Advanced Engineering Forum *Online: 2012-09-26*
ISSN: 2234-991X, Vols. 6-7, pp 1167-1172
doi:10.4028/www.scientific.net/AEF.6-7.1167

Study of Fault Detection Based on Benzene Ring in Wireless Sensor Networks

Qing Shao [1, a], Jia-lin Ma [1,b] and Yun Wei [1,c]

[1]School of Optical-Electrical and Computer Engineering, University of Shanghai for Science and Technology, Shanghai, 200093, China

[a]sq_usst@yahoo.com.cn, [b]os_usst@126.com, [c]weiyun@usst.edu.cn

Keywords: wireless sensor networks; benzene ring; fault detection.

Abstract. Large scale and limited resources of wireless sensor networks(WSNs) increase the need to cope with node failures. This paper proposes a novel mechanism for the detection of node failures in WSNs. We designed a structure of benzene ring with symmetry. A benzene ring consists of a center node and several child nodes. Reliable communication links among these nodes. Each node maintains a list of its neighbors. The center node delegates detection service and make decisions about faulty nodes based on its child nodes' available resources. Compared with other solutions, our mechanism can reduce energy consumption, decrease the number of neighborhoods and extend network lifetime. Simulation experiments show the performance and viability of the mechanism.

Introduction

Wireless sensor networks(WSNs) are composed of massive, small and low-cost sensor nodes deployed in a monitoring region, forming a multi-hop self-organized network system through wireless communication. These networks have been used in many application domains such as habitat monitoring, infrastructure protection, and scientific exploration. However, they also face challenges of limited resources and large-scale. Node failure is not the exception in WSNs, it is the norm. If a fault in any node occurs, it is difficult to assure the accuracy of individual nodes' readings. An important task in WSNs consists in detecting failure nodes. Furthermore, completeness and accuracy of fault detection are more important than time to fault detection[1-3].

In the recent past, there has been a considerable amount of work on developing abstractions for fault detection in WSN. In the literature [4] , the authors propose a consensus problem based solution to make all nodes reach an agreement without the sink. It can conduct actions more quickly and directly. [5] presents a technique based on neighborhoods detection in order to get a balance between the low energy consumption and the high accuracy. However, each node need the same number of neighborhoods and it also cause inefficient use of energy. A decentralized cluster based fault management scheme proposed in [6]. It detects and rectifies the problems that arise out of energy depletion in nodes. When a sensor node fails, the connectivity is still maintained by reorganization of the cluster. All these studies include deployment strategies of nodes(how/where they are deployed). There are three deployment strategies: random deployment, regular deployment and planned deployment. It is unclear whether regular deployment will offer advantages over uniformly distributed random deployment; if it does not, random deployment is preferable because of its low cost[7]. [8] compared several clustering algorithms. In these algorithms clusters are formed by virtual grid. The experimental results show that these methods provide longer lifetime of the network than that of low energy adaptive clustering hierarchy. [9] presents abstractions for detecting node failures caused by topology changes. It focuses on a class of failures, i.e. loss of communication links between nodes. Nodes are designed to be dispensable. It uses a middleware service that provides neighborhood information.

In this paper, we focus on the failure modes, such as energy inefficient, component aging, power failure etc. We designed a structure of benzene ring with symmetry. It can provide neighborhood information and reduce energy consumption. Simulation results demonstrate the performance and viability of the algorithm.

The remainder of the paper is arranged as follows. Section 2 studies the structure of benzene ring. Section 3 discusses the benzene ring based fault detection mechanism in WSNs. In Section 4 simulation implementation and result analysis are presented. Finally we conclude our research efforts and points out the future work.

Structure of Benzene Ring

Consider Fig.1, this is the most accurate concept of the structure of benzene ring. The structure of benzene molecule is best described in terms of molecular orbital treatment theory. The *C* atoms are arranged in a *H* atom, and each *C* atom has a *H* atom attached to it. There is a covalent bond between each pair of atoms within the structure. All single and triple bonds are interchanged. It makes the structure more stable.

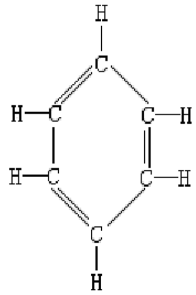

Fig. 1. A chemical structure of benzene ring

In this paper, the structure of benzene ring is applied to WSNs. In some literatures, the structures of decentralized cluster are used for fault management. Here we improve the cluster structure, and design the benzene rings to realize fault detection. It can reduce energy consumption, decrease the number of neighborhoods and extend lifetime of the network.

