# Scalable Distributed Diagnosis Algorithm for Wireless Sensor Networks

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**Abstract.** This paper investigates the distributed self diagnosis problem for wireless sensor networks (WSN). One of the fundamental algorithm design issue for WSN is conservation of energy at each sensor node. A heartbeat comparison based diagnosis model is proposed, which is shown to be energy efficient. Analytical studies and simulation results show that the performance of proposed algorithm is comparable to that of the existing known algorithms in both delay and message count prospective. At the same time, the per-node message overhead is substantially reduced and becomes scalable.

**Keywords:** Distributed diagnosis, Comparison based model, WSN, scalable diagnosis.

## 1 Introduction

Over recent years, the market for WSN has enjoyed an unprecedented growth. WSNs are subject to tight communication, storage and computation constraint. All the nodes in WSN rely on batteries or other exhaustible means for their energy and wireless links continue to have significantly lower capacity. WSNs are expected to be deployed in inaccessible and hostile environments and thus more prone to failure. The availability of these sensor nodes, however, remains a major concern, if faulty sensor nodes are allowed to corrupt the network. System level diagnosis appears to be a viable solution to this problem.

Many authors have investigated this problem in their literature [1, 2, 3, 4]. Article [1] presents a distributed fault detection algorithm for wireless sensor networks. The fault detection accuracy of a detection algorithm would decrease rapidly when the number of neighbor nodes to be diagnosed is small and the node's failure ratio is high. Article [4] address this problem by defining new detection criteria. Mourad Elhadef *et al.* [5] proposed a distributed fault identification protocol (Dynamic-DSDP) for MANETs which assumes a static network. Dynamic-DSDP differs from Chessa and Santis model [6] in their dissemination strategies. It uses a spanning tree (ST) and a gossip style dissemination strategy, where the ST is created at each diagnosis period. Our protocol uses the same dissemination strategy , but avoids creation of ST during each diagnosis period. In this paper,a heartbeat based scalable diagnosis algorithm (SDDA) is proposed. The time and communication complexity is compared with [5, 6].

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## 2 System Model

The system under consideration accommodates n number of stationary homogeneous sensor nodes with unique identity number and same transmission range, which communicate via a packet radio network.

The proposed algorithm assumes: all nodes are fault free during deployment with a single sink node, static fault situation i.e no node is allowed to be faulty during algorithm execution. The communication algorithm ensures that: each sensor knows the identity of its neighbor, MAC protocol solves contention problem over logical link, the link level protocol provides one hop broadcast and one hop unicast routing, clock synchronization is achieved by periodical timing information exchanges through beacon frames. and communication channels between the nodes have bounded delay and flawless.

**Communication Model:** The communication graph of a WSN is represented by a digraph $G = (V, E)$, where $V$ is set of sensor nodes in the network and $E$ is set of edges connecting sensor nodes. Two nodes $v_i$ and $v_j$ are said to be adjacent only when the distance between them is less than the transmission range. For convenience the algorithm assumes that $G$ is undirected that means $(v_i, v_j) \in E$ and $(v_j, v_i) \in E$.The send initiation time, $T_{init}$, is the time between a node initiating a communication and the last bit of the message being injected into the network. To simplify analysis, it is assumed that$T_{send_init}$ is a constant. The minimum and maximum message delays, $T_{min}$ and $T_{max}$, are the minimum and maximum times, respectively, between the last bit of a message being injected into the network and the message being completely delivered at a working neighboring node. [7]

**Fault Model:** Faults can be classified as either hard or soft fault. In hard-fault situation the sensor node is unable to communicate with the rest of the network, whereas a sensor with soft-fault continues to operate and communicate with altered behavior. This paper defines this altered behavior as random heartbeat sequence number, which does not match to heartbeat sequence number of other fault free sensors in WSN. This paper assumes only the permanent fault (hard and soft) situation, which uses a Spanning tree (ST) and a gossip style dissemination strategy. the spanning tree is created immediately after network deployment with sink node as root.

## 3 The Proposed Algorithm

In this section we introduce SDDA for WSN (see appendix), which is initiated by all the nodes simultaneously by sending a heartbeat message to its neighbors. A heartbeat message accommodates nodeID: the identification number of the node that initiated the heartbeat message and HB_seq_no: the physical sequence number of the heartbeat. In [6], nodes responds to each test request they receive, which increases the communication complexity and is suggested only when each sensor is required to diagnose the fault status of its neighbors. However, the proposed algorithm responds only to the earliest arrived test request.

