

Designing and Implementing Radio Based SCADA Systems – Lessons Learned

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ABSTRACT

Orange County Utilities uses a state-of-the-art radio based SCADA system to monitor and control over 300 sewage lift stations from three County wastewater treatment plants and related facilities. In order to construct this system, several real world challenges had to be addressed.

Several different kinds of radio surveys, performed, produced dramatically different results. A software survey initially calculated that 30-ft poles could be used for nearly all sites. Subsequently, a field survey was performed and mathematically manipulated to calculate the required antenna heights. The results of the survey showed that 30-, 50-, 70-, and 90-ft poles would be required at various locations. While a system using only 30-ft poles might not work, the 70- and 90-ft pole option had the potential to cause concerns within the community. Another solution had to be found.

In addition, some end sites that appeared to be capable of communicating, just would not communicate. This posed a mystery that was not resolved until radio experts were brought into the project. Bent antennas, internal cable RF shorts, and the finer details of antenna aiming were some of the hard to find problems that afflicted these sites until resolved.

Overall, the radio approach has been successful and has saved thousands of dollars in dedicated line fees. But for best results, some things should be done differently next time.

INTRODUCTION

Orange County covers approximately 1,000 sq miles in central Florida and is relatively flat. In many respects, it is a good location for high frequency radio; however, Orange County is in the nation's most lightning prone area with about 100 days of lightning a year. It also has periods of heavy rain, thick vegetation, and generally hot temperatures all of which can play havoc with radio systems.

Orange County's population has grown significantly in recent years, making it necessary for Orange County Utilities (OCU) to provide higher-capacity wastewater services, and to manage these services using cost-effective and efficient methods. The OCU wastewater collection system currently has over 600 lift stations and is growing by almost 50 lift stations a year. Each additional lift station increases this management effort exponentially. The tremendous number of lift stations is a tracking and coordination challenge. To help manage operations of these stations, the OCU determined that a radio based Supervisory Control And Data Acquisition (SCADA) system would be a cost-effective solution.

The SCADA system monitors each lift or pumping station through a radio communications system. Flow, wastewater levels, and pump status data is transmitted to a central location where personnel can be dispatched to make repairs and correct problems¹. Because of lightning concerns, the Remote Telemetry Units (RTUs) do not control the stations – existing relay logic panels were left in place for that purpose with a limited amount of control available for manual starting and stopping of pumps. Design criteria included robustness, standard products, lightning tolerance, sunshield protection of field panels, resistance to Radio Frequency (RF) interference, and low recurring charges for phone service.

Corrosion-resistant concrete poles were chosen after reviewing galvanized steel, fiberglass, aluminum, and 316 stainless steel. Since concrete poles are commonly used in Orange County for power and lighting, they blend into the background more easily. Also, these poles are designed to be foundation free, a plus in Orange County's sandy soil, yet still meet the stringent wind loading of 100 mph. Co-locating on Cell towers on Orange County property was also investigated. Unfortunately, this space had not been reserved during contract negotiations so this option was not available.

RADIO BAND SELECTION

Whenever possible, use a data only radio band for radio SCADA radio systems. Previous attempts to operate a SCADA system for the OCU Water division were unsuccessful. OCU Water division used two licensed frequencies in the 450 MHz range for SCADA data communications to 18 sites. Additions over the years required the use of repeater sites and a combination of series and parallel branches to achieve the required links. Failures at a sequential repeater site caused a loss of communications to sites located beyond that point. Because of this, the system was extremely vulnerable to interference, lightning strikes, thermal overload, and equipment failure. Additionally, the radio equipment was custom made and required specialized training and test equipment for calibration and repair. Adjacent radio users include the voice designation of "land mobile" which includes taxi service, trucking dispatch and the like. Interference was generated by adjacent frequency splatter and close proximity to transmitters as mobile users drove through the area. All these factors, coupled with the slow response of the communications (data bottleneck), made the former radio-based system less than desirable. The Water Division of OCU ultimately abandoned the 450 MHz radio system and moved their sites to ISDN phone lines.² This was economical for the Water department because there were fewer than 20 remote sites.

