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Reliability Assessment of Access Point of Advanced Metering Infrastructure based on Bellcore Standards (Telecordia)

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***Abstract*— Since Access Point (AP) is a vital part of the Advanced Metering Infrastructure (AMI) for communication and data collection from smart meters, its reliability issue has become one of the prominent issues in the context of the Smart Grid. AP is responsible for collecting data from humongous meters. Any defect in or malfunctioning of the device can result in humungous loss of data, consequently foundering the revenue. In this paper, we assess the reliability of the AP based on the Bellcore standards. Calculating the failure rate is facilitated by applying this reliability-driven method for the AP. The reliability prediction for electronic products has been used to speculate the probable reliability level, according to the selection in the design process, such as circuit structure, components, and reliability structural model as well as working environment, work stress and accumulated statistical data.**

Keywords: Access Point, Reliability Prediction, Failure Rate, Smart Grid, AMI etc.

I. INTRODUCTION

The requirement of reliability for electronic devices is becoming stringent both for military and civilian applications. Reliability prediction is an estimation method to forecast the reliability at the component as well as at the system level. Traditional unit component reliability is a manual/standard based prediction and its prophesized results are well recognized by the industry. All methods are empirical manuals based on the test data. A series of parameters including environmental issues may be determined from the manual in order to estimate the failure rate accordingly. Reliability prediction manual includes GJB/Z 299C [1], MIL-HDBK-217F [2], Bell core (Telecordia –SR-332) [3] etc. GJB/Z 299C is designed for components made in China, and MIL-HDBK-217F represents the imported components. Telecordia– SR-332 is appropriate for commercial electronics components. Bellcore standard was developed by the Bell Labs. It was then purchased by the SAIC Company and renamed Bellcore standard as Telecordia in 1997. The latest version of Telecordia is Telecordia –SR-332 [3].

Smart Grid is a modern electric power system utilizing innovative communication and distribution entities with improved monitoring, control and efficiency. A touted feature of Smart Grid is the constitution of bi-directional interaction among its entities. In Smart Grid, AMI is the distribution level building block. In AMI, smart meters record electricity consumption and send the collected data to the utility office, serving as an input for the implementation and control of Demand Response (DR), monitoring etc. In a cluster of smart meters, up to 3000- 4500 meters can report their data through an AP. An AP is connected to the back office of the utility company by reliable wireless/ wired/ optical communication protocols. Since a single AP is accessed by 3000-4000 smart meters, the reliability of AP is very crucial for the cumulative system reliability, as well as from revenue point of view. The failure statistics of a local utility company of Florida are shown in Fig 1.

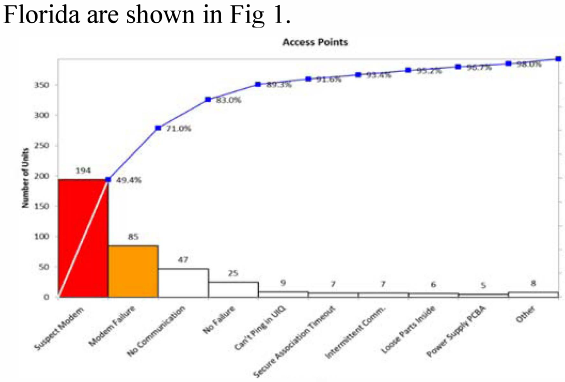

Fig 1. Statistics of AP failure of a local utility company

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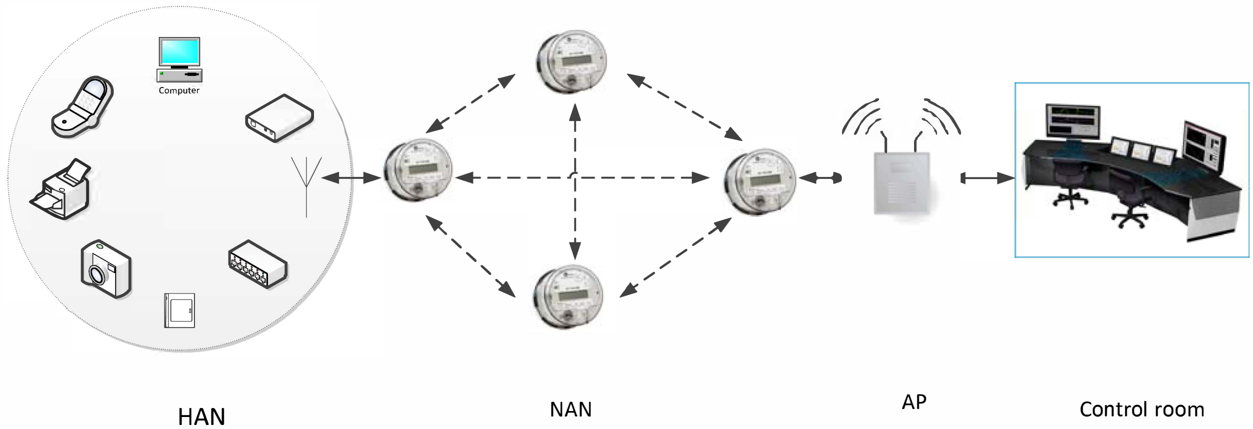

