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ON THE ISSUE OF CONSTRUCTING AN ENVIRONMENTAL MONITORING SYSTEM USING A NETWORK APPROACH

Sensor networks which are exploited for environment monitoring are very often negatively affected by surroundings. As a result, sensor nodes can often fail. The paper presents diagnosis technique based on mutual tests among sensor nodes. Such diagnosis is considered as system level self-diagnosis. Traditionaly, system level self-diagnosis is used for detecting of permanently faulty nodes. In the paper, we consider the problems of intermittent fault detection and suggest diagnosis procedures which allow distinguishing between different types of intermittent faults. For each type of intermittent faults we developed diagnosis procedure.

***Keywords**: diagnosis, sensor networks, environment monitoring, environment*

Problems of diagnosis of sensor networks applied for environment monitoring

Typical sensor network consists of great number of sensor nodes each of which consists of sensing, computing, communication, actuation, and power components [1]. These components are integrated on a single or multiple boards, and packaged in a few cubic inches. Sensor networks which can be applied for environment monitoring (e.g., wireless sensor networks) usually consist of tens to thousands of nodes that communicate through wireless channels for information sharing and cooperative processing. Communication among sensor nodes can be used for diagnosis purposes. In this paper, we are going to show how diagnosis of sensor network can be performed by using results of tests among sensor nodes.

Wireless sensor networks can be deployed on a global scale for environment monitoring and habitat study, over a battle field for military surveillance and reconnaissance, in emergent environments for search and rescue, in factories for condition based maintenance, in buildings for infrastructure health monitoring, in homes to realize smart homes, or even in bodies for patient monitoring [2].

Sensor networks which are used for environment monitoring have some specific features such as:
- autonomous functioning for a long time;
- working conditions can produce external faults for sensors;
- difficulties to provide centralized testing facilities and diagnosis;
- necessity in online testing;
- high requirements for fault-tolerance and survivability, etc.

In view of the listed above, the appropriate means and techniques for sensor network checking and diagnosis should be developed so as to satisfy the requirements of customer/ user of sensor network. In the paper, we propose network diagnosis based on the results of tests performed by sensor nodes (i.e., without external facilities). During diagnosis procedure sensor nodes test each other, and then all test results are used in diagnosis algorithm. Usually, such diagnosis was exploited to reveal permanently faulty components in complex systems. In view of the fact that sensor nodes are also susceptible to intermittent faults [3] , direct implementation of diagnosis based on mutual tests in sensor networks may be complicated. In this paper, we investigate how diagnosis based on mutual tests can treat the situations when one or more sensor nodes have both permanent and intermittent faults.

Diagnosis of intermittent faults

Based on the current literature available on fault diagnosis in most of the sensor network consisting of great number of semnsor nodes, many network components are subjected to intermittent faults as compared to any other kind of faults, such as permanent, transient and byzantine. Occurrence of intermittent faults may decrease the quality of service that a network delivers. In view of this, there have been performed a great number of researches on developing techniques for diagnosis of intermittent faults, modelling intermittent faults and designing detection experiments for them.

Intermittent faults can be defined as the faults whose presence is bounded in time. In other words, a unit can possess an intermittent fault but the effect of this fault is present only part of time.

For the diagnosis purposes the amount of time devoted to diagnosis procedure, t_d is very important. Depending on the amount of time t_d and on its position on the time axis (see Fig. 1), the same fault may be identified as a permanent fault (case of t_d^1) and as an intermittent fault (case of t_d^2). There is also probability that during the diagnosis procedure the effect of intermittent will not be present (case of t_d^3).

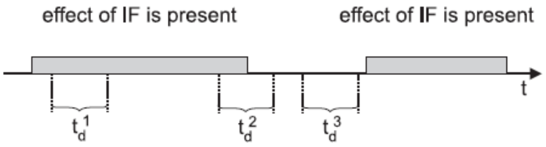

Fig. 1 – Intermittent fault in relation to the time t_d

There should be named some valuable works in the area of diagnosis of intermittent faults. Particularly, S. Kamal and V. Page in [4] considered the problem of how many times a digital circuit should be tested before the decision about its state is made. At the beginning of testing, the state of a unit is indefinite. The testing procedure (i.e., repetition of tests) is stopped either when the fault is detected or on the basis of a decision rule. The authors suggested some decision rules for termination of testing procedure with the result that a unit is fault-free. According to their research results, the intermittent fault present in the unit can affect the behavior of the unit only part of time. However, if the effect of the intermittent fault is present during the testing procedure, then such fault will be detected. Therefore, they describe the behavior of intermittent faults (particularly, the occurrence of their effects) with the help of the probability *P (Si/ωi),* where *Si* denotes the state of the unit when it possesses intermittent fault ωi and the effect of the fault is present.

