Wireless Monitoring of Critical Assets

Introduction

Wireless condition monitoring for critical assets can play an important role in plant management. In Section (1), this paper explores the practical issues surrounding the use of wireless sensors by reviewing the types of wireless sensors and standards available, and by considering range, power, bandwidth, capacity and security. 900MHz wireless is shown to have strong advantages in certain areas, particularly range. In Section (2), a field test is described where multiple sensors are deployed throughout a large industrial facility and used to monitor assets. The results of this test demonstrate the practical aspects of installing and maintaining a wireless monitoring network, and the advantages of operating the system.

Section 1: Primary Radio Design Factors

Bandwidth

Bandwidth is the amount of radio spectrum used by a radio transmitter. It affects the channel capacity of a connection, which is an upper bound on the amount of information that can be sent through a particular channel with a given bandwidth and signal to noise ratio (SNR). The Shannon-Hartley theorem describes the interaction of channel capacity with bandwidth, signal power, and noise by providing an upper bound on capacity in the presence of additive white Gaussian noise (AWGN). Even though industrial environments do not have ideal channel environments, channel capacity is a useful starting point to look at bandwidth and power trade offs between systems. In typical conditions (realistic SNR), bandwidth is linearly related to capacity, meaning a doubling of bandwidth provides a doubling of capacity. Power output, which directly affects the SNR, is related to channel capacity by a logarithmic function, so a doubling of power will give only a marginal increase in capacity compared to a doubling of bandwidth.

Frequency of Operation
The frequency of operation of a radio system has practical effects on its range. In typical industrial environments, lower frequency radio (RF) signals can propagate significantly further than higher frequencies. Higher frequency RF signals are more easily absorbed by interfering objects and less likely to propagate around objects. Depending on the material, a linear or squared relation between frequency and loss is typical. 5GHz or 2.4GHz signals can suffer over 5 times the loss in propagation of 900MHz signals, and losses higher than 7 times are observed in some studies. The net result of this increased path loss is significantly reduced radio range.

**Power Output**

Radio waves attenuate in the idea case at a rate proportional to distance squared:

$$ P \propto \frac{1}{D^2} $$

This ideal condition serves as a reference point for looking at the effect of power output and signal range. Higher output power radios significantly extend range, with a higher power 24dBm radio potentially extending range 16 times compared to a low power 0dBm radio. In practice, the increased range is typically less, around 4 to 8x. Visually, the affect of power output on coverage area can be seen below, where the higher power radio extends the coverage area by a square factor.
Antenna Gain

Antenna gain indicates the degree of shaping from a perfect antenna radiating in all directions (not that additional power is created by the antenna). A directional antenna can significantly increase range if the RF energy is focused toward the receiver. An ideal antenna radiates in all directions as shown below.

Antenna gain diagrams typically show a 2 dimensional image of the 3 dimensional propagation pattern of the antenna. Reference the diagrams below – the red lobes show the deformation of the energy from an ideal spherical pattern. If a receiver is located in one of the red lobes, it will receive the signal. The higher gains (directional antennas) focus energy into narrow beams. For general industrial settings, high gain antennas are not recommended, typically resulting in less coverage than lower gain antennas. As the beam becomes more focused (at higher gains) a wireless unit has progressively less chance of being in the coverage area.
Section 1: Existing Radio Solutions

WLAN

The dominant radio standard used for short range communication is Wireless LAN (WiFi, WLAN, or 801.11). Worldwide, over 8 billion WLAN units have shipped. The emergence of portable devices like smart phones and tablets that ship with WiFi support have resulted in highly integrated, low cost, and low power WiFi modules. Deployment of WiFi systems, and security related concerns, are well known by most IT departments who manage these networks as part of their business network. A number of 3rd party functions (video cameras, video displays, security monitoring as examples) that are not directly related to condition monitoring can be added to a WiFi network. For these reasons WiFi is an appealing technology when considering plant wide monitoring.

Wireless Hart and ISA100

Wireless Hart is based on a popular and well established protocol. ISA100 is targeted for industrial plant automation, and is backed by a number of leading companies. The radios used in these systems (802.15.4) were originally developed for short range communication at low bit rates. 802.15.4 radios have lower data rates and less performance than WLAN. Typically power output is 0-10dBM on 802.15.4 radios. The upper datarate of 250kbps limits applications such as video, full spectrum waveform capture or continuous streaming of data from a sensor.

