1. Introduction

It has been known for at least ten years that the United States electric grid is operating beyond its initial design specifications instantiating a decrease in reliability [1]. This has resulted in scheduled rolling black outs, unexpected black outs, and brown outs, all of which can potentially cost financial loss to businesses [2], not to mention emergency services can become overtasked and unavailable. In some instances not much can be done—unpredictable events cause failures in the system. In others, a network that is self-healing, incorporates resilience to intentional attacks, provides enhanced power quality, integrates on site power storage and generation, and operates more efficiently can reduce variations in power distribution and increase reliability. Research shows that a Smart Grid network would save between $46 and $117 billion over 20 years, the Smart Grid can bring “knowledge to power” causing an evolution in the electric grid industry [3].

The transition to a Smart Grid means adding intelligence to the existing utility grid. This new information needs to be transferred from remote sensors to a central point. As utilities deploy smart meters, it must be determined if their networks could be optimized by implementing a wireless infrastructure. In many cases this may be the most inexpensive route to deployment when compared to laying additional cables or upgrading power distribution hardware to accommodate data communications across power lines. A determination of potential frequency bands, both licensed and unlicensed, was conducted and a determination of suitable bands for Advanced Metering Infrastructure is made.

2. Background

The term Smart Grid is fairly generic and encompasses many aspects of the power communications network—particularly the Advanced Metering Infrastructure (AMI) between utilities and customers. A full Smart Grid implementation generally consists of three separate communication networks, two of which are considered components of the AMI: home area network and the neighborhood area network.

A home area network (HAN) where devices that consume power communicate with the power supplier through a gateway, usually integrated into a power meter. This enables devices to be central controlled and aware of the current distribution and demand environment. The HAN can communicate via low power wireless transceivers or in home power line communications.

A neighborhood area network (NAN) connects energy meters to data aggregating substations. This link can be established wirelessly, adding an additional wire line to the smart meter, or communicating over the power lines via power line communications (PLC) technology. In other applications this network is also known as the “last mile”. Finally, aggregation
substations must communicate back to a utility’s central servers. This connection is most often made with leased access lines, wireless microwave links or via PLC.

In the NAN the cost of non-wireless implementations is often prohibitively high for many areas as in many cases streets will have to be dug up to lay cables or power distribution hardware will have to be upgraded to allow data to travel across them. Proof of this is provided in California’s state-wide smart meter deployments. A number of utility operators in California are currently installing 11.7 million electric smart meters with an intended completion date of 2012 [4]. PG&E, SDG&E, and Southern California Edison are all using wireless technologies to communicate with smart meters in the NAN [5] [6] [7]. The city of Houston is deploying a Smart Grid network on top of 4G technology to provide public safety communications, Smart Grid communications, and free Internet with excess bandwidth [8]. This is projected to save millions of dollars each year compared with leased T1 lines [9].

The issue of deploying of wired metering infrastructure is amplified in rural areas where telecommunications service providers and broadband operators lack infrastructure. As of now wireless solutions are the most widespread and easily available since hardware and software are available commercially off-the-shelf. Deploying a wireless system will also take less time as fewer rights of way are needed and existing transformers and distribution hardware does not need to be upgraded. Many utilities are choosing wireless backhaul to support the AMI, and some are using wireless for their entire Smart Grid networks [10]. In many cases there exists a wireless network that a utility can piggy back on, such as a cellular network [10]. The economics of each system will be key in deploying and operating a viable, robust and cost effective technology that can sustain a scalable neighborhood area network.

2.1. Spectrum
The Federal Communications Commission (FCC) has two dominant mechanisms to regulate spectrum, the command and control model and the commons model, otherwise known as licensed and unlicensed spectrum, respectively. In the command and control model the FCC gives licenses to transmit on a specified spectrum chunk in a certain location. If others transmit or otherwise interfere within that spectrum, a licensee has legal recourse to collect damages and stop the interference. In the commons model spectrum is available for anyone to transmit at any location. However, maximum transmission power is limited to prevent the signal from covering too wide an area and over powering less powerful signals. In the United States the common spectrum bands exist at several frequencies, with the most popular being the ISM bands: 902 to 920 MHz, 2.4 to 2.5 GHz, and 5.725 to 5.875 MHz. These bands are becoming increasingly crowded and in the future may become unsuitable for mission critical communications [11].

