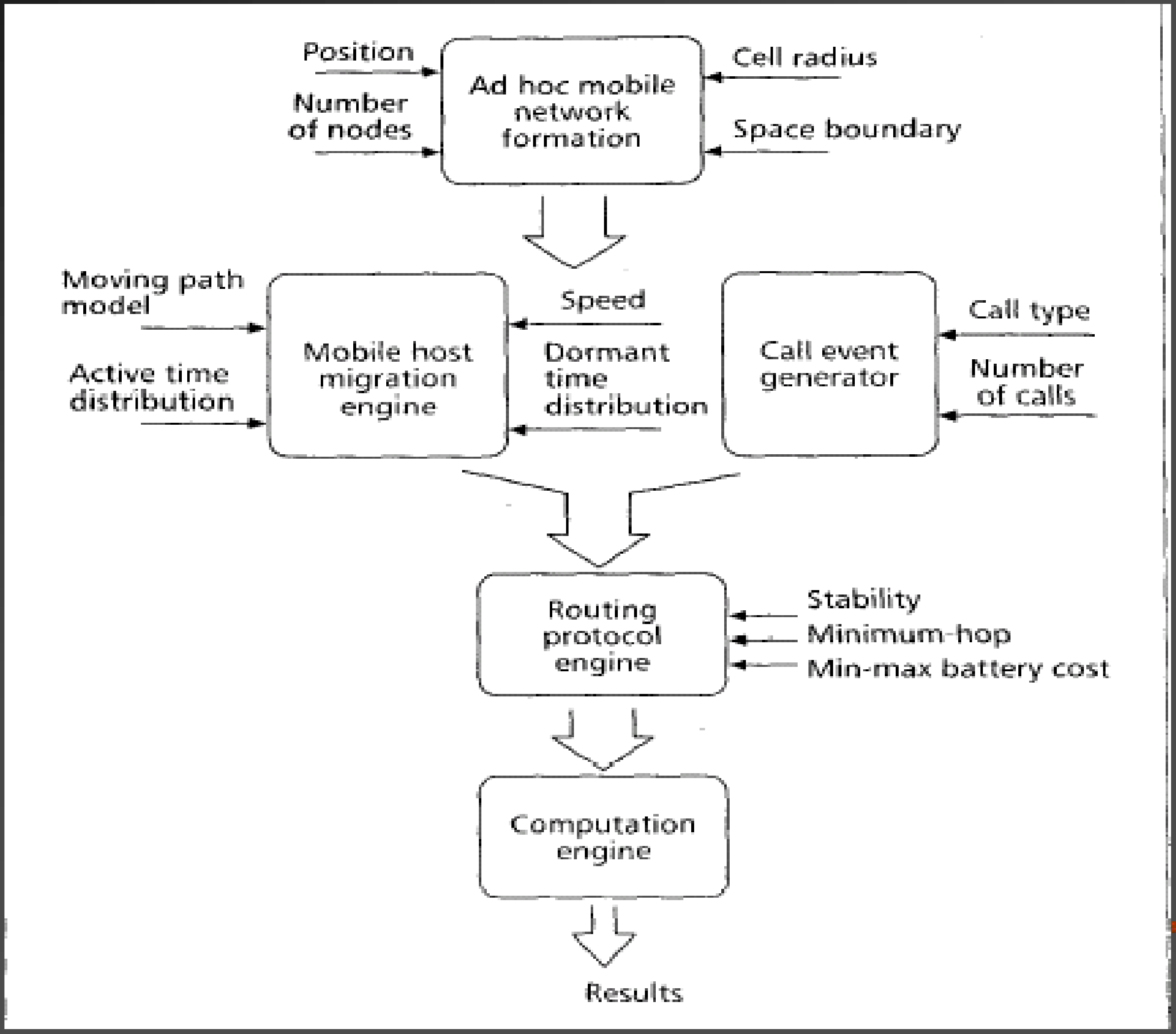
Routing Protocols Implementation

- A simplified routing implementation, when a new route request arrives or a route is broken, the source node will broadcast a route query message, and all nodes that may receive and forward it will consume the same amount of energy
- Implement five route selection schemes
  - Use minimum hop metric
  - Select route base on stability of the route
  - Use minimum battery cost metric
  - Use min-max battery cost metric
  - Use conditional max-min battery capacity scheme