Fig. 2. A general architecture of AMI

In [9], the reliability of AMI has been assessed based on Fuzzy Markov Model (FMM), focusing more on the integration for AM considering environment with both cognitive and non-cognitive uncertainties. On the other hand, to find the weak link in the design and provide a technical basis for improving the reliability of smart meters, a reliability software was proposed in [10]. The reliability of the communication system of the Smart Grid was addressed in [11] considering the hierarchical structure comprising Home-Area Network (HAN), Neighborhood-Area Network (NAN), and Wide-Area Network (WAN). In [12-13], the authors investigate the reliability of smart meters based on the component failure, electrical and environmental stress factor. However, the reliability of AP has not been addressed.

In this paper, we investigate the reliability of AP based on the Bellcore standard- Telecordia –SR-332. We aim to find component reliability and derive the system level reliability of whole AP from that result. We also incorporate environmental factors like temperature and humidity, and radio signal propagation reliability in calculating the reliability.

The rest of the contents of this paper are organized as follows. Section II describes the architecture of AMI and AP. In sections III & IV, the corresponding mathematical model, simulation and results have been described and illustrated respectively. Finally, a brief conclusion is given in section V.

II. Architecture

A. Architecture of AMI

AMI is a network of millions of meters which not only communicate among themselves but also with the utility service provider. It is responsible for sending and receiving huge volumes of data periodically through a Gateway, called AP. It is considered as one of the prominent components of the Smart Grid. It consists of different components which have different applications. We provide an insight into the outline of AMI that encompasses everything between home appliances and the control center.

Home appliance: Home appliances are usually electrically powered machines, such as a stove, microwave, or a dishwasher, which are used in homes to perform particular jobs. The energy consumed by these devices is encapsulated as a consumption unit of the Smart Grid system. The entire consumption unit is connected to a smart meter which measures and collects the power consumption information.

Smart meter: It is a solid state device which communicates between the consumption unit and the service providing unit. It can gather data for remote data reporting and enables two way communications.

It is capable of collecting, storing and sending data periodically using communication networks.

AP/ Data Concentrator/ Gateway: Each smart meter is connected to a network of smart meters called NAN. A NAN has a concentrator (i.e., AP/Gateway) to collect the data packets (i.e., HEMS traffic) from smart meters using short-range communication technologies (e.g., Wi-Fi, ZigBee, etc.). Different types of data packets with different Quality of Service (QoS) requirements can be stored in different buffers. These APs are further connected to the control center of the utility service provider.

Control center/ Hardware and software control system/ Utility Back office: The control center receives data and makes a bill for the consumer. This data is also used to optimize the electrical power generation and distribution. Controlling and monitoring can be done from remote locations depending on the usage and load requirement.

B. Architecture of AP

AP is a special-purpose communication device in wireless local area networks which allows smart meters to connect to the back office (control center) of the utility service providers using ZigBee, Wi-Fi, or similar standards. An AP might be connected to a router (via a wired network) as a standalone device, or as an integral component of the router itself. Usually the AP (i.e. Router) is connected to the back office/ Control center with wired/ optical fiber/wireless medium.

AP acts as a central transmitter and receiver of wireless radio signals. A typical AP can collect data from 3000-4000 meters. A mainstream wireless AP supports Wi-Fi and is most commonly used to support public internet hotspots and other business networks where larger buildings and spaces need wireless coverage.

From a hardware structural point of view, APs are small hardware devices, closely resembling home broadband routers. A typical AP's hardware consists of radio transceivers, antennas, CPU, WLAN, memory, clock, power supply and network and information security unit.