Not all frequencies propagate equally. Different frequencies transmitted at the same power will travel different distances, penetrate physical objects with varied effectiveness, and require different sized antennas to be received optimally. In general the higher the frequency the less distance it will travel [12]. As a result some spectrum is more valuable than others. Spectrum between 300 MHz and 3GHz is known as “beach front” spectrum, and is scarce and expensive to obtain as it has ideal propagation characteristics for many terrestrial applications [13].

2.2. Current State
Wireless NANs are currently deployed in various spectrum ranges, using various bandwidths and technologies. There is disagreement about what the requirements of a fully implemented Smart

1 Defined by ITU-R 5.138, 5.150, and 5.280
Grid system are. The Utilities Telecom Council (UTC), a registered lobbying group, suggests several key requirements for implementation [14]. These include at least four nines (99.99%) reliability in the network, increased bandwidth over current networks, ubiquitous coverage, tight security measures, and uninterrupted power back-up [14]. Current NANs make use of cellular data networks\(^2\), ISM band mesh networks\(^3\), and various wire line technologies\(^4\) to transport data from the smart meter to aggregation nodes on the utilities network. Each of these has unique pros and cons with regard to the reliability, security, coverage, available bandwidth, capital expenses, and operating expenses. It should be noted that all have been deployed and are thus feasible.

3. Research Topic and Question

The paper deals with the broad question of: Which bands of wireless spectrum (if any) are suitable for a nationwide residential AMI deployment? The goal is to examine how various available bands of wireless spectrum would be utilized in areas of high, mid, and low population density. These metrics are inputs to a custom model that determines the smallest nationwide infrastructure deployment, and thus determine the lowest cost to deploy a wireless NAN. The different population densities are defined via the US Census Bureau as urban, suburban, and rural. It is expected that different wireless bands will work best with different population densities as capacity and coverage requirements are different for each area.

4. Importance

There is no consensus on using licensed or unlicensed spectrum, what frequency to use, or how much bandwidth is required to operate a Smart Grid, or even if wireless technology is the appropriate solution [15]. The US National Broadband Plan makes a number of recommendations regarding communications networks for the Smart Grid, including considering enabling utilities to share a section of the 700MHz public safety spectrum, considering use of other federal spectrum for the Smart Grid, and studying the communications requirements of the Smart Grid.

It has also been suggested by the National Institute of Standards and Technology that a study of whether or not dedicated spectrum is necessary for utilities be conducted [16]. In fact, there has been much debate over whether or not utilities should be allocated licensed spectrum for their work [16]. The advantages and disadvantages of licensed versus unlicensed spectrum for the Smart Grid have been established [17]. Given these advantages and disadvantages, it has both been asserted that utilities should or should not be given a section of wireless spectrum [18] [19].

Utilities and other companies are spending billions of dollars on developing and deploying Smart Grid technology. The American Reinvestment and Recovery Act of 2009 (ARRA) provided approximately $4 billion in stimulus funds to Smart Grid deployment efforts. There is a guaranteed $4.5 billion in stimulus funds allocated and an additional $34.6 billion [20] has been earmarked and could be allocated to Smart Grids. Also, individual public utility commissions are independently mandating the updating of infrastructure meaning utilities are deploying smart

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\(^2\) General packet radio service on GSM networks
\(^3\) Silver Spring Networks
\(^4\) Copper lines, Fiber lines, and PLC
metering solutions with no guidelines or regulations which will lead to a patchwork of wireless networks operating in different fashions [21].