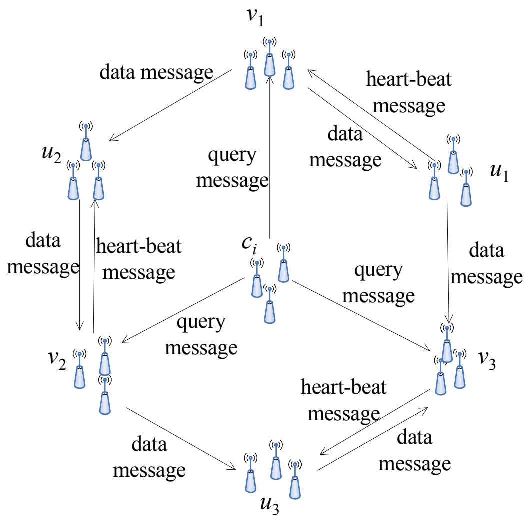

Fig. 2. A structure of benzene ring in WSNs

First, we describe relevant conceptions. A WSN will be modeled by a graph $G = (V, E)$, where V is a set of nodes and E is a set of links. A link between nodes v and v' means that v is within the transmission range of v', and vice versa. We use $e_{u,v} \in E$ to denote the link between node u and v. B_i is denoted to a benzene ring. C_i is the center node in B_i. A center node and all its neighbors form a benzene ring. In general, there are three child nodes link with the center node. We denote them as v_j, other three child nodes as u_j. In a benzene ring , each node maintains a list of its neighbors, and for each neighbor, the node keeps an account of whether it is perceived to be alive or failed. Each benzene ring realizes fault tolerance. Center Nodes in different benzene rings communicate with each other. Many such benzene rings can form a large-scale network.

Fig. 2 shows a structure of benzene ring in WSNs. Links between nodes have two kinds, one is for heartbeat detection and the other is for data communication. A center node C_i is added to exchange query messages with three child nodes. In each benzene ring, a fault detection algorithm is applied. Each recoverable intermediate node has a redundant node for fault tolerant to increase the rate of successful data reception. Heartbeat messages are sent between v_j and u_j. The energy of the center node in B_i can be used efficiently.

The structure of benzene ring can also mask Byzantine fault. For example, if a failed node exhibit arbitrary, it can be modeled as Byzantine fault. With $3f$+1 nodes, the benzene structure can mask f concurrent Byzantine failures.

Fault Detection Mechanism Based on Benzene Ring

In this section, we describe a fault detection mechanism which uses the structure of benzene ring to detect node failures.

In general, a node may fail due to accidental failures or may be compromised by a adversary and therefore exhibit failure due to malicious causes. If a failure is detected in a benzene ring, the detection result will be forwarded across many benzene rings, in a way that is resilient to node failure. As shown in Fig. 2, for each node v_j, its heartbeat enable it to participate in the failure detection service that executes in B_i. For each node u_j, its heartbeat will send to the center node through v_j which links with u_j. So every child node failure will be reported to the center node. Then the center node broadcasts such a failure message.

When a node sends a message, all its immediate neighbors may hear the message. If a message that announces that a detected failed node v cannot be forwarded successfully to all the operational nodes, some nodes may be unaware of node v's failure. For example, If a node v_j does not hear from some neighbor u_j for some specified length of time, v_j adds u_j to its suspect message. If, later on, v_j does receive a heartbeat from u_j, v_j realizes its mistake, and removes u_j from its list. When a node is failed, we can select a set of backup nodes. These backup nodes switch to sleep mode while they are not selected as backup nodes.

Table 1 Setting information of a center node

Data type	Description
NodeID	Unique identifier
Node position	Coordinate
Energy	Consumed energy, remaining energy
Neighborhood information list	Neighborhood identifier, position etc.
Information of the center node in an adjacent benzene ring	Node identifier, position etc.
Fault information	Identifier, position of faulty nodes and their neighborhood
Information of Backup node	Backup node identifier , position etc.

