Deliverable 3: Commercialization Plan Report

Project Title: Low-Cost, Robust, Threat-Aware Wireless Sensor Network for Assuring the Nation's Energy Infrastructure

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Abstract: The objective of this project was to create a low-cost, robust anticipatory wireless sensor network (A-WSN) to ensure the security and reliability of the United States' energy infrastructure. This document highlights Eaton Corporation's plan to bring these technologies to market.

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1. Executive Summary

The objective of this project was to create a low-cost, robust Anticipatory Wireless Sensor Network (WSN) to enable pervasive sensing using anticipatory technology capable of performing complex reasoning for threat analysis to ensure the physical security and reliability of the United States' energy infrastructure.

After interviewing several public utility companies, Eaton Corporation focused its efforts on the development of a ruggedized WSN which could stand up to harsh environments. The company has identified the most suitable candidates for commercialization of the technology developed under this contract. Eaton Corporation intends to build a new gateway product which integrates existing product lines with a suite of wireless sensor devices.

2. Network Protector Vaults

Power network protector relays are used to monitor and control the power flow of low-voltage AC to secondary network power systems. They are widely used in distribution networks with multiple power injection points that require high continuity of service in heavily loaded, high-population-density urban areas. The purpose of the network protector is to prevent the system from backfeeding and initiating automatic reclosing when the system returns to normal.

Network protectors are used by utility companies – domestic and foreign – as well as industrial plants, hospitals, universities and potentially any building with critical processes or computers.

These relays are often located below street level in large, cement-encased facilities, a.k.a. *Network Protector Vaults*. The network protector vaults present a wide array of logistical problems:

1. The underground vaults are often difficult to access. Located beneath buildings, access to the vaults may force street closings or require the utility companies to schedule maintenance during off-hours.
2. Located outside, the network protector vaults are subject to inclement weather including extremes in temperature, rain or snow. It is not uncommon for a vault to have water present or to be flooded.
3. Vaults are often small with barely enough room for the existing equipment (See Figure 1).

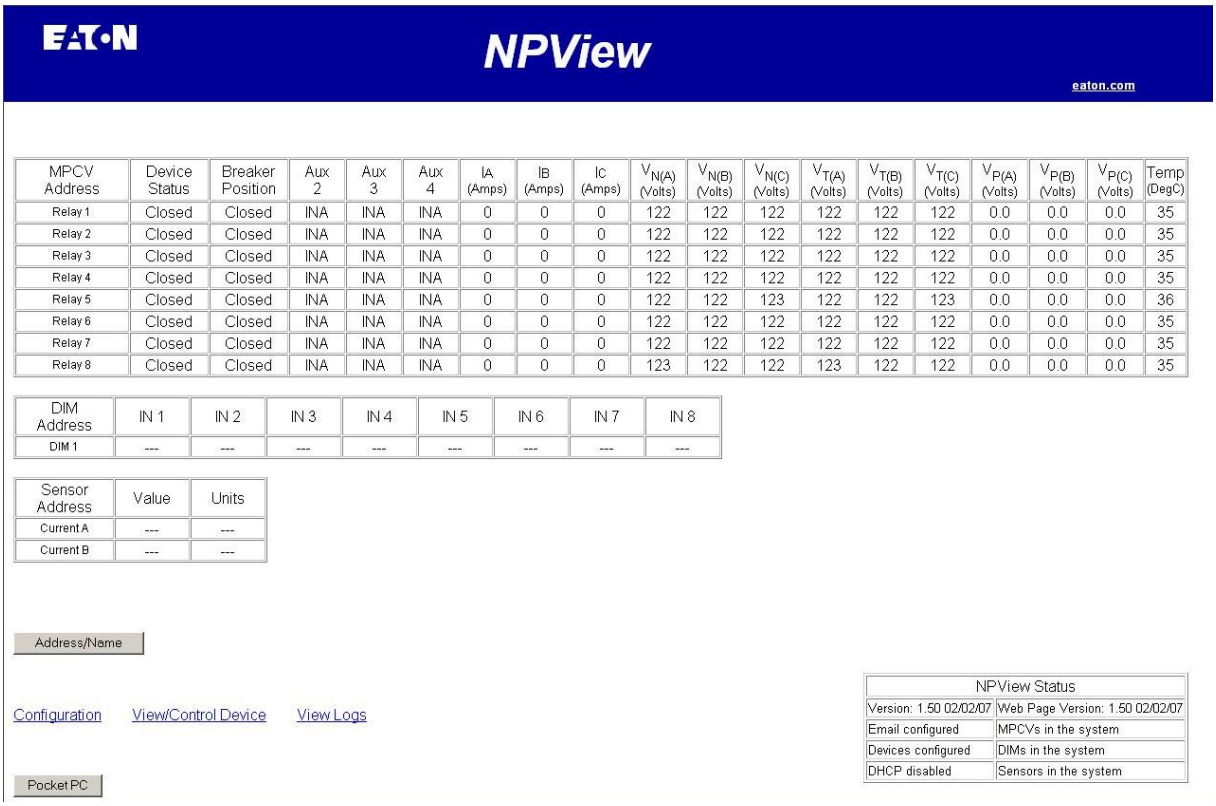
4. Gas from the network protectors themselves can often become trapped. This requires the utility companies to perform lengthy safety tests before gaining access.
5. Utility companies often build a series of vaults. The problem that occurs is that maintenance staff does not know which vault is experiencing issues. Each vault must first be checked for gas (See item 3). Once deemed safe, maintenance staff can then enter to determine if this is the vault with equipment malfunctions. The staff needs to move down the line until the problem has been located. This can be an extremely laborious process.

