An Online Heuristic for Maximum Lifetime Routing in Wireless Sensor Networks

IEEE Transactions on Computers 2006

Presented by L. C. Chen

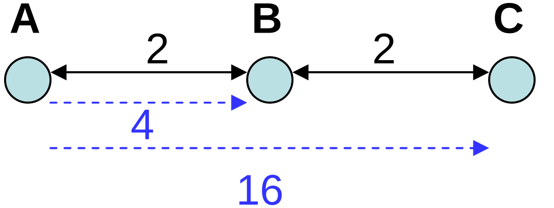
Jan. 31, 2007

Outline

- Introduction
- Terminology
- Related Work
- NP-Hardness of Maximum Lifetime Problem
- OML
- Distributed OML
- Evaluation
- Conclusion

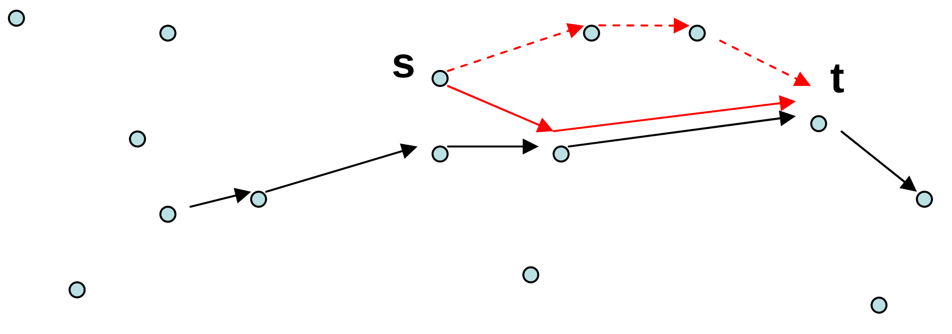
Introduction(1)

- We consider message routing in wireless sensor networks in which each sensor is battery operated.
- The energy required by a sensor to transmit, under ideal conditions, a unit length message a distance r is proportional to r^d for some d in the range.
- The lifetime of a sensor network is defined as the number of messages successfully routed before the first failed message route.



Introduction(2)

- An online routing algorithm routes r_i without knowledge of any r_j, $j > i$.
- An offline routing algorithm determines the routes for each r_i with full knowledge of all succeeding routing requests.

