"A Survey of Fixed-Base Wireless Automated Meter Reading Approaches"

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Abstract

Municipalities are now considering the use of Automatic Meter Reading (AMR) systems that are interrogated from antenna towers located throughout a service region. There is significant economic incentive for these fixed-base systems, but there are significant technical challenges. This article briefly reviews several different wireless options that have been considered by the industry.

Fixed-Base AMR

Throughout the last decade, Automatic Meter Reading (AMR) has become the primary method for collecting consumption data for water, gas and electric meters. With AMR, the meter readings are collected by an electronic means as opposed to manually reading the dial. The technology has been used principally to improve the efficiency of the billing process. Most AMR systems deployed today are either walk-by or drive-by systems that still require monthly utility employee interaction.

A new concept in utility management is beginning to emerge. It is inspired by the general availability of wireless data in our modern society and is driven by nationwide economic trends toward total resource management of valuable resources. The concept uses a fixed base for utility operation where AMR data is sent via wireless transmission to nearby towers and then integrated into our nationwide communication infrastructure for transmission to the utility operations center. Fixed base AMR not only provides for conventional billing, it also provides visibility into daily consumption trends and event detection such as leaks, theft, high flow, continuous flow, and reverse flow. Eliminating manual reads reduces utility operating cost and customer service is improved by providing immediate customer visibility into account status. The transition from drive-by systems to fixed-base systems is just beginning. Two major suppliers have announced rollouts in the fall of 2004.

Radio Frequency Options

Generally, the industry has considered three separate options for fixed-base AMR (FB-AMR):

- Single-frequency operation between 450 - 470 MHz
- Spread-spectrum operation in the 915 MHz ISM band
- Spread-spectrum operation in the 2.4 GHz ISM band

Wireless coverage for an entire utility service region rarely can be accomplished with a single access point into the communication infrastructure. The region is therefore broken into individual cells operating on separate radio nets. The industry has considered cell sizes ranging from a ½ mile radius to a 5 mile radius. In some instances the 5 mile radius systems can, in principal, cover the entire service region of a small utility.

If the number of access points is not excessive, the cost of a FB-AMR system is overwhelmingly driven by the transmitter equipment costs. Since viable AMR systems are extremely cost sensitive, this favors the use of one-way, transmit-only systems where each transmitter randomly accesses the channel. This architecture is assumed in the comparisons below.

450 - 470 MHz Single-Frequency

Utilities are eligible for frequency assignment of land mobile radio services in the 450 – 470 MHz band for low power use. Operation is authorized for 11.25 kHz narrowband emissions and the power output is limited to 2 Watts. Frequency assignment is made by a certified frequency coordinator after service and interference contours are verified. Operations are typically licensed for a radius of 5 miles.

Single channel operation has the distinct advantage of a unique frequency assignment that, in principal, is free of interference within its operating region. Further, of the three frequency bands considered, operation at 460 MHz will have the lowest propagation loss. For reference, the free space loss for a 2 mile radius cell is 95 dB.

Transmitter equipment cost is the driving economic factor for FB-AMR systems. Single-frequency operation requires very little control processing. However, the need for an accurate frequency reference can be significant. Since each site uses a unique frequency, factory or depot provisions must be made to set the operating frequency before each deployment. AMR transmitters must be battery operated, therefore power amplifier efficiency is an important factor. Power amplifiers operating at 460 MHZ can achieve efficiencies of 55%.

The most significant drawback of 450 - 470 MHz band operation is the administrative task facing each utility operator in obtaining an individual site license. A total of 20 MHz of bandwidth is available, but there are a limited number of frequencies that can be assigned. If coverage cannot be attained with a single frequency, then multiple frequencies must be requested, adding to the burden and reducing the likelihood of obtaining the necessary licensing.

Another drawback to narrow-band, single-frequency operation is its susceptibility to interference. If interference does exist, the system cannot compensate and the communications will be lost. Most of the AMR systems use one-way communications. Unlike voice communications where the listener can ask the speaker to repeat garbled transmissions, these one-way systems cannot recover the lost data. There are many aftermarket manufacturers of RF equipment in the 450 - 470 MHz band who marketed specifically to end-users. The opportunity for a novice to create interference is high. The only solution to such interference is via administrative means.

Some concern has been raised about the capacity of a single-channel system. Channel capacity is highly dependant on the meter-reading packet duration and the ability of receivers to detect and demodulate short bursts. If the burst duration was 1 second and 6 valid reads per day are required, the capacity of a single-channel net is 700 utility meters. If the burst duration is reduced to 14 milliseconds, the single-channel capacity is increased to 50,000 meters. In practical terms, the 11.25 kHz bandwidth limits the data rate to less than 5 kbps. If a 2.4 kbps link were assumed, a reasonable minimum burst duration would be 66 milliseconds. This would allow 10,000 meters to be served on a single net.