Power Consumption Computation

- Assume power consume for non-communication-related is fixed
- $$\sigma = \frac{Power_{CR}}{Power_{NCR}}$$
- Three cases are considered
  - Power consumption for communication-related is much larger than power consumption for non-communication-related
  - They are the same
  - Power consumption for non-communication-related is much larger than power consumption for communication-related
- All nodes start out with the same battery power level
- Simulation stop when there are only two nodes left

An Ad Hoc Mobile Network Simulation Model



Simulation Results

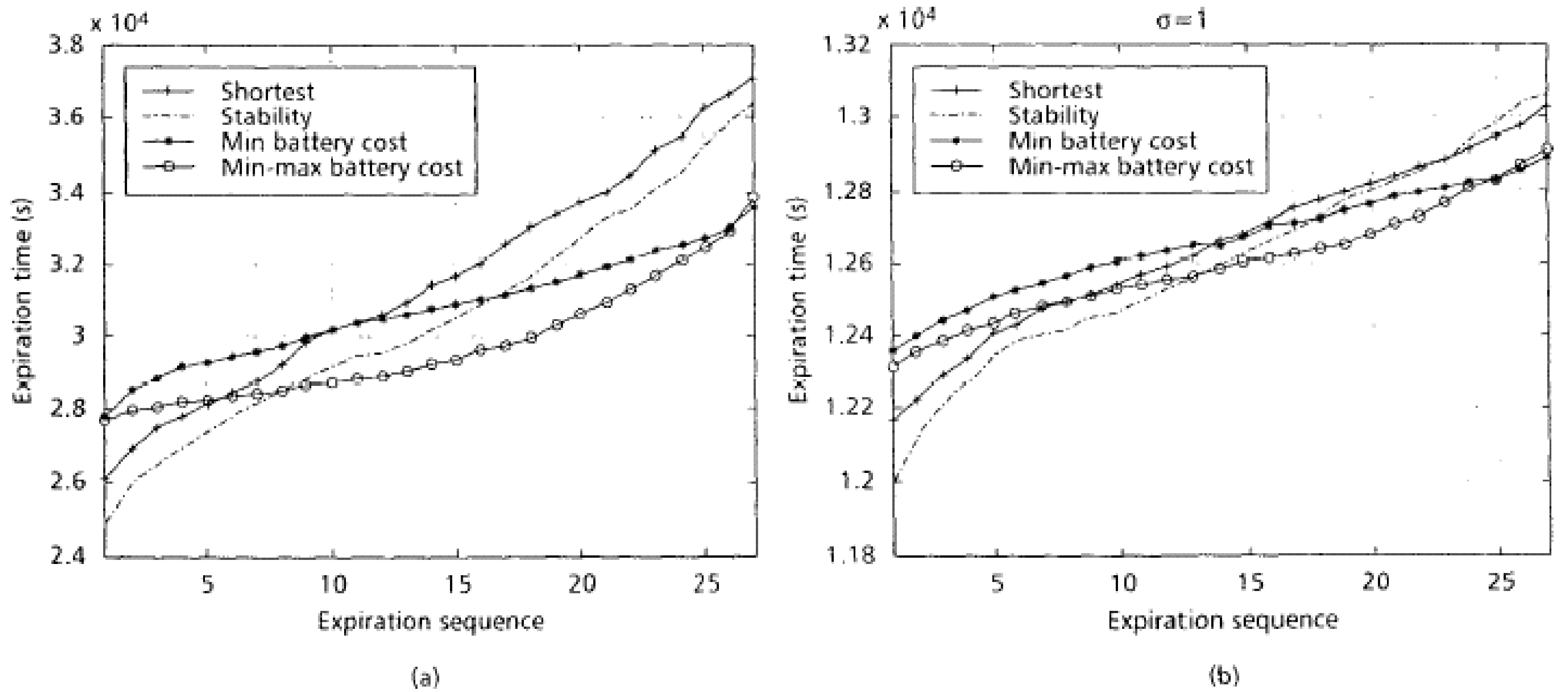


Figure 3. *a) Expiration time vs. expiration sequence when σ = 10; b) expiration time vs. expiration sequence when σ = 1.*

Simulation Result(contd)