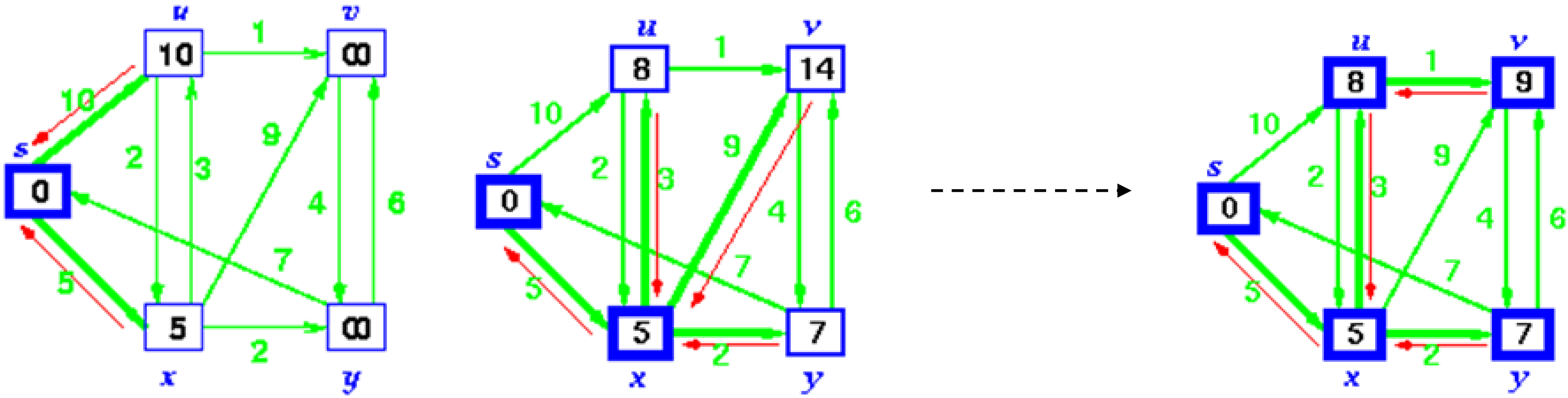


Terminology

- $G = (V, E)$
- $(u,v) \in E$
  - From sensor u to sensor v iff a single-hop transmission from u to v is possible.
- $ie(i) > 0$
  - initial energy
- $ce(i) >= 0$
  - current energy
- $w(u,v) > 0$
  - The energy required to do a single-hop transmission from sensor u to sensor v.
- $re(u) = ce(u) – w(u,v)$
- $r_i = (s_i,t_i)$

Related Work

- Dijkstra's shortest path algorithm
  - This metric tends to minimize the total (or average) energy consumed over a sequence of routes, it doesn't focus on the primary objective of maximizing lifetime.
- MRPC
- CMAX



Related Work --MRPC

- MRPC：maximum residual packet capacity

Eliminate from G every edge (u, v) for which $ce(u) < w(u, v)$.
For every remaining edge (u, v) let $c(u, v) = ce(u)/w(u, v)$.
Let L be the list of distinct $c(u, v)$ values.

- c(u,v) is the number of unit-length messages that may be transmitted along (u,v) before node u runs out of energy.
- We perform a depth- or breadth-first search beginning at the source to destination.

Related Work-- CMAX

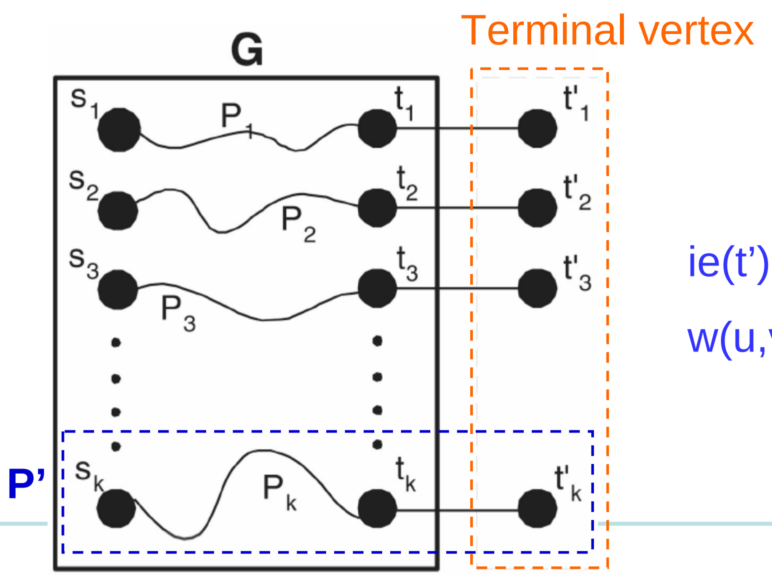
- CMAX：capacity maximization

Eliminate from G every edge (u, v) for which $ce(u) < w(u, v)$.
Change the weight of every remaining edge (u, v) to $w(u, v) * (\lambda^{\alpha(u)} - 1)$.

- Let α (u) = 1 – ce(u)/ie(u) be the fraction of u's initial energy that has been used so far.
- Let λ and σ be two constants.
- The weight of every edge (u,v) is changed from w(u,v) to w(u,v)*($\lambda^{(\alpha(u))}$ - 1).
- The shortest source-to-destination path P in the resulting graph is determined.

NP-Hardness of Maximum Lifetime Problem

- We show that the Maximum Lifetime Problem (ML) is NP-hard.
- The disjoint connecting paths (DCP) problem is known to be NP-complete.
- An instance of ML whose lifetime is k iff the answer to the given DCP instance is “yes.”
  - The answer to the given DCP instance is “yes.”
  - Network lifetime is k.