5. Intended Audience
This research is intended for three main audiences: utility and telecommunications executives, policymakers, and industry lobbyists. Business executives will be able to make use of the information to better understand the spectral environment and general implications of the residential Smart, making inferences about cost, efficiency, and deployments. Communications policymakers can utilize the research to aid in designing a regulatory system that protects core communications policies and opens the marketplace to interoperability and innovation. Finally, industry lobbyists will find the research useful when working with technology clients and politicians on spectrum reform and other Smart Grid spectrum issues.

6. Scope of Research
To best understand the business implications of flexible spectrum allocation, the research has been confined to the following:
- Design a quantitative study of propagation characteristics and capacity limitations on selected bands, and align this information with United States Census Bureau population data
- Analyze qualitative metrics and make a determination of suitable frequency bands based on these metrics
- Model the respective scenarios, developing finite conclusions on the appropriateness of each identified band
- All analysis is limited to the United States
- All data used consists of residential information only, commercial data is not included.

The following have been deemed out of the scope of this study:
- Study firms outside of the utility industry
- Smart Grid technologies outside of the wireless realm
- Develop new business models or evaluate current business models that pertain to residential Smart Grid deployments
- Determine appropriate regulations and policies for the implementation of a wireless spectrum allocation for Smart Grid
- Smart Grid recommendations outside of the United States
- Elements of the Smart Grid beyond the advanced metering infrastructure (AMI) (i.e. the “last mile” segment of the network).

7. Assumptions
The following are assumed:
- A significant portion of the last mile section of the Smart Grid network will use wireless technology.
- Individual meters will be connected to utilities via wireless access points or “cells”.
• The technology implemented will use a single channel to communicate that does not implement spread spectrum technology
• The wireless technology utilized is interference tolerant

8. Methodology
The limiting factors in the size of a wireless coverage area can either be capacity or the distance the wireless signal can propagate. In areas with dense populations, coverage may be limited by capacity and not propagation distance. If data transmitted by all smart meters in a coverage area exceeds the capacity of the network, that cell is considered capacity limited, affecting the cell size in those areas.

8.1. Capacity Limited Cells
For some cases, it is necessary to determine the number of meter transactions that could occur in one day. Hence, is required to determine the required bandwidth of a single meter. The bandwidth requirement of a single meter is dependent on the amount of data sent, how often data is sent, and the transmission parameters used. Meaning, the first step is to determine the amount of data sent across the network.

When data is sent across a network, it is encapsulated with header and trailer information that allow it to successfully traverse the network [22]. So, when calculating the total amount of data transmitted across a network it is important to include both the encapsulated data, or payload, and the encapsulating data, the header and/or trailer.

The main standards collection that tends to be used in commercial smart meter implementations today is the American National Standards Institute (ANSI) C12.X standards collection [23] [24]. The ANSI C12 standards encompass all elements of electrical meter design, from electrical characteristics to the physical dimensions of the meters [25]. Since this research is focused in the way that smart meters communicate, the model primarily used the ANSI C12.22 “Protocol Specification for Interfacing with Data Communication Networks”, to determine encapsulating data sizes, and ANSI C12.19 “Utility Industry End Device Data Tables”, to determine payload data sizes [26].

In determining the payload data size, two scenarios were considered: a non-real-time data transmission scenario and a real-time data transmission scenario. For the non-real-time data transmission scenario, it was assumed that the meter would be taking and storing usage measurements locally once every fifteen minutes. It was also assumed that, at the request of the controlling utility, every 24 hours the meter would send all of its daily usage information to the utility. In essence, every day the meter would send the stored data for the previous day to the utility, repeating the process every day. For the real-time data transmission scenario, it was assumed the meter would be taking and transmitting usage measurements every two minutes, indicating 720 transactions per meter per day. Each of these scenarios have unique data payloads that affect the overall analysis of infrastructure deployment. These assumptions were made due to the fact that the XCEL deployment of smart meters in Boulder, CO uses this method of obtaining information from the meters [27].