The Waste Water division of OCU needed to select a radio band for their new SCADA system. The experience in the water division ruled out using the 450 MHz band. Adapting the OCU 800 MHz trunking radio system was a possibility that was ruled out early in the process because this system is shared with other users and would be slow. Preliminary research indicated that there was no available licensed 928/952 MHz point to multipoint licensed frequencies in the Orange County area.

Spread Spectrum radios in the 900 MHz band were selected for the design because of their ease of use and license free status. Designed to tolerate interference well and operate in a data only band – there are no voice users --they are also widely available from a number of manufacturers. Because they operate using only 1 watt, properly locating the master radios is a critical issue, and might have involved telephone leased-lines from the control room to distant locations. By using an innovative combination of radio, computer network, and telecommunications equipment, OCU's existing investment in microwave communications was used to reach distant master radio sites spread throughout the county. The remote radio diagnostic software that came with the radios has proved invaluable in tracking down radio problems.

RADIO SURVEYS

SOFTWARE RADIO SURVEY

A software radio survey between county radio towers and wastewater lift stations was performed early in the design. Individual site latitude and longitude were identified on topographic maps. The computer generated terrain profiles are compared to detailed topographic maps in order to confirm their accuracy. Line of sight paths are drawn on the plots to verify the first order presence of possible communications links.

The results from this survey showed that 30-ft poles would be high enough to enable communication to most, if not all, sites. It appeared that using the 150-ft master radio towers and 30-ft poles at each end site, would suffice for good radio reception throughout the county.

FIELD RADIO SURVEY

Software surveys are only a rough determination that a radio path may exist; a field survey is required to confirm it. The field survey should be done early in the process, preferably during initial system design. A propagation component not shown on the path profiles is the height and density of foliage in the area. The signal strength measurements made during the field radio survey measure the RF attenuation contributed by the local foliage.

In this project, the field survey was performed late in the project. Five watt 928 MHz transmitters and antennas with known gains were temporarily installed at each master tower. Radio technicians at each remote location rotated a directional test antenna to maximize the intensity of the signal and to assure

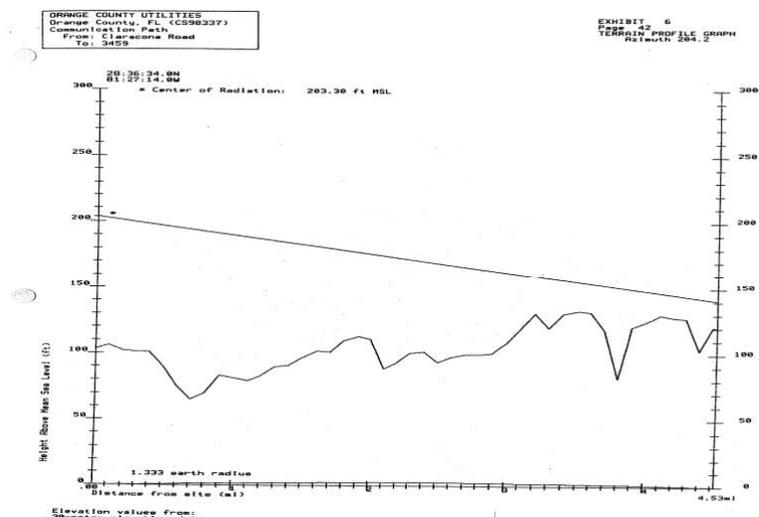


FIG. 1 – TERRAIN PROFILE

reception is through the main antenna lobe (figure 2). The received signal strength and the GPS measurements were recorded.

Correction factors applied to the field test data accounted for differences between the field test hardware and the proposed radio system hardware. This correction includes radio power, feed line, and antenna differences. For example: a 1-Watt field test radio compared to a proposed 2-Watt radio produces a correction factor of +3 dB. This indicates that the proposed radio system is 3 dB better than the test system.

A 20 to 30 dB fade margin is normally used for SCADA radio networks. In this case, a 20 dB margin was used with the -110 dBm sensitivity of the radio to produce a target -90 dB minimum signal strength. Sites producing at least -90 dB with the 20-ft test pole were assigned to the 30-ft pole group.