Figure 1: Network protector vault located below street level

6. Cement casing makes inter-vault communication difficult. Utility companies have examined the feasibility of running lines between vaults but the costs were prohibitive.
7. The wireless spectrum in urban areas is often saturated, making consistent wireless connectivity difficult.

Nevertheless, network protectors are extremely reliable due to their redundant equipment. These devices will remain a mainstay in the utility industry for the foreseeable future.

The decision to target network protector vaults was an easy one for Eaton. Customer partnerships drive the Identification, development and testing of solutions. The utility companies expressed a great interest in monitoring not only the equipment but also the network protector vault itself.



MPCV Address	Device Status	Breaker Position	Aux 2	Aux 3	Aux 4	IA (Amps)	IB (Amps)	IC (Amps)	$V_{N(A)}$ (Volts)	$V_{N(B)}$ (Volts)	$V_{N(C)}$ (Volts)	$V_{T(A)}$ (Volts)	$V_{T(B)}$ (Volts)	$V_{T(C)}$ (Volts)	$V_{P(A)}$ (Volts)	$V_{P(B)}$ (Volts)	$V_{P(C)}$ (Volts)	Temp (DegC)
Relay 1	Closed	Closed	INA	INA	INA	0	0	0	122	122	122	122	122	122	0.0	0.0	0.0	35
Relay 2	Closed	Closed	INA	INA	INA	0	0	0	122	122	122	122	122	122	0.0	0.0	0.0	35
Relay 3	Closed	Closed	INA	INA	INA	0	0	0	122	122	122	122	122	122	0.0	0.0	0.0	35
Relay 4	Closed	Closed	INA	INA	INA	0	0	0	122	122	122	122	122	122	0.0	0.0	0.0	35
Relay 5	Closed	Closed	INA	INA	INA	0	0	0	122	122	123	122	122	123	0.0	0.0	0.0	36
Relay 6	Closed	Closed	INA	INA	INA	0	0	0	122	122	122	122	122	122	0.0	0.0	0.0	35
Relay 7	Closed	Closed	INA	INA	INA	0	0	0	122	122	122	122	122	122	0.0	0.0	0.0	35
Relay 8	Closed	Closed	INA	INA	INA	0	0	0	123	122	122	123	122	122	0.0	0.0	0.0	35

DIM Address	IN 1	IN 2	IN 3	IN 4	IN 5	IN 6	IN 7	IN 8
DIM 1	---	---	---	---	---	---	---	---

Sensor Address	Value	Units
Current A	---	---
Current B	---	---

NPView Status	
Version: 1.50 02/02/07	Web Page Version: 1.50 02/02/07
Email configured	MPCVs in the system
Devices configured	DIMs in the system
DHCP disabled	Sensors in the system

Figure 2: Screenshot of Eaton's NPView product.

Additionally, Eaton Corporation has a solid path to market. The company's Power Control Systems (PCS) division has an 85% market share for the network protectors that have a communicating capability. This is primarily through the INCOM protocol and Eaton's NPView™ product which uses the INCOM protocol to communicate. This product enables utility companies to monitor status, breaker position, currents, network voltages, transformer voltages, phasing voltages, temperature, power, power factor, and

I/O state. It includes event and interval logging, operations count, I/O control, remote trip (See figure 2).