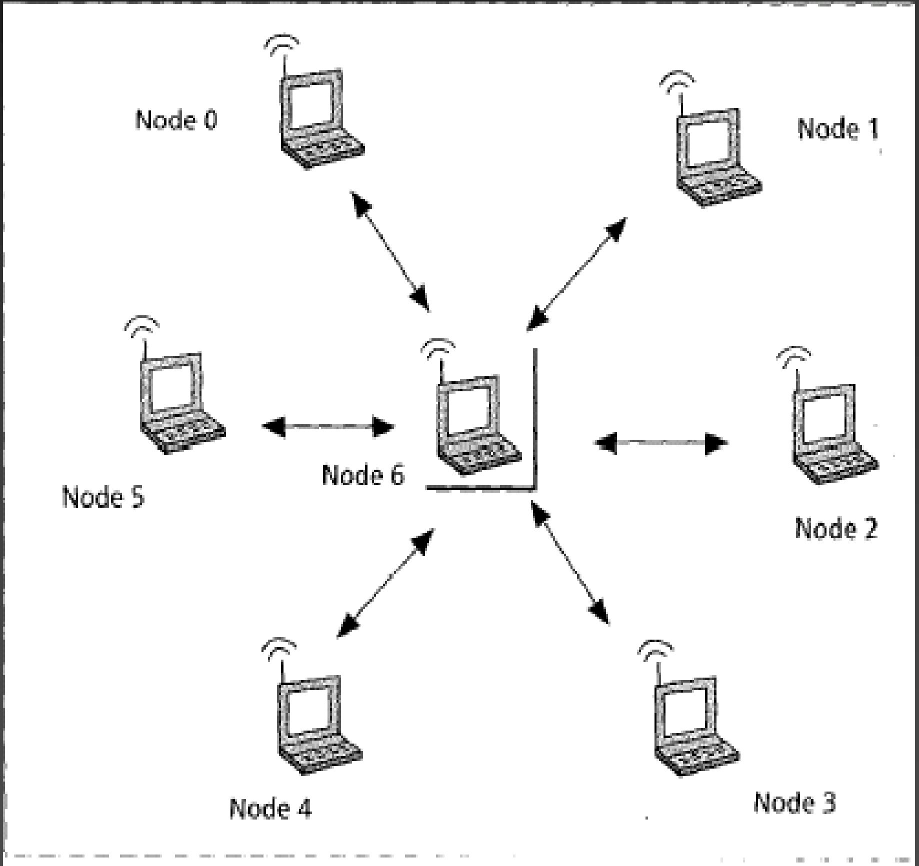


Figure 4. *An illustration of the shortcoming in minimum-hop routing.*

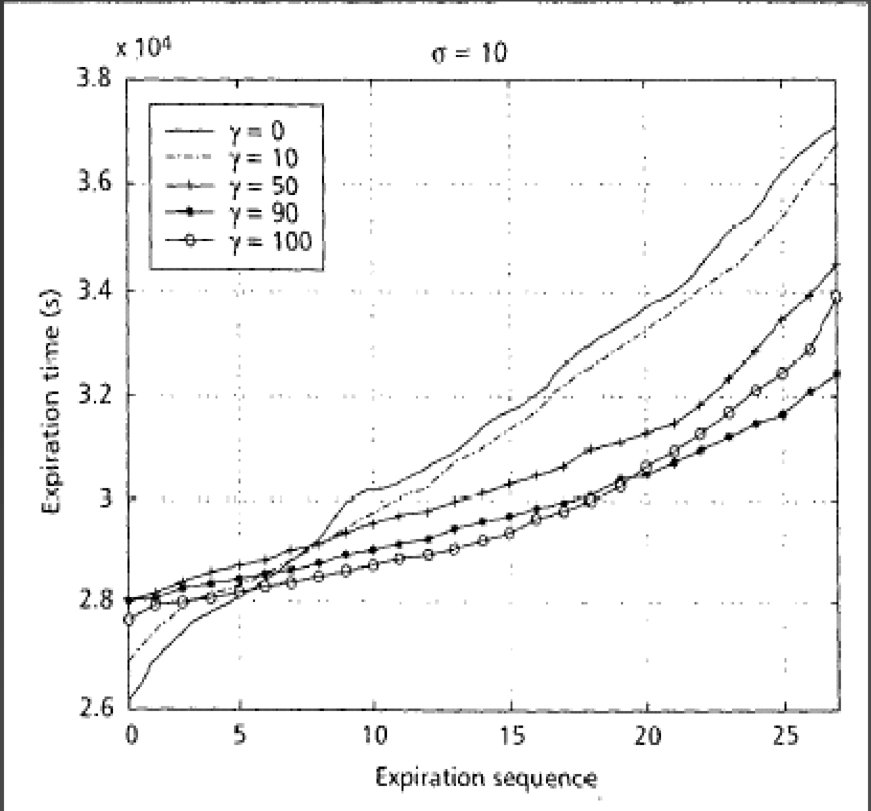


Figure 5. *Expiration time vs. expiration sequence for different values of γ when σ = 10.*

Simulation Result (contd)

