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Reliability of Sensor Nodes in Wireless Sensor Networks of Cyber Physical Systems

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Abstract

Sensors are a crucial component of any intelligent control system. Wireless sensor networks are one of the most rapidly developing information technologies and promise to have a variety of applications in Next Generation Networks, Internet of Things and for mission critical and safety relevant applications. Reliability is one of the most important attribute of such systems. In the paper Markov model for reliability analyses of sensor node in wireless sensor networks is proposed. It is shown that reliability of the sensor node depends on the strategy of it monitoring and is unimodal function of test period. For passive part of sensor node, the optimal time for test of functionality is defined.

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Keywords: Sensor node; Wireless sensor networks; Reliability

1. Introduction

Wireless sensor networks (WSNs) are one of the most rapidly developing information technologies and promise to have a variety of applications in Next Generation Networks (NGNs) and Cyber-physical system (CPS). Wireless Integrated Network Sensors combine sensor technology, signal processing, computation, and wireless networking capability in integrated systems[1]. Cyber-physical system addresses the close interactions and feedback controls between cyber components and physical components, where cyber components refer to the sensing and communication systems, while the physical components comprise of a wide range of systems in practice.

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CPS is expected to play a major role in the development of next-generation smart energy systems and data centres. Innovative computational methodologies such as green and energy efficient cyber-physical system design have become critical to enable the sustainable development of such systems.

WSNs are spatially distributed systems which consist of dozens, hundreds or even thousands of sensor nodes, interconnected through wireless connection channel and forming the single network. Fig. 1 represents an example of a WSN[2]. Here we can see a WSN which consists of twelve sensor nodes and a network sink, which also functions as a gate. Each sensor node is a device which has a transceiver, a microcontroller, and a sensitive element (see Fig. 2)[2]. Usually sensor node is an autonomous device.

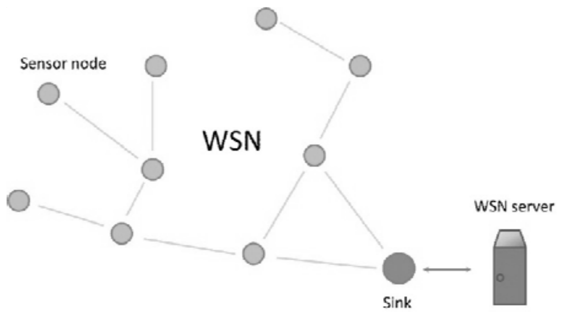

Fig. 1. An example of a WSN[2].

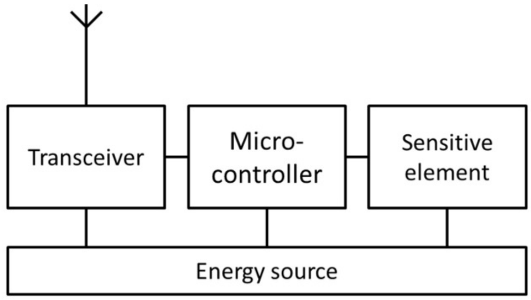

Fig. 2. Sensor node inner structure[2].

Reliability and data integrity is an important attribute of CPS. For some application fields, which have high demands in terms of reliability, it is particularly important to ensure the reliability of the network. At present, most researchers study wireless sensor network reliability from networks topology, reliable protocol and application layer fault correction[3,4].

Sensor node fault types mainly include hardware failure and communication channel fault[5], communication channel fault is generally transient fault that cause by disturbance, obstacle and so on.

The paper examines a focus on the reliability of the sensor node based on periodic test operations, which are conducted to identify the reliability of communication channel.

The rest of this paper is organized as follows. In Section 2 some important works in the area of reliability of WSN sensor nodes are reviewed. In Section 3 the main definitions and assumptions are presented and a model of reliability of sensor nodes in WSN of Cyber Physical Systems is proposed. In Section 4 the conclusions are presented.