Eaton's 802.15.4 wireless technology leadership, specifically in low-cost wireless for industrial/commercial sensor and actuator devices is critical for successful commercialization. The company has decided to use the ZigBee wireless standard. ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs). ZigBee is targeted at RF applications that require a low data rate, long battery life, and secure networking. In addition, ZigBee operates in the industrial, scientific and medical (ISM) radio bands; 915 MHz in the USA and 2.4 GHz in most jurisdictions worldwide. The technology is intended to be simpler and cheaper than other WPANs such as Bluetooth. Wireless communication and control enhancements to Eaton's network protector product line will form the sensor basis for this initiative.

The sensors will be designed for easy retrofit into existing vintage equipment. Expensive relay replacements will not be required. Eaton believes that it can develop a product that will have:

- Minimal installation outage
- Minimal intrusion into existing circuitry
- Minimal labor costs

Eaton would offer a complete turnkey installation with 365/24/7 callout and maintenance support available. The system would be scalable, enabling the utility customers to add features and modules as budgets permit. The company believes that this is the best path for meeting the performance and efficiency needs of the customer.

3. Sensor Suite Solution

Eaton used passive infrared sensors (PIR) and acoustic sensors in its demonstration at the Tennessee Valley Authority's (TVA) Roane substation to determine threat presence and/or proximity. In addition to these, the utilities identified areas of interest for wireless sensors. These include:

- *Phase voltage/current value sensor* – this sensor is critical to determine transience in the electric power system that can affect the reliability of the electrical distribution. This can be for a building or for an entire system.
- *Current presence sensor* – sensor is used to identify only if current for a given line is presence.

- *Load flow/direction sensor* – this can be used to determine the location of the energy source for building or protection purposes.
- *Temperature sensor (network protector)* – this sensor is used to measure the ambient temperature in the network protector as a first line of defense against over heating equipment or fire.
- *Temperature sensor (bus/wiring connections)* – this sensor is used to determine the temperature of the main bus and its connections.
- *Breaker diagnostics sensor* – sensor used to determine operating status of the system breakers, i.e…pass or fail.
- *Gas presence sensor* – sensor used to determine the hazardous / non-hazardous gas commonly found in vault or equipment. The ultimate benefit was to increase reliability by enabling maintenance teams rapid access to network protector vaults.