**Complexity Analysis:** Distributed diagnosis algorithms are usually evaluated with respect to their time complexity, space complexity and message complexity.

**Theorem 1.** *The message complexity is O(n).*

*Proof.* The message cost associated with each message is as follows:

| Message type | Message count | |
|---|---|---|
| Test | $n$ | All nodes generates at most one test message. |
| Response | $n$ | Each node responds to at most one test message. |
| Parent update | $n-1$ | If parent missing (faulty), it updates its parent field with a neighbor having lowest depth.In worst case $n-1$ messages are exchanged. |
| Local dissemination | $n-1$ | Each node sends one message to its parent |
| Global dissemination | $n-1$ | each node sends one message to its child in global dissemination. Where in worst case the depth of the ST is $n-1$. |

Thus, the total message cost is $5n-3$. □

**Theorem 2.** *The worst case time complexity is* $(2n+1)(T_{init}+T_{max})+\psi$.

*Proof.* Heartbeat generation phase ensures simultaneous initiation a heartbeat message simultaneously, which reaches at the neighboring nodes by at most $T_{init}+T_{max}$ time. In aggregation phase each node on reception of heartbeat message, evaluates the heartbeat sequence number and then initiates a response message. The farthest neighboring node receives this response message after $T_{init}+T_{max}+\psi$ amount of time, where $\psi$ is the processing time and assumed constant. At the end of this phase, nodes with faulty parents send the adopt request which needs at most $T_{init}+T_{send\_max}+\psi$ time. In local disseminating phase each node sends its own diagnostic to its parent. The parent collects all diagnostics of its children and merge these diagnostics to its own diagnostic. In worst case the depth of ST is $n-1$, hence the worst case time complexity of this stage is $(n-1)(T_{init}+T_{max})+\psi$. In global disseminating phase the root node disseminates the global view that reaches at the leaf node with highest depth costing time $(n-1)(T_{init}+T_{max})$. Thus, the total time is $(2n+1)(T_{init}+T_{max})+\psi$. □

**Simulation Results and Comparison With Related Works**

The proposed algorithm was simulated on randomly generated network of size n. A set of communication graph G were generated with a known connectivity $k$. $T_{init}$, $T_{min}$ and $T_{max}$ were kept fixed at $10\mu s$, $20\mu s$ and 25 $ms$. Simulation time is set to 200 seconds. Simulations were done using discrete event simulation techniques, where nodes were initially given one unit of energy.

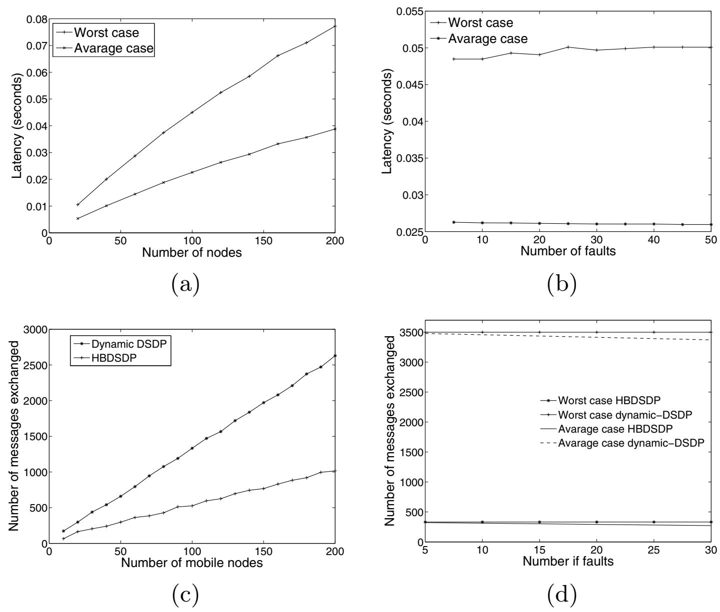


**Fig. 1.** (a)Latency in diagnosing failure events. (b)Time complexity of HBDSDP in presence of faults. (c) Message count in diagnosing failure events. (d)Message complexity of HBDSDP in presence of faults.

