

# White Paper #7-801

## Propagation and Coverage in Automatic Metering Infrastructure (AMI) Systems

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August 2007

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## Introduction

Over the past year, Micronet has worked with a series of clients regarding the propagation issues surrounding the development of Automatic Metering Infrastructure projects. Micronet has nondisclosure agreements in place that prevent discussion of specific cases, hence this discussion is based on totally representative sites and locations.

Two lines of discussion are present in this white paper, addressing two different layers of the protocol stack, namely those at the application layer and those at the physical layer.

At the application level, the case is made that a broadband standard has been developed that is Ethernet compatible. A logical approach to an AMI network is to utilize that protocol along the backhaul network to the data collector points, then transition to lower cost, more ad hoc network protocols such as Zigbee for major cost savings when connecting to the home or business. Equipment for that mapping may not exist at this point in time, but appears conceptually sound.

At the physical layer, the protocols sometimes dictate specific frequency bands. For example, Zigbee is specifically written to utilize an IEEE 802.15.4 radio, which in turn addresses operation in the 900 MHz and 2400 MHz unlicensed bands. Propagation conditions will dictate communications path lengths and link performance quality. In many cases, it will likely become more cost effective to move the backhaul out of the unlicensed bands because of EIRP limitations in those bands, to achieve the area coverage and link quality required.

While the design challenges are great, Micronet has a number of innovative approaches to assist client organizations with their AMI network physical layer planning needs, and these are addressed.

## Objectives

The objectives of the typical AMI project can be condensed into a relatively short list:

- Provide a network that reliably serves the information transfer needs of a client with individual homes and businesses where their customers reside
- Build on an architecture that provides flexibility in growth and development of the network, while keeping total equipment and maintenance costs as low as possible

- Achieve high coverage levels, both in densely populated areas, but also in the more thinly populated areas where individual homes and/or businesses are more likely to be “orphaned” from the mainstream network coverage
- Operate in frequency bands which provide support for the service, but do not burden the client, and their customers, and with unreasonably high frequency spectrum cost allocations
- Operate continuously in order that new services can be offered. For example, an electric utility might want to provide discounts for their customers turning off water heaters during some daytime hours. In order to facilitate such a service, the network must constantly check to see the status of these water heaters, and whether they are turned on or off based on authorized time frames.

## Application Layer Considerations

A number of groups are addressing the core issues of this white paper, with little consensus at the current time. This does not imply a lack of effort, or attempts to arrive at standards that will ultimately bring convergence to AMI systems at some point in the future.

For example, the IEEE Power Engineering Society has established the Power System Communications Committee (PSCC) and Substation Committee (PSSC) Wireless Working Group P1777 to address these issues.<sup>1</sup> This group is addressing older technologies such as spread spectrum and MAS (multiple address systems) and newer technologies such as WiFi, Bluetooth, Zigbee, WiMax and various forms of cellular systems. It is realized that some of these of technologies such as spread spectrum and MAS actually apply to the physical layer only. Regarding these technologies today, the assessment is summarized as follows:

*Very little information or in depth assessments of wireless technologies have been made on where they could, should, or should not be used in power system operations.<sup>2</sup>*

A standardization approach has been underway for several years, as exemplified by the following abstract:

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<sup>1</sup> [www.ewh.ieee.org/soc/pes/pscc/Wireless\\_WG\\_P1777/Wireless\\_WG\\_P1777\\_home.htm](http://www.ewh.ieee.org/soc/pes/pscc/Wireless_WG_P1777/Wireless_WG_P1777_home.htm)

<sup>2</sup> [www.ewh.ieee.org/soc/pes/pscc/Wireless\\_WG\\_P1777/uses\\_of\\_wireless\\_data\\_communicat.htm](http://www.ewh.ieee.org/soc/pes/pscc/Wireless_WG_P1777/uses_of_wireless_data_communicat.htm)

