Local Monitoring and Maintenance for Operational Wireless Sensor Networks

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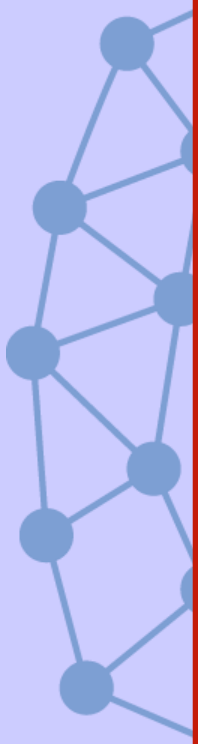
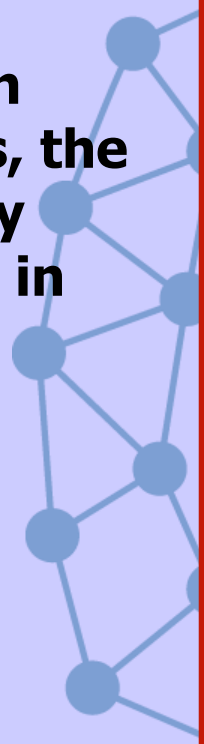
Outline

- Motivation
- Our Approach (LoMoM)
- Two-part Monitoring Architecture
- Local Monitoring and Maintenance
- Evaluation
- Conclusions

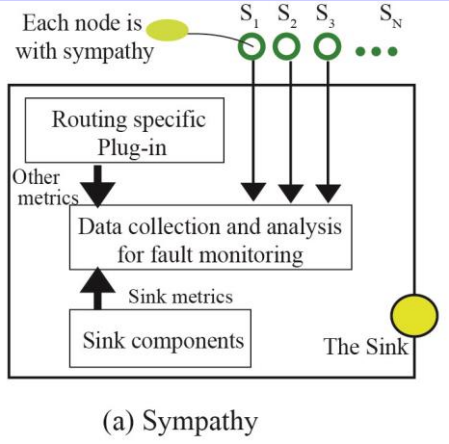


Motivation

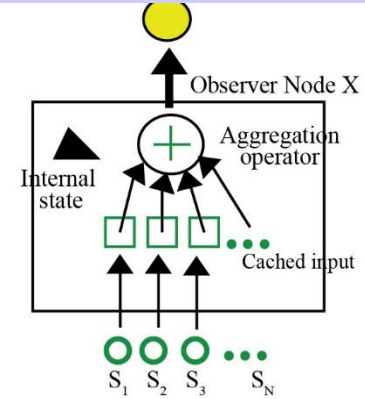
- **Wireless sensor networks are increasingly being designed and deployed for event monitoring and surveillance applications.**
  - **The single most important mechanism underlying such systems is the monitoring of the network itself, that is, the monitoring/control center (MC) needs to be constantly made aware of the existence/health of all the sensors in the network.**
    - **Fault monitoring: detection and localization**
    - **Fault removal/avoidance/recovery**



