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Table of Contents

Table of Figures

Table of Tables

Executive Summary

360°RF strongly recommends consideration of licensed operation in the 3650 -3700 MHz band using licensed WiMAX equipment. While radio coverage will be similar, it doesn't tell the whole story. Licensed operation will provide a measure of coordination and coverage and eliminate the vast majority of interferers. Although 3650 licenses do not provide traditional protection against other users, coordination is possible, practical and license registration provides and effective tool for coordinating use. License cost is also low.

WiMAX is also far more effective at meeting the requirements of VoIP operation, managing link capacity, and allocating capacity efficiently. While most of the coverage plots contained in this document are for 5 GHz unlicensed systems, 3650 operation will have slightly better coverage. Further, the use of WiMAX will provide better and more easily manageable service.

WiMAX also trades coverage and capacity more smoothly. It will provide service to larger areas of low density users. Licensed 3650 MHz operations allow much higher effective radiated power providing the option of expansive rural coverage. 360°RF was unable to plot WiMAX coverage under the current budget authorization, but with the option of higher power and more effective use of spectrum, the WiMAX options prove superior. The downside is that WiMAX infrastructure equipment is on the order of twice the cost of 802.11 based equipment targeting the same market. Most business cases, however, are driven by CPE costs.

Common Considerations

Operating Margins

Radio networks are subject to path loss variations. These variations can easily be a factor of 10 (10 dB) and can be as much as a factor of 100 (20 dB.) Radio system designs will include this margin, though manufacturer's specifications rarely do. Modern data radios will operate over a wide range of signal levels and scale data rates down to do so. Many WISPs will design around a target data performance with 10 dB of margin and accept the lower network speeds when fading occurs.

Tower/Mast Height

All of the bands available require line of sight and some Fresnel [1] zone clearance. 900 MHz is somewhat better at penetrating foliage, but not much. Line of sight and first Fresnel zone coverage is the ideal, meaning customer CPEs should be raised above the tree line. For 360°RF's analysis, engineers have assumed this to be about 30 feet. The Fresnel zone diameter for a one mile long 5 GHz path is under a meter.

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[1] See http://en.wikipedia.org/wiki/Fresnel_zone

Once line of sight and Fresnel zone clearance are obtained, there is rarely value in a taller support.

VoIP

A VoIP stream uses very little bandwidth; they will vary around 64 Kbps with higher rates for higher quality sound and lower rates for highly compressed links. VoIP also uses very short packets. This provides it effective priority over longer packets in a TCP stream.

A common first problem for WiFi VoIP is "jitter." Jitter is the variation in transmission time for a series of packets. If the average delay is 50 milliseconds, but packets can arrive as fast as 20 milliseconds and as slow as 60ms then the jitter is 40 milliseconds. If the delay is always within that 40 ms range, 40 ms of data can be held and re-sorted as audio packets arrive. While the audio will be delayed, the delays are almost imperceptible. If the delay varies more widely, a larger buffer is required, or the dropping of packets without playback which causes a clipping effect.

The obvious solution is to use the bigger buffer, but that has two problems. Delay begins to get obvious above 50 milliseconds, and becomes a problem above 200 ms. Above 200 ms people start to talk at the same time and echo cancellation gets harder and much more expensive. Audio codecs also add some fixed delay, and more compression generally means more delay.

The delay to be concerned with isn't just "ping" time. The frequency and size of ping packets will not have the same traffic characteristics as a VoIP call (or many VoIP calls.)

WiFi was designed around commodity data applications—packet delay was not a significant concern in the initial design. Much of that legacy is still limiting performance in the latest standards. WiFi provides windows of opportunity in which to send your packets.

VoIP is cheap in terms of total data transferred, but VoIP calls create a large number of packets. A common packetization period is 20 ms, so if a packet is sent every 20 ms, it represents 20 ms of audio, and 50 packets are being sent per second. A pair of VoIP calls can be accommodated on a newer home WiFi access point, but 100 packets per second can crash older access point/routers in the presence of other traffic.