915 MHz Spread-Spectrum

Operation in the band from 902 to 928 MHz allows deployment of a radio system without the need for obtaining a specific site license. Once certified, a common radio module can be deployed at all potential cites without the need for additional FCC licensing and the need to manage the frequency plan of the deployment. A total of 26 MHz of bandwidth is available to all users. For all new equipment, either frequency-hopping spread-spectrum (FHSS) or direct-sequence spread-spectrum (DSSS) techniques must be used. With FHSS, the transmit frequency is changed pseudo-randomly as a function of time. The hops are spread out over the band. With DSSS, a pseudo-random pattern is superimposed over the meter-reading data. The resulting pattern is sent at a higher rate than the original data giving a higher effective transmission speed and therefore a spread bandwidth. The use of spread spectrum allows transmitters to operate with a power output of 1 Watt under the FCC Part 15 rules, which govern operation in this band.

The availability of 26 MHz of bandwidth is a significant advantage of the 915 MHz band. The use of spread-spectrum techniques provides significant levels of interference immunity, even in a crowded band. For FHSS, the transmitters are able to hop to frequencies not occupied by interference. For DSSS, the de-spreading operation knocks down the level of the interferer by the ratio of the spreading amount. Further, since data rates up to 250 kbps can be supported in this band, the burst durations are not limited as the in 460 MHz narrowband channels. Using a data rate of 9.6 kbps, meter-reading burst durations can be as short as 14 milliseconds. This will support 50,000 meters on a single net. Finally, if provisions are made to select the hopping set or the spreading code, multiple independent networks can easily be created. This is useful in setting up adjacent cells in large service regions where one cell is insufficient.

The hardware costs of a 460 MHz transmitter and a 915 MHz FHSS transmitter are very similar. Even though a FHSS transmitter requires a controller to implement the frequency hop pattern, the amount of processing required on the transmit side of the link is small. Frequency oscillator costs associated with the narrow-band 460 MHz channels offsets the 915 MHz FHSS controller costs. In the 460 MHz band the required frequency accuracy is 2.5 parts per million which usually requires a temperature compensated oscillator. Such an oscillator can account for as much as ¼ of the cost of an AMR transmitter. In the 915 MHz band, frequency accuracy is effectively determined by the ability of the receiver to detect and demodulate the spread-spectrum signal. If receiver complexity is increased, the transmitter frequency accuracy can be relaxed, thus lowering cost of transmitter components and calibration. Since thousands of transmitters report to one receiver, even small savings in the transmitter cost is significant whereas an incremental increase in receiver cost is inconsequential.

DSSS transmitters require slightly higher-speed processing than FHSS transmitters and the power amplifier must operate linearly over a wider bandwidth. These two factors combine to make a DSSS transmitter slightly more costly. The receiver costs of DSSS is significantly more complex than a FHSS receiver, but once the investment in DSSS technology is made, the receivers are only slightly more costly and have little impact on overall system costs.

The battery conversion efficiency for 915 MHZ power amplifiers is less that those found at 460 MHz; at 915 MHz, efficiency peaks out at about 47%. Assuming a 10 year nominal battery life at 460 MHz, the lower efficiency at 915 MHz will reduce battery life to 8-1/2 years.

The biggest drawback to the 915 MHz band is that the spectrum is available to all users. The number of 915 MHz radios that can be deployed is virtually unlimited in any geographic region. Fortunately, each radio must comply with the requirements of FCC Part 15, providing means for sharing the channel and tactics for interference avoidance. The legacy, low-power, single-frequency radios are being phased out.

A rigorous analysis of the effects of interference on a spread-spectrum radio is complex; however, general trends can be cited. For FHSS systems, a second, interfering FHSS transmitter can only cause a meter reading to be missed if both the desired and the interfering transmitter use the same frequency at the same time. Since 1Watt FHSS transmitters must use a minimum of 50 frequencies, the probability of simultaneously using the same frequency is low. Even if the interfering transmitter were stuck on a single frequency, only 2% of the meter reads would be lost. There are many possible combinations of transmission bandwidths and burst durations, each causing a unique effect on the receiver. Nonetheless, none seem to be any worst than the stuck interferer case cited above. In contrast to FHSS interference, a DSSS interference source looks like a general increase in background noise to a FHSS receiver. The 1 Watt output of the DSSS interferer has been spread by a factor of 10:1, minimum. Even though the FHSS receiver is more likely to be on the same frequency as the DSSS signal, the magnitude of the DSSS interference has been reduced by at least 10 dB due to the spreading. In general, if an interference source is 10 dB below the desired signal, the meter-reading can be received.