*The **Utility Communications Architecture (UCA<sup>TM</sup>)** is a standards-based approach to utility communications which provides for wide scale integration at reduced costs, and which solves many of the most pressing communications problems for today's utilities. The UCA is designed to apply across all of the functional areas within the electric, gas, and water utilities. These functional areas include customer interface, distribution, transmission power plant, control center, and corporate information systems. The UCA includes detailed object models, which defines the tag, format, representation, and the meaning of utility data. This modeling effort goes far beyond the scope of any other utility communications approach, and provides for an unprecedented level of multi-vendor interoperability applicable in most industries.<sup>3</sup>*

The Electric Power Research Institute (EPRI) did take the lead on the UCA. Their final release of the functional requirements of the architecture were provided in a document entitled **The Integrated Energy and Communication Systems Architecture Volume II: Functional Requirements**.<sup>4</sup> The end result was an IEEE Technical Report 1550, commonly called UCA 2.0, as the IEEE took the initiative from EPRI. This in turn provided the technical foundation for an international standard, IEC 61850.<sup>5</sup>

The current status is a family of IEC 61850 Standards that were published in 2005, and are available for sale through ANSI as a rather substantial body of literature.<sup>6</sup> This standard is clearly on the horizon, will be adopted by equipment suppliers over time, and essentially offers a high speed Ethernet interface to AMI, SCADA (Supervisory, Control and Data Acquisition) and comparable systems.

A good summary of IEC 61850 is available on the EnerNex Corporation website, where they are providing support to manufacturers making the transition into applicable product lines in conformance with the standard.<sup>7</sup>

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<sup>3</sup> IEEE Utility Communications Architecture (UCA) applies mainstream standard Ethernet by Karlheinz Schwarz (02/00)- [www.nettedautomation.com/solutions/uca/articles/a\\_002.html](http://www.nettedautomation.com/solutions/uca/articles/a_002.html), published in February 2000

<sup>4</sup> THE INTEGRATED ENERGY AND COMMUNICATION SYSTEMS ARCHITECTURE, EPRI, Palo Alto, CA and Electricity Innovation Institute, Palo Alto, CA: 2003

<sup>5</sup> (International Electrotechnical Commission, Geneva, Switzerland, [www.iec.ch](http://www.iec.ch))

<sup>6</sup> IEC 61850-SER Ed. 1.0 en:2005 Communication networks and systems in substations - ALL PARTS, <http://webstore.ansi.org/RecordDetail.aspx?sku=IEC%2061850-SER%20Ed.%201.0%20en:2005>

<sup>7</sup> EnerNex Corporation – [www.enernex.com/practicelines/61850services.htm](http://www.enernex.com/practicelines/61850services.htm)

One early stage pilot program has been reported in Washington State in the 2006 time frame<sup>8</sup>. A follow-up discussion with the author of this reference indicated that they are currently using the older UCA 2.0 while waiting for equipment vendors to increase the IEC 61850 product offers. However, the results of the pilot were quite positive, and they feel that IEC 61850 is very much on target. They are quite aware of the limited adoption of the standard to date by the industry.<sup>9</sup>

This is underscored by a review of a leading power line communications (PLC) vendor, DCSI and their TWACS<sup>TM</sup> system. In that system, the Substation Communications Equipment (SCE) data sheet is listed as the interface between the TWACS<sup>TM</sup> network master station and the remote transponders. The protocol is described as Asynchronous ADLC (a UCA-Compliant Open Protocol). No mention is made of UCA 2.0 or IEC 61850.<sup>10</sup>

Another leading vendor, CellNet advertises UTILINET<sup>TM</sup>, based on spread spectrum radios in the unlicensed 902-928 MHz frequency band. No mention is made of UCA 2.0 or IEC 61850 on the UTILINET<sup>TM</sup> Wireless Communication data sheet.<sup>11</sup>

It is logical to address the applicability of IEC 61850 to AMI in its current state. While the design of the standard is based on object models, there is currently no logical node that is specific to wireless communications. However, there is a substantial library of primitives to support the addition of such a node with relative ease.

