Wireless Sensing Networks System Dependability Measurement

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Abstract: As dependability is an important activity in any engineering design, this paper is dedicated to the Wireless Sensing Networks (WSN) system design dependability measurement. The concepts of Reliability, Availability, and Mean Time To Failure (MTTF) related to system dependability will be explored, besides the major control system considerations. In this paper mathematical model and Fault Tree Analysis (FTA) tool for measuring and evaluating the system dependability have been used. Therefore, in the mathematical part, the probability theory has been used to measure Reliability R(t), and (MTTF) as the system dependability attributes. In the second part, the same test has been accomplished by (FTA) using Sharpe's tool software as an alternative method of check. Hence, the obtained measured results of these models were significant, tend to be identical, and helpfulness for improving the system dependability.

Keywords: Dependability Attributes, WSNs, probability theory, FTA..

Introduction

The WSN system is usually organized as a hierarchical network, consisting of heterogeneous devices with different functionalities [1]. At the very ends there are sensors and wireless embedded devices, which are connected by cables or wireless to a centralize device such as Programmable Logic Controllers (PLCs) that link and control field devices.

Nowadays, WSNs have been used with success into more and more critical application scenarios, such as large-scale industrial applications, where the dependability acquires an important consideration during the design and development of the systems. However, unreliable hardware, installed software, energy consumption and topology are the major constraints affecting WSNs dependability [2]. For this reasons, dependability evaluation of WSNs is gaining popularity since it could help to reduce risks and money lost before the deployment [3]. This paper studies the dependability attributes for WSNs from the systems' and components' point perspective.

Dependability

The ultimate goal of our work is the development of a dependable system. In broad terms, dependability is the ability of a system to deliver its intended level of service to its users [4]. The dependability is one of the most important and prominent design factors, which are related to WSN. Three primary dependability attributes are reliability, availability, and maintainability. Other possible attributes include safety, testability, performability, and security [5]. In the following sections we provide a brief definition to reliability. availability and maintainability concepts that are closely related with the purpose of the study.

Reliability

The focus of reliability theory studies is the overall performance of a system comprising failure-prone elements. Typically, the components of the system are not perfect with respect to their operation, and their underlying failure structure is assumed to follow certain probabilistic distributions. It is therefore important to characterize the behavior of the system in terms of the stochastic behavior of its components.
The reliability of a network is its ability to maintain its being operational over a period of time t. formally, the reliability R(t) of a network is:
R(t) = Pr (the network is operational in [0, t]}[6].

Availability

The availability of a network is often expressed as the instantaneous availability A(t) and/or the steady- state availability (i.e., limt→∞A(t)). The A(t) is defined as the probability that a system is operated at time t [7]. It allows one or more failures to have occurred during the interval [0, t]. If a system is not repairable (e.g., a spaceship), the definition of A(t) is equivalent to R(t). Dependability is used as a catch-call phrase for various measures such as reliability, availability … etc.

Maintainability

Mean Time To Failure (MTTF): is a basic measure of reliability for non-repairable systems. It is the mean time expected until the first failure of a piece of equipment.

Main system considerations

Availability - Readiness for correct service
Reliability - Continuity of correct service
The failure:

a. faults that can affect the dependability of the system:
Faults are the defects that can occur within the system. For this task only permanent faults are considered. Thus, only field devices can fail. The communication link, due to its wireless nature, are only affected by transient faults (if it is used) and thus are considered to be negligible (i.e., they do not fail).

b. Network failures may arise from topology considerations.

Inputs:
The following are inputs data: network topology, devices (sensors, different types of valves, starters, Microcontroller, communication modules, PLCs), and device's redundancy.

Outputs:
It is possible to evaluate the reliability, availability, and MTTF of the system.

Dependability Measurement Methods

In any system design, the reliability is concerned with the interconnectivity of various design elements in the form of network, or tree, as demonstrated by devices, wireless communication link, central control unit, and operation/application programs [8]. For example, the nodes might represent the physical components (sensors, valves, starter, motor, etc.) and wireless network might represent existing communication modules between these devices and control Unit (PLC). Each device or communication module can be either operational or, failure. Operational in this case means that a specific sender and specific receiver are able to communicate over certain wireless network, while failure means no complete transmission is available.