The general topic of WLAN vs. ISA100 vs. Wireless Hart is frequently discussed in forums and other documents, and all standards have supporters. WLAN has advantages in many areas, and when considering whether to invest in an 802.15.4 based plant network vs. a WLAN type network, the capability, management and maintenance of the network become key factors:

- WLAN is scalable in technology, and is enhanced consistently to keep up with the demands of improving PCs, smartphones, video services, and tablets. ISA100/Hart standards are based on less capable radio modulations, and the system runs at 250Kbit/s vs. multi Mbit/s for WLAN.
• Deployment and maintenance– WLAN systems are ubiquitous and have widespread availability of products, vendors, and content experts. Most network administrators have familiarity with managing WLAN networks, while management of ISA type networks requires proprietary configurations, and a smaller supply of experts is available to understand and maintain these systems.

• Security of WLAN is well known, and set procedures are in place and understood by IT managers to integrate these networks.

• Power usage. A primary goal of ISA100 type networks is an ability to run with low power and utilize battery technology or battery harvesting. The push of WLAN into cell phones and tablets created a class of WLAN devices capable of running in mixed modes and supporting lower power applications such as sensors. This enables a single type of network (WLAN) to provide many needs within an industrial setting.

• WLAN is based on OFDM (Orthogonal Frequency Division Multiplexing), a more flexible and adaptable technology than that used in ISA900 type radios. A large body of researchers and companies are actively investing in 802.11 and OFDM enhancements and improvements of capability, price, spectral utilization and power consumption.

• WLAN provides expansion to the existing system for other standard services.

**High Power low band ISM Radios**

High power low band ISM radios are traditionally used to transmit telemetry data over long distances. A 900MHz ISM module can output 24dBm of power and can run at datarates up to 250Kbit/s with multi mile ranges in outdoor environments. Radio protocols are simpler, resulting in lower complexity modules than WLAN and ISA100 type radios. Low Band ISM radios have primary benefits of easy installation and lower cost due to extended range (less infrastructure required).

Compared with WLAN/802.15.4 type radios running at higher frequencies (2.4GHz or 5GHz), these modules offer advantages:
• High output power and lower frequency modulation result in significant coverage increases over WLAN/802.15.4 radios.
• Datarate is equivalent to 802.15.4 radios.
• Deployment of these radios is less expensive, as a single base station can serve a large area, vs. blanketing an area with hotspots and managing this network.

Section 1: **Summary**

Three models emerge for configuring a plant, where each model uses the strengths of a particular technology.

WLAN can provide blanket coverage in a plant by using a dense set of base stations. This deployment scenario takes upfront costs to prepare the plant for the sensor network. A variety of devices can be used with this system, not just remote wireless sensor monitoring. WLAN provides a future proof upgrade path as new services are needed.

ISA100/Hart Solutions provide a path for monitoring arrays of low bandwidth sensors or devices. Meshing capability can potentially achieve coverage without a dense base station deployment. Achieving easy setup an addition of sensors with meshing is difficult, as there has to be a mesh path in the area where a sensor is being added. A widespread network with a few monitoring points spread out will be difficult with the mesh, resulting in additional base stations needed (and increasing infrastructure and upfront cost). It is unlikely that other services can be used in this network (communication with tablets, wifi sensors, video cameras and so forth). Frequency domain monitoring (full waveform and spectrum) is unlikely, as is streaming capability to dwell on a bearing or point of interest for further analysis. Power output is limited, and datarates and range are low in the system.