FIG. 2 – FIELD RADIO SURVEY

Received signal strength can often be improved by increasing the antenna height. The FCC regulates the transmitter power and antenna gain for spread spectrum radios. Improvements in signal strength by increasing antenna height are dependent on terrain and surrounding foliage. Instead of using test poles with different heights, a computer analysis using the Bullington signal strength technique³ estimated the potential improvement in signal strength by increasing the antenna height over the terrain. This analysis was performed for antenna heights of 30-, 50-, 70-, and 90-ft to determine which height would produce an Received Signal Strength Indication (RSSI) of at least -90 dB.⁴

In contrast to the initial software survey, the field results showed that 30-, 50-, 70-, and 90-ft poles would be required. Installing 70- and 90-ft poles in a commercial area may not pose a problem, installing them in a neighborhood would likely have a different result.

Later in the project, another software radio survey was performed by a different firm. The results of this survey also did not reasonably agree with actual field

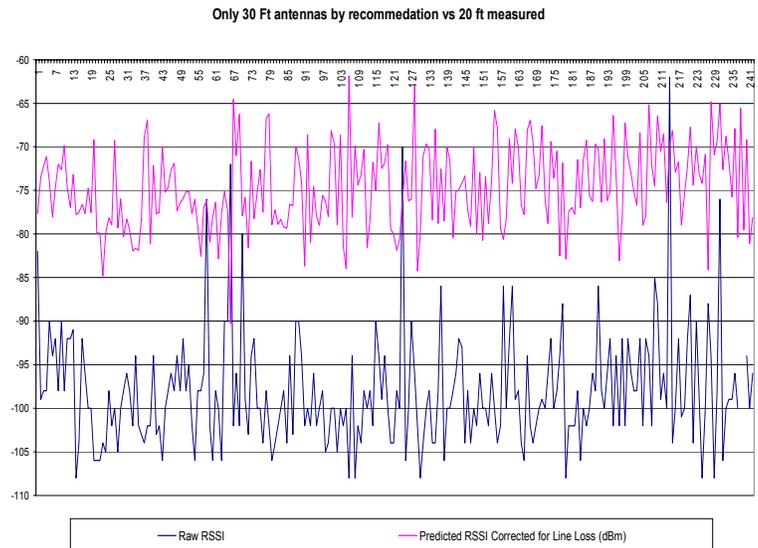


FIG. 3 – SOFTWARE SURVEY VS. ACTUAL SIGNAL STRENGTHS

measurements. In figure 3, the top line is the software survey prediction and the bottom line is the actual received signal strength. The actual signal strength is about 25 dB weaker than predicted.

FIELD VERIFY EXTRAPOLATED DATA

Since the field survey was adjusted mathematically to determine pole height, it needed to be verified with empirical data. To confirm the field survey results, 25 sites were installed to compare field radio survey to the actual real world radio signal strength. After installation, 6 sites had unexpectedly weak RSSI. A specialty communications contractor was employed to inspect those sites with the worst performance. Using a Time Domain Reflectometer (TDR) and visual inspection, various installation problems were found and corrected at each site.

- An internal jumper from radio to bulkhead connector on RTU was defective. This was a locally made cable that had a single strand of wire out of place making an RF short inside the connector. Using products from major manufacturers that specialize in RF cable would avoid this quality problem.
- An antenna mast was crooked and not truly vertical. This caused the antenna radiation to propagate ineffectively.
- Water was found in antenna connector at top of mast causing an RF short. Weather proofing was inadequate.
- Loose RF connectors were tightened eliminating bad electrical connections.
- An antenna was re-aimed for a 3 dB improvement in received signal.
- An antenna was very slightly bent during installation. The bend, though barely noticeable at arm's length, required that the antenna be replaced.