In this mission, two simulation models, which are mathematical and fault tree using SHARPE software [9] tool have been used to calculate the measurement metrics of dependability attributes that connected with a system designed for control the pump operation. This pump operates through a control circuit known as starter. This starter switched ON/OFF using switch sensor (SWs) according to controlled wireless signal from reservoir level sensor (Ls) as shown in Figure 1 [10]. Then the reading obtained from these two models are analyzed and used to improve dependability results.

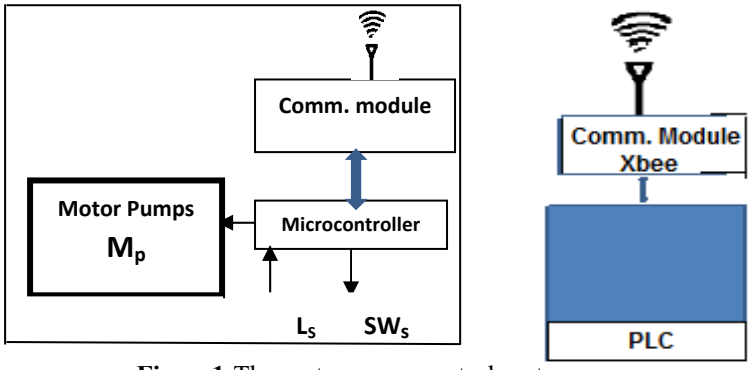


Figure1 The motor pump control system

Mathematical model measurement

The probability theory has been used to measure Reliability R(t) and MTTF of the system [10]. In order to master both the "model building" and the subsequent analysis of this model, we must have certain knowledge of basic probability theory.

Series components

Suppose two components are worked up in series, so in order the system works, both components must be functioning independently. Then the reliability of the system, R(t) can be obtained in term of the reliabilities R1(t) , R2(t) of the two components [11].

$$R(t) = P(T \geq t)$$
$$R(t) = P(T_1 \geq t, T_2 \geq t)$$

Where:

T_1 = life time of the first component

T_2 = life time of the second component

$$R(t) = P(T_1 \geq t).P(T_2 \geq t)$$

$$= R_1(t).R_2(t)$$

Considering the case n=2, and the failure law for i^{th} component equal $e^{-\alpha it}$ (exponential distribution), therefor:

$$R(t) = e^{-\alpha_1 t}.e^{-\alpha_2 t} = e^{-(\alpha_1+\alpha_2)t}$$

Where α is a failure rate.

For n components:

$$R(t) = R_1(t).R_2(t)...R_n(t) \qquad (1)$$

$$R(t) \leq Min\,[(R_1(t).R_2(t)...R_n(t)]$$

To generalize the equation

$$R_n(t) = \prod_{i=1}^{n} R_i$$

Mean Time To Failure MTTF:

In the case of the system design, MTTF is equal to:

$$MTTF = \int_0^{\infty} t.R(t).dt = \frac{1}{\alpha} \quad (2)$$

Parallel components

In parallel, the system fails to function only if all components fail. For the two components in parallel, the system is depicted below [11]:

The unreliability of the system (Q)

$$Q(t) = Q_1(t).Q_2(t)$$

Therefore, Q is representing the probability that the system doesn't work.

$$Q(t) = 1 - R(t)$$

$$R(t) = 1 - Q_1(t).Q_2(t)$$

$$R(t) = 1 - [(1 - R_1(t)).(1 - R_2(t))]$$

For n Components in parallel,

$$R(t) = 1 - [(1 - R_1(t)).(1 - R_2(t)).\dots.(1 - R_n(t))] \quad (3)$$

$$R(t) = R_1(t) + R_2(t) - R_1(t).R_2(t)$$

$$R(t) = e^{-\alpha_1 t} + e^{-\alpha_2 t} - e^{-(\alpha_1+\alpha_2)t}$$

MTTF:

$$MTTF = \int_0^{\infty} t.R(t).dt = \frac{1}{\alpha} \quad (4)$$

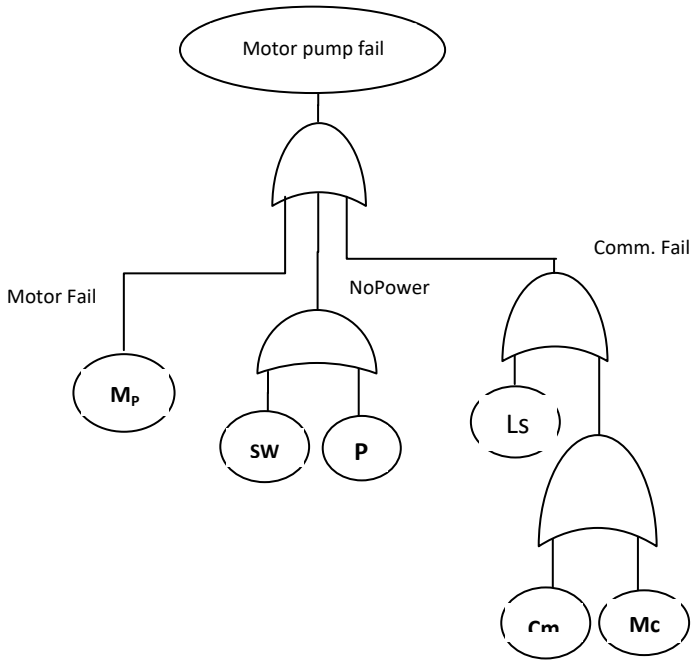
Because $[R_1(t) . R_2(t)]$ is small enough

$R(t) \geq Max\ [(R_1(t).R_2(t)]$

So, the parallel components usually are used to increase the reliability.

Fault Tree Analysis Model Measurement

In this part, the FTA model using Sharpe tool presents all components relationships which are involved in the system. FTA identifies this design model and evaluates the unique interrelationship of events leading to system failure as shown in figure 2 below [12].



Pump's motor	M_P	Power	P
Switch	SW	Level sensor control	Ls
Microcontroller	Mc	Communication module	Cm

Figure 2. The fault tree analysis design system for motor pump fail

Applying Model for the System Design

Mathematical Model outputs

This section measure the system dependability attributes when using mathematical model. The system mainly include the communication module, microcontroller, level and switch sensors, power system and motor device that are connected in series with AND gate with its industries failure rates shown in figure 3.

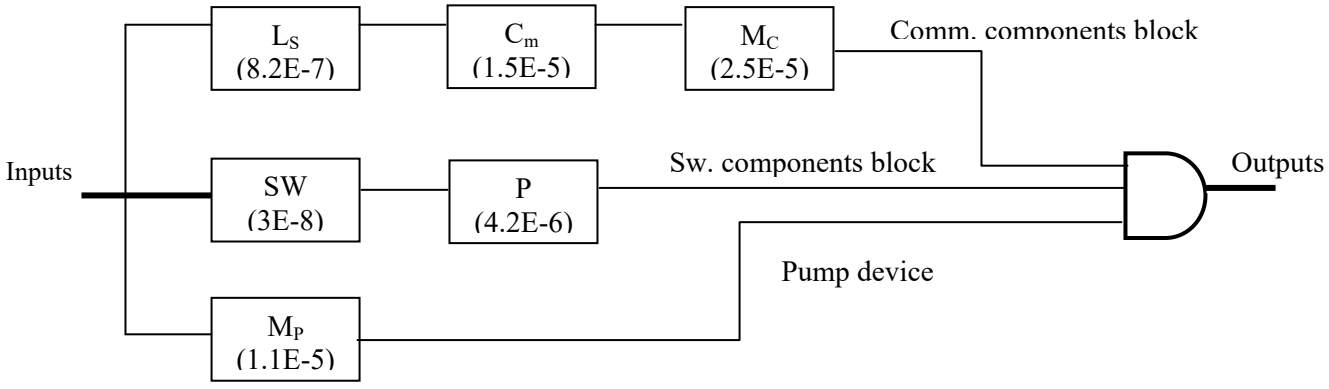


Figure 3 The mathematical demonstration for motor pump system design

Therefore, the measurement runs as follows:

According to equation (1) the reliability for communication components in series $R_{com}(t)$:

$$R_n(t) = \prod_{i=1}^{n} R_i(t)$$

$$R_{com}(t) = e^{-\alpha_{LS}t} \cdot e^{-\alpha_{SW}t} \cdot e^{-\alpha_{ME}t} = e^{-(\alpha_{LS}+\alpha_{SW}+\alpha_{ME})t}$$

$$\alpha_{com} = \alpha_{SW} + \alpha_{ME} + \alpha_{LS}$$

$$\alpha_{com} = 4.082E-5$$

For 24 hours of operation, the reliability of the communication block is equal to:

$$R_{com}(t) \simeq 0.999020 \simeq 99.90\ \%$$

According to equation (2), the MTTF equal:

$$MTTF_{hrs} = 1/\alpha = 24497.79\ hrs$$

$$MTTF_{yrs} = 2.7992\ years$$

According to equation (1) the reliability for switching components in series $R_{switch}(t)$:

$$R_{switch}(t) = e^{-\alpha_{SW}t} \cdot e^{-\alpha_{P}t} = e^{-(\alpha_{SW}+\alpha_{P})t}$$

$$\alpha_{switch} = \alpha_{SW} + \alpha_{P}$$

$$\alpha_{switch} = 4.23E-6$$

For 24 hours of operation, the reliability of the switching block is equal to:

$$R_{switch}(t) \simeq 0.999898 \simeq 99.98\ \%$$

According to (2), the MTTF:

$$MTTF = \int_0^{\infty} t \cdot R(t) \cdot dt = \frac{1}{\alpha}$$

$$MTTF_{yrs} = 26.9898\ years$$

According to equation (2) the reliability for pump device $R_{pump}(t)$:

$$R_{pump}(t) = e^{-\alpha_{PMP}t}$$

$$\alpha_{pump} = 1.1E-5$$

For 24 hours of operation, the reliability of pump is equal to:

$$R_{pump}(t) \simeq 0.999736 \simeq 99.97\ \%$$

Then the main time to failure (MTTF) for pump is equal to:

$$MTTF = \int_0^{\infty} t.R(t).dt = \frac{1}{\infty}$$

$$MTTF_{hrs} = 99988.09\ hours$$

$$MTTF_{yrs} = 10.3804\ years$$

Finally, the reliability for the control subsystem used in intake phase of the plant can be calculated as follows:

$$R_{sys}(t) = R_{com}(t).R_{switch}(t).R_{pump}(t)$$

$$R_{sys}(t) \simeq 0.998634 \simeq 99.86\ \%$$

According to equation (2), the MTTF:

$$MTTF = \int_0^{\infty} t.R(t).dt = \frac{1}{\infty}$$

Then, the $MTTF_{sys}$ for the control subsystem used in intake phase equal to:

$$MTTF_{yrs} = 2.0366\ years$$

Improve the Dependability Results:
According to the design, the component with high rate failure will back up with the same redundant components to improve the systems reliability. As shown in the Figure 4, the redundant microcontroller device has been added in parallel to the design.

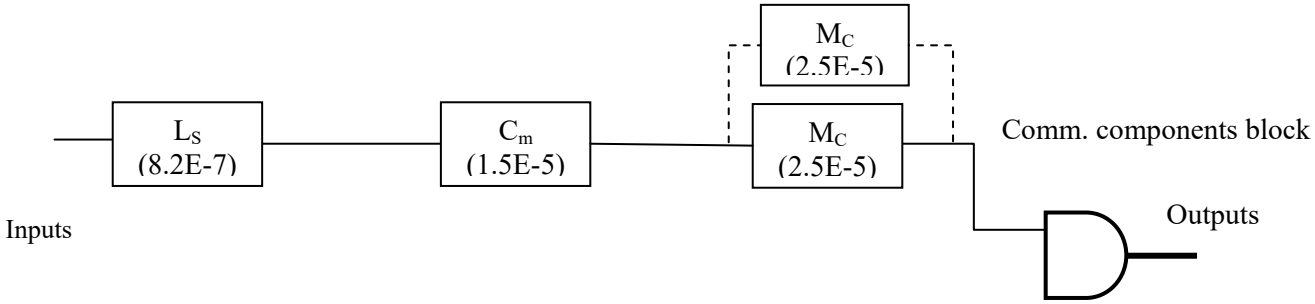


Figure 4 Thesystem design with redundant microcontroller installed in parallel

In this case, to obtainthe measurement results the equation1(1& 3) will be used for serial and parallel components; therefore, the reliability for this branch will be increase in line with the following law

$$R_{com}(t) = e^{-(a_{in}+a_{out})t} \cdot \left(1-\left(1-R_{Mc}(t)\right)^{2}\right)$$

