MAKING WIRELESS SENSOR NETWORKS TRULY WIRELESS USING RF POWER

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Abstract: ***In real deployments, robust intelligent wireless sensor networks (iWSNs) require reliable power for data acquisition, data communication, and data acknowledgment. In data intensive applications or when battery replacement is not convenient, some form of power harvesting is needed. IntelliSensor and FireFly Power Technologies have successfully tested and deployed radio frequency (RF) power harvesting in a real environmental monitoring situation***.

Penguins are found in different habitats ranging from the frozen land of Antarctica to the warmer climates in Peru and South Africa. Each of the penguin species prefers a slightly different temperature range. However, as the temperature increases above certain limits, the birds can become heat stressed. Heat stress increases the susceptibility to disease which can increase the cost for care and recovery. Penguins are valuable assets and the premature death of a single penguin is a substantial loss. To help monitor the temperature and humidity without disrupting the penguin exhibit, it was decided to install an intelligent wireless sensor network (iWSN). Figure 1 shows an overhead view of a portion of the penguin exhibit at the Pittsburgh Zoo & PPG Aquarium.

Figure 1

The area around the exhibit consists of masonry block and concrete walls, firberglass reinforced plastic scaffolding and walkways, metal railings, piping and pumps for water circulation, and metal and wire underlayments within the artificial rock and brick providing the natural environment backdrop to the penguin exhibit. These surroundings provide a moderately harsh environment for low-power radio frequency (RF) communication, however, the installation of wired sensors would have required cutting through the concrete and simulated rock and disrupting the exhibit. Wireless sensors were installed unobtrusively as shown in the figure above. From their placement, they are not visible to the spectators.

As in any real world deployment of iWSN technology, cost and reliability are major issues. Cost scrutiny mandated the deployment of a minimum number of temperature and humidity sensors, while limited access required reliable data communications and battery longevity. An engineering evaluation of the site led to the initial placement of six wireless sensors as shown in figure 2. Software was developed to write the measured temperatures and humidity values to a database, prepare network administration reports and management reports, and graph the data for specified intervals. In addition, an alarm could be issued to a pager or telephone if a predetermined level was exceeded. Network administration reports were issued via e-mail at hourly intervals, providing the current temperature, humidity, state of battery charge, and the minimum, maximum, and average temperatures over the previous 24-hour period. A daily management report providing the same information was sent by e-mail to the appropriate zoo staff. The data could also be observed on IntelliSensor's website (www.sensormgmt.com).