Another approach to describing behavior of intermittent faults is presented in [5]. In this case, an intermittent fault has two states - active (AS) and passive (PS). When an intermittent fault is in AS, the effect of intermittent fault is present. Whereas, when an intermittent fault is in PS its effect is not present. Transfers from one state to the other one are described with the corresponding intensities λ and μ (see Fig. 2)

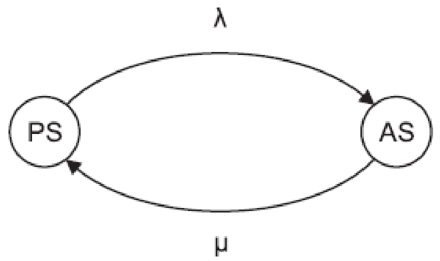

Fig. 2 – Model of intermittent fault

The process of transfers between these two states can be described as continuous Markov chain, where the time period during which the intermittent fault stays in state AS (PS) is random value. This random value has exponential probability distribution with mean 1/μ (1/λ).

The probabilistic models for describing the behavior of intermittent faults are used for computer modeling of intermittent faults and for designing intermittent fault detection experiments.

Among the first problems that were considered in the area of system level self-diagnosis accounting intermittent faults were the problems of developing the diagnosis procedure and the algorithm allowing to identify intermittently faulty units.

Considering intermittent faults in context of system level self-diagnosis is very important since imperfect test fault coverage can lead to the same effect as the presence of intermittent faults can produce. Thus, the assumption that $P_{AT} = 1$ (where P_{AT} is the probability that fault-free unit will identify correctly the tested faulty unit) can be relaxed when intermittent faults are taken into consideration.

Attempts to exploit the same methods for diagnosis intermittent faults as the ones used for diagnosis of permanent faults can considerably complicate the diagnosis and can lead to receiving incorrect (confusing) diagnosis results.

So, for example, for diagnosis of intermittent faults there should be considered three states of a unit, i.e., fault-free, permanently faulty and intermittently faulty. It means that probabilistic algorithms have to consider 3^N hypotheses that may be time-consuming even for diagnosing the systems with not very large number of units. In case of homogeneous systems, there can be received the result of diagnosis indicating that two hypotheses made upon system unit state have equal posterior probability (or near equal). This situation can arise when system units have approximately equal values of prior probabilities of fault-free state.

In case of table algorithms, it is very probable that a confusing result of diagnosis will be received, since presence of intermittent faults contradicts the main assumptions made for table algorithms (e.g., $P_{AT} = 1$).

The situation when a system contains an intermittently faulty unit is depicted in Fig. 3.

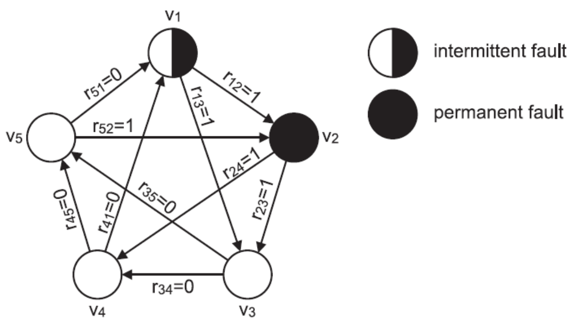

Fig. 3 – System with intermittently faulty unit

In the given case, the system consists of five units. Let unit u_1 be intermittently faulty and unit u_2 be permanently faulty. The obtained syndrome is compatible with the actual faulty situation in the system.

Given the obtained syndrome, it is not possible to make decision which of the units, u_1 or u_3, is fault-free, and which one is intermittently faulty. To detect an intermittent fault may be very difficult for the reason that the behavior of a fault (expressed by the values of λ and μ) may be such that the fault either may stay in PS for a long time (i.e., small value of λ), or may appear in AS for a very short time (i.e., great value of μ).