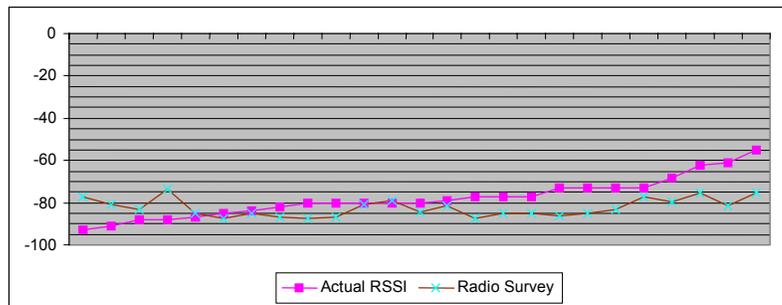


FIG. 4 – FIELD SURVEY VS. ACTUAL MEASUREMENTS

After the repairs, the field data closely matched the predicted results of the field survey (Figure 4), proof that the number of 30-, 50-, 70-, and 90-ft poles called for was accurate.

KEEPING A LOW PROFILE

It was clear that the 30-ft poles at all sites would not work. At this point in the project, there were approximately 365 remote sites designated for poles taller than 30-ft. OCU decided not to use antennas over 50-ft for maintenance and visual reasons. At the same time maintaining, a robust communications network was desired.

The best technologies to meet these constraints were narrowed down to spread spectrum repeaters and license radios. While the technology solution was being investigated, OCU conducted a visual impact survey to determine which sites were problematic.

VISUAL IMPACT SURVEY

In order to gain homeowner association acceptance and continue to be a good neighbor, OCU limited most pole heights to 50-ft, especially near residential areas. Exactly which sites needed to reduce their pole heights was not obvious.

The visual impact survey, a joint effort of OCU and the Designer/Builder, was performed at all sites to determine the visual impact on the surrounding community. Each of the end sites were visited to assess the pole height that could be tolerated, based on surrounding land use, light poles and buildings in the area, covering vegetation, among others. Sites were assigned a maximum pole height of 10-, 30-, or 50-ft. A shorter pole was installed wherever the field radio survey showed that it would work satisfactorily.



FIG. 5 – TYPICAL 30-FT POLE

REPEATERS

A repeater retransmits the radio signals received to increase the overall area that can be served. In Orange County, a repeater pole holds two antennas: a directional antenna and an omni-directional antenna. The minimum pole height for a repeater site is 50-ft. A directional antenna, mounted at 30-ft, receives the radio signal from the master and an omni-directional antenna mounted above it re-transmits the signal to the end sites.

In order to provide rough estimate of repeaters needed, the field RSSI measurements in the previously completed field radio survey were analyzed. On the average, a 100-ft master antenna provides an *average* range of 2.75 miles for a RSSI at or above -90 dB (Figure 6). Based on this, a 50-ft spread-spectrum repeater should have an average effective range of about 1.25 miles. Since a single level of repeaters won't reach enough sites, the number includes a second tier of repeater of repeaters. Using these assumptions, 55 repeaters will be required for full coverage throughout Orange County. Since the project was still underway, it was decided to perform a repeater field survey at only those sites that appeared unlikely to be able to communicate without repeaters.

Potential repeater sites were selected from the sites that could communicate to the Master radios at a 30-ft height as documented in the field radio survey. The sites were further narrowed to those that could visually permit a 50-ft pole. These sites were then examined to see if they were in an area that needed improved communications. Using this procedure, 30 sites were identified as likely repeater sites.

After the repeater site selection was complete, a field radio survey was conducted. A portable 50-ft pole with an omnidirectional antenna was placed at the proposed repeater site to establish a spread spectrum radio beacon. Measurements at nearby sites were taken to determine the effective coverage. A check back to the master tower site was done using a directional antenna at 30-ft. All of these steps were repeated for each repeater cell.