High power low band ISM radios can be deployed quickly with only a few base stations. This type of system allows quick deployment of sensors with minimal
upfront cost, and allows rapid expansion, as large network coverage areas can be achieved with a single base station. The disadvantage over WLAN is that it will not support other services requiring higher bandwidth.
Section 2: **Field Study of low ISM band Sensor Network**

**Overview**

Long range 900MHz ISM radio technology was used to deploy sensors over a distributed industrial environment. Four base stations were used to cover three large paper machines and associated pulp mill. Full spectral data (1600 to 3200 lines of resolution) was collected from AC/vibration sensors. DC type (process) data collected single data points. Sensor types for AC channels included accelerometers, proximity probes, and ultrasonic sensors.
Plant Topology

The plant is shown below. Three paper machines are housed in two buildings. The pulp area is located near the paper machines. The area of coverage is over 300x300 meters. Outside construction is typical of industrial plants with sheet metal sides with breaks for doors, fans, vents. The interior of the buildings are primarily solid with machines, cranes, and infrastructure. Each paper building is 4+ stories high, with some pulp buildings being 12+ stories high.
The plant is shown schematically below. Locations of base stations and machines are marked. Four base stations were used, one for each area. All base stations run on separate RF channels. The base stations are capable of multi-mile transmission outdoor, and 500-1000 meters indoor depending on the topology. Base3 was placed outside the building (due to the location of the nearest Ethernet connection) and used to monitor the back and front side of Paper3, even after passing through the constricted metal entrances on the side of Building2. Base stations connect over Ethernet (some using POE) to the server controlling the network.
A blowup of the interior of Building1 around Machine1 is shown below. Sensors were placed alongside both the back and front side of the machine. The base station is blocked from the front side by the machine, which runs with large metal doors covering each side, particularly in the dryer sections.
The side view for a similar type machine is shown below. The challenge for the radio system is to reliably reach all four sides of the machine, as no matter where the base is placed 3 sides are not in the line of sight, and large amounts of metal obstruct the signals.

**Sensors on Machine1**

17 Wireless units were used to monitor 13 areas of Paper Machine1. 96 AC/Vibration channels and 6 DC/process channels were sampled. AC channels capture full spectrum data. The units were sampled in a round robin fashion and run continuously. Sensors were added to new points on the machines and within the pulp mill without additional base stations.
**Wireless Performance**

Signal strength around the wireless units across all four base stations are shown below. Signal strength is high, close to 100% in most nodes. A few nodes toward outer ranges have lower signal strength, but still within operating parameters.
Software Analysis

The following is a short description of the programs used to maintain the wireless network system and to analyze data from it.

**Screen Viewer:** "Live time" data collection is displayed for each sensor point. Data gauges represent the values being recorded for each sensor input. If a spectral band value goes into alarm, the arrow color changes to yellow or to red if the value is in a fault condition. The live view SW provides single or multiple displays of waveforms, spectra, trends and orbits. Text and email messages are triggered (as programmed) on critical events.

**Database Configuration:** The Database Editor is used to configure and edit the database used by the monitoring unit(s). This program allows the user to create the database tree that will be used by the system and then set the important database parameters for each level in the database tree.

**Historian:** the historian is used to get historical data from the database, for machinery diagnostics and analysis. The historian has many tools and features developed specifically for the machinery analyst. Data may be viewed graphically or as raw data.

**Remote Monitor:** This program allows plant wide visibility to the live data from the sensor network, and is used as a “view only” function whereby the user cannot change the configuration of the vibration system.

**Data Export:** Critical parameters from the wireless monitoring system are exported using 4-20ma outputs, OSI PI tags (file based) or MODBUS TCPIP. This provides a mechanism to allow data captured wirelessly to be injected into the overall plant control system. Data logged to the plant system includes overall vibration, DC/process data, and other parameters of interest (including extracted parameters such as power per frequency band of a critical bearing).
A typical screenshot of the monitoring system is shown below. Wireless signal strength is shown in the small box on upper right. The graphs show multiple spectrums or waveforms.
The main monitoring screen with gauges is shown below:
Challenges to Maintaining 24/7 Monitoring

The sensor system has been running for multiple years, including some outside sensors and base stations (exposed to weather). Critical areas have been categorized, and are grouped as follows:

- **IT Infrastructure and stability**: If network drives are used for database storage, they might fail without RAID reliability, or more likely the server might be shut down for maintenance, preventing the wireless system from archiving data at that point. Computers and servers running the analysis or sampling program might be shut down for updates. Laptops might initially be set to power down without user activity. Ethernet switches might be turned off or rebooted, firewalls changed, or Ethernet cables might be damaged.