For determining the size of the encapsulating data we utilized the ANSI C12.22 standard, which defines the protocol layer for communication between a smart meter and the utility [25]. All underlying network layers are undefined, allowing the use of whatever protocols best suit the implementation [25]. For these calculations it was assumed that the connection uses TCP, since
reliability is more important than performance in this application. Due to the depleting source of IPv4 addresses, we assumed that any Smart Grid implementation would use IPv6 [28]. For the data-link and physical layers we did calculations for 802.15.4 (Low Rate WPANs), 802.16 (WiMax), Motorola Canopy, and GSM to model transmitted bits that are related to enabling communications.

The amount of data transmitted by a single meter was then used in conjunction with the characteristics of the wireless transmission, such as the modulation type, frequency, band-width, and maximum transmit power to determine the amount of time a single transmission would take for both real-time and non-real-time scenarios.

The result of the corresponding modeling analysis yields, the meters per cell, which highlights the cluster size of the meters in a region that send data to a particular regional collector (depends on the meter capacities and the utilities). This is a very important aspect that will need to be incorporated this into any Smart Grid network design [29]. The channel capacity and the symbol rate are based on the modulation type selected for the wireless transmission [12]. The average data per transaction time is the fraction of the data per transaction and the bits per second obtained in earlier calculations.

8.2. Propagation Limited Cells
The max cell size based on propagation was then calculated from the link budget analysis, limited by the distance of propagation. Using link budgets the model can account for all the gains and losses of the power of a radio signal in a wireless link. This includes the transmitter and receiver antenna gains, losses in the transmission media, cables, path loss, fading margins, body loss, etc., to gauge the coverage area based on the receiver sensitivity and transmitted power [12].

The link budget used takes the following elements into account:
- Fading margin
- Free space loss
- Gains of the antennas
- Cables losses between antennas and transceiver
- Receiver sensitivity

Together, these elements define path loss, which is the attenuation in power of the radio signal between the transmitter and the receiver [12]. In this case, the path loss being considered is the Free Space Path Loss (FSPL). FSPL gives the estimate of signal strength and the distance covered assuming no obstacles in the path. FSPL is proportional to the square of the distance between the transmitter and receiver, and proportional to the square of the frequency of the radio signal [30]. The FSPL equation is generally used as a simple rule of thumb to determine the power loss in open air of a radio signal. It does not take into account reflections, scattering, or propagation through objects. More advanced models exist to do this that can better account for specific different environments but the FSPL equation is best suited to generically model the entire range of radio environments. The equation for FSPL is as follows:

\[
\text{FSPL} = \left( \frac{4\pi d}{\lambda} \right)^2 = \left( \frac{4\pi df}{c} \right)^2
\]
Where:

- \( \lambda \) is the signal wavelength (in meters),
- \( f \) is the signal frequency (in hertz),
- \( d \) is the distance from the transmitter (in meters),
- \( c \) is the speed of light in a vacuum, \( 3 \times 10^8 \) meters per second [12]

It is also expressed in dB as

\[
FSPL(dB) = 20 \log_{10}(d) + 20 \log_{10}(f) + 32.45
\]  

(2)

From the equation it is clear that higher frequencies exhibit more FSPL per distance [12].

Maximum allowable path loss is the maximum amount of attenuation the system can tolerate between the transmitter and receiver and maintain reliable communication across the link. This is calculated by a link budget analysis [12]. The maximum path loss determines a cell’s coverage area and can estimate the subscriber count (number of households) in a cell’s maximum coverage.

