Combs, Needles, Haystacks: Balancing Push and Pull for Discovery in Large-Scale Sensor Networks

X. Liu, Q. Huang and Y. Zhang

SenSys 2004

Outline

- Introduction
- Comb-Needle Discovery support model
- Simulation
- Reliability
- Adaptive comb-needle Strategy
- Conclusion and Discussion

Introduction

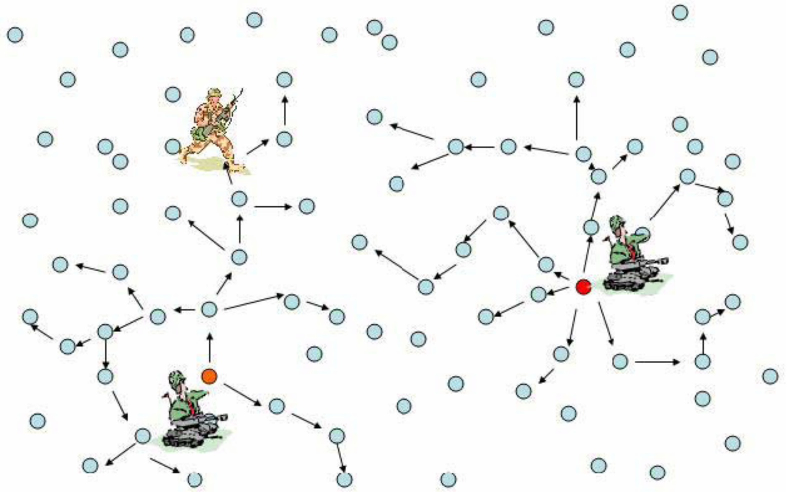
- Many emerging sensor network applications involve dissemination of observed information to interested clients.
  - Fire emergency system
  - Ecological environment observation
  - Battlefield monitoring

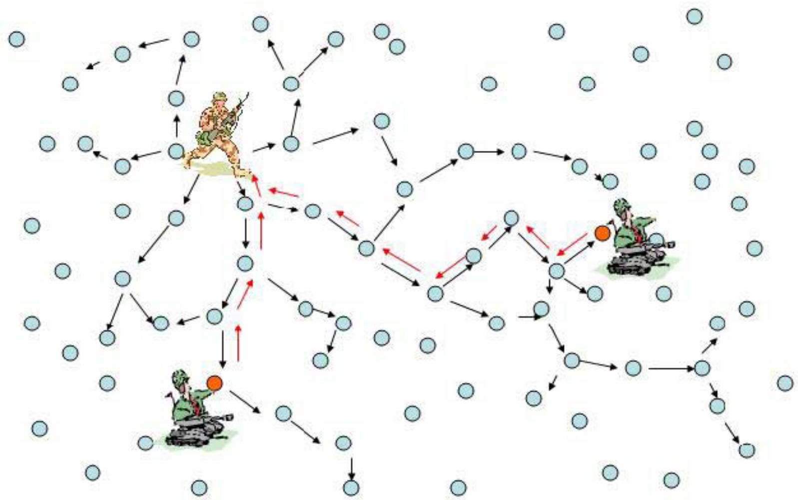
Introduction

- Flooding is a simplest method for obtaining data from a large scale sensor network.
  - Large cost
- Many strategies have been proposed to reduce the cost of discovery and query in large scale sensor network.
  - Improve flooding efficiency
  - Reduce discovery/query cost by taking into account application semantics
  - Reduce search cost by using distributed indexing scheme

Introduction

- (Push-based) Sensor nodes push the sensed information throughout the network.
- (Pull-based) The soldier broadcast a query for the information when it is needed.