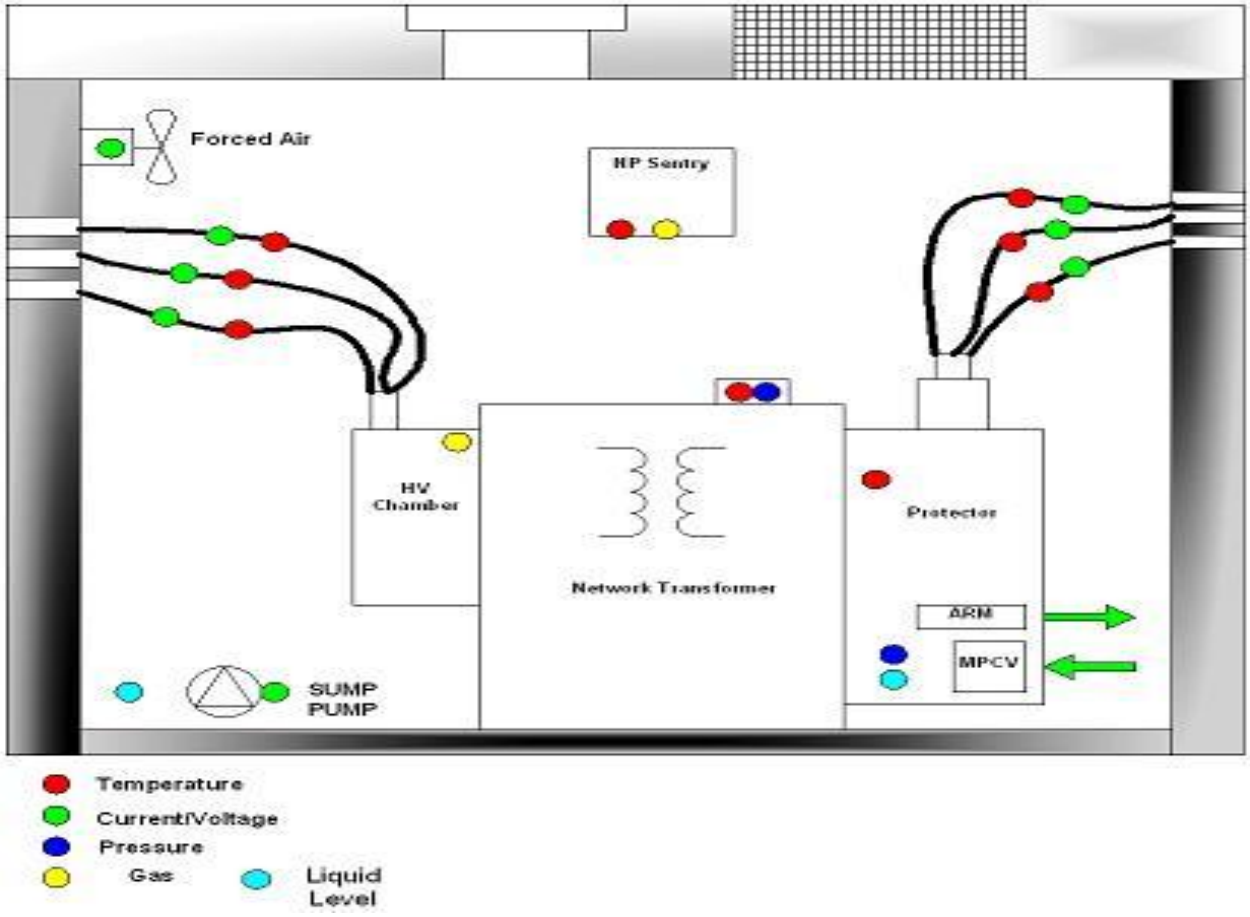


Figure 3: Recommended placement of priority sensors in a network protector vault.

- *Pressure sensor* – sensor identifies the ambient pressure in a network vault. Increased pressure may be a sign
- *Water presence sensor* – sensor determines whether water is in the vault or in specific equipment, i.e.…network protector.
- *Liquid level sensor* – sensor commonly used in place of water presence sensor to determine if water in vault has risen to significantly high levels.

Eaton was able to narrow this list down through continued meetings with its utility customers. The utilities sensor priorities in order are: current presence, temperature (network protector), phase current/voltage value, pressure, gas, and liquid level. A suggested placement of these sensors is shown in figure 3.

In order to connect these wireless sensors to the INCOM network, Eaton Corporation is in the process of designing and developing a ZigBee to INCOM gateway. The gateway will enable the one-way transmission of data from the wireless sensors to NPView software for display and additional analysis. Testing of the gateway is scheduled for late 2007. (See figure 4)