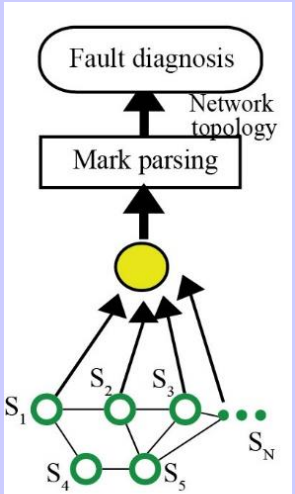
Difficulties in Existing Solutions



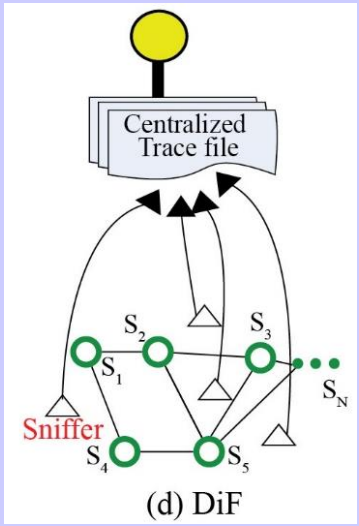
(a) Sympathy



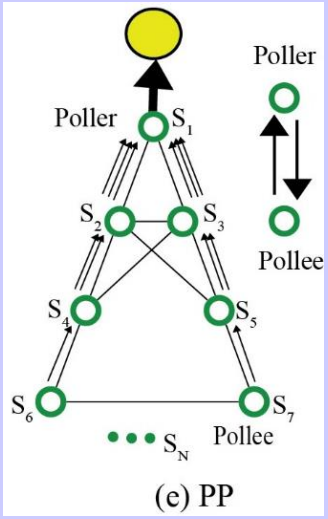
(b) Memento



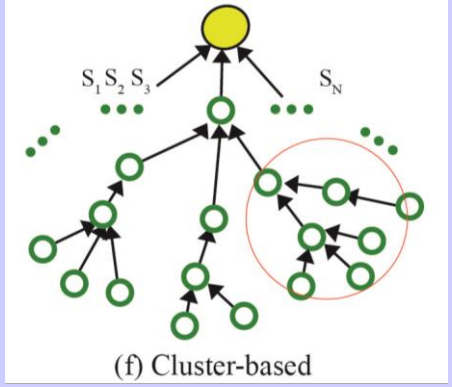
(c) PAD



(d) DiF



(e) PP

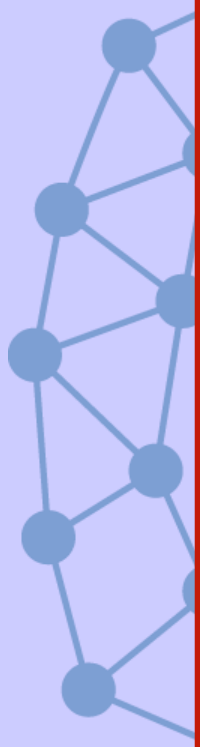


(f) Cluster-based

[1] N. Ramanathan et al. Sympathy for the sensor network debugger, in SenSys'05.
[2] S. Rost et al. Memento: A health monitoring system for wireless sensor networks, in SECON'06.
[3] Y. Liu at al, Passive Diagnosis for Wireless Sensor Networks, ToN, 2010.
[4] D. Yu et al. DiF: A diagnosis framework for wireless sensor networks, in INFOCOM'10
[5] C. Liu et all. Distributed monitoring and aggregation in wireless sensor networks, in INFOCOM'10.
[6] S. Tati et al. netCSI: A Generic Fault Diagnosis Algorithm for Large-Scale Failures in Computer Networks, SRDS'11

Difficulties in Existing Solutions

- **Many are centralized**
  - **The sink is responsible for fault monitoring**
    - **It actively sends requests to the network for retrieving states of the network**
- **Some are partially distributed**
    - **Add-on modules, evaluation tools, etc.**
    - **Need extra hardware for node monitoring**
  - **Pros: Accurate**
  - **Cons: Too much energy consumption, poor scalability, message implosion, not real-time.**



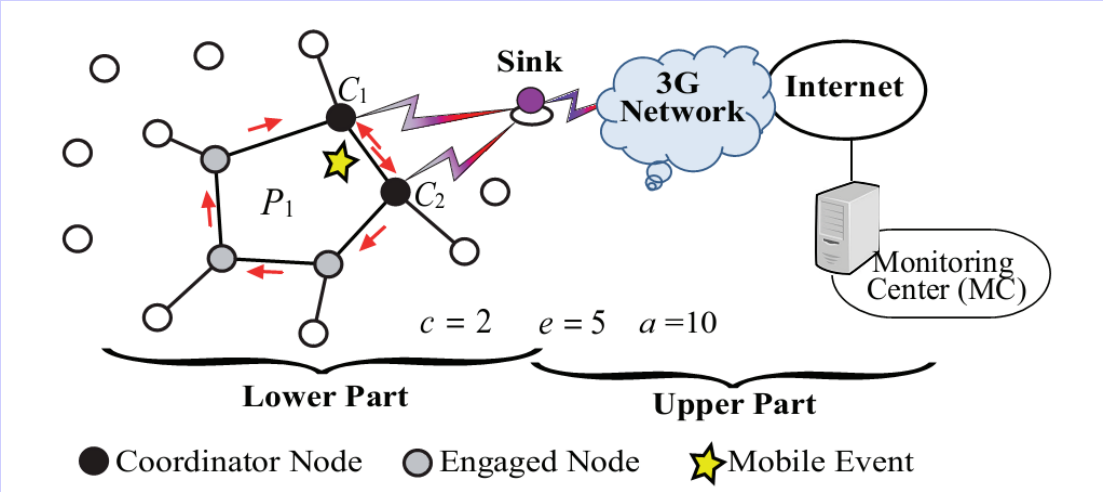
More Importantly

- **Those approaches are not feasible in practice for a large scale resource-constrained WSN**
  - **First, they require a large number of active nodes for the monitoring function.**
  - **Second, the monitoring function is carried out separately, which should be, arguably, performed in conjunction with the normal operation of an application.**
  - **Third, monitoring link behaviors are not seriously focused.**
  - **Fourth, it is commonly assumed to deploy a PC close to the sink; it is, however, infeasible in practice**

Need a fully distributed approach

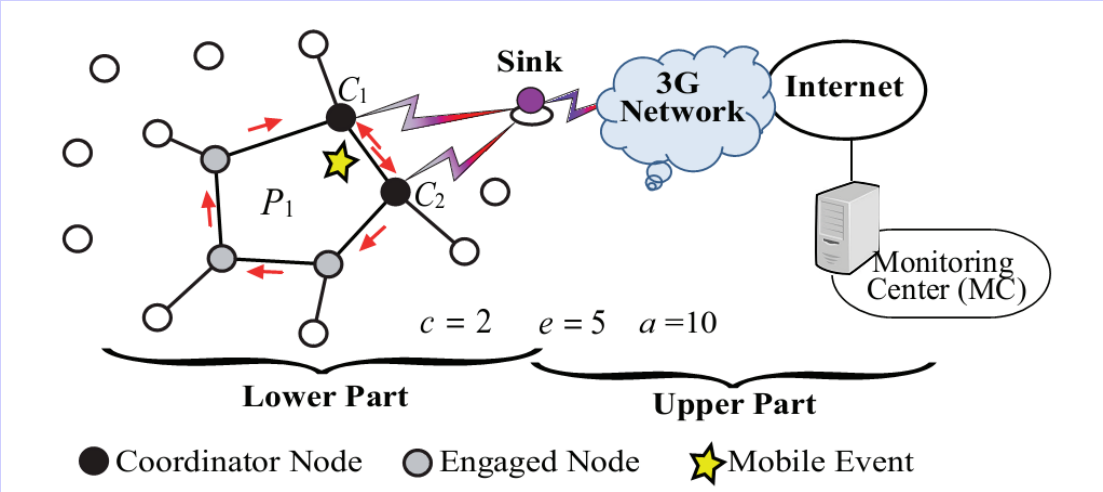
Our Approach: LoMoM

- **Local Monitoring and Maintenance for a WSN**
  - **It performs monitoring operations, together with the operations of a mobile event monitoring application.**
    - **Suppose that a subset E_i of engaged nodes, which are engaged in detecting an event of interest as it appears in a region P_i of the WSN, will monitor themselves (node/link failure, node faults, H/S/W faults, application flaws, etc.).**