2. Related works

The paper[6] presents a survey on existing data transport reliability protocols in wireless sensor networks (WSNs). Authors review several reliability schemes based on retransmission and redundancy techniques using different combinations of packet or event reliability in terms of recovering the lost data using hop-by-hop or end-to-end mechanisms.

The paper[7] presents a survey on existing reliability models in wireless sensor networks.

Most WSNs reliability assessments are based on graph theory and probability theory. Connectivity reliability[8,9,10,11] investigates the probability that the network is still connected for a given period of time under the case of some nodes or links failure. Performance reliability[12,13] analyzes the end-to-end delay, packet delivery rate, and other network parameters.

WSNs reliability is influenced by many factors such as component failure, environmental influences, task changes, and network update. These factors and network behavior are difficult to be described or calculated by mathematical models. Network simulation becomes an important method to analyze network reliability.Monte Carlo[14], Petri nets[15], Bayesian networks[16], and other simulation methods have been used.

In the paper[17] the key components of sink nodes adopt spare parts measures that have been adopted in the field of machinery to improve reliability of WSN, Markov state diagram and probability analysis method are applied to realize solution of reliability functional model, establish the relationship between reliability and characteristic parameters in sink nodes, analyze reliability model of sink nodes, so as to determine the reasonable parameters of the model, and ensure reliability of sink nodes.

Transmission is an important mission of WSNs, and the reliability evaluation from the perspective of transmission can better satisfy the need of network users.

To provide a more effective and accurate evaluation for the transmission reliability in WSNs, the paper[18] analyzes the transmission from two directions (uplink and downlink) and proposes a dynamic evaluation framework.

To provide a more effective and accurate evaluation for the operational reliability in WSNs, current paper analyzes the reliability of sensor node with periodic test. The optimal parameters of test operations are obtained.

3. Model formulation and solution

For WSN of cyber-physical system with critical missions or safety relevance it is important to know that the sensor nodes are on operation at any time. During operation some of WSN sensors operate in a cyclic mode. Operating duration of the sensors can be many times smaller than the length of pause (see Fig. 3). In this case, the periodic testing can be used to detect potential faults in the pause of sensor's operation. Let's develop a model of reliability of this category of sensors.

The following symbols have been used to develop equations for the models:

λ - Failure Rate
μ - Repair Rate
A - Availability
T_0 - Mean time between failures, $T_0 = 1/\lambda$
t_r - Mean time to repair, $t_r = 1/\mu$
P_i - Probability of being in state H_i
T_m - Periodicity of test operations with parameter of Poisson's flow $\varphi = 1/T_m$
t_m - Time of test operations
ψ - Parameter of exponential distribution of t_m

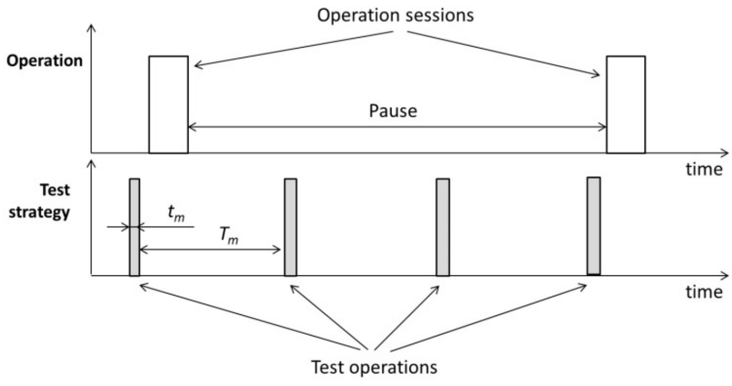

Fig. 3. Time diagram of sensor node operation and it testing.

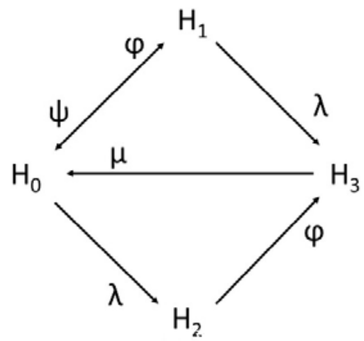

Fig. 4. Markov Chain state transition diagram.