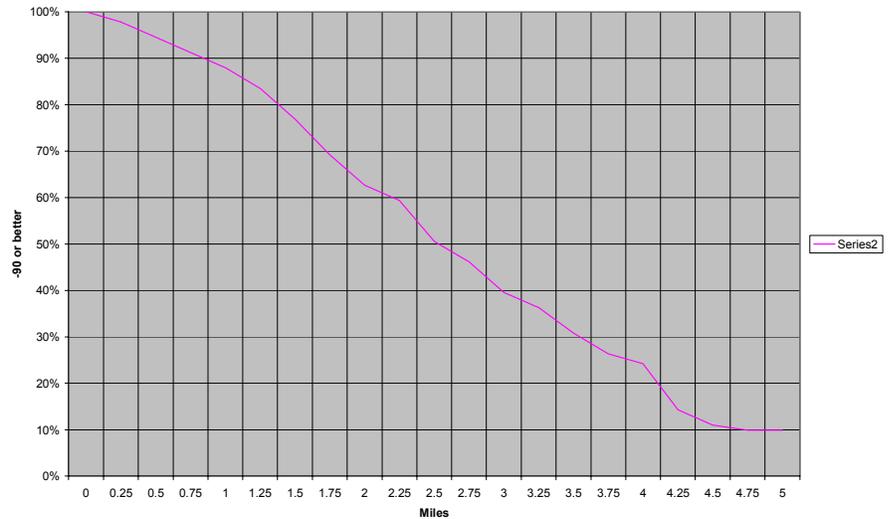


FIG. 6 – ACCEPTABLE SITES VS. DISTANCE

The cost of a radio survey is determined from the number of paths surveyed. With 30 repeater sites and 142 end sites, 345 paths were evaluated. Adding additional repeaters causes the cost to escalate rather quickly. Using care in the selection of potential repeater sites will help limit this cost.

Based on the repeater survey results, it was possible to reduce the pole height at 96 sites to the heights recommended in the visual survey. Of the 30 sites surveyed, 20 repeater sites picked as the best repeater locations. A total of 307 sites were identified that can be installed and meet both the visual survey recommendation and the target RSSI level.

LICENSED RADIO

Because of recent FCC frequency re-farming in the 900 MHz band, a new set of frequencies became available during the project. OCU successfully obtained ten licenses in the 938/952 MHz band. The possibility of replacing spread spectrum radios with licensed radios in-order to improve the RF fade margins in the system was discussed.

OCU suggested and CDM agreed that the funds required to perform an additional licensed radio field survey would be better spent in purchasing licensed radio equipment and self-performing a limited field test and comparing the system performance change associated with the licensed radios. OCU and CDM staff converted one of the ten channels from spread spectrum radios to licensed radios over a 4-day period.

The licensed radios improved field system performance in all key areas: Received Signal Strength Indication (RSSI) increased by 10 dB, each site's percent of communication failure improved dramatically, and channel polling speed improved 10%.

RECEIVED SIGNAL STRENGTH

An increase of 7 dB in received signal strength was expected when changing the radios from 1 watt spread spectrum radio to 5 watt licensed radio because of increased power. However, the average measured RSSI increase was 10 dB (figure 7). Sites that were previously above the minimum signal strength now have additional margin that protects against signal fading and dropouts.

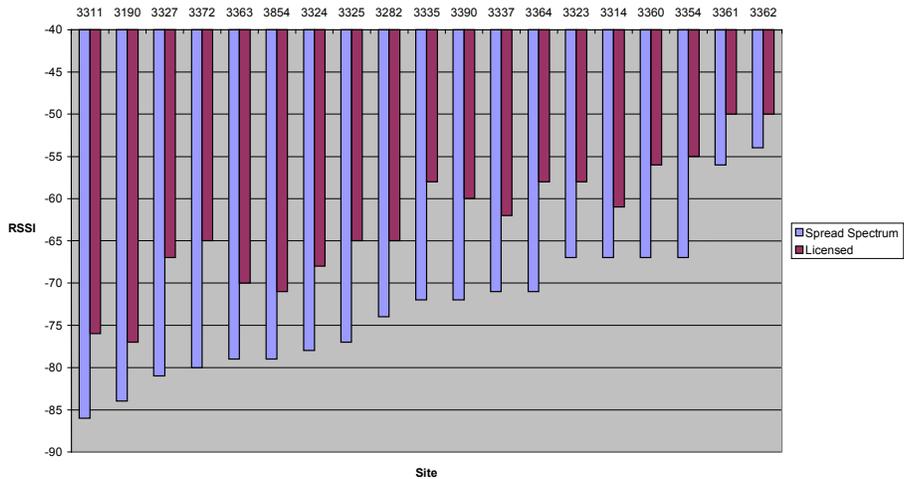


FIG. 7 – LICENSED VS. SPREAD SPECTRUM RSSI

COMMUNICATION FAILURE

The percent of failure for each site and the channel overall went down dramatically (figure 8). This is directly linked to the overall improvement in radio signal strength and the reduction of data rate. Sites with a large percent of communication failures significantly slow down the response for the entire channel.