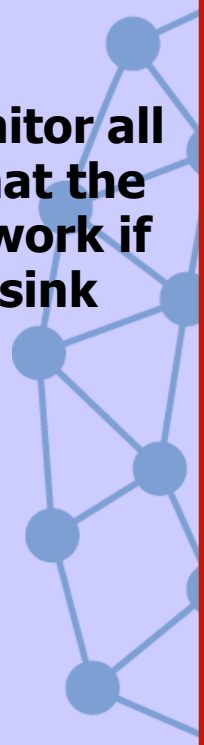
Our Approach: LoMoM

- **Local Monitoring and Maintenance for a WSN**
  - **It performs monitoring operations, together with the operations of a mobile event monitoring application.**
    - **A small subset C_i (of two or more nodes) from E_i, which has higher detection probability are called coordinators that collected both the event and node monitoring status. They repair the faults locally, also report to the sink if needed**



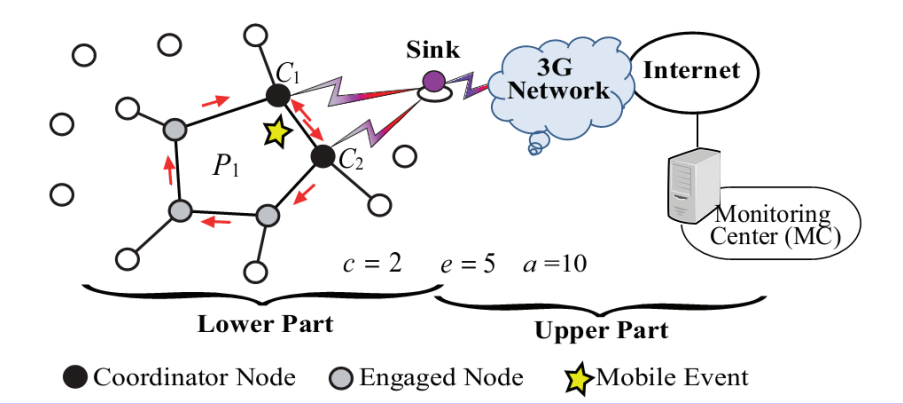
The Problem

- **Given**:
  - A resource-constrainted WSN with N identical nodes, a sink, a MC (located at a remote placed)
- **Find**:
  - **Coordinators** (C_i) from the engaged nodes (E_i) that monitor all the engaged nodes and themselves and the links such that the coordinator gather monitoring status and repair the network if there is any fault status and reports to the sink, and the sink then reports to the MC.
- **Objectives**:
  - Reducing the false alarm rate, $F_c(h, T_d)$
  - Reducing the detection latency
  - Increasing lifetime, $T = w_r / w_m$



Monitoring Architecture

- **Two-part monitoring architecture**
  - **Lower part is the WSN**
    - **It is built on planar graphs. We apply related neighborhood graph (RNG) for our purpose [7-11]. A connected planar subgraph $G' \subseteq G$ is achieved without crossing edges, is neither unidirectional nor disconnected.**
  - **Each subgraph contain one or more polygonal regions (faces in face routing techniques) [7-11]**



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[8] J. Cartigny et al. "Localized LMST and RNG based minimum-energy broadcast protocols in Ad Hoc networks," in Ad hoc Networks (Elsevier)
[9] Y.-J. Kim, R. Govindan, B. Karp, and S. Shenker, "Lazy cross-link removal for geographic routing," in Proc. of ACM SenSys, 2006.
[10] M. Welsh and G. Mainland, "Programming sensor networks using abstract regions," in Proc. of USENIX NSDI, 2004.
[11] G. Toussaint, "The relative neighborhood graph of finite planarset," Pattern Recognition, vol. 12, no. 4, pp. 261–268, 1980.