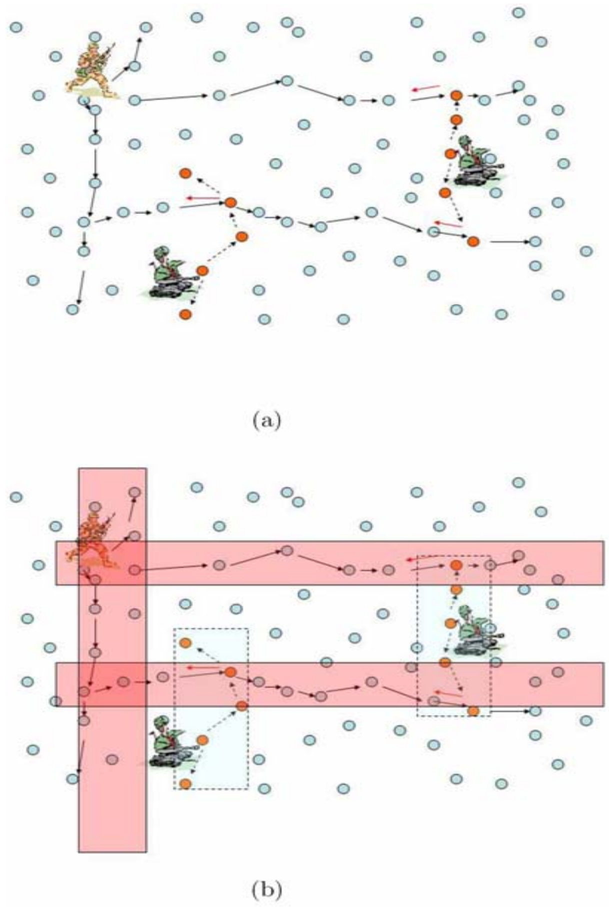


Introduction

- Goal
  - To investigate efficient and reliable routing mechanisms for supporting queries in large scale ad hoc wireless sensor networks.
- This paper intend to combine the advantages of both push and pull strategies and build an efficient query-support mechanism that adapts to the frequencies of query and events

Comb-Needle Discovery support model

- Each sensor node pushes its data to a certain neighborhood and the query is disseminated only to a subset of the network.
  - The query process builds a routing structure dynamically that resembles a comb.
  - The sensor nodes push the data duplication structure like a needle.



Comb-Needle Discovery support model

- The principle of the comb-needle structure:
  - Adjust the communication strategy based on the frequency of the query and events.
- Assuming that events and discovery queries occur uniformly in space and time across the sensor network.
  - f_q: the arrival frequency of discovery queries.
  - f_e: the arrival frequency of relevant events.

Comb-Needle Discovery support model

- Compute the minimum push/pull cost
  - Each node sends its data push to 2l of its vertical neighbors.
    - Data push cost: $C_l \sim 2l$
  - The query process first sends the query vertically then fans out horizontally.
    - Query dissemination cost:

$$C_{qd} = n - 1 + (n-1)(\lfloor \frac{n-1}{s} \rfloor + 1)$$

Comb-Needle Discovery support model

- Compute the minimum push/pull cost
  - The total cost per query:

$$\begin{aligned} C &= C_{qd} + C_{qr} + f_e * C_l / f_q \\ &\simeq C_{qr} + 2(n-1) + \frac{(n-1)^2}{s} + s * \frac{f_e}{f_q} \\ &\geq C_{qr} + 2(n-1) + 2(n-1)\sqrt{\frac{f_e}{f_q}} \end{aligned}$$

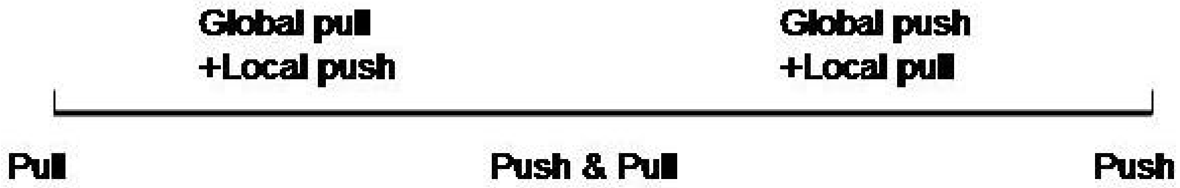
  - This minimum of the cost is around

$$s_{optimal} \sim (n-1)\sqrt{\frac{f_q}{f_e}} \sim \sqrt{N}\sqrt{\frac{f_q}{f_e}}$$

  - The query cost is reduced to $O(\sqrt{N})$

Comb-Needle Discovery support model

- The proposed model can cover the whole spectrum of the push and pull strategies.
  - $f_q < f_e$: the global-pull-local push model
  - $f_q = f_e$: special push-pull strategy
  - $f_q > f_e$: reverse combing