This leads to the conclusion that an AMI network designed to use a protocol like Zigbee can be constructed such that the physical layer data frames from Zigbee are mapped to Ethernet Frames at data collector sites, and the AMI data mapped to a new logical node in IEC 61850 at the Application Layer.

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<sup>8</sup> [http://www.ieee.org/portal/cms\\_docs\\_pes/pes/subpages/meetings-folder/T\\_D\\_2005\\_2006/tuesday/pn10/05TD0478.pdf](http://www.ieee.org/portal/cms_docs_pes/pes/subpages/meetings-folder/T_D_2005_2006/tuesday/pn10/05TD0478.pdf)

<sup>9</sup> A very special note of thanks is extended to Joe White, Project Engineer at Grant County Public Utilities District in the State of Washington, for insight into the IEC 61850 standard and for significant editorial input to this white paper.

<sup>10</sup> [www.twacs.com/Support/2004%20Spec%20Sheets/SCE.pdf](http://www.twacs.com/Support/2004%20Spec%20Sheets/SCE.pdf)

<sup>11</sup> [www.cellnet.com/content.asp?section\\_id=55](http://www.cellnet.com/content.asp?section_id=55)

## Design Considerations

A fundamental issue in any AMI network is the interface at the home or business, as these networks are typically quite beneficial to utilities. Yet water meters tend to be underground, gas meters tend to be about 1-2 feet above ground, and electric meters tend to be at eye level for a standing adult, meaning about 6 feet or 2 meters. Since ostensibly a wireless relay capability can be utilized for underground meters, or even for gas meters, in order to raise the height of the network interface, the two meter (2) mark is utilized in this discussion where wireless network implementations are considered.

### *The Physical Layer Connection*

A variety of alternatives exist for the physical layer of an AMI network, and include the following as a minimum:

- Power Line Communications (PLC) Connections
- Wireless Base Stations
- Mesh Networks Using Transmitters/Receivers in the Network Interface

There will no doubt be situations where one or more of these alternative physical layer approaches is appropriate for the needs of a particular utility. To gain some insight, each is reviewed at a very high level.

### **Power Line Communications**

PLC is a well established and accepted technology as witnessed by the long term success of the TWACS™ system. Essentially, this system relies on the power line from a nearby substation to connect to a transponder in a meter, located at the customer's home or business location.

The backhaul connection between the customer side of the substation and the network control center is based on another technology, which can be anything from land lines, fiber optic cable, microwave, satellite, wireless, etc. While data rates tend to be relatively low (1200 bps to 9600 bps), PLC provides excellent access to orphaned meters in rural areas.

## Wireless Base Stations

Wireless Base Stations come in a wide variety of sizes and configurations, depending on the frequency band of operation and the markets they are designed to serve. They are always capacity limited, and always have limited area coverage. Yet they can potentially cover wide areas, and their successful use in various cellular systems, WiFi hotspots, and in newer WiMax systems make them a potentially major component in AMI systems. Furthermore, like the PLC systems, some type of backhaul to a central network control point is required. This can consist of microwave, fiber optics, satellite communications, etc.

## Mesh Networks

The concept of a mesh network is fundamentally to make each home or business the location of a transponder, each of which can originate data messages and/or pass messages from a nearby transponder to another nearby transponder. Clearly mesh configurations have the potential for a very high number of data delivery paths, and require some type of spanning tree protocol to prioritize delivery paths and minimize looping. Mesh radios can be extremely low power devices, and can be readily integrated into meters, making them attractive candidates for the implementation of AMI networks.

A leading industry vendor, CellNet, is using spread spectrum technology in the 902-928 MHz license-free band, to implement mesh networks, and has validated the technology as a viable alternative in those markets where it applies.

The use of spread spectrum technology has both advantages and disadvantages. It is quite helpful in mitigating the effects of interference in license-free spectrum, but does tend to reduce the data bandwidth, typically to 19.2 kbps or below.

Because of the wide distribution of transponders, and propagation over both buildings and severe variations in terrain, design of a mesh network is not a trivial exercise.