However, for some types of intermittent faults there exist special methods which make it easy to diagnose intermittent faults.

It is worth noting that in case of intermittent faults, it is important not only to identify intermittently faulty units, but also to define the further step relating to the treatment of the detected intermittently faulty units. So, for example, a unit possessing the intermittent fault belonging to a certain type can operate further on even without any recovery operations performed on it.

Given testing assignment, instances of performing the tests and time durativ of a test, there can be performed computer modeling of diagnosis of intermittent faults. Computer modeling is performed for different values of λ and μ and is aimed to determine the number of tests repetitions, k, ensuring the correct detection of intermittent faults. Depending on the obtained values of k, all intermittent faults can be subdivided into three types.

Type 1. Includes the intermittent faults which can be detected after repetition of each test several times (not greater than few dozens).

Type 2. Includes the intermittent faults which although can be detected by way of tests repetitions, but the number of tests repetitions must be great (in the order of 10^6).

Type 3. Includes the intermittent faults which, with high probability, may appear in AS for a short time and not more than once during the diagnosis procedure.

It should be noted that the classification of intermittent faults presented here depends considerably on the parameters of diagnosis procedure (time duration of a test, number of tests performed in one round of tests repetitions, instants of tests performing ect.).

Concurrent running of diagnosis process and intermittent fault occurrence process is depicted in sequence diagram (see Fig. 4)

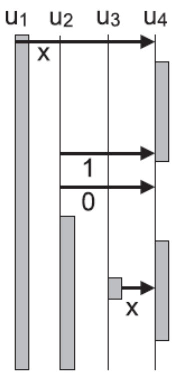

Fig. 4 – Sequence diagram

The diagram consists of the vertical dimension (time) and horizontal dimension (tests among the units). The tests among the units are shown as horizontal arrows. Their vertical position defines the instants when test is performed. The result of test is shown under the arrow. When the test is performed by a faulty unit, the result of test may take value either 0 or 1. That is why such test results are expressed by X. Faulty state of a unit is shown in the diagram as gray rectangle on the vertical line of the corresponding unit. The height of rectangle corresponds to the time duration of the faulty state of the unit.

As it follows from Fig. 4, unit u_1 is permanently faulty, unit u_2 is also permanently faulty, but the fault occurs in the unit during the diagnosis procedure. Moreover, this fault in unit u_2 doesn’t influence the diagnosis result since unit u_2 has performed all assigned tests before the instants of fault occurrence.

Unit u_3 has intermittent fault. This fault was in AS for a short time. During the diagnosis procedure this intermittent fault was in AS only once. Such intermittent fault belongs to Type 3 of the above presented classification of intermittent faults.

Unit u_4 also has intermittent fault. However, as distinct from the intermittent fault of unit u_3, the fault of unit u_4 has been in AS several times and, thus, influences considerably the diagnosis result. Intermittent fault of unit u_4 rather belongs to Type 1 than to Type 2, since this fault stays in AS longer than in PS, and, thus, it can be detected after few times of test repetitions.

For the diagnosis of intermittent fault of Type 1, there were suggested methods [6] based on summary (updated) syndrome, R_Σ. Summary syndrome R_Σ is obtained after performing m rounds of test routine. Test routine is the testing which is performed according to testing assignment.

Summary syndrome R_Σ is computed as

$$R_\Sigma = \{r^*_{ij}\}, \quad r^*_{ij} = \bigcup_l r^l_{ij},$$

Where $r_{ij}^{\,l} \in R_l$, R_l - syndrome obtained during l-th round of test routine repetition.

It can be easily seen that summary syndrome is a subsyndrome of the syndrome which would have resulted from a test routine if all the current faults in units were of a permanent type.

Anytime the summary syndrome is consistent, a diagnosis can certainly be performed and a set of units can be identified as being faulty. Thus, diagnosis can be performed if the following condition is met

$$R_\Sigma \in R_0, \qquad (1)$$

Where R_0 is the set of summary syndromes which would have been obtained if all the current faults were permanent, and the number of faults didn’t exceed the value of t.