### Table 1 - Link Budget Utilized for Analysis

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Link Budget Item</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTX</td>
<td>transmitter output power (dBm)</td>
<td>30</td>
</tr>
<tr>
<td>GTX</td>
<td>transmitter antenna gain (dBi)</td>
<td>0</td>
</tr>
<tr>
<td>LTX</td>
<td>transmitter losses (coax, connectors...) (dB)</td>
<td>2</td>
</tr>
<tr>
<td>LM</td>
<td>miscellaneous losses and margins (dB)</td>
<td>6</td>
</tr>
<tr>
<td>GRX</td>
<td>receiver antenna gain (dBi)</td>
<td>0</td>
</tr>
<tr>
<td>LRX</td>
<td>receiver losses (coax, connectors...) (dB)</td>
<td>2</td>
</tr>
<tr>
<td>PRX</td>
<td>receiver sensitivity(dBm)</td>
<td>-94</td>
</tr>
<tr>
<td>LFS</td>
<td>free space loss or path loss (dB)</td>
<td>54</td>
</tr>
</tbody>
</table>

The simple calculations in table 1 indicate a free space loss of 54 dB. Using this value an estimation of the maximum coverage distance that can be obtained from a single transceiver site can be calculated. This distance is then used to obtain an estimate of the infrastructure that would be necessary to connect the AMI meters in the United States using the specified wireless parameters in various regions as defined by the Census Bureau. The values obtained for the link budget were determined after reviewing specification sheets for smart meters using multiple technologies, investigating transmitter output power allowed at each respective frequency [31] [32] [33] [34], and adding a 6 dB loss margin. All this can be easily changed in the model that was developed.

### 8.3. Population Data

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5 The values are based on FCC regulations, standard practice in the wireless industry, free space loss, and manufacture data sheets
Different areas of the North America were identified based on a census data. According to a report issued by the Congressional Research Service, the Federal Government classifies three major population types by geographic region—urban, suburban, and rural [35]. Urban environments are those with population densities greater than 1000 people per square mile (621 people per kilometer). Suburban is classified as those areas with population densities of 500 – 999 people per square mile (311 – 620 people per square kilometer), and rural is any region with a population density greater than 1 and less than 499 people per square mile (1 – 619 people per square kilometer) [35]. Utilizing Census data granulated by county and by population density per square mile, a determination was made to select the maximum housing unit density of each of the respective categories to estimate a ‘maximum state’. Additionally, the data was aggregated to sum the total number of housing units in each category based on the above criteria.

Since the households per kilometer varies with the geographic locations and the density of population, there is a lower density of meters in lower household density areas (rural areas) and a higher density of meters in higher population density areas (urban). Thus, the coverage distance for each cell site is not uniform across every geographic area. Hence, it is incorrect to assume that any one cell coverage distance is valid coverage area for all cases. Additionally, different modulation techniques require different transmission distances to maintain efficient communications. In our research, we used these considerations (equation 2) to arrive at the transmission distances suitable for different frequencies.

Thus the categorization into urban, suburban, and rural was used to determine region specific requirements of Smart Grid deployments due to changes in population density. This was done to check that a cell would not be limited by radio propagation distance and not capacity.

8.4. Frequency Band Selection

As an unlimited number of frequencies exist, only those that are feasible were selected as input into our model. Feasibility was determined primarily by spectrum availability. This includes unlicensed bands and bands currently unallocated. While more suitable bands may exist, the reallocation and allotment of spectrum is an extremely time consuming and costly process and thus were not included in this analysis. However, spectrum explicitly suggested by some vendors and industry groups were also considered, regardless of their availability. Because the U.S. wireless industry as a whole has only deployed 250,000 cell sites nationwide [36], it has been determined any spectrum band requiring more than 3 million cell sites will be deemed infeasible and will not be included for recommendation.

9. Results

After running a nationwide scenario based on the aforementioned network design details for each of the respective potential frequencies, metrics on the number of meters per cell site and total number of cells for urban, metropolitan, and suburban was collected. These metrics were
examined as an indication of the overall cost of a wireless Smart Grid metering system for residential use in the United States. Based on the Xcel Energy deployment, two test cases were developed to test both a non-real time and a real-time network scenario. The details of how those scenarios were evaluated are shown in Table 2 and Table 3 below.