## ***Establishing an Appropriate Network Architecture***

Micronet is acutely aware of the limitations on communications systems planning imposed by propagation limitations. Consequently, when challenged by clients to address architecture issues for wireless applications, Micronet started with propagation considerations.

The mesh network architecture is a logical starting point for AMI applications for a number of reasons:

- The radio transponders are simple to build and inexpensive to purchase
- The IEEE 802.15.4 standard specifies a physical layer that supports mesh applications in the 902-928 MHz and 2.400-2483.5 MHz bands
- The Zigbee wireless networking protocol sits above the IEEE 802.15.4 to provide the spanning tree and network management support required in a mesh network application

Clearly as the CellNet reference illustrates through their spread spectrum approach, Zigbee is not the only way to implement a mesh network. It is however, easily implemented in inexpensive radio modules and enjoys contemporary lower level protocol support. Furthermore, Zigbee also utilizes a form of spread spectrum to withstand interference in a highly congested licensed-free spectrum environment.

Micronet postulates that a very logical way to implement an AMI network is a combination of mesh subnetworks, small and large base stations, augmented by the PLC connections to really remote locations to the degree that the business case can be made. The rationale supporting this is as follows:

- Within any market area, if all subscribers were taking a service from a given utility, it would be a relatively simple matter to place small data collector sites using Zigbee or a comparable protocol on the top of every light pole in a neighborhood. In a competitive marketplace, no supplier can expect to have every home and every business as a customer, and there are not as many light poles as there are homes and businesses.
- A mesh network based on a protocol such as Zigbee can generally be constructed such that the transponders are at eye level on the side of each customer premise. Thus, if a data collection site is located on a power pole or light pole three or four houses away from a particular customer, the transponders in each customer premise location can pass packets among themselves to reach the nearest base station.

- The fact that IEC 68150 supports Ethernet means that Zigbee packets can be aggregated at collection sites and mapped to Ethernet frames, thus providing a backhaul solution that is standard compliant throughout, and compatible with a variety of wireless transmission standards such as WiMax and WiFi.

## ***Designing a Mesh Network at the Home and/or Business Level***

Considering that the mesh networks will necessarily communicate between homes and office buildings, the modeling of propagation quickly becomes a serious challenge. A review of popular propagation models will quickly show limitations on minimum base station heights and minimum propagation path lengths. For example, the standard propagation tool used by the FCC and the frequency coordination community is the Longley-Rice model. The minimum path length for Longley-Rice is one kilometer, rendering it unsuitable for the planning of communications paths between homes/businesses located within 100-200 meters of one another.

The more logical way to plan mesh networks is to utilize an appropriate parametric model to establish a representative inter-site distance over which an acceptable bit error rate (BER) can be maintained. Then the customer sites can be analyzed on an individual basis for their proximity to a neighbor, using cluster analysis. This is the approach that Micronet has taken.

For the inter-transponder paths contemplated herein, most of the parametric propagation models such as Okumura, Hata and Cost 231 are not appropriate as they are based on minimum base station heights of 30 meters, and a minimum path length of 1 kilometer, the same as Longley-Rice. The only one that comes close to fitting this requirement is the COST 231 Walfisch-Ikegami model. The COST Walfisch-Ikegami Model is included in Report 567-4 by ITU-R, and shows results that compare favorably with a modified Hata Model on propagation paths long enough to apply to both models, on the reference web site.<sup>12</sup>

Formally, Walfisch-Ikegami was originally derived for situations where the base station was a minimum of 4 meters above ground level, and the subscriber station fell in the range of 1-3 meters. This is quite close to the situation being analyzed whether both ends of the path are assumed to be at a height of two (2) meters. The minimum path length of this model is 20 meters.

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<sup>12</sup> <http://www.ee.bilkent.edu.tr/~microwave/programs/wireless/prop/costWI.htm>

## Parametric Link Analysis

Using the COST Walfisch-Ikegami propagation model to establish the propagation loss, it becomes relatively easy to model a representative link based on common antennas. A representative link model is given here.