Monitoring Architecture

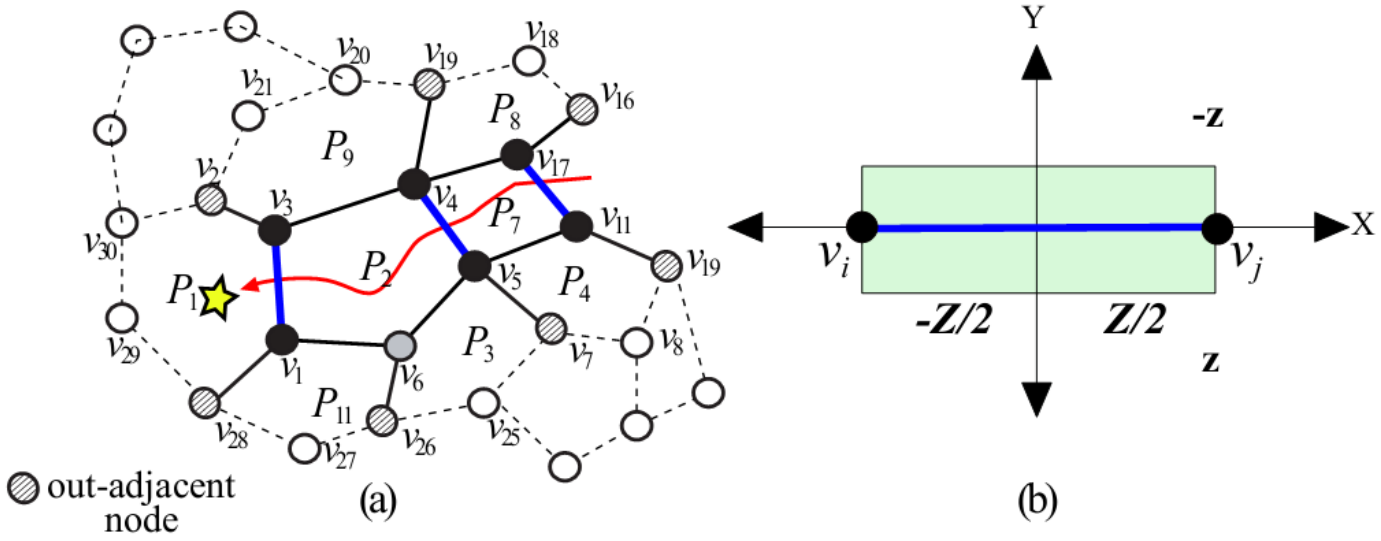


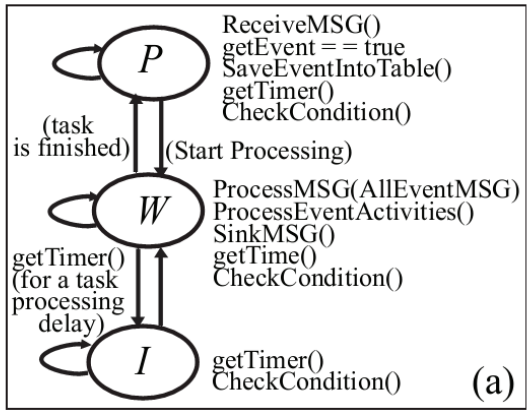
Fig. 2. Planarization techniques: a planar graph decomposed by polygons, showing the connected nodes and the edges between them that are associated to P_2; (a) event detection in a rectangular spot; (b) the entry of an event into P_i; both P_i and its edge intersection leaves a trail of edges.

- **Edge Intersection Probability**
  - **It is computed as an event goes across the common edge between P_i and P_j**

Local Monitoring: Node Self-Monitoring

- **We trace the faulty reasons by characterizing their fault patterns.**
  - **Generally, a node usually has different modes of operation (e.g., active, waking, and sleeping).**

>We divide the active mode into three consecutive process states.
>Each such process state consists of a lot of components.
This node can be monitored by the monitoring of its component run-time behaviors (e.g.,"1" for a successful run)



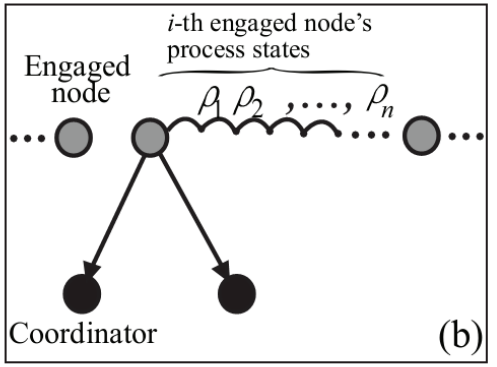
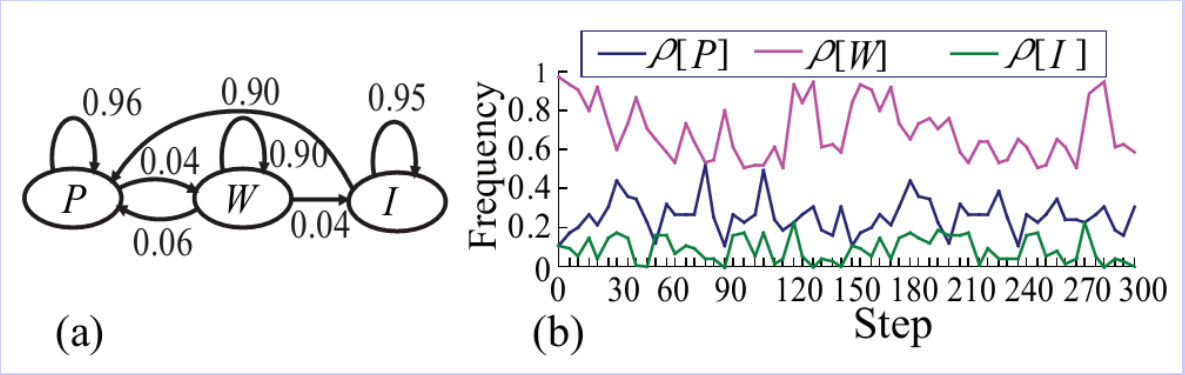


Fig. 3. (a) Some event detection tasks in the three process states, including the *CheckCondition()* function; (b) a finite set of processes of such a state, as long as an event exists.