Comb-Needle Discovery support model

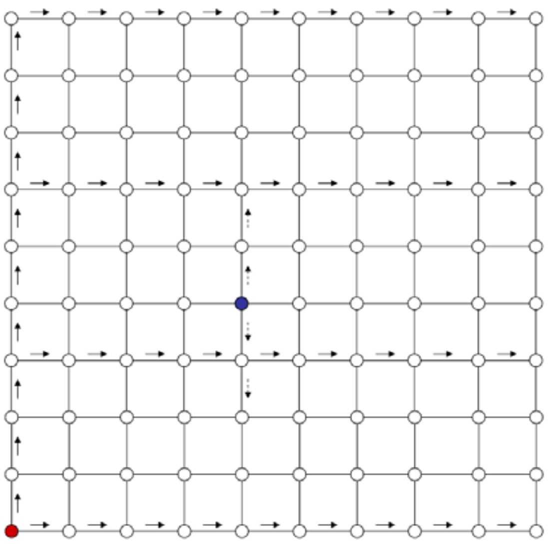


Figure 5: Combing

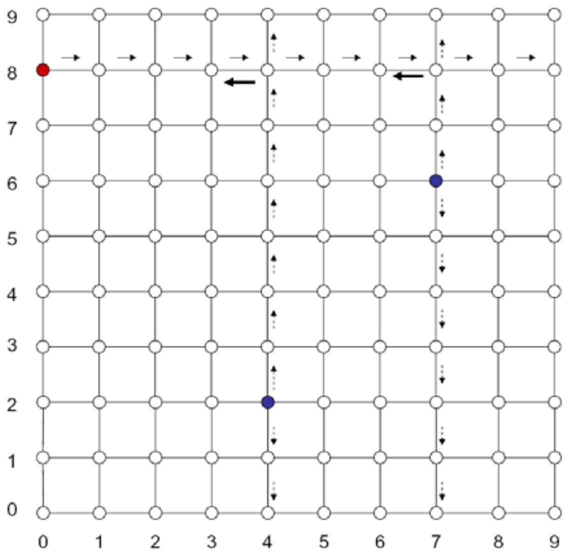


Figure 4: A Special Push-Pull Strategy

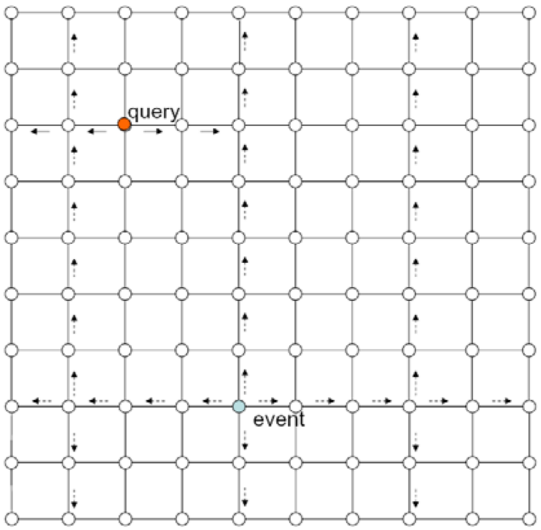


Figure 6: Reverse comb

Simulation

- The simulation environment:
  - Radio propagation Model

$$P_{rec,ideal}(d) \leftarrow P_{transmit}\frac{1}{1+d^{\gamma}}, \quad where\ 2 \leq \gamma \leq 4$$

$$P_{rec}(i,j) \leftarrow P_{rec,ideal}(d_{i,j})(1+\alpha(i,j))(1+\beta(t))$$

  - Topology Model
    - Random grid topology
  - Routing Protocol
    - Constrained Geographical Flooding (CGF)
    - Define CFG width (*w*), inter-spike distance (*s*), and the needle push length(*l*)

Simulation

- Given query rate and event rate, what is the best spacing for the comb.
  - $f_q = 0.1$p/s $f_e = 1$p/s
  - $f_q = 0.1$p/s $f_e = 0.1$p/s