The screenshot shows the 'Zigbee Network' software interface. The 'Propagation Model' is set to 'Walfisch-Ikegami' and the 'Area and Terrain Description' is 'Medium City and Suburban'. The interface is divided into three main sections: 'Propagation Parameters', 'Interference-Free Link Calculations', and 'Interference Effects'. The 'Propagation Parameters' section includes settings for Frequency Band (902-928 MHz), Modulation (BPSK), Data Rate (40 Kb/s), Channel Number (1), Rain Zone (A), Polarization (V), and Rain Outage (0.001). The 'Interference-Free Link Calculations' section lists various parameters such as Transmit/Receive Antenna Ground Elevation (2.5 m), Path Length (0.18 km), Propagation Loss (93.27 db), Frequency (906 MHz), Transmit/Receive Power (10 mW/10.0 dbm), Transmit/Receive Antenna Gain (1.6 dbi), Receiver Noise Figure (5), Rain Loss (0.001 db), Link Fade Margin (0.5 db), Spreading Code Rate (600.0 Kchip/sec), Bandwidth (0.7 MHz), C/N Thermal Ratio (-1.2 db), Eb/No (Thermal) (11.37 db), and BER (Thermal) (8.3E-08). The 'Interference Effects' section includes Number of Interferers (30), Average Interferer Transmit EIRP (300 mw), Average Distance From Receiver (100 m), Received Interference Power (-120.5 dbm), C/I (9.9 db), C/N System Ratio (-1.5 db), Eb/No (System) (11.04 db), Degradation in Eb/No (0.33 db), and BER (System) (2.3E-07). At the bottom right, there are buttons for 'Cancel', 'Generate Report', 'Save', and 'Save and Continue'.

Section	Parameter	Value	
Propagation Parameters	Frequency Band	902-928 MHz	
	Modulation	BPSK	
	Data Rate	40 Kb/s	
	Channel Number	1	
	Rain Zone	A	
	Polarization	V	
	Rain Outage	0.001	
	Rain Availability	99.999	
	Interference-Free Link Calculations	Transmit Antenna Ground Elevation (m)	2.5
		Receive Antenna Ground Elevation (m)	2.5
Path Length (km)		0.18	
Propagation Loss (db)		93.27	
Frequency (MHz)		906	
Transmit Power (milliwatts)		10	
Transmit Power (dbm)		10.0	
Transmit Antenna Gain (dbi)		1.6	
Receive Antenna Gain (dbi)		1.6	
Receiver Noise Figure		5	
Rain Loss (db)		0.001	
Link Fade Margin (db)		0.5	
Spreading Code Rate (Kchip/sec)		600.0	
Bandwidth (MHz)		0.7	
C/N Thermal Ratio (db)	-1.2		
Eb/No (db) - Thermal	11.37		
BER (Thermal)	8.3E-08		
Interference Effects	Number of Interferers	30	
	Average Interferer Transmit EIRP (mw)	300	
	Average Distance From Receiver (m)	100	
	Received Interference Power (dbm)	-120.5	
	C/I (db)	9.9	
	C/N System Ratio (db)	-1.5	
	Eb/No (db) - System	11.04	
Degradation in Eb/No (db)	0.33		
BER (System)	2.3E-07		

Using tools of this nature, the designer can address a wide variety of conditions, with or without the effects of other interference sources such as cordless telephones, microwave ovens, medical scanners, etc. that may be prevalent in particular areas. At the end of the day, the output of such studies is an average separation distance between the transmitter and receiver that delivers an acceptable bit error rate (BER).

## The Cluster Analysis

When such a separation distance has been established, a cluster analysis program can be utilized to define those neighborhoods where members of each cluster are within the average separation distance of at least one other member of the cluster. In short, each cluster represents a set of transponders where any member on one extreme edge could pass a packet through successive members locations, and arrive at the other side of the cluster with an acceptably low BER.

Micronet finds Google Earth to be an excellent tool for presentation of cluster analysis results, since it is possible to take the clusters down to the individual transponder if desired, yet also see the composite areas that each cluster covers.

