Demo Abstract: Wireless Sensor Network for Substation Monitoring: Design and Deployment

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ABSTRACT

We present the design and performance of a wireless sensor network that is deployed in a substation for monitoring the health of power subsystems such as circuit breakers, transformers and transformer bushings. The sensor network consists of 45 low power nodes for temperature sensing and a high power node that is capable of performing more specialized computations. All nodes communicate over a multihop mesh network that uses a dynamic link-quality based routing protocol. The nodes are solar powered and are capable of operating autonomously for multiple years.

Categories and Subject Descriptors

C.3 [**Special Purpose and Application-Based Systems**]: real-time and embedded systems, signal processing systems

General Terms

Design, experimentation, performance.

Keywords

Substation monitoring, sensor networks.

1. INTRODUCTION

Power utility companies can derive significant benefits from utilizing wireless sensor technology for monitoring the health of critical and expensive equipment in power stations and substations. Advantages include elimination of the hazards of onsite data collection from the high-voltage substations, lower installation cost, and utilization of the distributed processing capabilities of wireless sensors to potentially provide smarter sensing mechanisms in comparison to existing online monitoring systems. This paper describes the design and deployment of a large scale wireless sensor network in a TVA substation in Kentucky. The main objectives of this project are to experimentally verify the viability of using wireless sensors in substation environments, determining the reliability of such networks for long term use, and meeting the challenges for instrumenting the sensor network for health monitoring of substation equipment. Deployment of the sensor network was initiated in May 2007 and expanded over multiple phases. Currently the network has 45 wireless sensor nodes in place.

2. SYSTEM DESCRIPTION

The network was designed using Crossbow's *MICAz* wireless sensor nodes [1], which are equipped with the Atmel ATmega128L processor running at 8MHz and uses the 2.4 GHz Chipcon CC2420 radio. The nodes are deployed over an area that is approximately 1000×700 feet and is covered by metallic structures typical to a substation environment. The nodes use multihop networking to transmit data to a base station that is housed in a protected trailer and has connection to the Internet through a VPN. Although the nodes use built-in quarter-wave dipole antennas, the base station has been equipped with an external 9.9dBi omnidirectional antenna for better connectivity.

A number of substation monitoring applications are being developed using this sensor network of which the following have been completed:

- *Transformers:* Transformer surface temperatures are continuously monitored in order to detect anomalous conditions.
- *Circuit breakers:* Oil-filled circuit breaker surface temperatures are continuously monitored, and relative tank temperature differences are used to indicate fault conditions.
- *Transformer bushings:* Transformer bushings degrade over time. Indication of bushing degradation can be obtained by detecting phase differences between the voltages obtained at the bushing taps. A bushing monitoring node that captures representative data for measuring phase differences and transmits over the wireless network has been developed.

Each transformer and circuit breaker surface temperature monitoring node uses six resistance temperature detector (RTD) sensors that are connected to a *MICAz* mote using Crossbow's *MDA320* data acquisition board. The RTDs are physically embedded onto magnets attached at the base of each node enclosure (see Figure 1). These same magnets are also used to attach the nodes to the surface of the transformer or circuit breaker. Averaging over 6 RTDs removes

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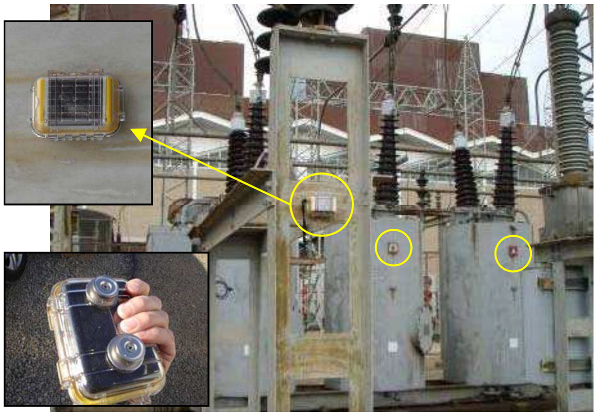

Figure 1: Wireless nodes on circuit breakers.