The behaviour of the examined system is described by the Markov Chain state transition diagram (see Fig. 4), where: H_0 – completely good state of the sensor node; H_1 – test of the sensor node without failure; H_2 – hidden failure of the sensor node; H_3 – detection of the failure state.

On the base of the state transition diagram for a Markov's process shown in Fig. 3, we can write the system of Chapman–Kolmogorov's equations[19]:

$$\begin{aligned} P_0{}'(t) &= -(\lambda+\varphi)P_0(t) + \psi P_1(t) + \mu P_3(t) \\ P_1'(t) &= \varphi P_0(t) - (\psi+\lambda)P_1(t) \\ P_2'(t) &= \lambda P_0(t) - \varphi P_2(t) \\ P_3'(t) &= \lambda P_1(t) + \varphi P_2(t) - \mu P_3(t) \end{aligned} \quad (1)$$

In this system (1) of equations $P_i(t)$ is the probability of finding the system in the state $H_i, i = \overline{0,3}$.
The normalizing condition is:

$$\sum_{i=0}^{3} P_i(t) = 1 \quad (2)$$

The availability $A = P_0$ of sensor node and it unavailability $U = 1 - A = P_1 + P_2 + P_3$ may be defined by solution of the Kolmogorov's above mentioned system of equations, where P_i - stationary probability values of $P_i(t), i = \overline{0,3}$. For high reliable systems with $\lambda \ll \mu$ the equation for unavailability is

$$U = P_1 + P_2 + P_3 = \varphi/(\psi+\lambda) + \lambda/\varphi + \lambda/\mu + \lambda\varphi/\mu(\lambda+\psi) \quad (3)$$

The analysis of the $U(\varphi)$ shows that it is an unimodal function with the extremes in φ_{opt} point. The expression for the definition of optimal value of the periodicity of control $T_{m\ opt} = 1/\varphi_{opt}$ is possible to find out from the condition $dU/d\varphi=0$:

$$T_{m\ opt} = \sqrt{T_0 t_m \frac{T_0 + t_r}{T_0 + t_m}} \quad (4)$$

At the Fig. 5 the function of the optimal value of the control periodicity $T_{m\ opt} = f(t_m)$ is shown for typical reliability parameters of WSN sensors.

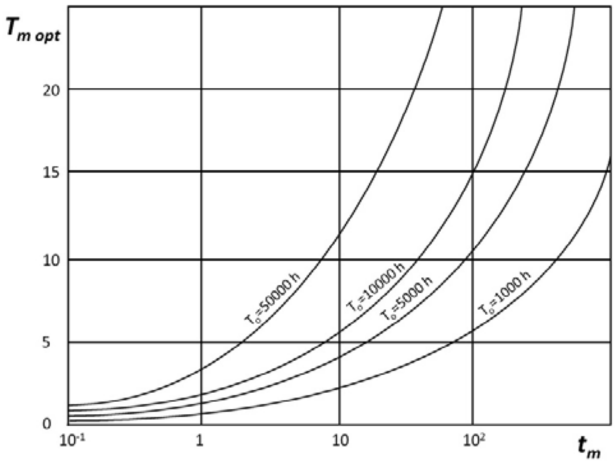

Fig. 5. The function the optimal value of the periodicity of control.

4. Conclusion

In the paper Markov model for reliability analyses of sensor node in wireless sensor networks is proposed. It is shown that reliability of the sensor node depends on the strategy of it monitoring and is unimodal function of test period. For passive part of sensor node, the optimal period for test of functionality is defined. The optimal test period increases with the increase of MTBF and the duration of test. In future perspective it shall be implement more artificial intelligence into the sensor node for early data evaluation based on self-learning ontology models of CPS.

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