A large number of calls (say 100 VoIP calls x 50 packets per second, or 5000 packets per second) can overwhelm a wireless radio and most small routers. This will either result in very high jitter, many dropped packets, or both.

WiMAX, LTE, and to a lesser degree Motorola's Canopy have a much more sophisticated timing and scheduling mechanisms that should avoid most of the problems present in WiFi.

Over the Air Standards

WiFi (IEEE 802.11 standards)

Many WISP oriented products are based on WiFi. WiFi was developed for short range indoor use. This is a very specific radio environment. Long range outdoor applications require substantially different radio compensation schemes. WiFi requires a very benign radio environment to operate effectively. This often limits WiFi range and data rates to far less that predicted. WiFi also has throughput challenges. While the specified channel rate may be "54 Mbps" the actual effective throughput will be much lower. Small packets (like VoIP) tend to be inefficient in 802.11. While later standards have been optimized for this fact, to a large degree the problem remains.

Motorola Canopy

Canopy is a product line developed by Motorola for WISP-like applications in outdoor environments. It overcomes many of the radio environment shortcomings of WiFi in outdoor applications. Motorola has added features to Canopy, but about five years ago began to focus on WiMAX and more recently LTE. This effectively stalled Canopy development. There is some indication that Motorola is once again investing in Canopy, but there are also rumors that the division is for sale. Canopy is a sole source product with an uncertain future.

The big problem for Canopy in this application is its peak aggregate throughput of 11 Mbps. It doesn't meet the 15 Mbps requirement.

WiMAX (IEEE 802.16 standards)

WiMAX was developed for WISPs and outdoor applications. It was designed to scale over a very wide range of applications, from Manhattan, New York to rural Manhattan, Illinois (population 6,000.) WiMAX can be cost effective in very low density applications if care is taken in design and deployment. WiMAX was designed to consider packet priority and latency across the network—not just for a single user. It also provides many tools for managing user performance.

WiMAX is a menu of features, though not all features are required, and there is no guarantee that one vendor's feature selection will support interoperation with another vendor's feature set. Extensive testing has historically been done within classes of applications to insure compatibility and vendor interoperability where that is claimed.

Aggregate throughput for a WiMAX BTS using a 10 MHz channel will be on the order of 25 Mbps. While this may sound low when compared to WiFi, it is in *half* the channel bandwidth of WiFi, but it scales very effectively to a channel at capacity.

A WiMAX based solution will scale much more effectively than WiFi, but will also be more expensive to acquire. The WiMAX system should be much less expensive to manage and will result in a better end user experience.

The risk with WiMAX is availability in the future. The product volume is in other standards and WiMAX may not sustain enough investment to remain viable.

LTE (European Telecommunications Standards Institute Long Term Evolution)

LTE is the next evolution in the GSM (2G) family of standards after WCDMA (3G) formulated as a response to WiMAX. It seems to have won the “standards war” as virtually every large operator has selected it for their evolutionary roadmap. This includes Sprint, a major force in the only WiMAX operator of any size (Clear, aka Clearwire.) Most equipment vendors seem to be focused on large, very high capacity deployments, particularly in licensed 700 MHz space. While LTE is likely to be the best long run option, at present there seems to be a dearth of equipment available for low density WISP applications.

LTE vs. WiMAX

Both standards have very similar features. LTE focuses more on mobility features and battery life, and also has a more rigid standard. This rigidity means that interoperability is more likely, but that scaling is very poor at low deployment densities. WiMAX and 802.16 are more of a menu and features can be ignored allowing low density deployments to ignore costs that do not supply commensurate value.

Licensed versus Unlicensed

Licensed options have many advantages. They are protected from other users by coordination and the licensing process. No one can legally interfere with you and the process does a good job of insuring this. Licensed equipment can usually use higher power and therefore results longer, higher bandwidth links.

The biggest disadvantages of licensed options are license and equipment costs. Licensing costs are often overstated, but fixed microwave links in congested areas can cost more than $10,000 to *initially* coordinate and license. Once licensed, renewals are a minor cost.