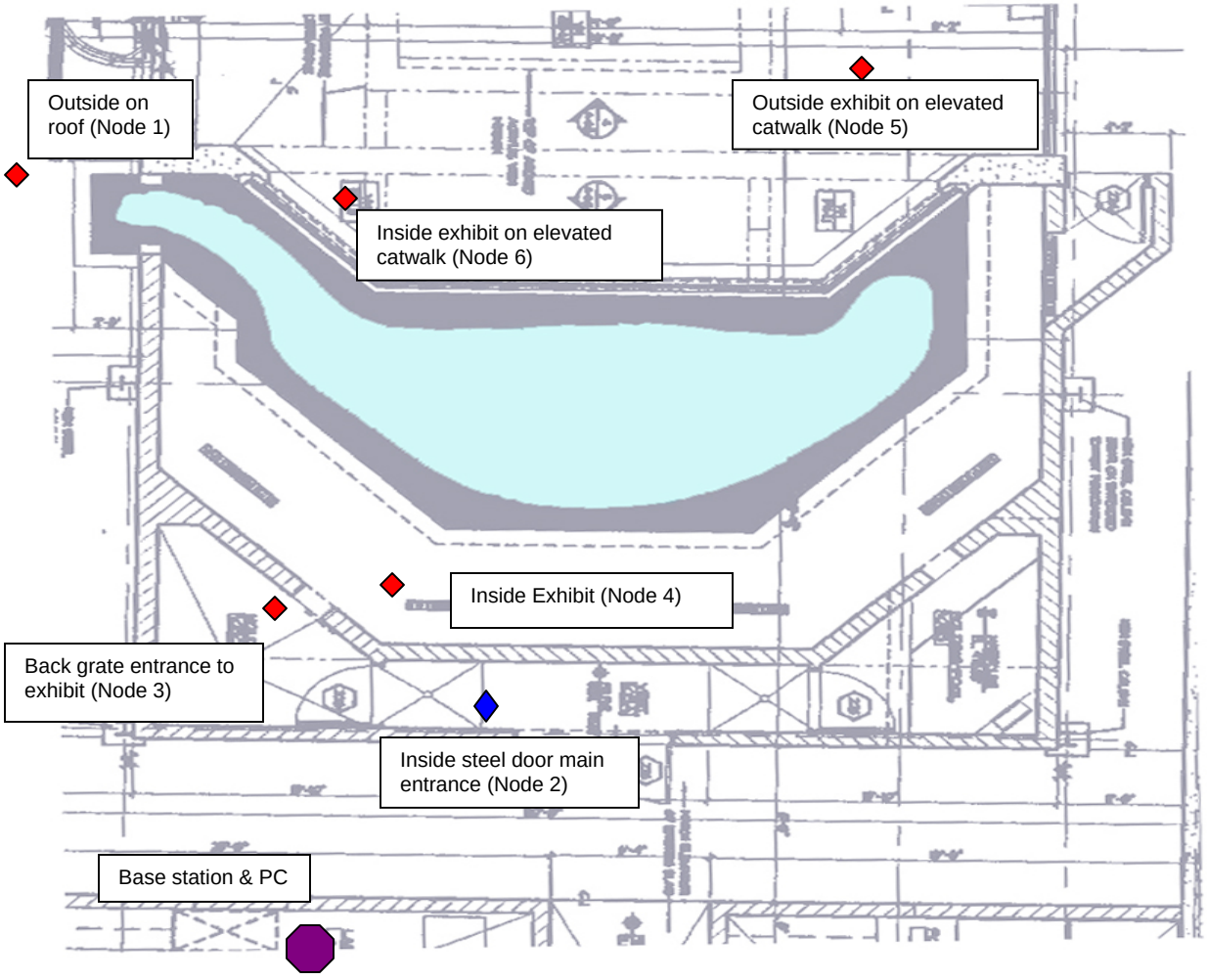

Figure 2

With a data sampling rate of once per minute, the advertised battery lifetime was supposed to be two years. The data sampling rate was set to once every two minutes. Even with the reduced sampling time, the observed mean time to battery exhaustion was approximately 100 hours A investigation revealed that, in addition to the cold battery harsh environment, the vendor's low power networking software running on the sensor nodes did not place the radio into low power sleep states. Although the sampling and data transmittal interval was reduced to only once every 2 minutes, the active radio power consumption for listening resulted in premature battery exhaustion.

Natural occurrences can also increase the wireless power requirements. Communication difficulties resulting from interference are inevitable and can increase the power consumption. Furthermore, data intensive situations, in which the magnitude of data being transmitted through the network or the need for a high data sampling rate can also increase the power consumption requirements. Then there are times when it is not easy or it is undesirable to change batteries. In each of these situations, some means of power harvesting can provide the power needed to keep an intelligent wireless network alive and truly wireless.

The initial experience led IntelliSensor into a joint power harvesting test program with FireFly Power Technologies, LLC. FireFly Power Technologies has developed a Wireless Power Platform™ which enables power to be safely and reliably transmitted through the air. This enables the intelligent wireless network nodes to be continuously powered without wires and without the need to frequently change batteries, a truly wireless sensor deployment.

FireFly has engineered and developed the Wireless Power Platform™ to work with IntelliSensor's intelligent wireless temperature and humidity sensors. In the initial test deployment, a FireFly Wireless Power Transmitter™ supplied wireless power to a FireFly Wireless Power Supply™ which maintains rechargeable batteries at their full charge level. This configuration was chosen to ensure an uninterrupted data stream. Should the FireFly power harvesting process be interrupted, the battery power supply would maintain the data transmittal. When the interruption is removed, the FireFly power harvesting would resume and restore the battery voltage to full charge. Figure 3 shows the installation of a FireFly Wireless Power Supply™ in an IntelliSensor wireless temperature and humidity sensor.