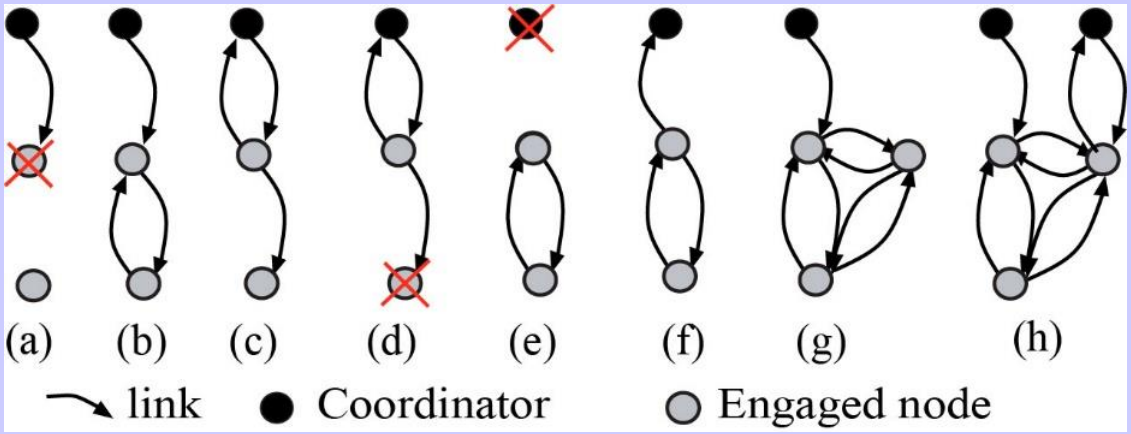
Local Monitoring: Node Self-Monitoring

- The process state automation is modeled as a DMC (discrete time semi-Markov chain), by which, a node estimates the fault detection probability ($\beta = \Lambda, Q$).
  - Node status-- An engaged node $v_i \in E_i$ is said to be faulty if at least a process state of v_i is altered and the node transmits inconsistent values., In such a case, $\beta \leq 0.5$



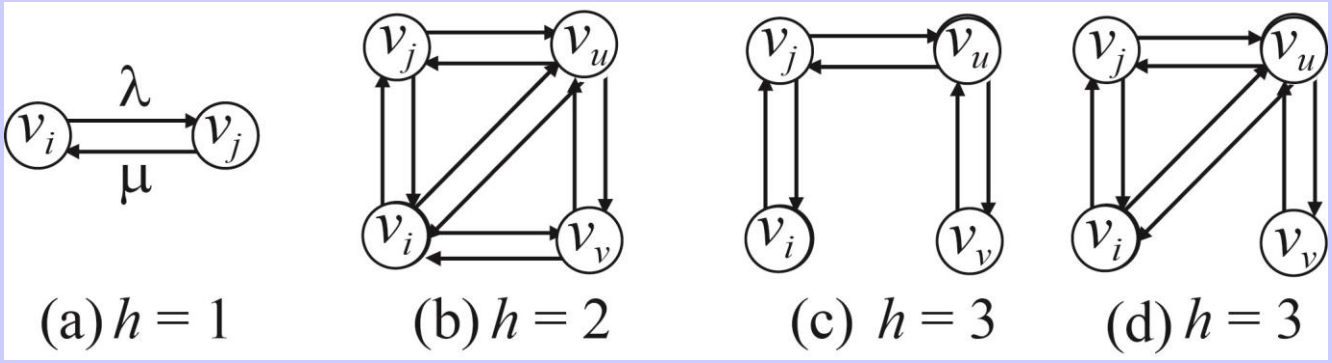
Local Monitoring: Link Monitoring

- **Link failure:**
  - **A node itself may fail before a report transmission.**
  - **A node may transmit the report, but there is an incident of consecutive report packet loss.**
  - **A node is unreachable (the coordinators or the sink does not receive the status in a given time bound).**



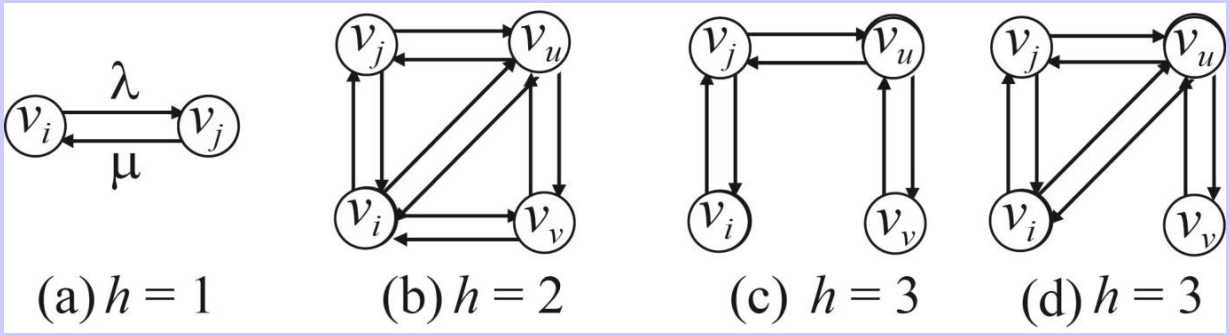
Local Monitoring: Link Monitoring

- **Techniques:**
  - **We apply CMC (Continuous-time Markov Chain) technique.**
    - **Each link is a part of a chain between two nodes. Each coordinator has the start and the end of the chain of links.**
    - **Each node also individually monitors the links to its 1-hop neighbors, including the all adjacent neighbors in a *Pi*.**
  - **State transition:**



Local Monitoring: Link Monitoring

- We assign a transition status for each chain between node v_i to v_j, and node v_j to v_i, respectively.
  - For a single hop communication, "1" is for a direct successful chain from v_i to v_j and "1" is for v_j to v_i, otherwise, it is "0".
  - For a two-hop communication, "11" is for a successful chain from v_i to v_j; otherwise, it is "01" or "10" for a broken link.
  - The link failure detection probability $\alpha = \mu(\lambda + \mu)^{-1}$ is set to calculate the false alarm rate $F_c(h, T_d)$.