Table 2 Setting information of a child node

Data type	Description
NodeID	Unique identifier
Node position	Coordinate
Energy	Consumed energy, remaining energy
Neighborhood information list	Neighborhood identifier, position etc.
Counter	If the node received a heart-beat message, add 1 to the counter.
Information of center node in adjacent benzene rings	Node identifier, position etc.
Fault information	Identifier, position of faulty nodes and their neighborhood
Information of Backup node	Backup node identifier , position etc.

Table 3 Setting information of a message for fault detection

Message type	Description
Heart-throb	Heart-beat detection
Query-fault	Query for fault detection
fault[i]-appear	Information of suspected node
i-kown-fault[i]	the Faulty node' s information that the center node broadcast
fault[i]-recovery	Information of recovered node
i-kown-falut[i]-recovered	Recovered node's information that sent from center node

According to the structure of benzene ring, we have designed the information of nodes and the message for fault detection. The descriptions are explained in table 1 to table 3.

Based on the above description, a fault detection algorithm is designed for node failures. Appropriate backup nodes can be selected by detecting the faulty nodes. It has characteristics of low energy and low latency. The pseudo-code of the algorithm is given in Fig. 3.

```
I. Timer start;
  For G（i=0; i<n; i++）
     B[i] information Init;
II. Repeat
  Every 3T time:
  B[k](in G[k]) to B[l](in G[l])
  Every T time:
  v[j] send to u[j], vice verse;
  Receive heart-throb message;
  If v[i] or u[i] fault then
     u[i] send u[i]-fault to v[i];
     v[i] send v[i]-fault to C[j];
  End if
Center detect fault every 3T
  If v[i] && u[i] both fault then
     broadcast to other node;
  End if
  If (B[j] receive fault-message from v[i]) Then
     Send ack-message to v[i] whether u[i] fault;
    If (node fault appear) then
      broadcast to other nodes;
    Else
      false message;
    End if
  End if
```

Fig. 3. The fault detection algorithm

Performance Evaluation

In this section we evaluate the performance of our proposed mechanism. OMNeT++ is used as the simulator platform. We obtained the experimental results and compared it with other solutions.

The simulation environment is as follows. A number of nodes are regularly deployed in 1km×1km area where each node has the same sensing and transmission range of 30m. A transmission range is 30 meter, the energy is 0.5J at the beginning, and the message length is 200bit.

Our evaluation focuses on the following aspects: network lifetime and energy consumption.

Network lifetime is the important metric for the evaluation. As a measure for energy consumption, network lifetime occupies the exceptional position that it forms an upper bound for the utility of WSNs. In the simulation, we use the time until the first node in the network dies as the definition of network lifetime.

Energy consumption measures the average energy dissipated by the node in order to transmit a message. We demonstrate the use of our energy model as follows. It is based on a theoretical model[10].

Time to send *k* bit:

$$E_T(k,d) = k(E_{elec}) + k(e_{fs})d^2, \quad \text{if } d \le d_0 \tag{1}$$

$$E_T(\mathrm{k,d}) = k(E_{elec}) + k(e_{mp})d^4, \quad \text{if } d > d_0 \tag{2}$$

where,

$$d_{0}=\sqrt{\frac{e_{fs}}{e_{mp}}} \tag{3}$$

Time to receive k bit:

$$E_R(k) = k(E_{elec}). \tag{4}$$

Where, E_{elec} is the consumed energy to receive one bit, and its value is 50nJ/bit. e_{fs} and e_{mp} is the multi-path fading energy and its value is10pJ/bit/m^2 . e_{fs} is the free space fading energy and its value is 0.0013pJ/bit/m^4.

Fig. 4 shows the variation in the remaining energy of the center node and a child node in B_i according to the increase of the communication distances. We can see the energy consumption of the center node is higher than that of the child node. When the distance is short, the energy consumption of the child node is higher. As the distance is increased, the remaining energy of the center node is reduced rapidly. If the benzene ring provides fault detection successfully, the center node will have high energy consumption.