III. Mathematical Model

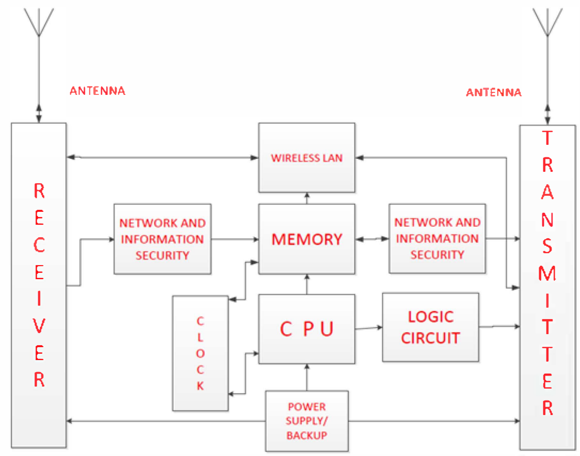

Fig 3. Architecture of AP

The following models are taken from the Telcordia SR-332 with the environmental factors influencing the device reliability. A frequency factor known as Radio/ Frequency link reliability [7] has also been considered in the overall reliability calculation.

Unit Steady-State Failure Rate Using the Parts Count Method: According to Telcordia SR-332, the traditional technique used for prediction is parts count method which states that the rate of failure of one unit is equal to the sum of the failure rates of all the devices present in the unit. This technique is computed as a product of environmental factor per unit and sum of the device failure rate predictions. The mean steady state failure is given by

$$\lambda_{PC} = \pi_E \sum_{i=1}^{n} N_i \lambda_{BB_i} \tag{1}$$

where N=n number of devices based on the units' environment in Telcordia SR-332. The environmental factor is divided into five classes. The prediction technique used in this paper is based on Telcordia SR-332 black box integrated with the field data method which assumes that the required field data on the device is available for prediction.

The prediction of the steady-state failure rate for a device is based on a generic steady-state failure rate for the type of the device. This generic value is then modified for the desired quality, stress, and temperature. The black box steady-state failure rate λ_{BB_i} for device i is-

$$\lambda_{BB_i} = \lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{T_i} \tag{2}$$

where λ_{G_i} = mean generic steady state failure rate

π_{Q_i} =quality factor for the device

π_{S_i} =stress factor

π_{T_i} =temperature factor

If we consider the humidity factor and radio frequency link reliability, the equation (2) becomes

$$\lambda_{BB_i} = \lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{HT_i}\pi_{F_i} \tag{3}$$

where

π_{HT_i} is the humidity and temperature factor

π_{F_i} is the reliability for the frequency link

Electric stress factor π_{S_i} **:** The value of electric stress ranges from 0.1 to 10.6 when the minimum and maximum stress varies from 10% to 90% on most sensitive devices. An unknown stress designates a value of 50% which produces a stress factor value of 1 for all device types.

The electrical stress factor π_{S_i} can be calculated by

$$\pi_{S_i} = \exp[m\,(p_1 - p_0)] \tag{4}$$

where, m define the curve obtained from the device failure rate.

p_0 is the reference stress and p_1 is the stress percentage.

Temperature and Humidity factor π_{HT_i} **:** The temperature factor which is known by the Arrhenius equation is given as π_{T_i}

$$\pi_{T_i} = Exp\left[\frac{E_a}{k}\left(\frac{1}{T_0} - \frac{1}{T_1}\right)\right] \tag{5}$$

T_0 is the reference temperature in ^oK.

T_1 is the test temperature ^oK.

k is the Boltzmann constant = $8.62e^{-5}$ eV/^oK.

E_a is the Activation Energy.

If we incorporate the humidity factor with temperature, equation (5) becomes

$$\pi_{H_i} = \left[\frac{RH_t}{RH_u}\right]^3 \frac{E_a}{k}\left(\frac{1}{T_r} - \frac{1}{T_t}\right) \tag{6}$$

where

RH_t is the humidity at test

RH_u is the reference humidity

E_a is the Activation energy (.7eV)

k is the Boltzmann's constant ($8.61*10^{-5}$eV/k)

Frequency link reliability π_{F_i} **:**

The reliability of radio frequency has been defined as

$$\pi_{F_i}(r_0, r_1 \ldots r_n) = \prod_{i=1}^{h} \exp\left(\frac{-dr_i - 1r_i}{Snr_{r_i} - 1r_i}\right) = \exp\left(-\sum_{i=1}^{h}\frac{-dr_i - 1r_i}{Snr_{r_i} - 1r_i}\right) \tag{7}$$

where h is the distance of a meter from the AP.

SNR is the signal to noise ratio.

r_0, r_1 …r_n are the different routes of the radio frequency channel.