Local Maintenance

- **LoMoM is adaptive to network dynamics, and supports local maintenance as a link/node fault occurs.**

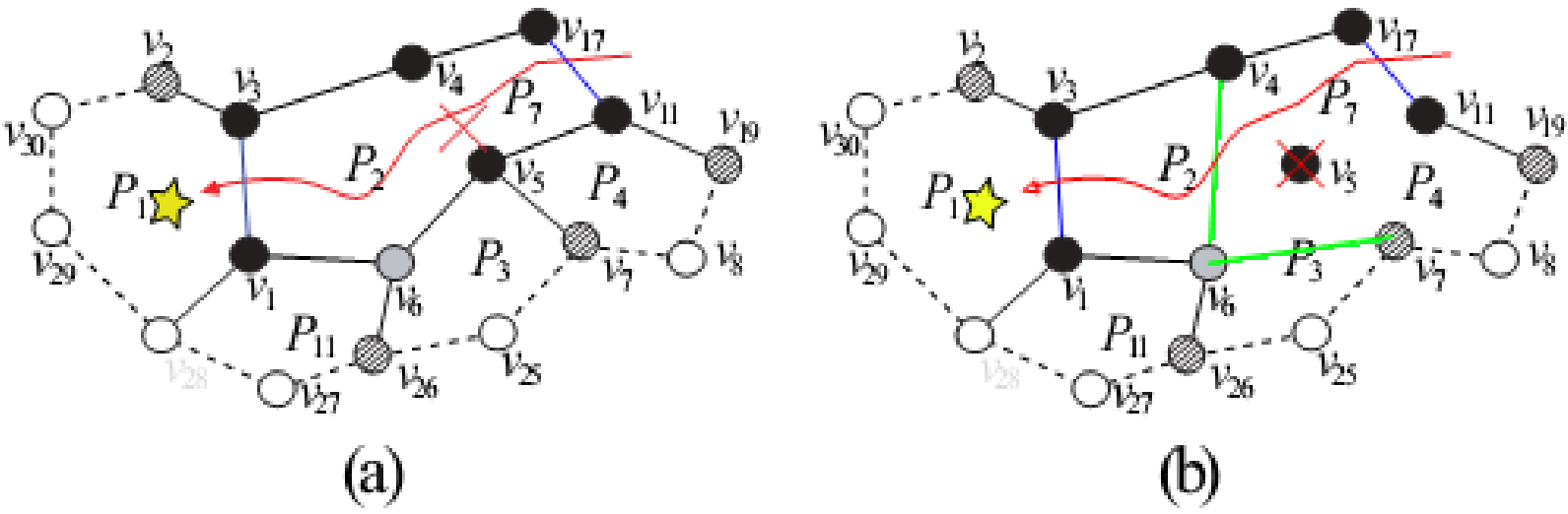


Fig. 5. An example of the local maintenance: single link failure; (b) single node failure.

Evaluation

- **Simulations are performed with OmNet++ platform in two scenarios**
  - **Scenario I and Scenario II are comprised of 200 nodes and 800 nodes that are randomly distributed in 2D planar fields of 200m*200m for Scenario I and 800m * 800m for Scenario II, respectively.**
    - **We inject different types of faults (up to 20% of the nodes) randomly into the WSN. This invalidates the sensing and radio capabilities of 10% (5%+5%) of the nodes, and provides minimum power to 10% of the nodes so that they fail during runtime.**
  - **More schemes are implemented: Memento, PP (poller-pollee), and DiMo (distributed monitoring), which are proposed only for monitoring WSNs.**

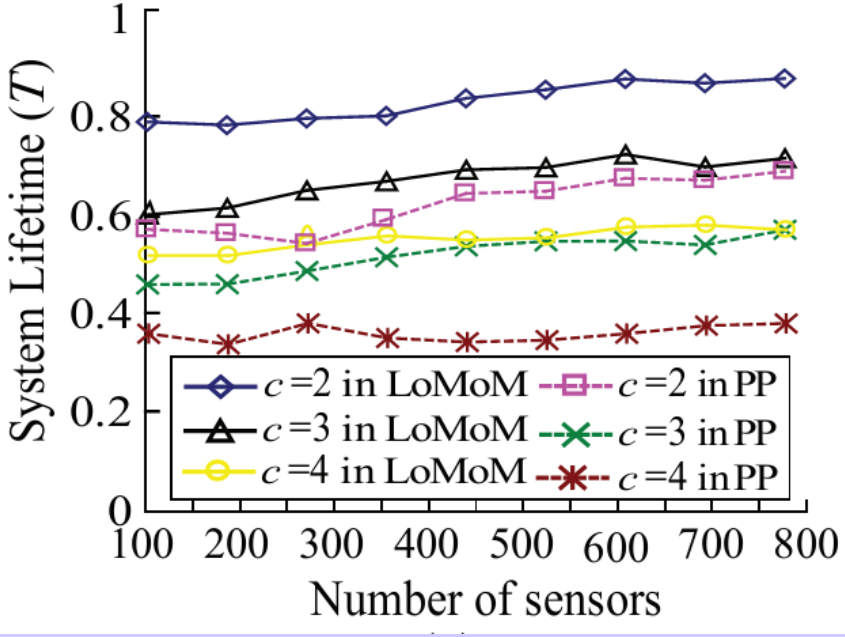
Results (1)