In the following picture, a hypothetical AMI mesh network is postulated in the San Francisco Bay area. Each member of a given cluster exhibits both the number and the color of that cluster.



Knowledge of the clusters is immensely helpful, as Zigbee collector sites can be placed at low levels on lamp posts, signal lights, power poles, etc. at periodic points throughout the cluster, thus minimizing the number of hops required to get from any given home/business transponder to a collector site. Zigbee has a maximum hop count which can be used to minimize the chances of loops.

Now, consider an aerial view of the clusters in this network.



The clear delineations between clusters show the areas where larger base station coverage is required to bridge clusters and provide direct access to any transponder sites that are not close enough to be included in any cluster.

### ***Larger Base Stations***

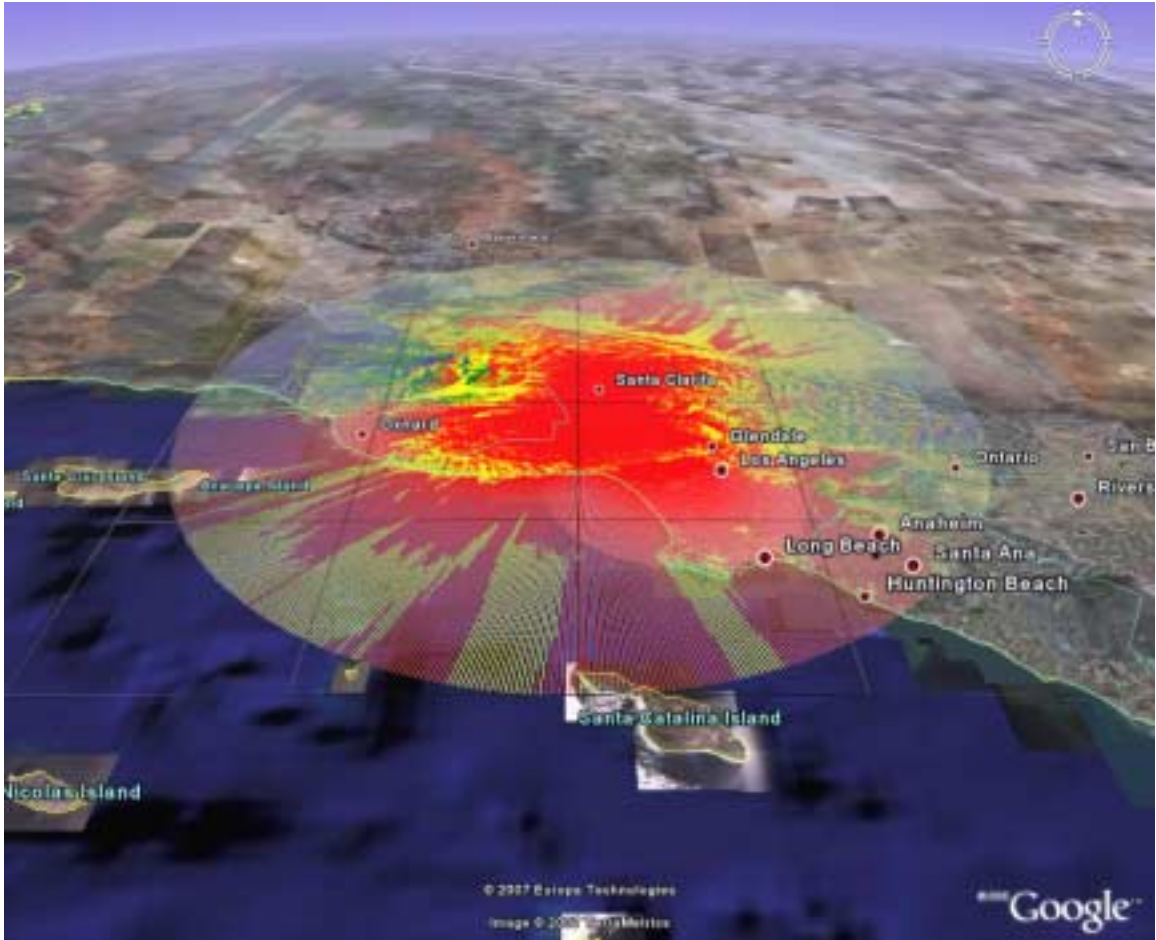
By postulating thirteen base stations with Omnidirectional coverage at nominal 30 meters above the ground, much of these gaps can be filled in. In this case, the base stations are limited to an EIRP of one watt when they operate in the 2.4 GHz unlicensed band.