For DSSS systems, the original pseudo-random code that was used to spread the transmitted signal is used in the receiver to reconstruct the incoming signal. In the receiver, a matching of the incoming signal is made against the pseudo-random code. If the code is a match, the signal gets reconstructed and becomes 10 dB greater, assuming a 10:1 spreading factor and perfect match. If there is an incoming DSSS interference that does not match the code, there is no reconstruction and interference still appears like background noise; still 10 dB lower than the reconstructed signal. Likewise, if the incoming interference is a narrow FHSS signal, the processing of trying to match the code actually spreads out the interference making it appears as background noise. Once again the reconstructed signal sits 10 dB above the noise. If we can get the interference 10 dB below the desired signal, or conversely, the desired signal 10 dB above the noise, the meter-reading can be received.

Other than having a interfering 1 Watt transmitter operating in the immediate vicinity of the FB-AMR receiver, the biggest threat to 915 band operation is the general rise in noise floor of the whole band as a result of many independent radios operating at the same time within the same coverage area. The larger the coverage radius, the more interference. Cursory measurements have been made in suburban areas with antenna heights up to 40 feet. The background noise has been observed as high as 10 dB above the natural noise floor and is typically 3 to 5 dB above this floor. This forces the antenna heights to remain low and the cells to stay small. Even though the FB-AMR range in an interference free region may extend to 2 miles, the maximum reliable range in an interference environment will be closer to 1 mile.

The free space loss for a 2 mile radius at 915 MHz is 102 dB. This is 6 dB more loss than at 460 MHz. If all else were equal, the 460 MHz link would have twice the range of a 915 MHz system. Also note that in the channel capacity discussion we assumed that the data rate of a 915 MHz system was 4 times greater than the 460 MHz system. Increasing the data rate requires more power, in this case, 6 dB more power. This would cut the operating range of the 915 MHz system in half with respect to the 460 MHz system with all else being equal. Additional coding can be added to a 915 MHz spread-spectrum system to make up for some of the losses incurred when moving from 460 MHz; however, this adds complexity and development costs.

2.4 GHz Spread-Spectrum

Currently some utilities use 2.4 GHz wireless systems for supervisory control and data acquisition (SCADA). There are recent reports of this technology being considered for FB-AMR. The FCC Part 15 rules for 2.4 GHz operations are very similar to 915 MHz operations. The most notable difference is the availability of 83.5 MHz of bandwidth at 2.4 GHz. The use of the 2.4 GHz band is most often associated the IEEE 802.11b, 11g standards and is commonly known as Wi-Fi.

The original motivation for wireless technology moving from 915 MHz to 2.4 GHz was the availability of greater bandwidth to support higher data rates. For example, 915 MHz systems support data rates from 9.6 to 115 kbps whereas Fi-Wi typically operates with data rates from 1 to 5 Mbps for 11b and much higher for 11g. Since a single meter reading can be transmitted with less than 64 bits of information, large-scale AMR systems can be deployed with transmit data rates as low as 4.8 kbps without sacrificing network performance. Consequently, the wideband capability of the 2.4 GHz band is unnecessary.

Integrated circuit chips sets are readily available that make the implementation of Wi-Fi systems straightforward, however the chip sets are significantly more expensive than the 450 MHz and 915 MHz technology. The dominance of Wi-Fi does not preclude a developer from employing a spread-spectrum system with lower data rates and therefore a longer transmission range; but this involves a commitment to significant development costs and the need for high volume production to offset these costs.

The battery conversion efficiency for 2.4 GHz power amplifiers is the least of all three bands considered and rarely exceeds 40%. Most 2.4 GHz power amplifiers devices peak out at 200 milliwatts. This represents yet another shortfall for the 2.4 GHz links and the nominal 10 year battery is reduced to 7 years.

The maximum outdoor range of Wi-Fi using omni-directional antennas is generally regarded to be 1200 ft. This range limitation would force the use many access points to achieve coverage over even a medium size service region. Even with a custom, low-data-rate, spread-spectrum implementation, the free space loss for a 2 mile radius cell at 2.4 GHz is 110 dB. This is 8 dB more loss than at 915 MHz and 14 dB more than the loss at 460 MHz. All else being equal, a 915 MHz system would have 2.5 times the range as a 2.4 GHz system and a 460 MHz system would have 5 times the range. Operation at 2.4 GHz only seems possible with a large up-front investment in technology and the proliferation of many access points and relays.

Summary

Both 460 MHz single-frequency operation and 915 MHz spread-spectrum operation offer economically viable solutions to FB-AMR for cell sizes limited to 2 miles in radius. The use of 2.4 GHz is a more expensive option with no obvious advantages. This author recommends the use of spread-spectrum operation over single-frequency operation since it eliminates the need for individual site licensing. It also takes advantage of the availability of wider bandwidths to provide intrinsic interference avoidance. The 915 MHz band is a good compromise between propagation loss, bandwidth availability and design complexity, but the cell sizes will be somewhat more limited than with 460 MHz. Additional propagation and interference studies are needed to determine the true reliability and consequent acceptability of any FB-AMR system. Such investigations are underway.