**Table 1.** Comparison with related work

| | Message complexity | Time complexity |
|---|---|---|
| Chessa *et al.* model | $nd_{max} + n(n+1)$ | $\delta_G T_{gen} + \delta_G T_f + T_{out}$ |
| Dynamic-DSDP | $nk + 3n - 1$ | $\delta_G T_{gen} + 3d_{ST} T_f + 2T_{out}$ |
| HBDSDP | $5n - 3$ | $(2n+1)(T_{init} + T_{max}) + \psi.$ |

$d_{max}$: The maximum of the node degree $\delta_G$: The diameter of graph G.
$T_f$: The upper bound to the time needed to propagate a dissemination message
$T_{gen}$: An upper bound to the elapsed time between the reception of the first diagnostic message and the generation of the test request.$d_{ST}$: Depth of the spanning tree.

## 4 Discussion

This paper addresses the fundamental problem of identifying faulty (soft and hard) sensors in WSN. Both analytical and simulation study of the proposed algorithm is presented. The use of heartbeat based approach, further reduces the number of bits exchanged per message. Both the message and time complexity of the algorithm is $O(n)$ for an n-node WSN. An interesting open question is whether a self diagnosis algorithm for dynamic fault situation with lower message cost can be developed that can either have same or less latency. In the future work we are investigating this open question.

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## Appendix

The proposed scheme comprises of three main stages like heartbeat generation phase, aggregation phase, disseminating phase.

**Algorithm 1.** Heartbeat Generation Phase

{HBrequest is initialized to FALSE and Set to TRUE once the sensor u generates its HBrequest.}
**if** $HBrequest == FALSE$ **then**
  $HB\_seq\_no = 1;$
  $Broadcast(nodeID, HB\_seq\_no);$ $HB\_seq\_no{+}{+};$ $HBrequest = TRUE;$
**else**
  **if** $HB\_seq\_no == Max\_seq\_no$ **then**
    $HB\_seq\_no = 1;$
  **end if**
  $Broadcast(nodeID, HB\_seq\_no);$ $HB\_seq\_no{+}{+};$
**end if**
$SetTimer(T_{out});$

**Algorithm 2.** Aggregation Phase

```
{Message has been sent by sensor v ∈ N(w). ResponseFlag is initialized to FALSE}
repeat
   if (v.HB_seq_no ≠ w.HB_seq_no−1) OR (v.HB_seq_no ≠ w.HB_seq_no) then
      F_w = F_w ∪ {v}; {Message from a faulty node: may be a soft fault}
   else
      if (v.HB_seq_no == w.HB_seq_no − 1) AND (v ∉ F_w) AND Flag ==
      FALSE then
         Increment and broadcast HB_seq_no and Flag = TRUE;
      end if
      if v.HB_seq_no == w.HB_seq_no then
         FF_w = FF_w ∪ {v}; Node_w[v].status = working;
      else
         F_w = F_w ∪ {v};
      end if
      if T_out == TRUE then
         F_w = F_w ∪ {N(w) − (F_w ∪ FF_w)};
      end if
   end if
until (F_w ∪ FF_w ≠ N(w))
if w.parent ∈ F_w then
   {Find the node with lowest depth from FF_w and declare it as new parent of w}
end if
```

**Algorithm 3.** Disseminating Phase

```
{LocalDiagnosis and GlobalDiagnosis is initialised to FALSE.}
repeat
   if w.children == NULL then
      Unicast(parent, F_w, Node_w)
   end if
   if v ∈ w.children then
      Node_w = Node_w ∪ Node_v; F_w = F_w ∪ F_v; Children = Children ∪ {v};
      if w.children == Children then
         Unicast(parent, F_w, Node_w);
      end if
   end if
   if w == initiator then
      Broadcast(F_w, Node_w); LocalDiagnosis = TRUE;
   end if
until (LocalDiagnosis == FALSE)
repeat
   if w.children ≠ NULL then
      Node_w = Node_w ∪ Node_v; F_w = F_w ∪ F_v; Broadcast(F_w, Node_w);
   end if
   if w.Depth == ST_Depth then
      GlobalDiagnosis = TRUE;
   end if
until (GlobalDiagnosis == FALSE)
```