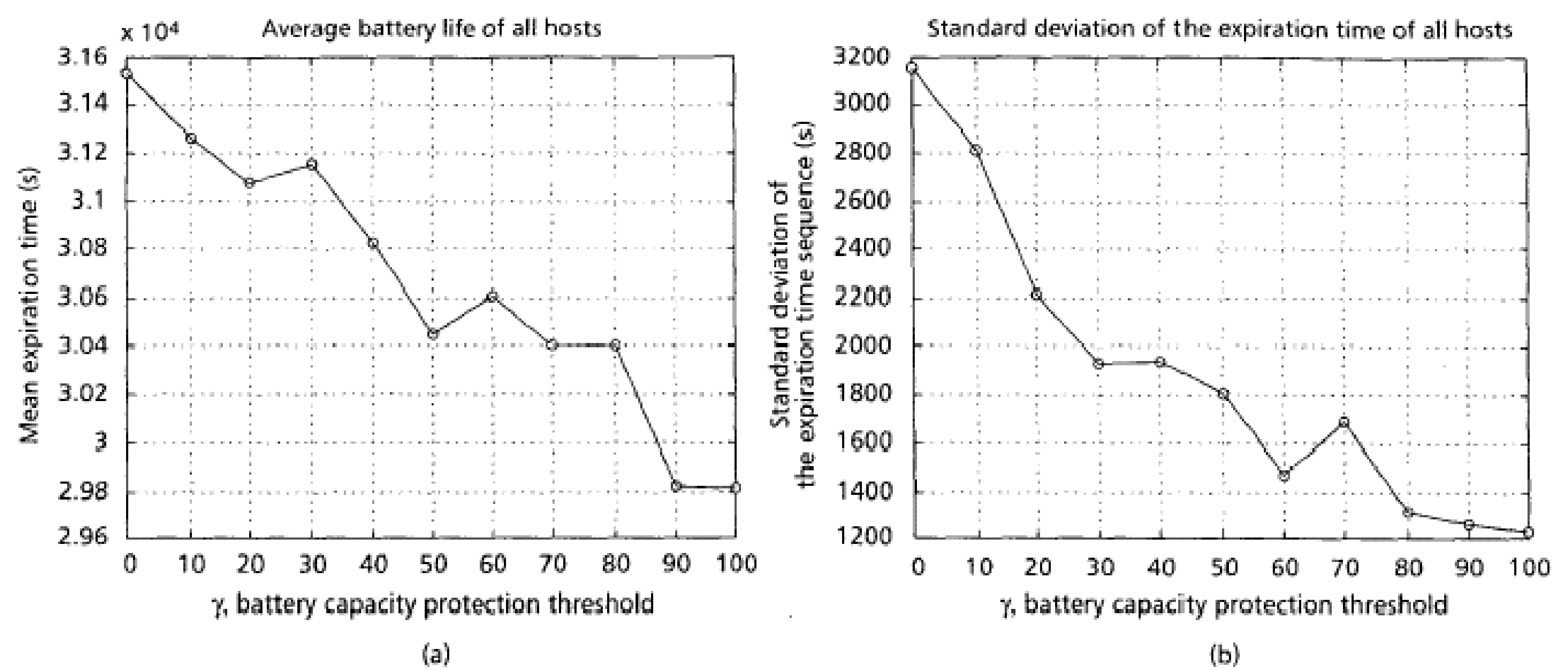
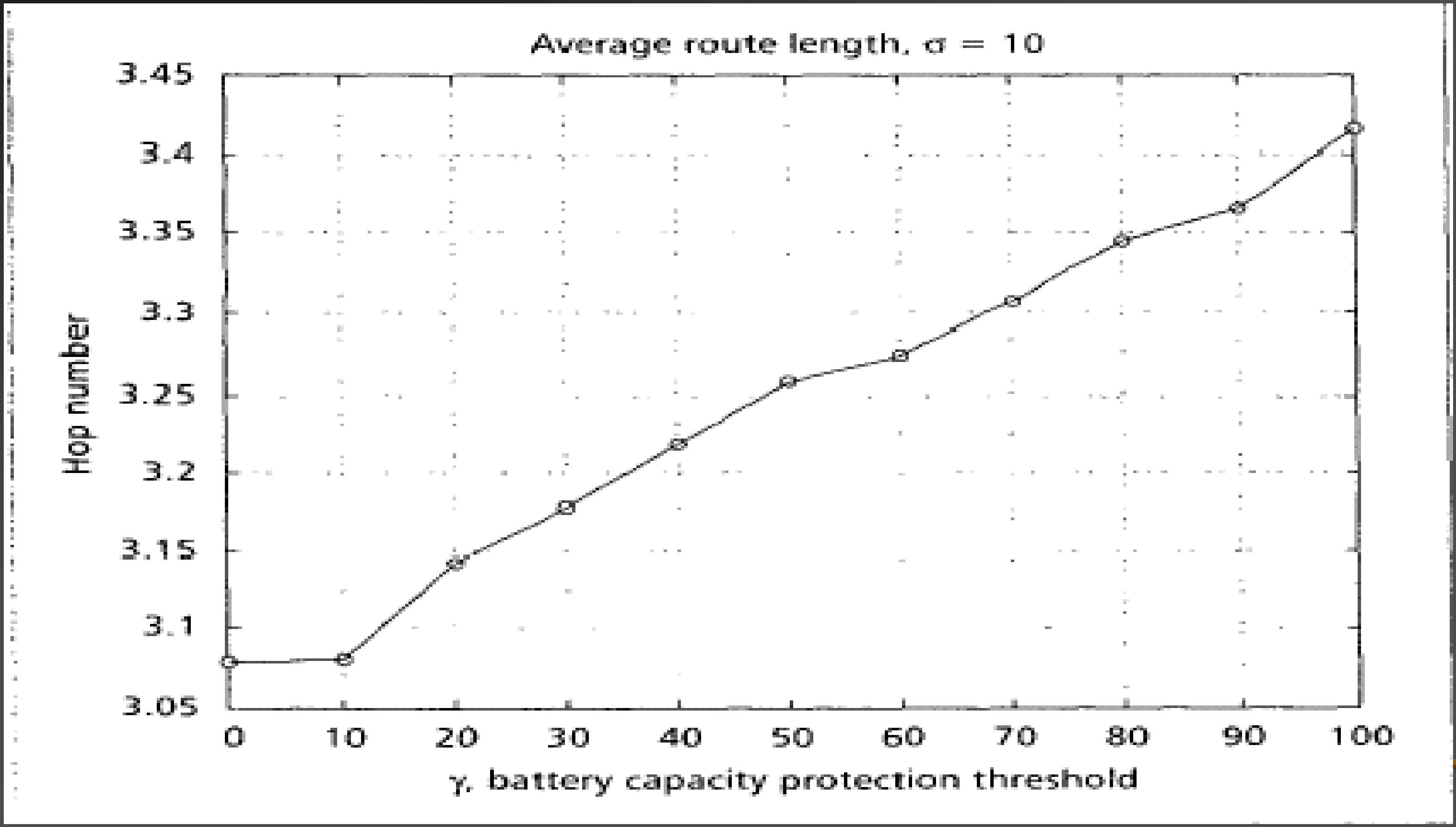


Figure 6. *a) Average host lifetime vs. increasing γ; b) standard deviation of lifetime of all nodes vs. γ.*

Simulation Result (Contd)



Conclusion

- Battery power capacity, transmission power consumption, stability of routes, and so on should be considered
- The two goals: to use each node fairly and extend their lifetimes are not compatible
- CMMBCR scheme chooses a shortest path if all nodes in all possible routes have sufficient battery capacity
- Can maximize the time when the first node powers down or the lifetime of most nodes in the networks
- If power use in communication subsystem is small compare to the overall power consumption then the difference of performance for all protocols is negligible doesn’t matter what routing metric used.