If condition (1) is met, the diagnosis can be performed by using the methods and algorithms used for diagnosing the systems which can have only permanently faulty units. But, this time, the units identified as faulty may indeed be either permanently faulty or intermittently faulty. When condition (1) is not met, the obtained summary syndrome R_Σ is inconsistent and contains conflicting test results (i.e., some of the test results conflict with each other). The result of diagnosis received on the basis of inconsistent summary syndrome will be incompatible.

Diagnosis result is incompatible when some unit is evaluated by one fault-free unit as fault-free but, at the same time, another fault-free unit evaluates this unit as faulty.

In this case, the diagnosis usually doesn't continue and ends with the reset that a system cannot be correctly diagnosed. This case can occur when system units have intermittent faults either of Type 2 or Type 3. When situation allows to continue the diagnosis procedure, there could be performed additional rounds of test routine (testing) with the aim to catch the intermittent faults in AS, and afterwards to eliminate the inconsistency from the summary syndrome.

The alternative solution of how to resolve the conflicts in test results doesn't require additional rounds of testing. It is worth noting that this alternative solution has a risk that the diagnosis result will be inaccurate. This solution makes the basic assumption that all undetected intermittent faults belong to Type 3. Thus, the probability of receiving inaccurate reset of diagnosis, in the given case, is equal to the probability that the made basic assumption will not be true. The reasoning for making this assumption can be explained by the fact that in current complex systems the intermittent faults of Type 3 can occur much more frequently than the other types of intermittent faults can.

The suggested alternative solution consists in the following.

At the first step, the subset *Z* is determined. The subset *Z* contains all of the units that, according to the summary syndrome, are identified as fault-free.

At the second step, the consistency of all test results performed by the units of subset *Z* is verified. In other words, there will be checked if the units of subset *Z* evaluate the units which don't belong to subset *Z* equally.

Checking procedure can result in one of the situations depicted in Fig. 5.

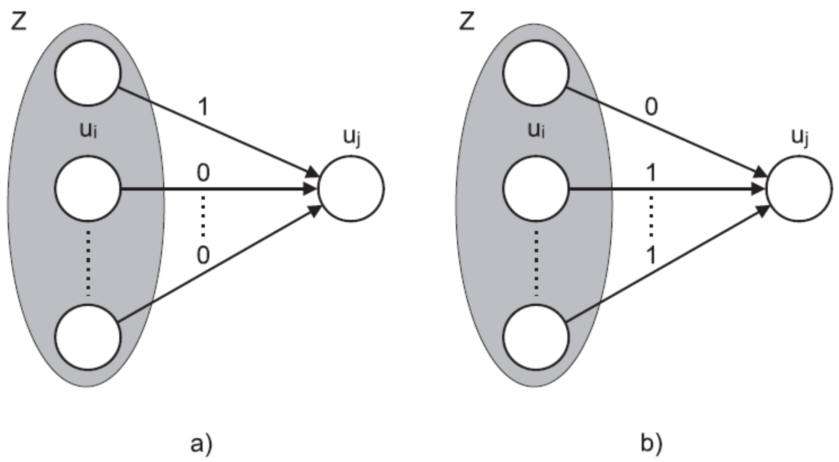

Fig. 5 – Situations caused by intermittent faults of Type 3

Situation A depicted in Fig. 5a can occur by reason of:

1. Unit u_j fails at the moment right before its participation in the last test in the last round of testing. In the given case, it is the test τ_{ij} that was performed by unit u_i on unit u_j .

2. Unit u_j has intermittent fault of Type 2, and unit u_i is the single unit whith has detected this fault.

3. Unit u_i is permanently faulty. The test τ_{ij} is the first test that has been affected by this fault. It means that before test τ_{ij} unit ui was fault-free.

4. Unit u_i is intermittently faulty. This intermittent fault was detected only by test τ_{ij} .

5. Either unit u_i or unit u_j has intermittent fault of Type 3. This intermittent fault was in AS at the moment of performing test τ_{ij} .

The situation A can also occur when both units, $u_{\rm i}$ and u_j , are intermittently faulty, but the probability of occurrence of such situation is very small (negligible). Some examples of occurrence of situation A are shown in Fig. 6.

