Reliability Analysis in Wireless Sensor Networks

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***Abstract* —This paper presents a Markov model for reliability using different types of Sensors and spares that replace sensors in case failure occurs. The primary idea in this paper is to address and analyze the reliability issues to device a reliable and fault tolerance model for a sensor network system. We analyzed the model in terms of reliability and MTTF (Mean-Time-To-Failure). Our research work focus on the mechanism for providing an alternative of a redundant network by replacing the faulty sensor with the available spares.**

***Index Terms*—Reliability, Absorbing State, Wireless Sensor Network, MTTF, Fault Tolerance, Markov model.**

I. Introduction

Wireless sensor networks (WSNs) are the topic of intense academic and industrial studies. Research is mainly focused on energy saving schemes to increase the lifetime of these networks [1][2]. There is an exciting new wave in sensor applications-wireless sensor networking- which enables sensors and actuators to be deployed independent of costs and physical constraints of wiring. Sensor networks do not rely on any hard -wired communication links; there fore, they can be deployed in places without infrastructure, and they can be used in medical assistance, surveillance, reconnaissance, disaster relief operations [5][6]. Increasing computing and wireless communication capabilities expand the role of sensor from mere information dissemination to more demanding tasks as sensor fusion, classification etc. Fault tolerance and reliability performs exclusively vital role for embedded systems, such as obscured wireless sensors, which are deployed in some applications where it is difficult to access them physically. For a wireless sensor network to deliver real world benefits, it must support the following requirements in deployment: scalability, reliability and fault tolerance, responsiveness, power efficiency and mobility. The complex inter-relationships between these characteristics are a balance; if they are not managed properly, the network can suffer from overhead that negates its applicability. In order to ensure that the network supports the application's requirements, it is important to understand how each of these characteristics affects the reliability.

II. Reliability and fault tolerance

The fault tolerance is ability for a system to continue functioning properly even after failures in any part of the system have occurred. Fault tolerance in wireless sensor network can be provided in three ways [3]: 1. through hardware improvement and backup components, 2. through traffic management and 3. through redundant network design. Wireless Sensor Network (WSN) is transforming into a multi service medium leading to the convergence of voice, video and data communication. Each type of service has a particular constraint and it has to be satisfied for the communication to be effective. In [4] an interesting research regarding the fault tolerance aspects of a sensor network assumes that the nodes are either active or inactive with Bernoulli model. In case that one or more sensor fails, other sensors of a different type can substitute their work, such that the fault goes.

Reliability: The probability that a component survives until sometime t is called the reliability R(t) of the component. Let X be the random variable representing the life time of a component then R(t)=P(X>t)=1-F(t); where F(t) is called the unreliability of the component.

The unreliability of a system is F (t) = 1 - R (t). For any system, Initially the system is functional at t=0: R(0)=1, F(0)=0. Eventually the system will fail at t=T, R(T)=0, F(T) =1.

MTTF: the expected life or the mean time to failure (MTTF) of the component is given by

$E[X] = \int_0^\infty t.f(t)dt = \int_0^\infty tR'(t)dt$; where R' (t)=-f(t) and R(t)=P(X>t).

$$E[X] = -tR(t)\,|_0^\infty + \int_0^\infty R(t)dt$$

Now, since R(t) approaches 0 faster than t approaches ∞, we have $E[X] = \int_0^\infty R(t)dt$.

Failure rate: Failure rate, h(t), is the conditional probability that a component surviving to age t will fail in the interval (t, t + Δ t).

h(t)=f(t)/R(t)= $R'(t)$ / R(t). if component life time is exponentially distributed, then R(t)=$e^{-\beta t}$ and

h(t)=β $e^{-\beta t}$/ $e^{-\beta t}$ =β

The spares can replace faulty components. We consider in our models hot or stand-by spares, which means that they replace immediately the failed sensor (there is no gap in time between the moment the sensor has failed and the moment the spares replace it) When the spares substitutes a module, then it has the same failure rate as the module. We study two models. 1. We start with a model in which no spare is used. 2. a model in which a spare can replaced a faulty sensor. We continue with spares that can replace any type. In order to achieve a better reliability of the system, one solution is to improve the quality of spares; another one is to increase the number of spares.

III. PROPOSED MODEL

Consider a two sensor parallel-redundant system with replacement rate r as shown in fig 1.