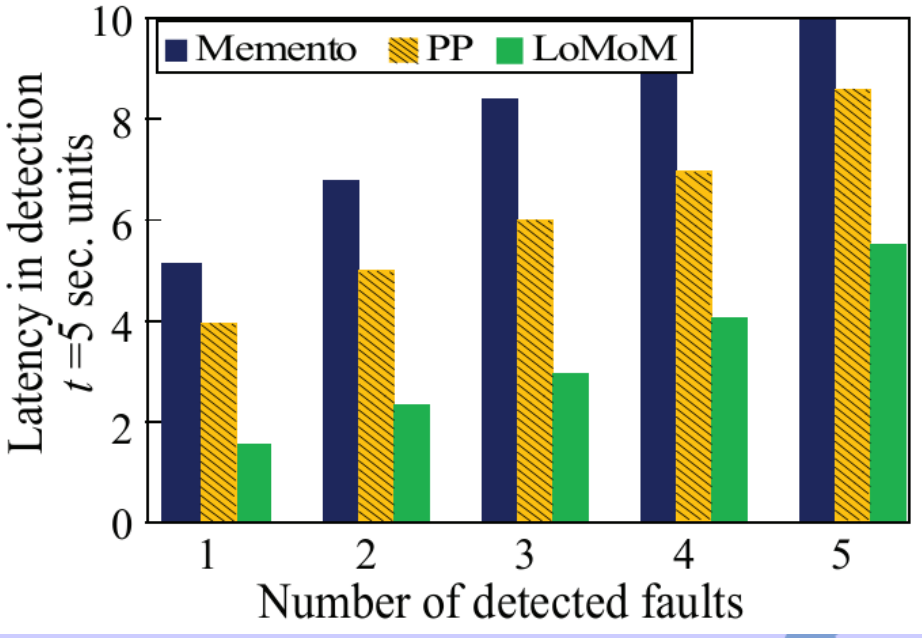
TABLE I

$F_c(h, T_d)$, h = 3 TO 5, DIFFERENT PPRS

PRR	80%	85%	90%	95%	98%
PP	0.061	0.041	0.0288	0.02	0.012
DiMo	0.113	0.091	0.071	0.05	–
Memento	0.151	0.122	0.107	0.071	–
LoMoM-C	0.043	0.029	0.019	0.011	0.007
LoMoM	0.025	0.017	0.009	0.006	0.004

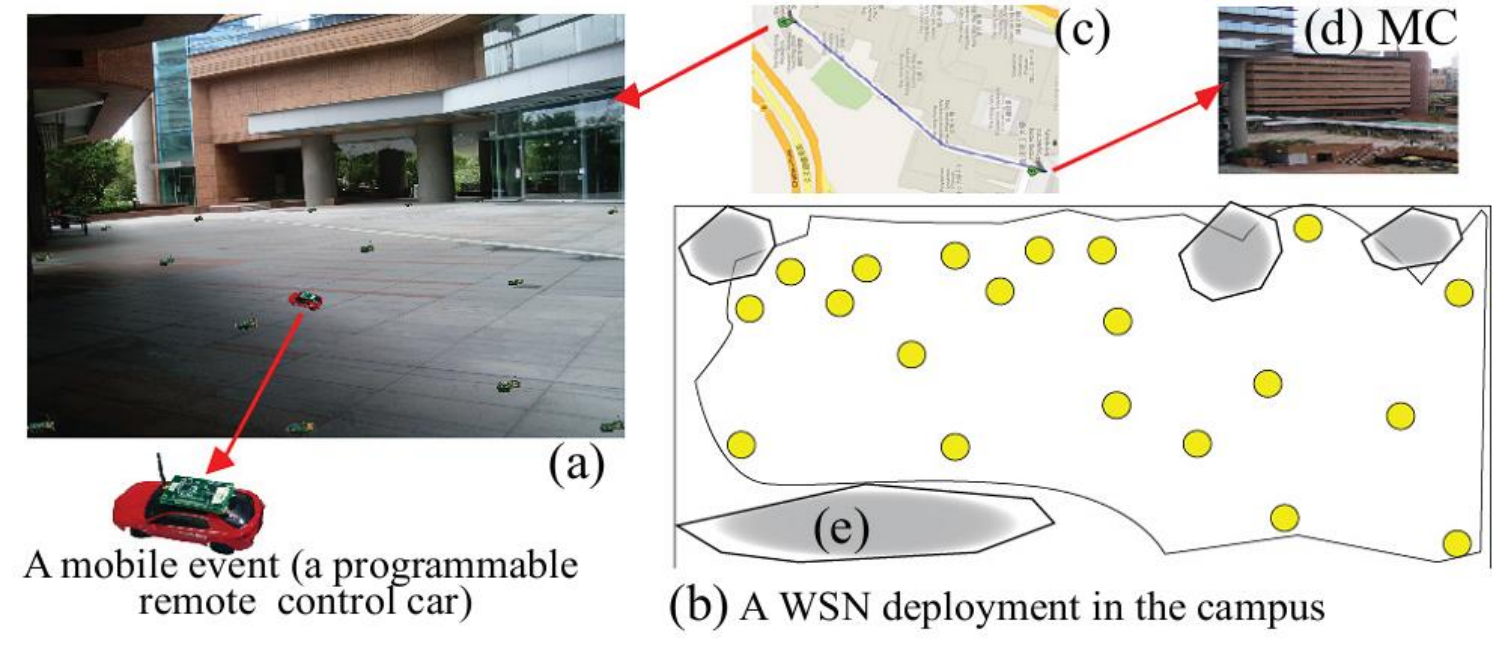
Results (2)


System Lifetime (T)
1
0.8
0.6
0.4
0.2
0
100 200 300 400 500 600 700 800
Number of sensors
c =2 in LoMoM
c =2 in PP
c =3 in LoMoM
c =3 in PP
c =4 in LoMoM
c =4 in PP