The Online Maximum Lifetime Heuristic(1)

- In the first step
  - $G' = (V,E')$ where $E' = E - \{ (u,v) | ce(u) < w(u,v) \}$
  - P_i' is the shortest path from s_i to t_i in G' using Dijkstra's algorithm.
  - If there is no such P_i', the route request fails, stop.
  - minRE = $\min\{ re(u) | u \in P_i'$ and $u \neq t_i \}$
  - $G'' = (V,E'')$ where $E'' = E' - \{ (u,v) | ce(u) - w(u,v) <$ minRE $\}$

- This pruning is an attempt to prevent the depletion of energy from sensors that are low on energy.

The Online Maximum Lifetime Heuristic(2)

- In the second step
  - eMin = min{ w(u,v)|(u,v) $\in$ E'' }
  - ρ (u,v) = 0 , if ce(u) – w(u,v) > eMin(u)

    c , otherwire

    c is a nonnegative constant
  - α (u) = minRE / ce(u)
  - w''(u,v) = (w(u,v) + ρ (u,v))($\lambda^{(\alpha(u))}$ - 1)

    λ is a nonnegative constant

- The weight assignment is done so as to balance the desire to minimize total energy consumption as well as the desire to prevent the depletion of a sensor's energy.

The Online Maximum Lifetime Heuristic(3)

- ρ , assigns a high weight to edges whose use on a routing path cause a sensor's residual energy to become low.
- All edges emanating from a sensor whose current energy is small relative to minRE are assigned a high weight because of the λ term.
- Complexity
  - OML：O(nlogn + e)
    - two shortest-path computation
  - CMAX： O(nlogn + e)
    - only one shortest-path computation
  - MPRC： O(nlogn + elogn)
    - O(logn) shortest-path computation * O(n+e) time

Distributed OML

- We may develop a hierarchical zone-based version, and each zone has a host sensor that does local routing.
- We use the limited flooding approach.
- Each node computes the shortest path to the destination and forwards the message to the next hop on this shortest path.
- With some periodicity, each sensor broadcasts its current energy level to sensors within some distant r from it.
- The distributed algorithm is augmented with loop avoidance defenses.

Evaluation(1)