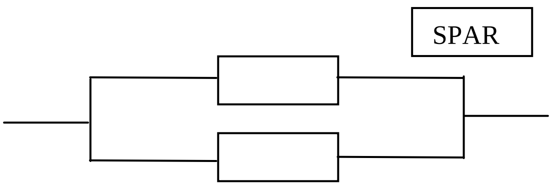

Fig 1 Reliability block diagram

Assuming failure rate of both sensors is β. When both sensors have failed, the system is considered to have failed & no replacement is possible. Let number of sensors properly functioning be the state of the system. The state space is {0, 1, 2} where 0 is the absorbing state. State 1 & 2 are transient states. State diagram is shown in fig 2.

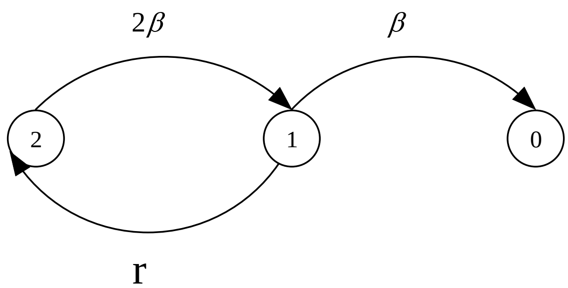

Fig 2 Finite Markov chain with absorbing state for 2 sensor parallel redundant system

Assume that the initial state of Markov chain is 2 when both sensor are functioning properly; that is, p2(0)=1, pk(0)=0 for k=0, 1.

Then pj(t)=p2j(t) and system of differential equations becomes:

$$\frac{dp_2(t)}{dt} = -2\beta p_2(t) + rp_1(t)$$
$$\frac{dp_1(t)}{dt} = -2\beta p_2(t) - (\beta + r)p_1(t)$$
$$\frac{dp_0(t)}{dt} = \beta p_1(t)$$

Taking Laplace transform, system can be reduced as under:

$$s\, P_2(s) - 1 = -2\beta \overline{P_2}(s) + r\overline{P_1}(s)$$
$$s\, \overline{P}_1(s) = 2\beta \overline{P_2}(s) - (\beta + r)\overline{P_1}(s)$$
$$s\, \overline{P}_0(s) = \beta \overline{P_1}(s)$$
$$\therefore \overline{P_0}(s) = \frac{2\beta^2}{s[(s^2 + (3\beta + r)s + 2\beta^2]}$$

After taking inverse Laplace, we can obtain P0(t), the probability that no sensors are working at time t ≥ 0. Thus the reliability of system at time t is R(t)=1-P0(t)

Laplace transform of failure density

$f_x(t) = \frac{-dR}{dt} = \frac{d\ P_0(t)}{dt}$ is then given by

$$L_x(s) = \overline{f_x}(s) = s\overline{P_0}(s) - P_0(\overline{O}) = \frac{2\beta^2}{s^2 + (3\beta + r)s + 2\beta^2} \qquad = \frac{2\beta^2}{\alpha_1 - \alpha_2}\left(\frac{1}{s + \alpha_2} - \frac{1}{s + \alpha_1}\right)$$

Where $\alpha_1; \alpha_2 = \frac{(3\beta + r) \pm \sqrt{\beta^2 + 6\beta r + r^2}}{2}$

Taking the inverse transform

$$f_x(t) = \frac{2\beta^2 (e^{-\alpha_2 t} - e^{-\alpha_1 t})}{\alpha_1 \alpha_2}$$

Thus the MTTF (Mean-Time-To-Failure) of the system

$$E[X] = \int_0^\alpha x f_X(x)dx = \frac{2\beta^2}{\alpha_1\alpha_2}[\int_0^\alpha xe^{-\alpha_2 x}dx - \int_0^\alpha xe^{-\alpha_1 x}dx]$$

$E[X] = \frac{2\beta^2}{\alpha_1\alpha_2}[\frac{1}{\alpha_2^2} - \frac{1}{\alpha_1^2}]$; Re-calling that $\int_0^\alpha xe^{-\alpha x}dx = \frac{1}{\alpha^2}$

$$E[X] = \frac{2\beta^2(\alpha_1 + \alpha_{2)}}{\alpha_1^2\alpha_2^2} = \frac{3}{2\beta} + \frac{r}{2\beta^2}$$

MTTF of the two sensor parallel-redundant system, in absence of a replacement facility (i.e. r=0), is equal to $E[X] = \frac{3}{2\beta}$ Therefore, the effect of a replacement facility is to increase the MTTF by $\frac{r}{2\beta^2}$ or by a factor of $\frac{r}{3\beta}$.