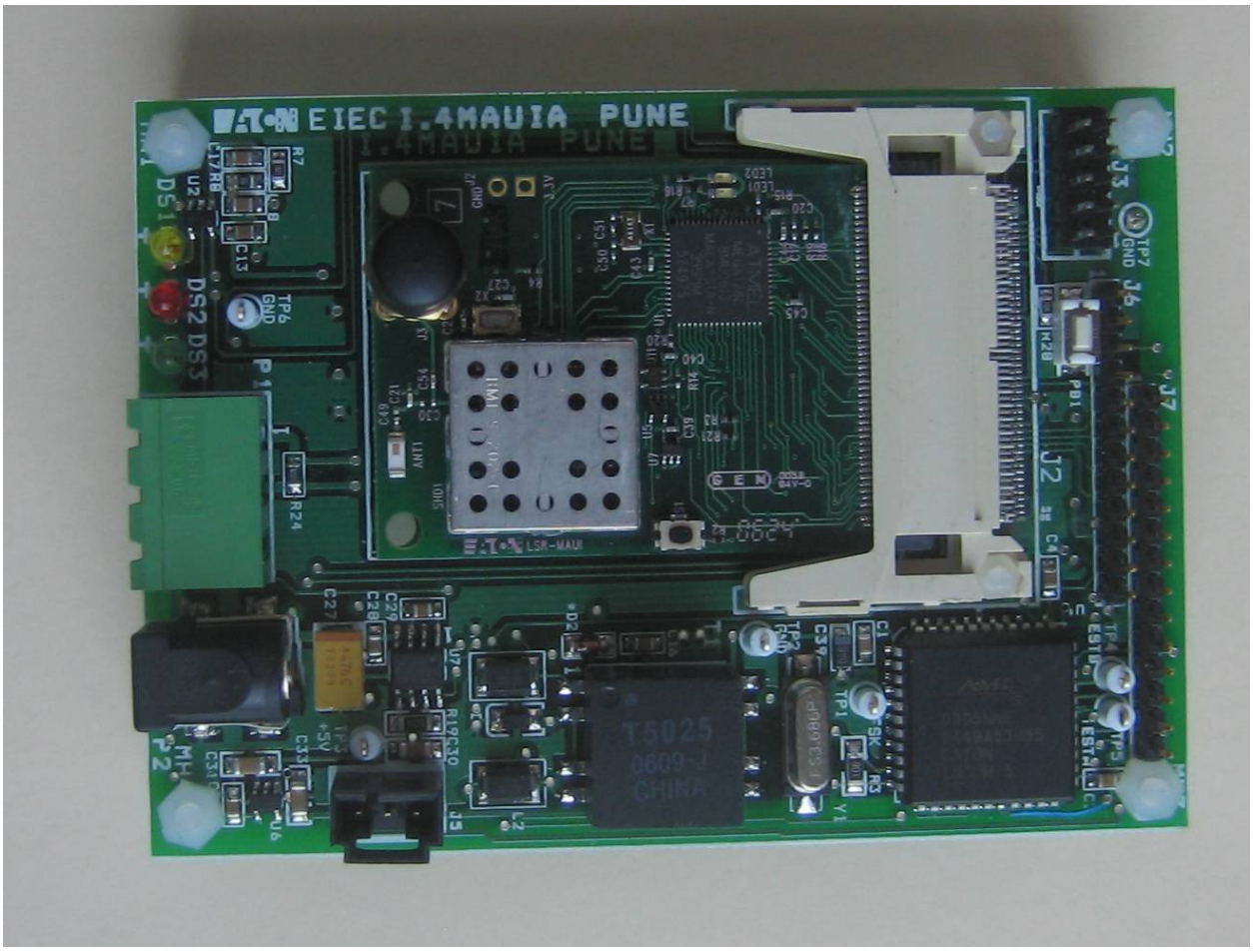


Figure 4: Current prototype of a ZigBee-INCOM gateway.

4. Continuing R&D Efforts

4.1 Anticipatory Theory – Diagnostic/Prognostic Algorithms

The anticipatory theory developed on this project was based on Bayesian belief networks. Bayesian belief networks are effective and practical representations of knowledge for reasoning under uncertainty. They have many successful applications in many fields such as diagnosis, planning, learning, vision, natural language processing, and decision support systems. The latter involves interaction with human users, and therefore it is crucial that users be able to understand the underlying probabilistic model,

its assumptions, and its recommendations. Since Bayesian networks are graphical models, they are cognitive and similar to human reasoning constructs, distributed algorithms for inference and learning, modular representation of knowledge, and intuitive (possibly causal) interpretation. In many of these applications, systems are fairly autonomous and their most important characteristic is the ultimate reasoning performance.

The utility partners have a high interest in any method that would enable them to anticipated failure in electronic devices. Eaton continues to research and field test various diagnostic/prognostic algorithms to meet this need.

4.2 Eaton Wireless Link Assessment Tool

As part of this project, Eaton developed a wireless link assessment tool to determine the quality of wireless connections. This system is a completely automated wireless site survey system. It measures wireless link level performance of the wireless communications over an extended period of time – days, weeks or months. The scans are a six dimensional space of link characteristics: Tx and Rx node pair, channel, transmit power, packet length, and time (See figure 5).

This technology is critical to environments which require high security and reliability. Currently, the system is put in place prior to a wireless installation to map the optimum position of sensors in a network. With this information, Eaton engineers are able to analyze the root causes of system reliability degradation. It is Eaton's belief that the next logical step is to migrate this technology to an embedded system. This would not only enable the sensors to alert utilities of performance degradation, but would allow the sensors to perform a self-healing function whenever possible. The sensors would have channel (frequency) hopping algorithms based on the wireless link and network assessment field tests.

The company is also considering the possibility of offering the link assessment as a service offering from Eaton Electrical Support and Services (EESS) group.