The red circles in the center deliver signal strength above  $-30$  dbm, while the next level of yellow delivers above  $-100$  dbm, which is quite acceptable for most of these systems.



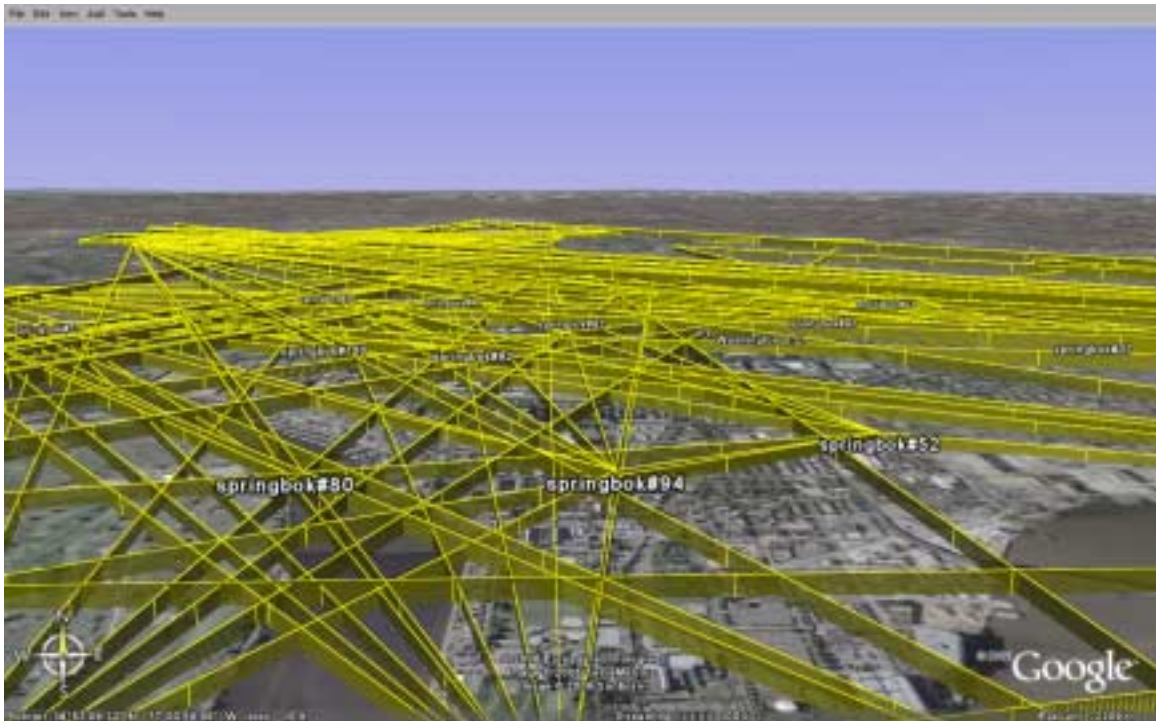
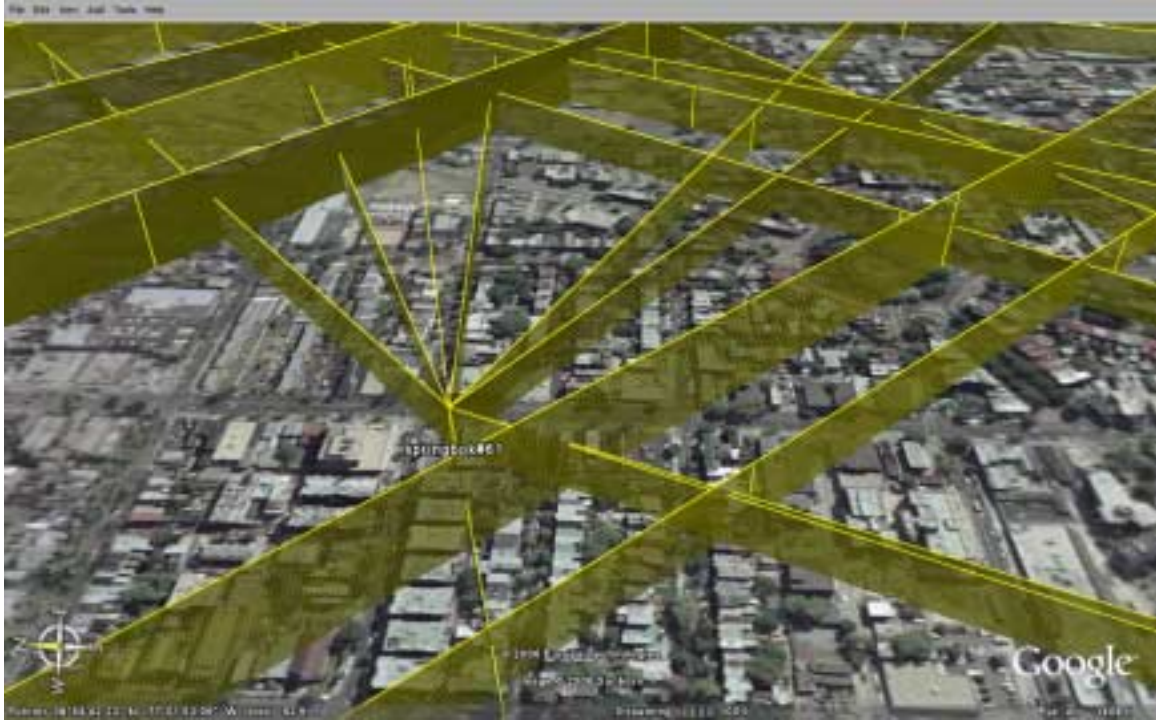
In effect, these base stations can provide linkages between clusters, but also provide the vehicle for network by those orphaned meters that fall between clusters.