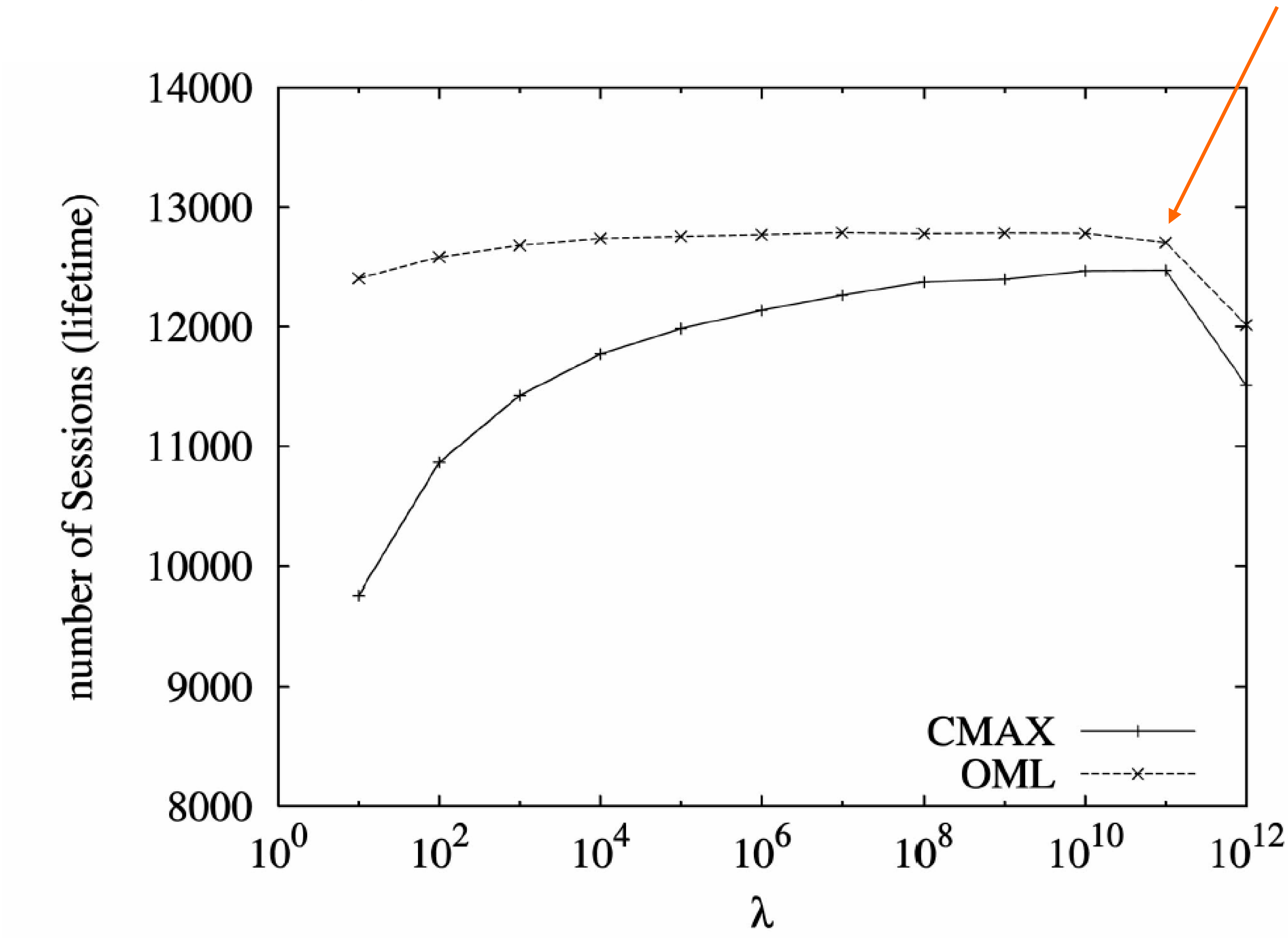
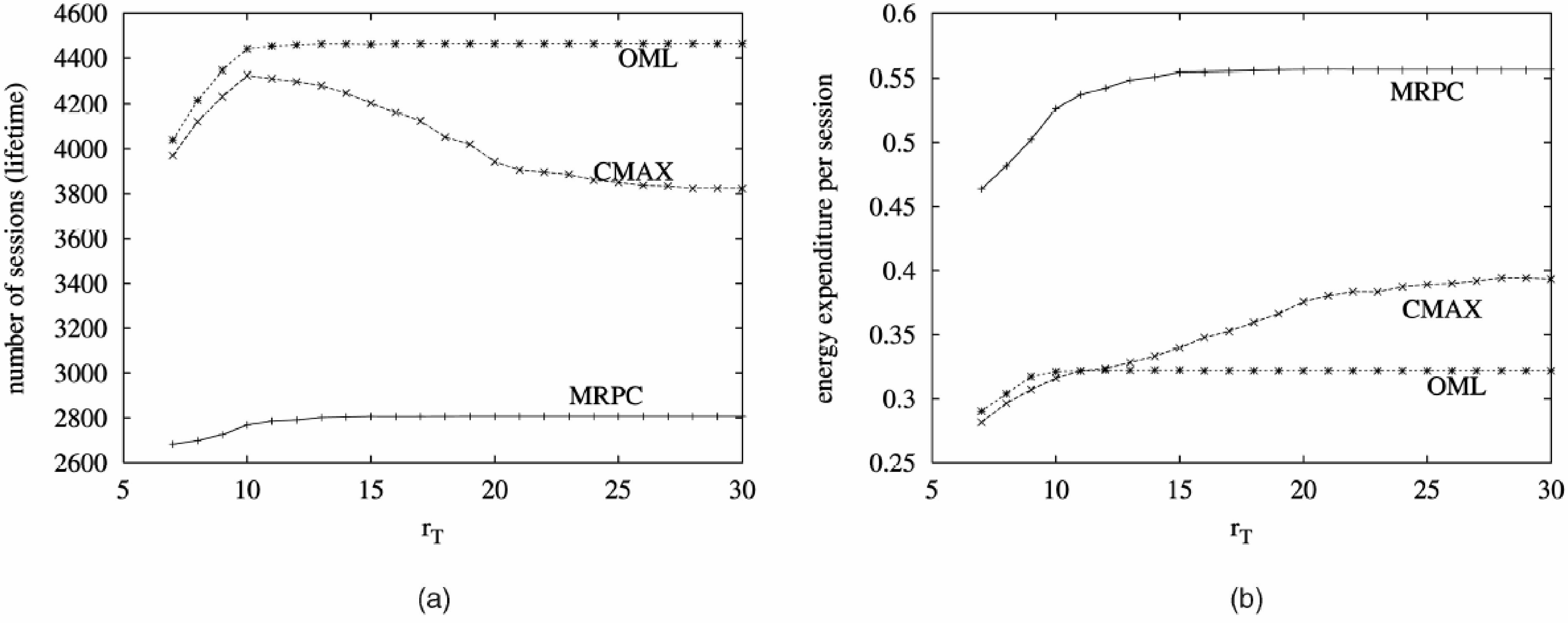