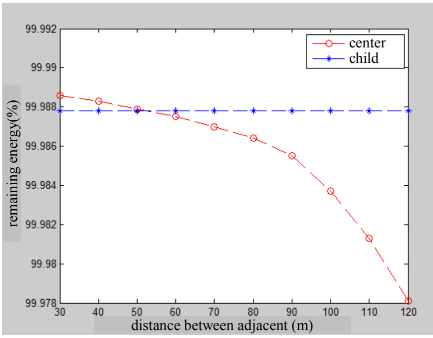

Fig. 4. Comparison of remaining energy for center node and child node

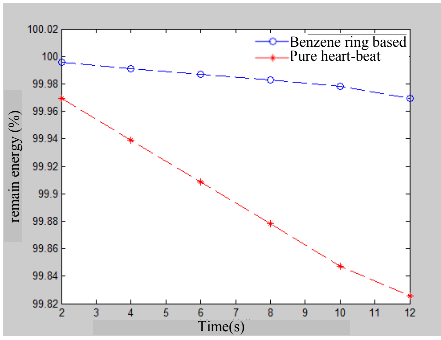

Fig. 5. Remaining energy vs. time

Fig. 5 illustrates the relationship between remaining energy of node and time by two different mechanisms. The curves reveal that with the benzene ring based mechanism, nodes remain higher energy. As time passes, the pure heart-beat mechanism increase energy consumption rapidly. The results show a improvement in the benzene ring based mechanism.

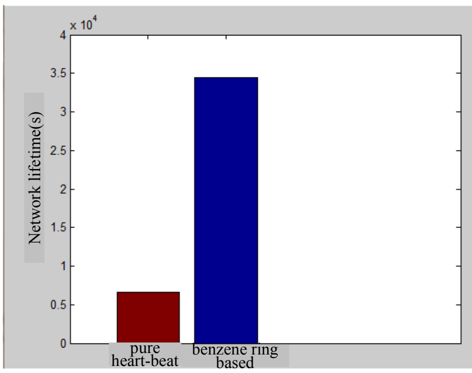

Fig. 6. Comparison of network lifetime

Fig. 6 shows the normalized network lifetime before the remaining network becomes disconnected with two different mechanisms. Similarly, the benzene ring based mechanism achieves about seven times the lifetime of the pure heart-beat mechanism. This is due to the fact that the benzene ring based is the energy efficient mechanism.

Summary

In this paper, we propose a benzene ring based mechanism for fault detection to support reliable data transfer in WSNs. By exploiting a structure of benzene ring, we are able to make the fault detection service for node failure. The experiment shows our scheme can provide significant benefits in term of energy consumption and network lifetime effectually.

Further work is to extend functions of fault detection model, improve intelligent management, combine in a more concrete and practical study, and to explore other fault tolerant mechanisms in WSN performance design.

Acknowledgement

This work was supported in part by the Key Project of the National Nature Science Foundation of China (No. 61170277), Project of the Shanghai Committee of Science and Technology (No. 08JC1400100), and the Research and Innovation Project of Shanghai Municipal Education Commission(No. 02120557).

References

[1] X. Chen, Y. Kim, Fault-tolerant monitor placement for out-of-band wireless sensor network monitoring, Ad Hoc Networks. 10 (2012) 62-74.

[2] S. Nanda, D. Kotz, A multi-radio mesh monitoring and management system, Computer Communications. 31 (2008):1588-1601, 2008.

[3] H. Seba, FTKM: A fault-tolerant key management protocol for multicast communications, Computers & Security. 25 (2006) 426-434.

[4] H. C. Hsieh, J. S. Leu, W. K.Shih, A fault-tolerant scheme for an autonomous local wireless sensor network, Computer Standards & Interfaces. 32 (2010) 215-221.

[5] M. N. Halgamuge, M. Zukerman, An estimation of sensor energy consumption, Progress In Electromagnetics Research B. 12 (2009) 259-295.

[6] S. Babaie, A. R. Rezaie, S. R. Heikalabad, DFDM: Decentralized Fault Detection Mechanism to Improving Fault Management in Wireless Sensor Networks, Communications in Computer and Information Science. 166 (2011) 685-692.

[7] S. Tilak, N. B. Abu-Ghazaleh, W. Heinzelman, Infrastructure Tradeoffs for Sensor Networks, Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications, Georgia, USA. 2002, pp.49-58.

[8] A. Berton, D. Hodouin, Synchronized node imbalances for fault detection and isolation in plant networks involving material circulation, Computers and Chemical Engineering. 31 (2007) 815-832.

[9] H. A. Zia, N. Sridhar, Failure detectors for wireless sensor-actuator systems, Ad Hoc Networks. 7 (2009) 1001-1013.

[10] G. Pottie, W. Kaiser, Wireless Integrated Network Sensors, Communication of ACM. 43 (2000) 51-58.