Clearly, base stations can be constructed that cover larger areas, but without the restrictions on EIRP that exist in the unlicensed bands. For example, Micronet recently did some work for a utility in California for high altitude sites that operate down in the 40 MHz range. The result is substantial area coverage as the following plot illustrates.



## ***Backhaul***

Naturally, a backhaul network must now be superimposed on this network, and that can be accomplished by fiber optic cable, microwave, etc. Micronet is not lacking in tools in this area as well, as the following generic plots illustrate:



## Summary

A case has been made in this paper that the IEC 61850 is a very good building block at the application level for the backhaul of an AMI network. Considering the extremely high number of potential data gathering points at homes and businesses in some systems, the use of lower cost and lower bandwidth mesh networking devices based on protocols such as Zigbee, are shown to be a logical tool for the end points of an AMI network.

Data frames from Zigbee, carrying data from electrical, gas or water metering instrumentation, have been shown to require a logical node in IEC 68150 to accept the data at the applications layer after a physical mapping to an Ethernet format is accomplished at the Zigbee data collection points. That node does not exist today. However, IEC68150 is object oriented and has a substantial library of primitives, making the task of creating such a node relatively straightforward.

In the design of the physical layer, the analysis of links, area coverage, identification of clusters, and design of the backhaul network, is the forte of Micronet. Micronet has made great strides in tool development in the past year for providing support to AMI and comparable networks.

Should your firm have needs in these areas of planning, please contact Jerry Armes at Micronet by telephone on (972) 422-7200 or by e-mail at [james@micronetcom.com](mailto:james@micronetcom.com)