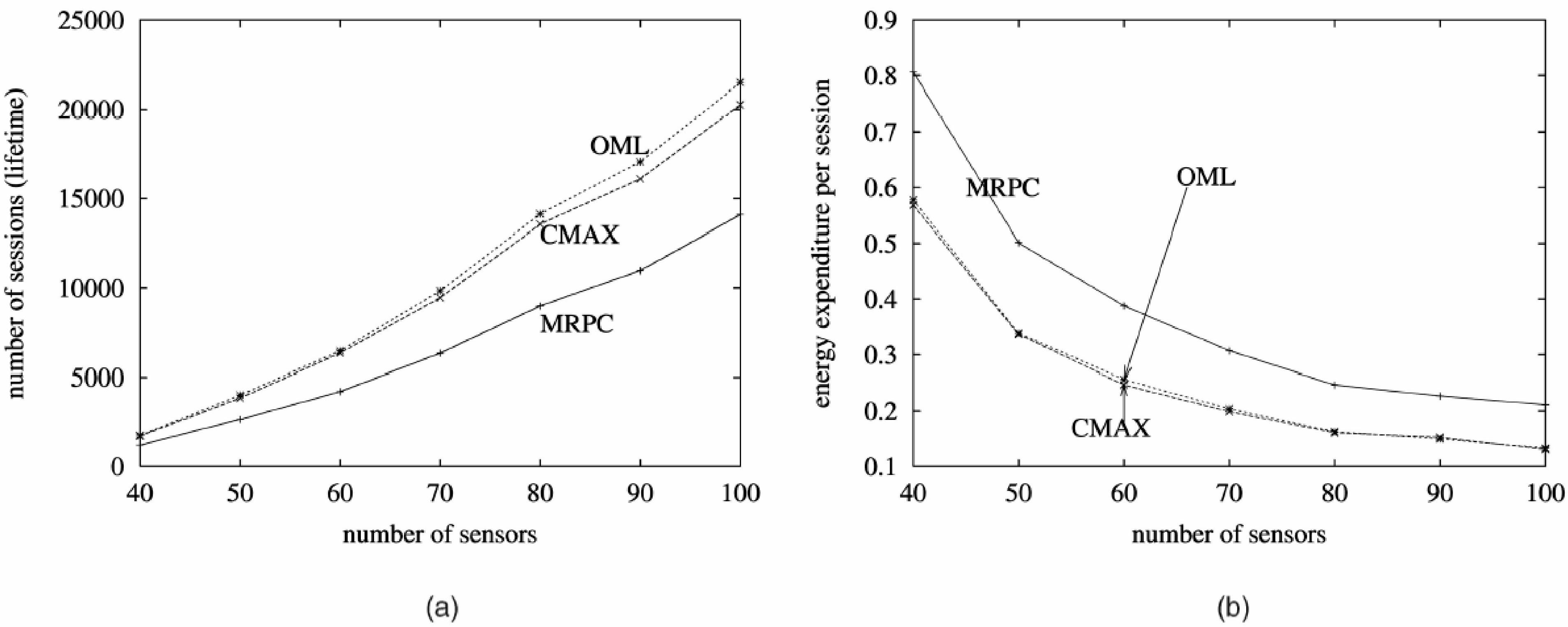
Fig. 6. Average lifetime for different λ values.