CHANNEL POLLING SPEED

There are two major factors that affect the polling speed of a channel: communication failures (i.e. retries) and data rate. Before field results were available, it wasn't clear whether time saved in less retries would balance time spent using slower data rates. On one hand, the system is slowed down because the data rate was reduced from 19,200 to 9600 baud (spread spectrum vs. licensed radio). On the other hand, the system saves time because there are fewer communication retries. The use of 5-watt radios has reduced the percentage of failures by increasing the RSSI. The extra power and the slower data rate make the system more robust and the data gets through the first time more often. Although the theoretical maximum speed in the system was reduced in half, the actual field measured channel polling speed improved from

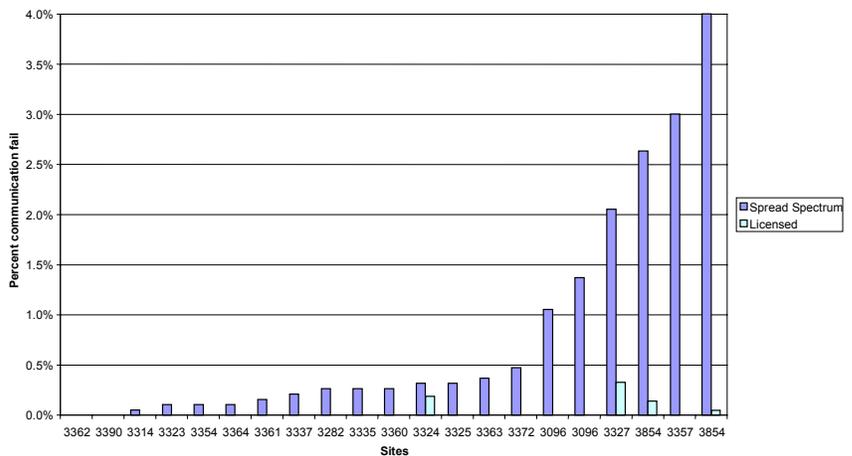


FIG. 8 - LICENSED VS. SPREAD SPECTRUM RETRIES

around 49 seconds to 44 seconds, and improvement of 10%. This improvement is a result of reducing the number of communication failures by both increasing radio signal strength and reducing the data rate.

OCU is now planning to replace most of the spread spectrum radios with licensed radios to get the benefits of increased fade margin.

CONCLUSION

Several lessons were learned during this project:

- Whenever possible, use a data only radio band for SCADA radio systems.
- Software surveys are a rough determination that a radio path *may* exist. A field survey will confirm that the path exists. The field survey should be done early in the process, preferably during initial system design.
- System design constraints need to be identified early. These include not only technical constraints but also site-specific issues. Few people want a 90-ft pole visible from their back yard.
- Field verify extrapolated data. If a field survey uses extrapolation to determine pole heights, it needs to be field verified to demonstrate that the assumptions made hold true.
- Intelligently choose repeater sites to reduce the number of paths studied. Evaluating multiple radio paths can become very expensive and time consuming. Choose what appear to be the best candidates for repeater field surveys.
- Radio data stability is enhanced both by power and lower data rates. For SCADA radio systems, use the most powerful transmitters possible and minimize the data that is sent so that high data rates are not required.

The OCU radio SCADA project is a positive example of the using the design / build process. The project team built upon a foundation of technical expertise and professional respect to produce a successful project. OCU now has a state-of-the-art SCADA radio system that reliably monitors over 300 sewage lift stations, facilitates proactive decision-making for enhanced operation of the County's facilities, and provides real-time data about flow characteristics and other functions.

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