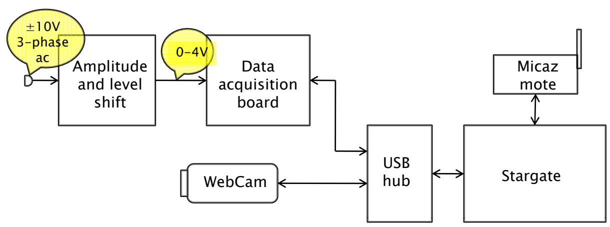

Figure 2: Block diagram of the bushing monitoring node.

possible variations due to insufficient surface contact. These nodes are housed in environmentally protected enclosures that are equipped with a 2.5 × 4″ solar panel and charging circuit for two 1.2V NiMH batteries (*Heliomotes* from Atla Labs [2]).

The network uses Crossbow's *XMesh* link-state routing protocol that adaptively determines the most stable multi-hop routes from the nodes to the base station. The interval between successive route updates, by which the nodes obtain link state information, is set at 5 minutes. The nodes perform periodic sampling of surface temperatures with the RTDs at intervals of 15 minutes.

Bushing monitoring requires phase difference estimates with errors less than 0.1 degrees. A wireless bushing monitoring node has been developed that captures and transmits constructed signals similar to that generated by a commercial bushing monitoring system. The data capture requires samples of at least two cycles of the bushing tap voltages at a rate greater than 20KHz. Samples are obtained using a data-acquisition board interfaced to a *Stargate Netbridge* node from Crossbow. This node is also equipped with a Logitech 2MP camera that can be optionally used for security monitoring. A block diagram of this node is shown Figure 2. This system has been successfully tested in the laboratory and is awaiting deployment in a substation.

3. PERFORMANCE

Samples of signals obtained from the sensors are shown in Figure 3. The nodes employ low-power sleep cycles and periodic wake-up to detect network activity, resulting in average current consumption below 0.3mA. The expected direct

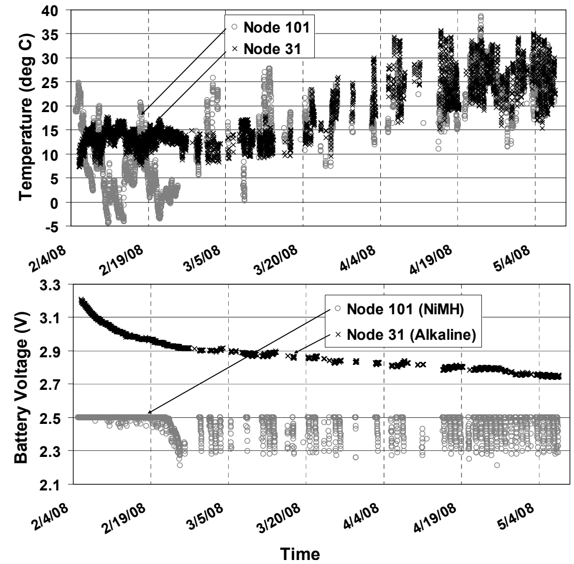

Figure 3: Samples of signals received from the sensor network.

solar radiation per day that is required to sustain such activity is 14 minutes at that location. However, long overcast conditions and low temperatures resulted in the nodes to eventually fall into a cycle of active and inactive periods as observed in Figure 3. While the number of packets received in the first month is high due to the initial charge in the NiMH batteries, the number of packets received drop down to 30–50% in steady state, depending on available sunlight. We used alkaline batteries in a few of the nodes for comparison with the solar nodes, which dropped by 0.3V in 4 months, indicating a lifetime of approximately 8 months for our applications. The bushing monitoring node works on external power that is available at the transformer.

4. CONCLUSIONS AND FUTURE WORK

The sensor network currently transmits all captured data to the base station without performing any local processing. This was done to obtain proof-of-concept and initial performance results. We are currently working on the following: (a) development of energy efficient local processing algorithms to generate alarm signals at the sensor nodes; (b) design of end-to-end bulk data transfer schemes for transmitting large chunks of data such as images from the webcam; (c) enabling energy dependent node operations for maintaining reliable communications over the wireless network under the observed connectivity characteristics and (d) incorporating additional monitoring applications that include gas, vibrations, and acoustic discharge sensing.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] http://www.xbow.com.
[2] http://www.atlalabs.com.