Evaluation(2)



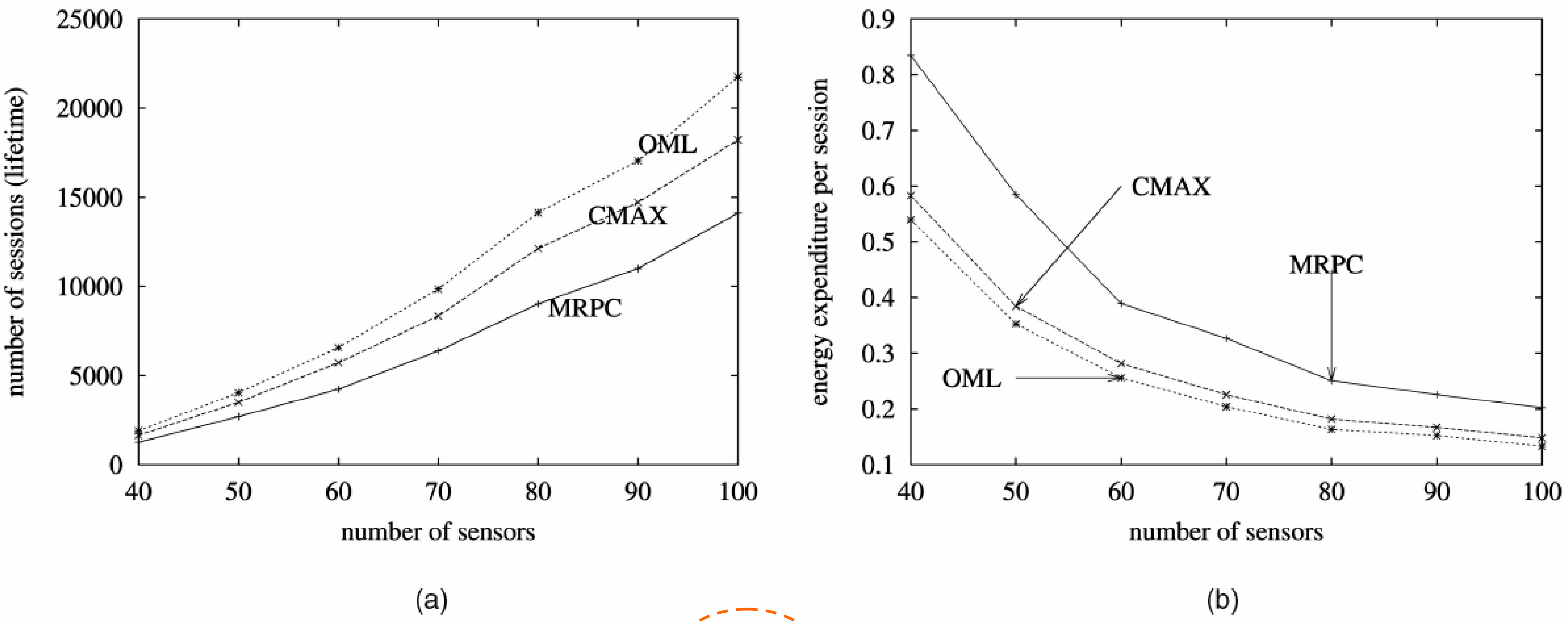
Average lifetime and energy consumption as a function of transmission radius. (a) Average lifetime. (b) Average energy per session.