**Table 2 – Data Transmission Scenarios – 6.78 MHz Test Case**

<table>
<thead>
<tr>
<th>Transmission</th>
<th>Non-Real-Time</th>
<th>Real-Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Standard</td>
<td>ANSI</td>
<td>ANSI</td>
</tr>
<tr>
<td>IPv4 / IPv6</td>
<td>IPv6</td>
<td>IPv6</td>
</tr>
<tr>
<td>Frequency</td>
<td>6.78 MHz</td>
<td>6.78 MHz</td>
</tr>
<tr>
<td>Power Level</td>
<td>36 dBm</td>
<td>36 dBm</td>
</tr>
<tr>
<td><strong>Modulation Type</strong></td>
<td>QPSK</td>
<td>QPSK</td>
</tr>
<tr>
<td>Bits / Sec / Hz</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Symbol Rate</td>
<td>30 Kbps</td>
<td>30 Kbps</td>
</tr>
<tr>
<td>Data Rate</td>
<td>60 Kbps</td>
<td>60 Kbps</td>
</tr>
<tr>
<td><strong>Meter Data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Interval (mins)</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Transactions Per Day</td>
<td>720</td>
<td>1</td>
</tr>
<tr>
<td>Data Samples Per Transaction</td>
<td>1</td>
<td>96</td>
</tr>
<tr>
<td>Data Per Transaction</td>
<td>3300 bytes</td>
<td>2200 bytes</td>
</tr>
<tr>
<td>Average Transaction Time</td>
<td>430 msec</td>
<td>300 msec</td>
</tr>
</tbody>
</table>

The metrics collected from each of these scenarios include:
- Number of meters in cell, based on population densities
- Number of cells deployed, based on population densities
- Total number of cells deployed nationwide

Additionally, increasing the modulation techniques and data standards yielded little changes in the overall infrastructure deployment because a majority of cells were propagation limited, not affecting overall capacity in those cells. Modulation encodes several bits into one symbol (symbol rates) and thus the capacity for propagation of data or essentially the bandwidth of the system. In our simulations, we have examined that using a higher order modulation only does not affect propagation limited cells because these cells do not use their full bandwidth as is. However, the number of meters per cell increased significantly when the modulation technique was changed to accommodate higher symbols per second (higher data rates) in capacity limited situations. For example, using QPSK over BPSK would essentially double the number of meters per cell in a capacity limited cell. This result only occurs in urban environments, with low bandwidth and low frequency, such as the unlicensed 6.78 MHz band with a bandwidth 30 kHz, under a real-time data transmission scenario.

After a careful analysis of the results, it was determined only 4 of the 17 modeled bands were feasible in a nationwide deployment of AMI infrastructure, based on the requirement a deployment would consist of fewer than 3 million cell sites. Appendix 1 displays the results of the feasible frequencies generated by the model, using a non-real-time transmission scenario and real-time data transmission scenario, respectively. The results of this chart indicate the expected
meters per cell for each geographic category, as well as the total number of cells expected for a nationwide deployment for each band. These values can be extrapolated to make estimations of total infrastructure cost for rural, suburban, and urban geographies for each band evaluated. The results of these scenarios proves that although there are multiple options for deploying a wireless smart metering system for residences in the United States, there could be a better option in terms of spectral access, overall cost, and deployment and development. An analysis of these results and a recommendation for the optimal bands and bandwidth can be found in the recommendations section of this paper.

10. Conclusion and Recommendations

While it is difficult to predict the legal, regulatory, or financial situations involved with acquiring or using each of these bands on a nationwide basis, there are obvious indicators about the efficiency and usability of each band described based on the ease of deployment, the infrastructure required, the costs associated with deployment and upkeep, and the overall implications of managing an already complex network.

Based on the selected scenarios, it is obvious that the main limitation for smart grid deployments will be propagation distance associated with various bands and their respective transmitting powers. Even under a real-time pricing scenario, only certain environments, namely urban environments, are affected by channel capacity limitations. This means that the overall bandwidth associated with each of these bands in most cases is overly sufficient and many estimates of bandwidth for Smart Grid deployments are overstated.