- **Power systems**: The mill power system is critical to maintaining the sensor network. Areas of the mill might be shut down for maintenance (even if the machine is still running). Power cords can be cut or appropriated for other uses. GFI circuits can be tripped in wet environments and not reset.

- **Physical Damage**: Antennas are a likely area for damage, as are sensors. Units and sensors must be placed with low profile mountings and out of the way of routine maintenance paths. Physical damage was not found to be a common failure point compared to IT and power reliability.

- **Radio interference**: No radio interference from other sources and into the wireless system network was detected during the operational period. No interference from the wireless sensor network into another system was detected.

- **Electrical Interference**: No electrical interference was found to affect the sensor networks.

- **Radio Range Issues**: New nodes were routinely added, or older ones moved, without issues with Base station access.
Monitoring System Results

The system ran reliably over a multi-year period. If a critical area was identified, particular focus could be placed on that bearing by setting alarms and guard bands. Sensors could be quickly added or moved depending on short term needs of the reliability department.

Case studies are described below:

1) Lumpbreaker

Problem: Unable to load the lumpbreaker roll beyond 100 pli without the roll bouncing.

Solution: “Installed 2 wireless vibration units to monitor the XYZ direction on both the front and backside of the lumpbreaker roll. We started collecting data instantly and were able to slowly increase the load to the lumpbreaker. Within 30 min we had an idea of the problem. The vibration peaks were at 12 times running speed, which lined up with a head fit issue. The roll was removed and sent off to a roll shop and the problem was verified, and the head was removed and installed properly. We now have full loading capabilities with this roll. We fought this problem for over 2 years. Using the wireless continuous sampling mode allowed us to quickly find the problem. The same exercise with our route base equipment would have required 2 men and 2 days of sampling and analyzing to possibly come up with the same results.”

2) 1P2 Felt Roll

Problem: Bearing on roll has a history of failing unexpectedly.

Solution: “Installed wireless sensor to constantly monitor the position. The wireless sensor picked up a bearing defect. The bearing defect was confirmed and the bearing did not have a catastrophic failure as had previously occurred. The event was picked up between normal route data collection and probably would have failed before the next route collection.”

3) #18 DS Dryer Bearing

Problem: Routine monitoring on critical equipment. Using route based data collection, this critical equipment was checked during normal routines and an inner race defect was identified. However, it was still two weeks until the next scheduled outage.
Solution: “Installed wireless sensor on the bearing to allow us 24/7 monitoring. We were able to establish a failure rate using the wireless system and reschedule the outage to an earlier date.”

4) HSB Pumps

Problem: These pumps were failing on a regular basis due to an intermittent problem. Using route based data collection this critical equipment is checked once each 30-45 days.

Solution: “Installed wireless unit on the pumps to allow us 24/7 monitoring on critical equipment. We were able to identify a severe cavitation problem that would come and go and was so bad it would rip the hold down bolts out of the base. Had this equipment failed, it would have shut down one of our recoveries.”

5) Line Shaft Turbine Coupling

Problem: Routine monitoring on critical equipment. Using route based data collection this critical equipment is checked once each 30-45 days.

Solution: “Installed wireless unit on the turbine to allow us 24/7 monitoring on critical equipment. The wireless unit caught an impending coupling failure, and we were able to monitor and change the coupling on the next shutdown. Had the line shaft failed it would have shut down the paper machine, and we would have lost the forming fabric and possibly the wire on the fourdriner.”

6) Kamir/ Top Separator

Problem: Routine monitoring on critical equipment. Using route based data collection this critical equipment is checked once each 30-45 days. This critical asset is a ¼ mile away and 256 step up in the air.

Solution: “Wireless sensor detected an event April 29th. Analyst verified the event with route equipment. After further investigation, it was found to be a process issue. The production manager was contacted and told of the event. The process engineer changed the flows and the event went away. This event has never been caught in the past and could have led to a nozzle failure.”
Section 2: Summary

The field study confirmed that long range 900MHz ISM radio technology was able to successfully monitor a large industrial plant over a period of years. Upfront infrastructure investment was minimal, and the initial system was operational within a day and was able to scale quickly to meet growing demands. The continuous monitoring ability with full spectral data allowed the plant reliability group to detect and correct several serious problems.
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