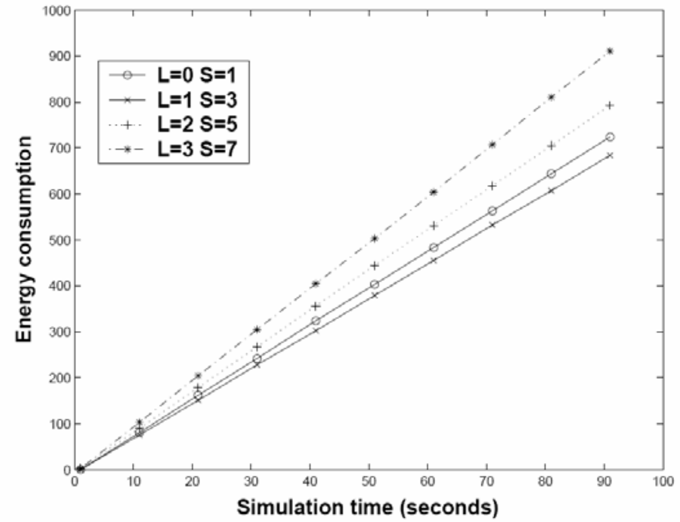


Figure 10: Energy consumption: $f_q = 0.1$, $f_e = 1$

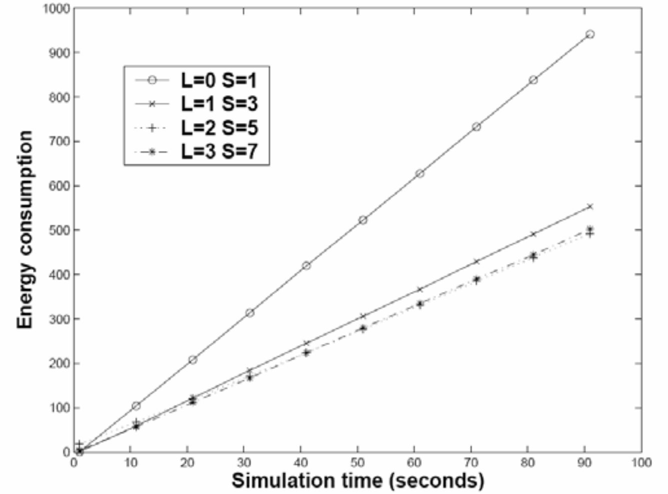


Figure 11: Energy consumption: $f_q = 0.1$, $f_e = 0.1$

Simulation

- Showing the robustness of the protocol with a varying query (CGF) width
  - f_q = 0.1p/s, f_e = 1p/s
  - l=1, s =3

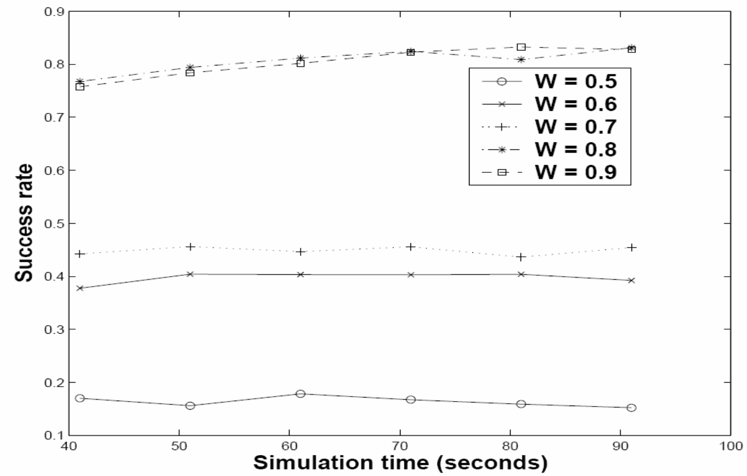


Figure 12: Success rate for different query widths

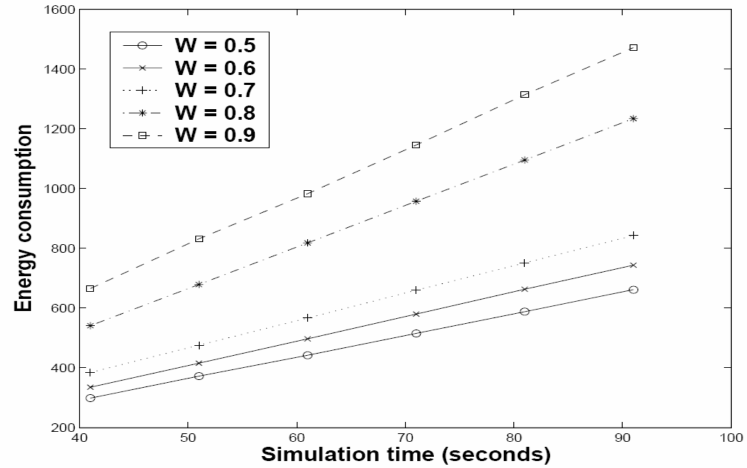


Figure 13: Energy consumption for different query widths

Reliability

- Wireless links are unreliable due to the nature of wireless communications.
- This paper study some reliable query and report strategies.
  - Local re-enhancement
    - Use interleaving paths
    - Redundancy scheme
  - Spacial redundancy