For 24 hours of operation, the reliability of pump $R_{com}(t)$is equal to:

$$R_{com}(t) = 0.999622 * 0.999999$$

$$R_{com}(t) \simeq 0.999621 \simeq 99.96\ \%$$

According to equation (4), MTTF:

$$MTTF = \int_{0}^{\infty} t.R(t).dt = \frac{1}{\alpha c}$$

Then, the MTTF:

$$MTTF_{com} = 4.0931\ years$$

Accordingly, the reliability for intake subsystem will increase to:

$$R_{sys}(t) \simeq 0.999255 \simeq 99.92\ \%$$

Therefore, the MTTF will increase to:

$$MTTF_{sys} = 2.6212\ years$$

Sharpe Tool Model Output

After running the program to 24 hours per day the results was attained for the system design. It is worked first with basic components as shown in figure 4, then after added redundant microcontroller in parallel.
The system out
Case one: without redundantdevice:

t=23.000000

Reliability (t): 9.98711681e-001

Mean time to failure, MTTFval: 1.78412132e+004

Case two: when we add to the microcontroller a redundant one in parallel (OR Gate):

t=23.000000

Reliability (t): 9.99285775e-001

Mean time to failure, MTTFval: 2.33443635e+004

Results Discussion and Assessment

The reliability and MTTF obtained results are arranged in the Table 1 for both mathematical model and FTA using Sharpe tool. It contains summary obtained results for subsystems design before and after adding redundant components.

Table 1: Mathematical and Shape results summary

System Model	The measurement results for the main design		The measurement results after adding redundant component	
	Reliability	**MTTF (years)**	**Reliability**	**MTTF (years)**
Mathematical	0.998654	2.0366	0.999255	2.6212
Sharpe	0.998711	2.0366	0.999285	2.6648

Mathematical and Sharpe tool output graphs:
As it can be observed the reliability for the systems without redundant device was low or below the system requirement and it's around 99.43%. However, after adding redundant device in parallel to the weakest device in both cases of model design, the system dependability improved (i.e. the reliability increased to around 99.89%). The obtained results represented the effectiveness of the methods used; therefore, the safety of the system may depend only on a very small and cheap device.

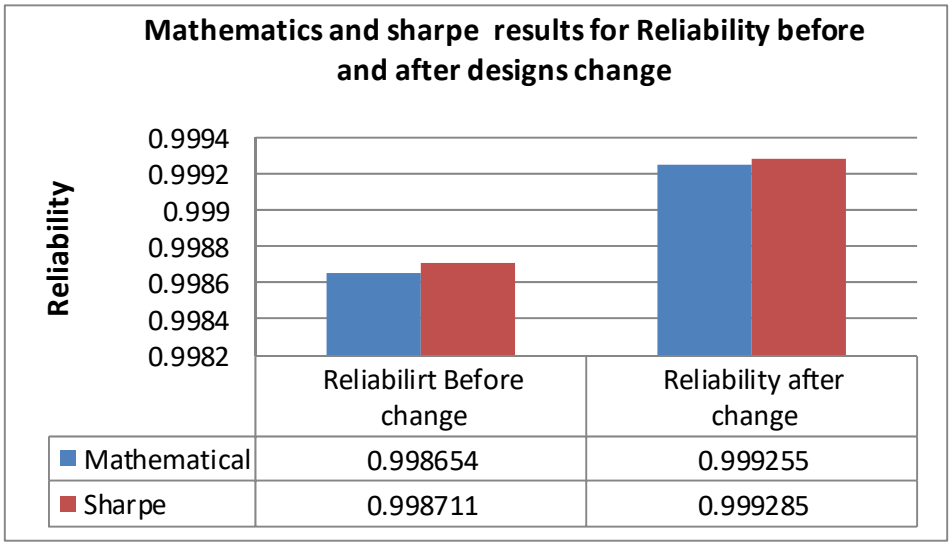


Figure 5 Reliability Chart before and after models design change

Simultaneously, when the system becomes reliable, the life time will also be prolonged. Hence, the MTTF maximized by around 23 %, however, the realization of the supplied factory data is very important that helps to achieve accurate results.