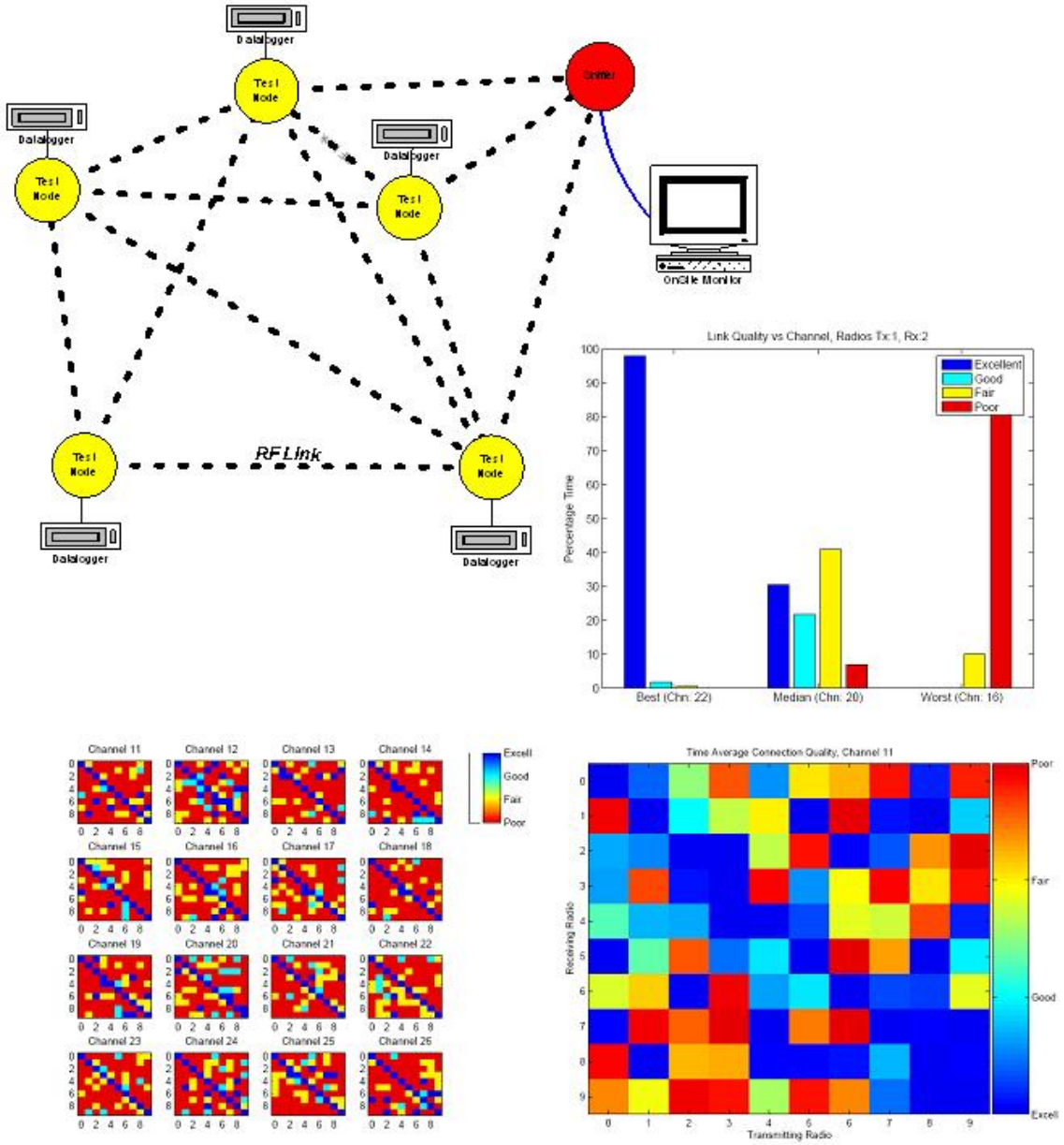


Figure 5: Analysis of data from Eaton's wireless link assessment tool.

4.3 Power Harvesting

As part of this project, Eaton investigated several options to parasitically power the suite of sensors. The company continues to work with different vendors to extend the useful life of these devices.

5. Conclusion

Eaton is using the technology developed on this government project in conjunction with a proven pathway to market to ensure the reliability of the United States' energy infrastructure. The company is targeting network protector vaults because:

1. Eaton's Power Control Systems (PCS) division has an 85% market share for the network protectors that have a communicating capability (INCOM), and
2. Network protectors are widely used in the distribution of electricity.

The company is developing a suite of sensors based on the ZigBee wireless standard because it is targeted to RF applications that require a low data rate, long battery life, and secure networking. Eaton will integrate the suite of sensors by designing and developing a ZigBee-INCOM gateway which will enable the devices to communicate over existing networks.

Long-term research continues in on diagnostic/prognostic algorithms, wireless channel-hopping, and power harvesting.