Reliability

- Spacial redundancy
  - Constructing an additional vertical query propagation path (level-2 redundancy)
  - Extending the needle length to *2s*
    - Called 2-level redundancy scheme
    - each report can reach two nodes that are on the query propagation path.

Reliability

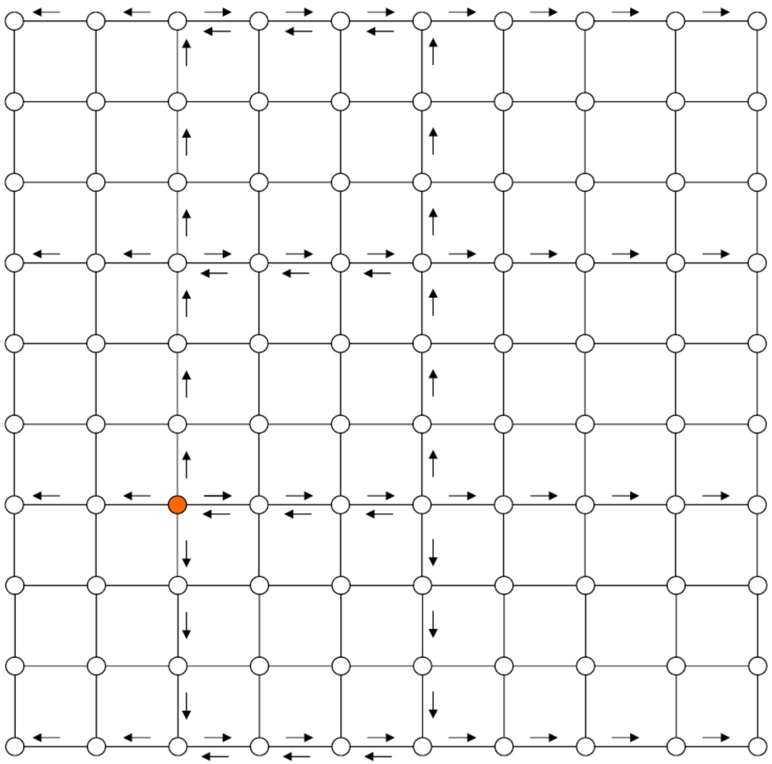


Figure 15: level-2 redundancy

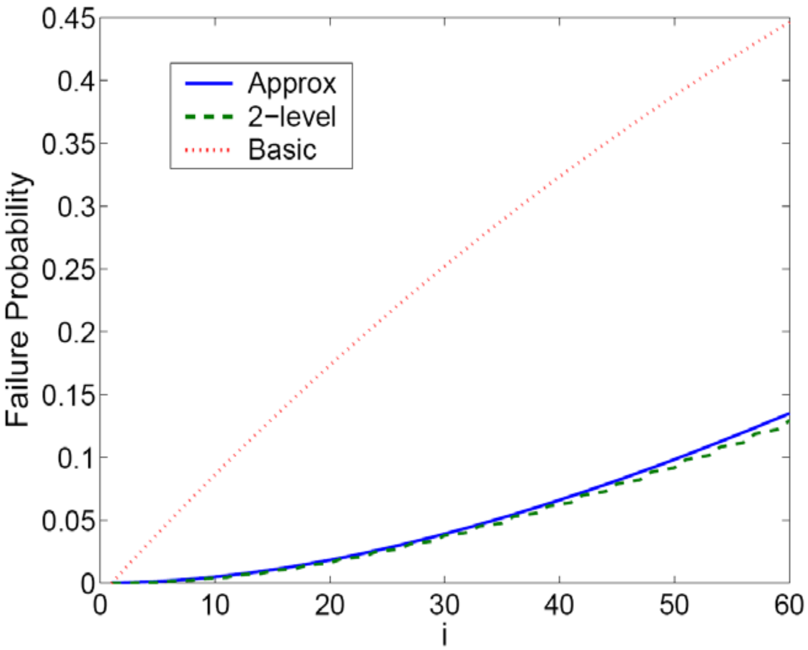


Figure 16: Compare the difference between the calculation and approximation.