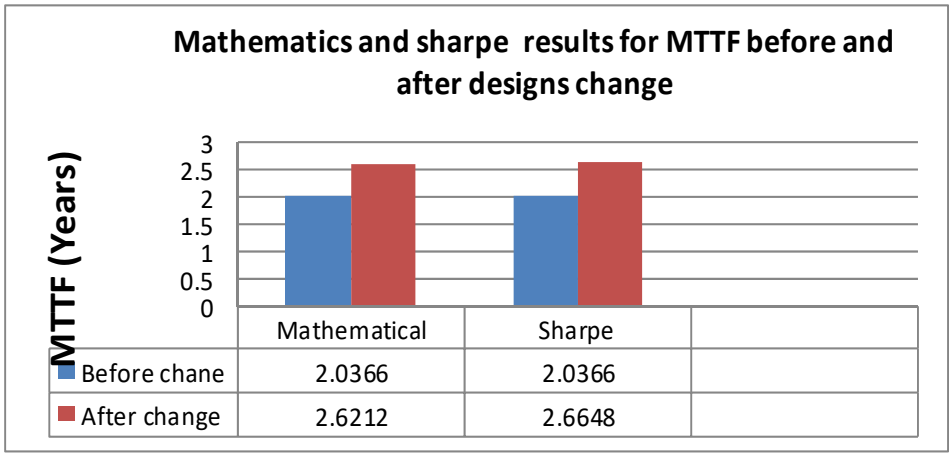


Figure 6 MTTF Chart before and after models design change

The output from Sharpe program, Figure 7 shows the systems exponential reliability graphs, prior and after the design modification. Therefore, comparing the two graphs shows to what extent the reliability of the system can be improved after adding redundant device.

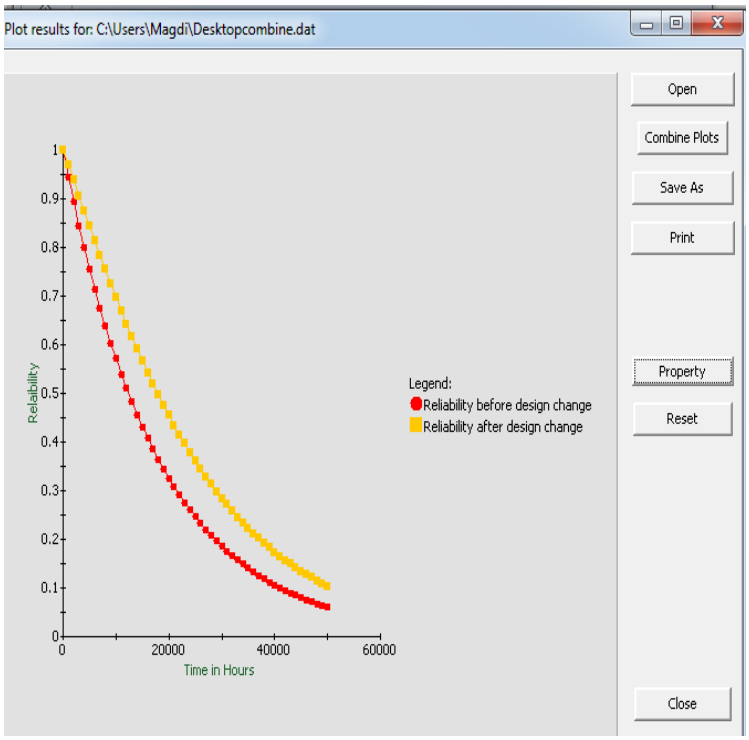


Figure 7 Sharpe tool Reliability output graphs

Conclusion

By means of WSN considered as a model technology for the use in many advanced systems, its dependability should be monitored and improved. Two types of models; Mathematical and FTA using Sharpe's tool has been used and implemented in this paper. The readings collected from the system design models outputs before and after adding redundant device to the weak device in the system. The obtained results have been tested and assessed accordingly. Therefore, in two models the readings tend to be identical, even when the designs modified, showed a significant improves in the system dependability attributes. Thus, without care about the issue of dependability concerning the developing and improving the processes especially those related to human health and safety, this might cause undesirable effects.

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