Figure 3:
FireFly Wireless Power Supply

The lower left portion shows an IntelliSensor wireless temperature and humidity sensor connected normally to a battery supply. The upper left figure shows the same type of wireless temperature and humidity sensor with the FireFly Wireless Power Supply™ replacing the battery supply. The right side of the figure shows a close-up of the FireFly Wireless Power Supply™.

To evaluate technology, the IntelliSensor node, Powered by FireFly, was deployed next to an existing identical wireless temperature and humidity sensor inside the penguin exhibit. Physically the test sensor Powered by FireFly was placed next to node 6 as shown in Figure 2. This location was chosen to provide a direct test comparison to an existing wireless temperature and humidity sensor for data response and reliability and for a comparison with the power consumption.

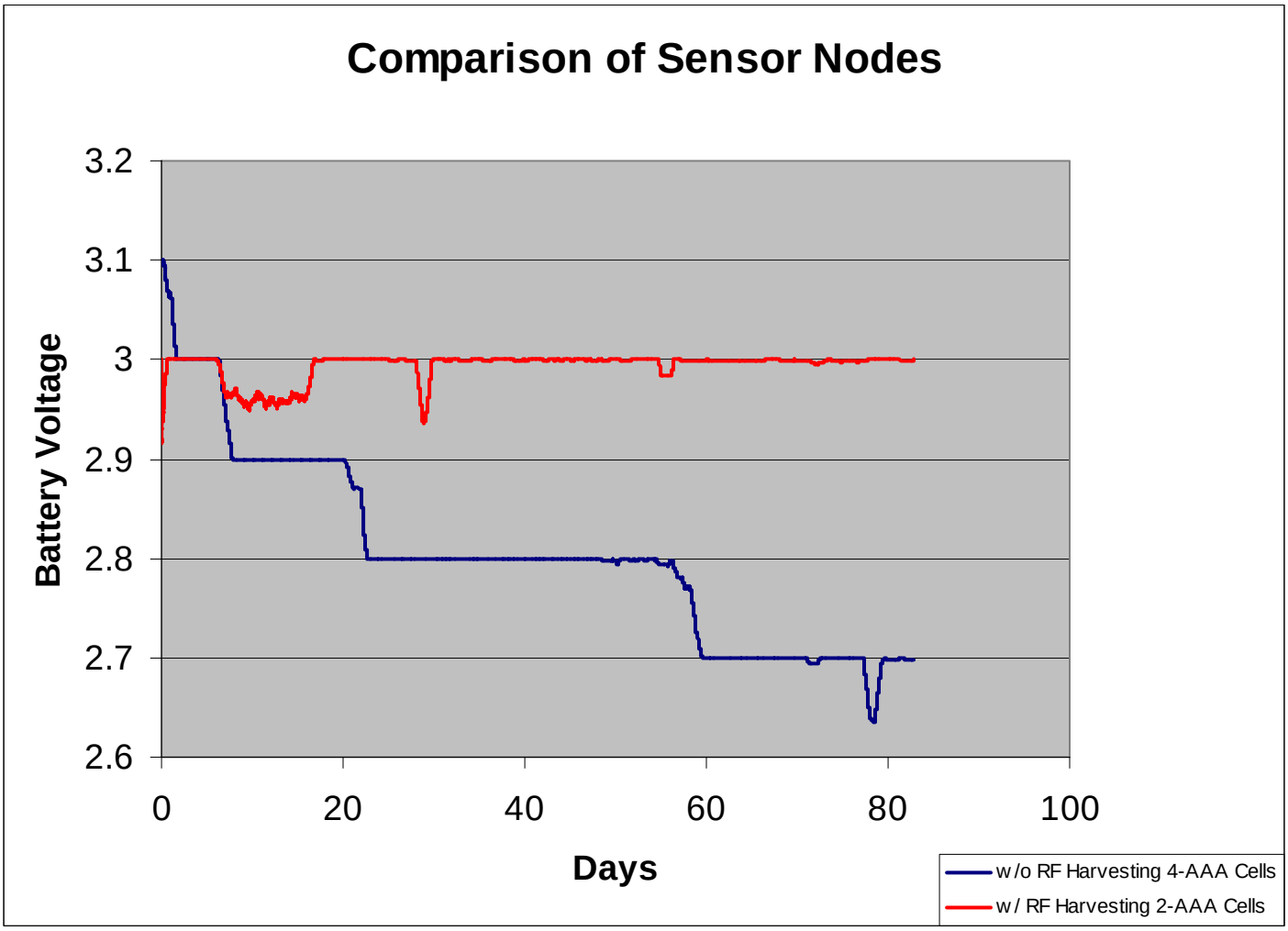

Figure 4

Comparable data readings for temperature and humidity were observed in the wireless sensor node with the conventional battery power and the IntelliSensor node Powered by FireFly. Figure 4 shows the battery voltage in the IntelliSensor wireless temperature and humidity sensor without RF Harvesting (conventional battery powered) and the IntelliSensor node Powered by FireFly (with RF Harvesting) for the period from March 9, 2006 through May 30, 2006. The voltage of the conventional battery powered IntelliSensor temperature node started at 3.1 volts but quickly dropped to 3.0 volts. The battery voltage of the IntelliSensor node Powered by FireFly started at approximately 2.9 volts and was quickly charged to 3.0 volts.. Approximately 10 days into the test, maintenance activities in the catwalk area above the

penguin exhibit influenced the wireless power being supplied to the IntelliSensor node Powered by FireFly. This was initially observed on data displayed at the IntelliSensor website, and the problem quickly corrected itself a few days later when maintenance activities were completed. Full battery voltage was quickly restored to the IntelliSensor node Powered by FireFly while the battery voltage had dropped to 2.9 volts in the conventional battery powered IntelliSensor node.