In case of 2, 4, 5, there exist many possibilities of how situation A can occur, but only one example is depicted. Exception is made only for the case of 5 when two examples are depicted. According to the basic assumption made, there are considered only intermittent faults of Type 3 (case of 5).

Thus, we can conclude that either unit ui or unit uj is intermittently faulty.An intermittent fault in a unit with high probability will not be in AS more than once during system operating. It means that the unit possessing such intermittent fault can operate correctly for a long time after the intermittent fault has transferred into PS. In view of this, it is not important which of the units, ui or uj , has intermittent fault. The main goal, in this case, is to eliminate inconsistency from the set of test results. Consequently, the solution consists in changing the result of test τij from 1 to 0.

Situation B depicted in Fig. 5b can occur only in the case when unit uj has intermittent fault which was detected by all units of subset *Z* except the unit ui. In Fig 7, there are shown some examples which result in occurrence of situation B.

In the given case, the solution is straightforward. It is sufficient to change the result of test τij from 0 to 1.

More complex situation arises when subset *Z* has only two elements (see Fig. 8)

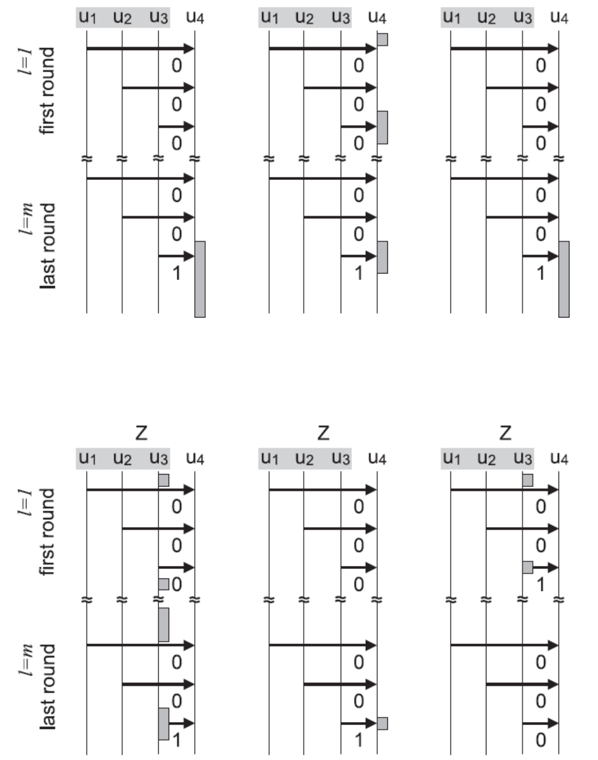

Fig. 6 – Examples of occurrence of situation A

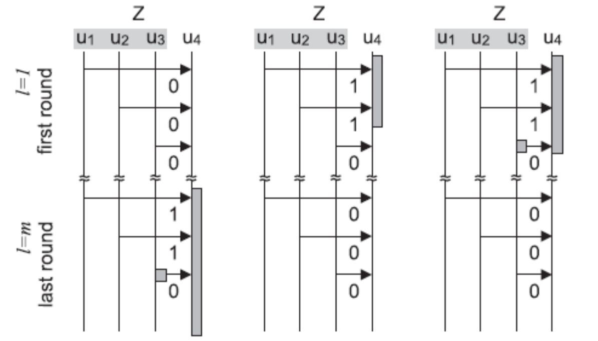

Fig. 7 – Examples of occurrence of situation B

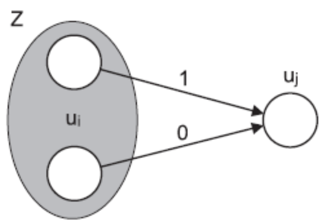

Fig. 8 – Case when subset *Z* has only two elements

In this case, it is possible to interpret the obtained result either as situation A or situation B. For making the choice between these two situations it is necessary to compare the probabilities of these situations. When situation A is chosen, one can conclude that either unit u_i or unit u_j possesses an intermittent fault of Type 3. When situation B is chosen, unit u_i possesses an intermittent fault of Type 2. Since the probability of occurrence of intermittent fault of Type 2 is lesser that the probability of occurrence of intermittent fault of Type 3, it is reasonable to give preference to the situation A.