The results gleaned from evaluating the available and recommended bands for the Smart Grid yield results which indicate deploying a nationwide wireless Smart Grid technology for residences in the United States would be done best on unlicensed bands. The band the model demonstrates is the best is the unlicensed and low frequency 6.78 MHz band, due to the fact most of the cell sites in the United States are propagation limited. The propagation characteristics of this band would yield the smallest infrastructure deployment, particularly in suburban and rural areas. In fact, based on the various scenarios, rural and suburban geographies were always propagation limited, even under the most demanding of data loads. Of the seventeen bands evaluated, the only four that are feasible in terms of least infrastructure deployed are in unlicensed spectrum, indicating the overall suitability of unlicensed bands. Only in dense urban environments is each cell site limited by capacity, making this the only scenario in which larger bandwidths or higher order modulation would be useful.

In response to both trade groups and government regulators, two bands were evaluated especially for inefficiencies. First, the UTC advocates for a 20MHz band of spectrum at 1800MHz for AMI applications [37]. Our calculations show that a frequency allocation at this band would be a greatly inefficient use of spectrum and require over 15 million cell sites. Even in high-population density urban areas the cell size would be limited by the propagation distance of the signal. Each cell would likely service only 32 smart meters. There would be such an excess of capacity that even collecting real-time data from meters would not utilize all available spectrum. Additionally, the National Broadband Plan has suggested possible use of the 700MHz spectrum band for Smart Grid applications as well [34]. Although the cell size would be larger with this band, allowing for up to 76 meters per cell, there would still be a high degree of inefficiency with regard to spectrum use when compared to unlicensed spectrum options in
particular and a nationwide deployment would require over 25 million cell sites based on the modeled data.

Ultimately, it is hard to make a convincing case for the deployment of residential smart meters in the United States using licensed spectrum. In fact, it may be in various utilities best interests to more heavily explore unlicensed bands—particularly the lower frequency bands—as the overall costs associated with deploying the infrastructure network are many times higher when considering licensed bands, which does not even include the costs of acquiring such frequency licenses. Finally, with a political push to deploy smart meters to residences, utilizing unlicensed spectrum may provide the only feasible timetable for a rapid deployment.
## Appendix A: Infrastructure Deployment Results By Frequency

<table>
<thead>
<tr>
<th>Center Frequency (Mhz)</th>
<th>Symbol Rate (Mbps)</th>
<th>Morphology</th>
<th>Non-Real-Time Data Transmission</th>
<th>Real-Time Data Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Meters Per Cell</td>
<td>Number of Cells</td>
</tr>
<tr>
<td>6.78</td>
<td>0.03</td>
<td>Rural</td>
<td>280</td>
<td>220,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suburban</td>
<td>330</td>
<td>45,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urban</td>
<td>27,000</td>
<td>1,500</td>
</tr>
<tr>
<td>13.56</td>
<td>0.014</td>
<td>Rural</td>
<td>140</td>
<td>440,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suburban</td>
<td>170</td>
<td>90,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urban</td>
<td>13,000</td>
<td>3000</td>
</tr>
<tr>
<td>27.12</td>
<td>0.326</td>
<td>Rural</td>
<td>69</td>
<td>880,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suburban</td>
<td>83</td>
<td>180,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urban</td>
<td>6,700</td>
<td>6,000</td>
</tr>
<tr>
<td>40.68</td>
<td>0.04</td>
<td>Rural</td>
<td>46</td>
<td>1,300,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suburban</td>
<td>55</td>
<td>270,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urban</td>
<td>4,400</td>
<td>9,000</td>
</tr>
</tbody>
</table>
References


[28] Internet Corporation for Assigned Names and Numbers. (2011, February) IANA IPv4 Address Space Registry.


[40] Tylor Seaman, Charles Upshaw, Ehab Haron Melissa Lott, "The Smart Grid in Texas, A Primer," University of Texas, 2011.