Data transmittal demands occasionally cause the battery voltage to fall below 3.0 volts in the IntelliSensor node Powered by FireFly. However, full battery voltage is quickly restored. After 20 days, battery voltage in the IntelliSensor node with the conventional battery supply had dropped to 2.8 volts. Approximately 28 days into the test, a planned power outage occurred and the battery voltage in the IntelliSensor node Powered by FireFly decreased slightly. Once the power outage was over, battery voltage was quickly restored to 3.0 volts. Approximately 55 days into the test, voltage on the conventional battery supply began to fall below 2.8volts. On the 57th day, an inadvertent power outage interrupted the power harvesting process and the voltage briefly dropped below 3.0 volts in the IntelliSensor node Powered by FireFly. Again, once power was restored, the full charge of 3.0 volts was quickly restored. Approximately 60 days into the test, voltage in the conventional battery supply had dropped to 2.7 volts. Approximately 76 days into the test, it appears that interference may have caused a large number of data re-transmittals resulting in a temporary decrease in the conventional battery supply voltage. While the IntelliSensor node powered by FireFly would be expected to experience the same interference, the RF power harvesting was able to maintain the rechargeable battery level at 3.0 volts.

Conclusions

Intelligent wireless sensor networks can provide the solution to data acquisition when wired sensor data is impractical or too costly. Real world deployments of low power sensor networks do not always perform as advertised, and naturally occurring interference and data intensive applications can dramatically increase power requirements. Frequent battery replacement is often not possible or desirable in iWSN deployments. Therefore, some form of power harvesting is necessary to ensure reliability of the iWSN. IntelliSensor has successfully tested and deployed a truly wireless solution where battery replacement is inconvenient. FireFly Power Technologies' Wireless Power Platform™ has maintained the battery voltage at the full charge level throughout the testing process. IntelliSensor is convinced that the reliable deployment of an iWSN in a data intensive situation or when battery replacement is not convenient requires power harvesting capabilities. Today those power harvesting capabilities are available from FireFly Power Technologies.

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