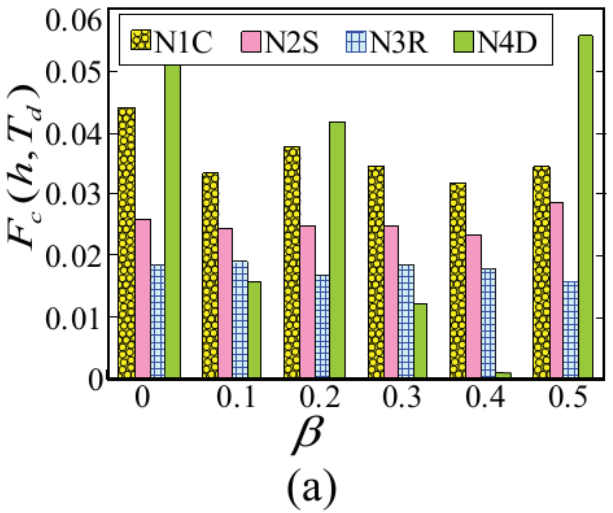

Latency in detection
t =5 sec. units
10
8
6
4
2
0
Memento
PP
LoMoM
1 2 3 4 5
Number of detected faults

Real Implementation

- A proof-of-concept system is implemented using the TinyOS on Imote2 sensor platforms.
  - We deploy 20 Imote2, plus 1 sink Imote2.



Result (3)



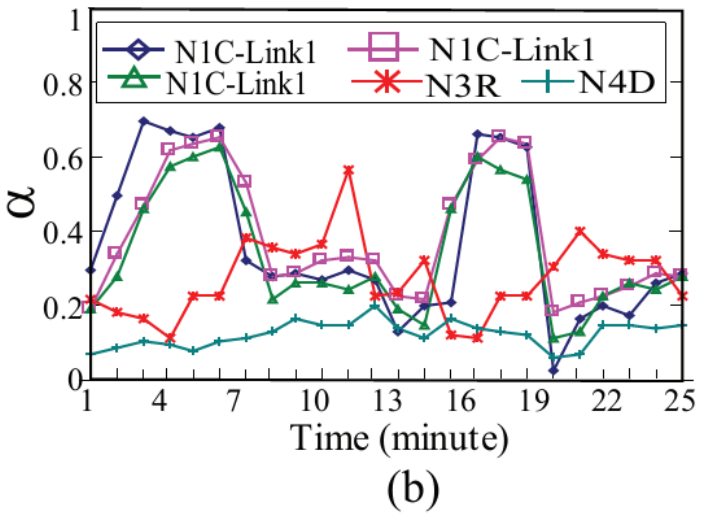


Fig. 9. (a) $F_c(h, T_d)$ vs. β; (b) achieved α (the link failure detection probability) at different times.

We inject 4 types of faults into four sensors:

>The communication fault (restarting radio) and sensing faults (invalidating sensing module) are injected every two minutes into two sensor nodes (N1C and N2S).

>One sensor (N3R) is set to restart every minute.

>Another sensor (N4D), preloaded with a local decision program, is set in a way in which it makes false decisions every three decisions.

Conclusions

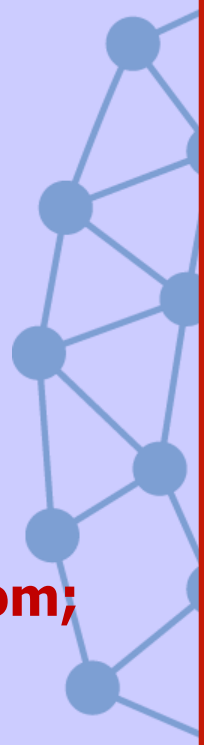
- An interesting research area since it is a practical issue for WSNs.
  - Papers on distributed network monitoring on this issue are still lacking
  - Instead of maintenance operation by the sink, software/system level maintenance by using neighbor nodes' cooperation in a distributed manner should receive more attention.
- The performance of event monitoring and the cost of local maintenance in WSNs can be further analyzed

Our previous work

- G. Wang, M. Z. A. Bhuiyan, J. Cao, and J. Wu, "Detecting movements of a target using face tracking in wireless sensor networks," IEEE Transactions on Parallel and Distributed Systems (TPDS), http://doi.ieeecomputersociety.org/10.1109/TPDS.2013.91, 2013.
- G. Wang, M. Z. A. Bhuiyan, and L. Zhang, "Two-level cooperative and energy-efficient tracking algorithm in wireless sensor networks," Wiley's Concurrency and Computation: Practice & Experience, vol. 22, no. 4, pp. 518–537, 2010.
- M. Z. A. Bhuiyan, G. Wang, and J. Wu, "Polygon-based tracking framework in surveillance wireless sensor networks," in Proc. of IEEE ICPADS, 2009, pp. 174–181.
- M. Z. A. Bhuiyan, G. Wang, and J. Wu, "Target tracking with monitor and backup sensors in wireless sensor networks," in Proc. of IEEE ICCCN, 2009, pp. 1–6.

Thank you for your attention

Q & A



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Approaches

- **Offline Approaches**
  - **Collect the data of system states so that later we can perform fault analysis.**

(not suitable for a resource-constrained WSN

- **Online approaches** **(Received more attention)**
  - **Find a fault during system runtime**
    - **Component/module faults**
    - **Link failure**
    - **The energy level of some node are much lower…**
    - **Sensor board temperature is larger…**