Summarizing the above consideration of diagnosis of intermittent faults, there could be listed the following specific features of such diagnosis:

I. Some intermittent faults which belong to Type 3 cannot be identified unambiguously. In this case, there should be resolved the conflicts among the test results produced by the fault-free units.

II. The diagnosis procedure consists in the following:

Step 1. Performing m rounds of test routine and obtaining summary syndrome R_Σ.

Step 2. Checking the condition $R_\Sigma \in R_0$. If the condition is met, the subsequent diagnosis is performed in the same manner as diagnosis of permanent faults. Otherwise, there should be performed the next step.

Step 3. Determining subset *Z* by using the summary syndrome. Subset *Z* contains all of the units which were identified as fault-free by using the summary syndrome.

Step 4. Verifying the consistency of test results produced by the units of subset *Z*.

Step 5. Resolving the conflict situation.

III. Intermittent faults can be subdivided into three types according to the value of *m* (number of rounds of test routine repetition which is needed to detect an intermittent fault). Intermittent faults of Type 1 can be indentified at Step 2. Some intermittent faults of Type 2 can be identified after performing Step 3. Intermittent faults of Type 3 can be detected (i.e., we can assert that the system has an intermittent fault), but cannot be identified. Usually, the system can tolerate these intermittent faults and is able to continue in delivering correct services. Conflict situations caused by intermittent fault of Type 3 are resolved at Step 5.

IV. The main drawbacks of intermittent fault diagnosis based on tests repetitions are as follows:

- the diagnosis is time-consuming;
- it may be difficult to provide tests among the system units when the system operates (i.e., concurrently with delivering services).

Conclusions

Sensor networks used for environment monitoring are offen working in surroundings which can produce negative effects on sensor network. For example, radiation can cause intermittent faults in sensor nodes. Temperature and humidity can also impact negatively on sensor's functioning. Current diagnosis techniques which are used for checking and diagnosing of sensor nodes mostly deal with permanent faults. In this paper, we have considered specifics of intermittent fault diagnosis and have shown how diagnosis based on mutual sensor tests can be used to diagnose faulty sensor nodes. We have considered different types of intermittent faults and suggested diagnosis procedure for each of them.

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ДІАГНОСИКА СЕНСОРНИХ МЕРЕЖ, ЯКИ ЗАСТОСОВУЮТЬСЯ ДЛЯ ЕКОЛОГІЧНОГО МОНІТОРИНГУ

О.А. Машков, В.А. Машков, В.Р. Косенко

Сенсорні мережі, які використовуються для моніторингу навколишнього середовища, дуже часто піддаються негативному впливу самого середовища. У статті представлені діагностичні методи, засновані на взаємних контролях між окремими сенсорами. Таке диагностироване сенсорної мережі відноситься до самодигностированию на системному рівні. Традиційно самодіагностування на системному рівні використовується для виявлення модулів з постійними відмовами. У статті розглядаються проблеми, пов'язані з виявленням переміжних відмов і пропонуються діагностичні процедури, що дозволяють розрізняти різні типи переміжних відмов. Для кожного типу переміжних відмов розроблена окрема процедура діагностування.

Ключові слова: діагностика, сенсорні мережі, екологічній моніторинг, навколишнє середовище

ДИАГНОСТИКА СЕНСОРНЫХ СЕТЕЙ ПРИМЕНЯЕМЫХ ДЛЯ ЭКОЛОГИЧЕСКОГО МОНИТОРИНГА

О.А.Машков, В.А. Машков, В.Р. Косенко

Сенсорные сети, которые используются для мониторинга окружающей среды, очень часто подвержены отрицательному влиянию самой среды. Следствием такого влияния могут быть частые отказы сенсоров. В статье представлены диагностические методы, основанные на взаимных контролях между отдельными сенсорами. Такое диагностирование сенсорной сети относится к самодигностированию на системном уровне. Традиционно самодиагностирование на системном уровне используется для обнаружения модулей с постоянными отказами. В статье рассматриваются проблемы, связанные с обнаружением перемежающихся отказов и предлагаются диагностические процедуры, позволяющие различать различные типы перемежающихся отказов. Для каждого типа перемежающихся отказов разработана отдельная процедура диагностирования.

Ключевые слова: диагностика, сенсорные сети, экологический мониторинг, окружающая среда