IV. Simulation and Results

To determine the reliability of the AP, the following parameters have been considered from Telcordia SR-332.

Table I. Parameter I

Stress parameter	Value according to Telcordia	Criteria
1. Quality factor π_Q	1.0	**(a)** Steps must have been taken to ensure that the components are compatible with the design application and manufacturing process. **(b)** An effective feedback and corrective action program must be in place to identify and Resolve problems quickly in manufacture and in the field. **(c)**Purchase specifications must explicitly identify important characteristics

		(electrical, mechanical, thermal, and environmental) and acceptable quality levels (i.e., AQLs, DPMs, etc.) for lot of control. **(d)**devices and device manufacturers must be qualified and identified on approved parts/manufacturer's lists (device qualification must include appropriate life and endurance tests). **(e)** lot-to-lot controls, either by the equipment manufacturer or the device manufacturer, must be in place at adequate AQLs/DPMs to ensure consistent quality.
2.Environment factor π_E	2.0	Environmental stress with limited maintenance and usually in the areas subjected to atmospheric variations, temperature, vibrations.
3.Reference electrical factor P_O	50%	This percentage reference of electrical stress is assumed when the reference stress is unknown and where the stress can vary from 10% to 90%.
4.Activation energy E_a	0.22	This is the amount of activation energy required for the silicon devices used in the Arrhenius equation.
5.Fitting parameter m	0.0024	This is the fitting parameter for the electrical stress.

Table II. Parameter II

Reliability Factor	**Parametric Values**	**Reliability Failure rate**
Temperature Factor(π_{T_i})	45°C	0.7397
Electric Stress Factor(π_{S_i})	50%	1
Humidity Factor(π_{H_i})	89%	0.933
Frequency Factor(π_{F_i})	4 Hops/SNR = 13dB	0.0815
Black Box steady state Failure rate (λ_{BB_i})	$\lambda_{G_i}\pi_{Q_i}\pi_{S_i}\pi_{H_i}\pi_{F_i}$	0.2241
Mean Steady State Failure Rate (λ_{PC})	$\lambda_{PC} = \pi_E \sum_{i=1}^{n} N_i \lambda_{BB_i}$	0.4499
Mean generic steady state failure rate (λ_{G_i})	Obtained from Fig. 1	4

By using the above the parameter, we observed that the reliability depends on different factors. In Figure 4, reliability of a silicon device against different temperatures is plotted. The plot is a gradually decaying curve.

Figure. 5 shows the variation of humidity in percentage with the corresponding temperature. As the humidity increases, there is a decrement in the device reliability. Figure 6 shows a similarly