Adaptive comb-needle Strategy

- In practice, the query and event frequencies may be time-varying, and thus a good query strategy should adapt to such changes.
- Based on the estimate of f_q and f_d, the query node calculates s.
  - f_d : the probability that a query in generated in a time slot

$$f_d = \frac{f_e}{n^2} \qquad s_{optimal} \sim \sqrt{\frac{f_q}{f_d}}.$$

Adaptive comb-needle Strategy

- Data node estimates the total needle length L by using the query success probability.

$$P_s = P(L \geq s) + E\left(\frac{L}{s} | L < s\right) P(L < s)$$
$$= E\left(\min\left(\frac{L}{s}, 1\right)\right).$$

- Since the value of f_d is small, the value of s obtain form previous queries are important for estimating L.
  - Obtaining s when its data is successfully queried
  - Rotation of the query horizontal duplications

Adaptive comb-needle Strategy

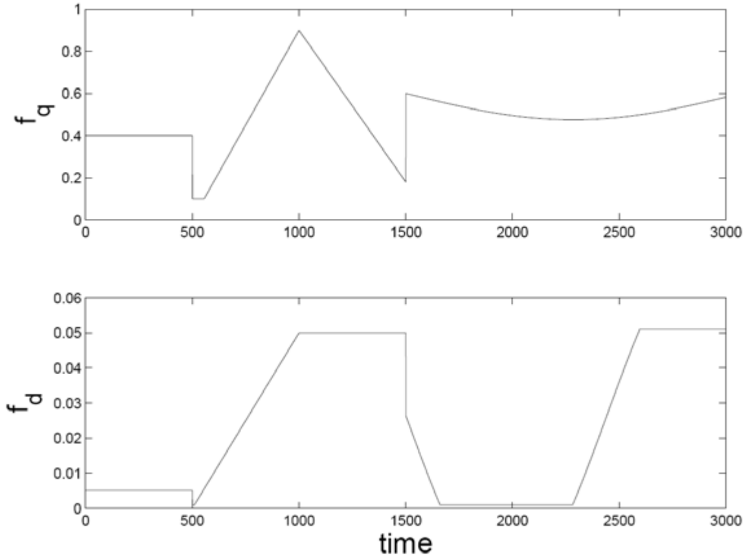


Figure 17: The query frequency and the event frequency.

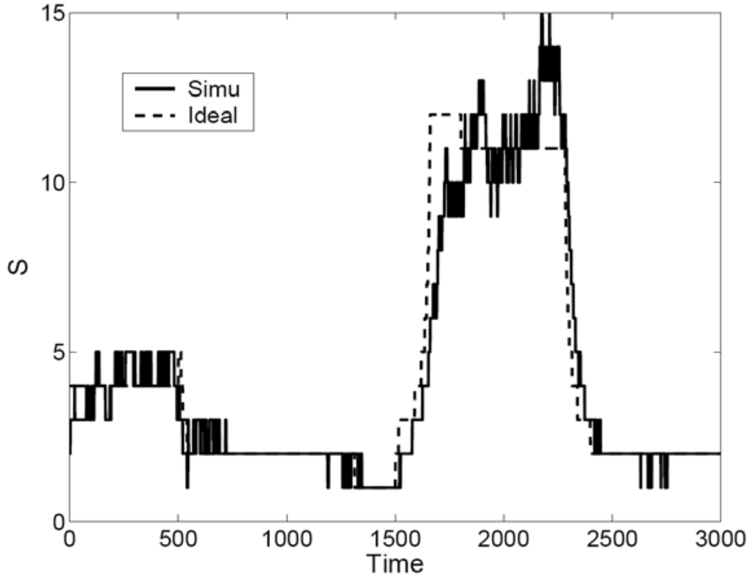


Figure 18: The ideal comb width and the estimated comb width.

Conclusion and Discussion

- This paper proposed the comb-needle model for supporting queries in large scale sensor networks.
- Some enhancement of the reliable schemes have proposed.
- An adaptive comb-needle Strategy have proposed for the query and event frequencies time-varying environment.
- The total cost is reduced to $O(\sqrt{N})$