Evaluation(2)



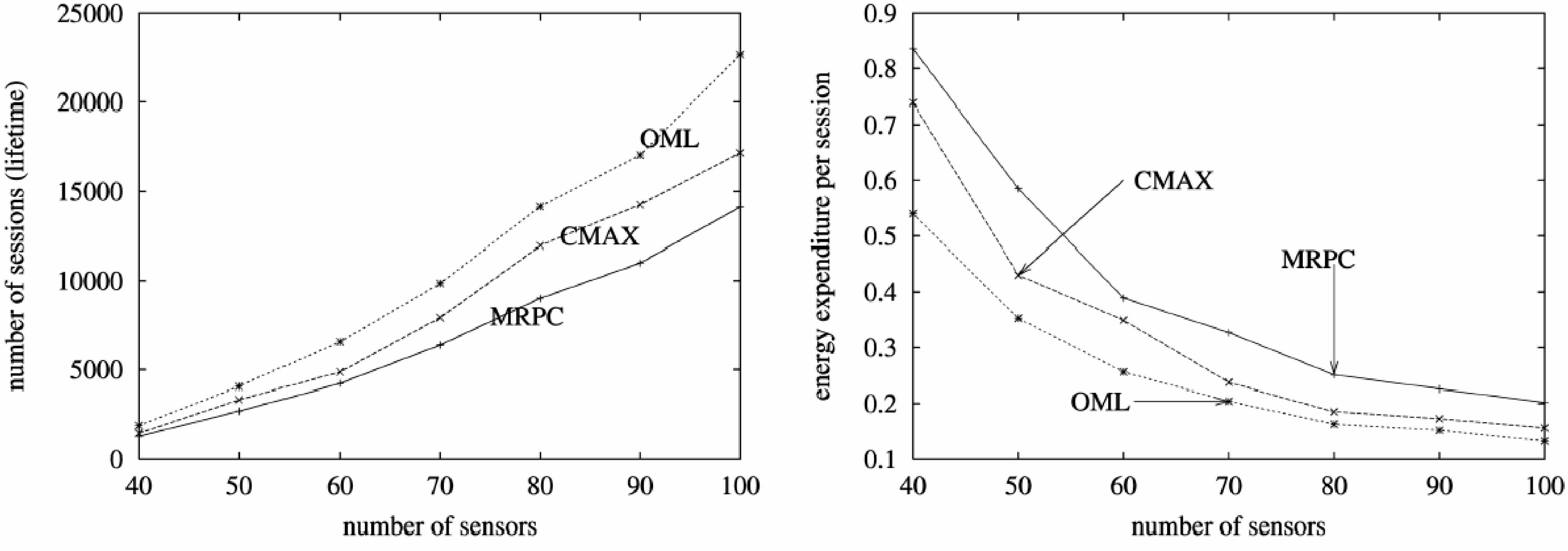
Lifetime and energy consumed as a function of n, $r_T = 10$. (a) Average lifetime. (b) Average energy per session.

Evaluation(3)



Lifetime and energy consumed as a function of n, $r_T = 20$. (a) Average lifetime. (b) Average energy per session.

Evaluation(4)



(a) (b)

Lifetime and energy consumed as a function of n, $r_T = 30$. (a) Average lifetime. (b) Average energy consumed per session.

Conclusion

- We have shown that the lifetime maximization problem is NP-hard.
- We have also proposed a new online heuristic-OML for lifetime maximization.
- The superior performance of OML is due to its making a conscious effort to balance the desire to minimize total energy consumption as well as the desire to prevent the depletion of a sensor's energy.