IV. RESULTS

Fig 3.1, 3.2, 3.3 and 3.4 shows the mean time to failure, taking particular values for β: 0.01, 0.02, 0.03, 0.04, 0.05 and 0.06 as the number of failures per 10000 seconds. Fig 3.1 shows the comparison between the systems with replacement rate r=0 and r=β. Fig 3.2 shows the comparison between the systems with replacement rate r=0 and r=0.001. Fig 3.3 shows the comparison between the systems with replacement rate r=0 and r=0.009. Fig 3.4 shows the comparison between the systems with replacement rate r=0.001 and r=0.009. in all the cases, if a spare sensor replaces a failed sensor then MTTF increases by a factor $\frac{r}{3\beta}$.

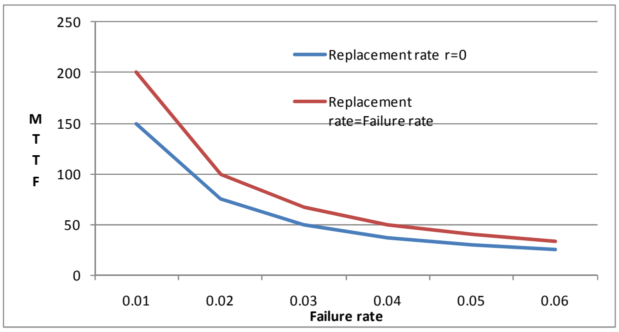

Fig 3.1 MTTF versus Failure rate

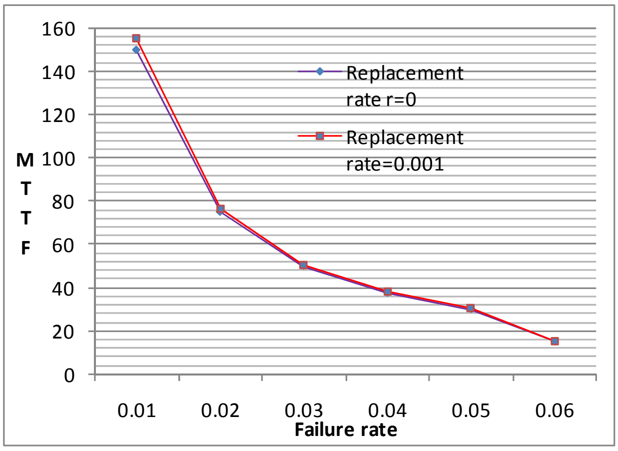

Fig 3.2 MTTF versus Failure rate

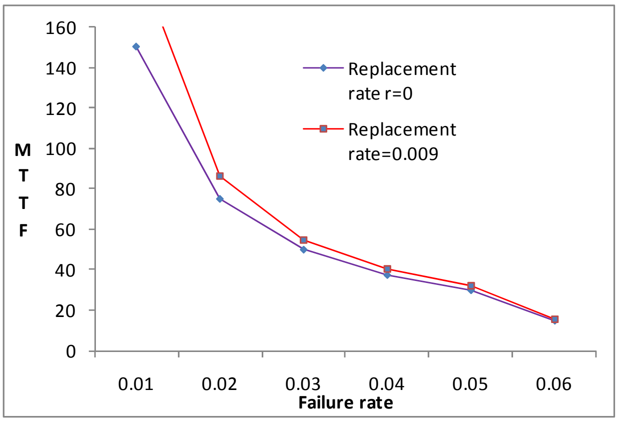

Fig 3.3 MTTF versus Failure rate

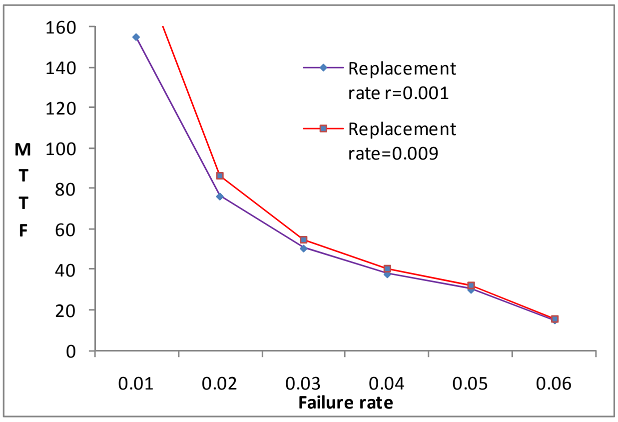

Fig 3.4 MTTF versus Failure rate

V. Conclusion

This paper is a contributing effort to explore the reliability issues in wireless sensor networks. We presented the system reliability for the two cases: 1. without provision of standby spares, 2. with the provision of standby spares. The system lifetime is calculated and the suggestive values for the different β are given. We compare these two models in terms of MTTF (Mean-Time-To-Failure). In second model MTTF increases by a factor of $\frac{r}{3\beta}$.

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