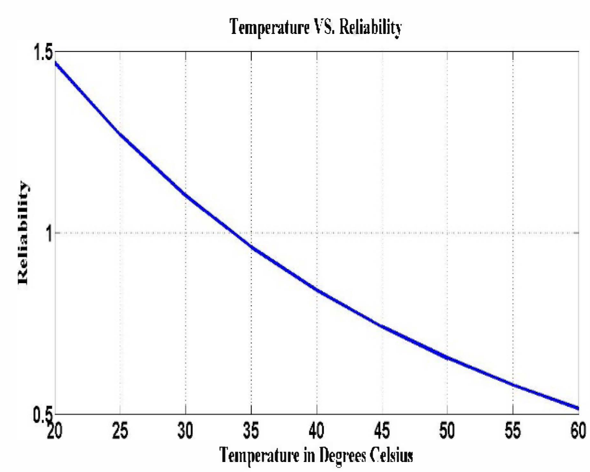

Figure 4:Reliability dependence on temperature

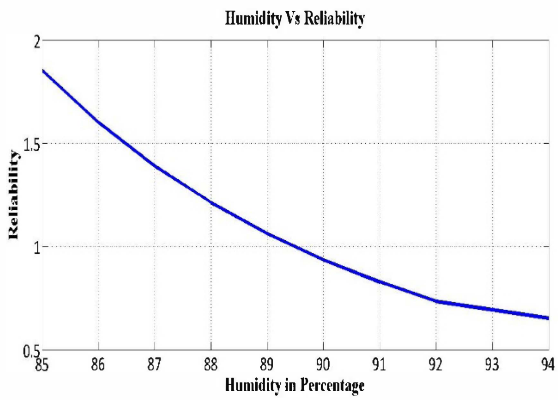

Figure 5: Reliability dependence on humidity

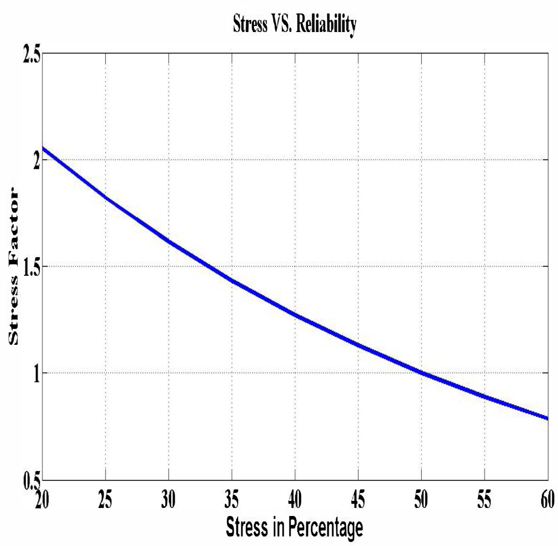

Figure 6: Reliability dependence on electrical stress

fashioned curve with a slightly less decaying curve of electrical stress versus temperature.

In Figure 7, it is observed that the reliability decreases with the increase in the number of Hops (links). There is a gradual decrement in the reliability with the increase in paths to the destination from the source.

Figure 8 plots the reliability against Signal to Noise Ratio (SNR).There is an increment in the reliability with an increase in the SNR signal.

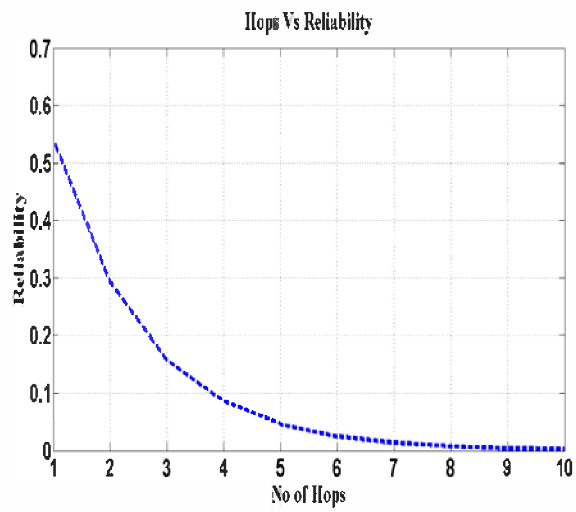

Figure 7: Reliability dependence on hops

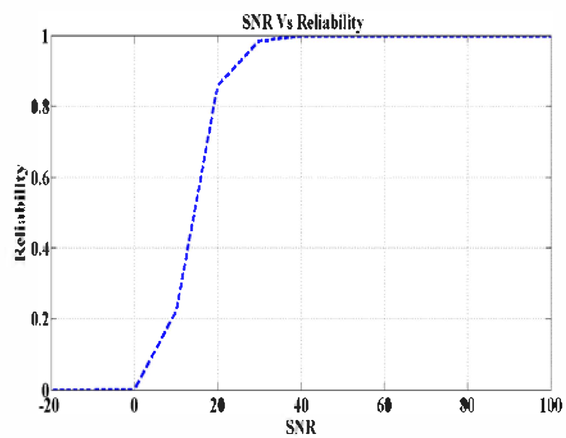

Figure 8: Reliability dependence on electrical stress

The overall system reliability is calculated using the values of Table.1 and Table.2. These values are substituted in the Equation.1 and Equation.3 to get the following results.

The overall system reliability is given as follows:

$$\lambda_{PC} = 2 \text{ x } 4 \text{ x } 0.7397 \text{ x } 1 \text{ x } 0.933 \text{ x } 0.0815$$

$$= 0.4499$$

V. CONCLUSION

Reliability analysis of AP shows an overall Mean Steady State failure rate of 0.4499. This assessment assumes certain standards from Bellcore, which have been included in the calculation for the overall reliability of the component. The system parameters affecting the reliability of the system such as temperature, humidity, electrical stress and radio links can have a higher impact than the software, procedural errors or unexpected failures. The prediction of reliability of AP based on Bellcore standards Telcordia SR-332 version has met the requirements.

Based on our assumption, the overall system reliability is 0.4499. This number can be used to predict the actual life of AP when exposed to above conditions. This number can be multiplied by the total life of the AP mentioned by the manufacturer, the product of which gives the actual life of AP. This reliability model of AP will help us to predict the life span of AP. So it will allow the utility service provider to design the network accordingly and plan a replacement schedule for AP without any interruptions.

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