Terrain and loss models

All of the information presented in this document is based on the Longley-Rice propagation model using 1/3 second Shuttle Radar Topography Mission (SRTM) elevation data. This model is complex and requires a number of inputs for local terrain conditions. Average values were used for this analysis, and should provide representative indications. A calibration survey will be required to get truly reliable results.

Backhaul (Transport Network)

In the absence of information on the specific points of presence in "Major Town", 360°RF postulated locations likely to work for most of the city. This may have resulted in more facilities than will be required. Engineers avoided locations on the continental divide because challenging maintenance and power access.

Capacity Requirements

While not strictly accurate, a simple estimate of peak capacity requirements can be made by:

$$Required\ Capacity \approx \frac{Subscribers \times Bandwidth}{Oversubscription\ Ratio}$$

Thus, for 150 subscribers in xyz USA at 50% penetration this works out to:

$$\frac{160 \times 50\% \times 15\ Mbps}{10} = 120\ Mbps$$

Assuming similar penetration and subscriber rates Area "A" will need 1.8 Gbps, Area "B" 2.9 Gbps. Assuming more modest penetration rates of 10% for Area "A" and Area "B" the numbers become:

Table 1 Capacity Requirements

	Likely Available POPs	Pen. Rate	Capacity req. at 15 Mbps/sub
Area "B"	3788	10%	568.20
xyz USA	160	50%	120.00
Area "A"	2327	10%	349.05
Total			1037.25

Represented is the likely required capacity on paths from "Major Town" for *guaranteed* subscriber rates of 15 Mbps. Committed (guaranteed average) rates of 1.5 to 2 Mbps and bursts to 15 Mbps are typically desirable. If this is the case, the capacity demands will be about 1/10 of these numbers. The actual values are a little higher, but 1/10 works for rough planning, thus, something over 104 Mbps will be needed. 360°RF has not included "Major Town" in these calculations because that will be a largely local distribution problem typical of a local internet access POP.

Radio Options

There are two broad classes of options for distribution network capacity, licensed point-to-point microwave and unlicensed 802.11 based units. The two representative units we will evaluate are Ubiquiti's Airgrid M5, and Proxim's Tsunami GX800 6 GHz licensed microwave.

Ubiquiti AirGrid M5 (unlicensed)

The Ubiquiti Airgrid M5 is representative of the performance of unlicensed backhaul solutions (in terms of range and data rate.) At the highest single channel coding rate (MSC7, 65 Mbps) it provides transmit power of 15dBm and requires a receiver level of -74 dBm. With +27 dB gain grid antennas and 10 dB of path margin this translates to a free space link length of about five and 1/2 miles. On flat ground with suitable towers, it would take 10 hops with these units, and two parallel paths would be required. On the terrain in the area between xyz USA and "Major Town", it will take far more. Each will add delay and jitter. The result is almost certain to be impractical and a maintenance challenge during Wyoming winters.

However, these radios may be candidates for serving very remote customers with lower peak data requirements, or local distribution. If lower data rates are allowed much longer links are possible. For 11 Mbps operation with 15 db of margin, 20 mile links are possible if line of sight is available.

Proxim Tsunami GX800 (6 GHz licensed)

A concept network is shown in Figure 1. This is a concept, not a detailed design. The locations shown were checked for line-of-sight at 100 feet above ground and overall path loss. The initial models use four foot diameter dish antennas. Some of the long paths (specifically "Major Town" Hop to West Town) will likely require larger antennas for additional margin to provide highly reliable service. The modeled signal levels support 300 Mbps data throughput. Note that these radios are full duplex, so that unlike WiFi demand in one direction, they do not impact capacity in the opposite direction. Table 2 shows the locations identified.

Table 2 Conceptual Microwave Network Locations

Site Name	Latitude(°)	Longitude(°)	Elevation (m)
“Major Town”	41.12602	-104.80300	1840
“Major Town” Hop	41.27305	-105.19800	2270
xyz USA	41.75994	-104.82400	1620
Area “B”	42.06195	-104.18200	1249
Area “B” Hop	41.88190	-104.64710	1583
West Town	41.79105	-105.11680	2109
Area “A”	42.05490	-104.96490	1448

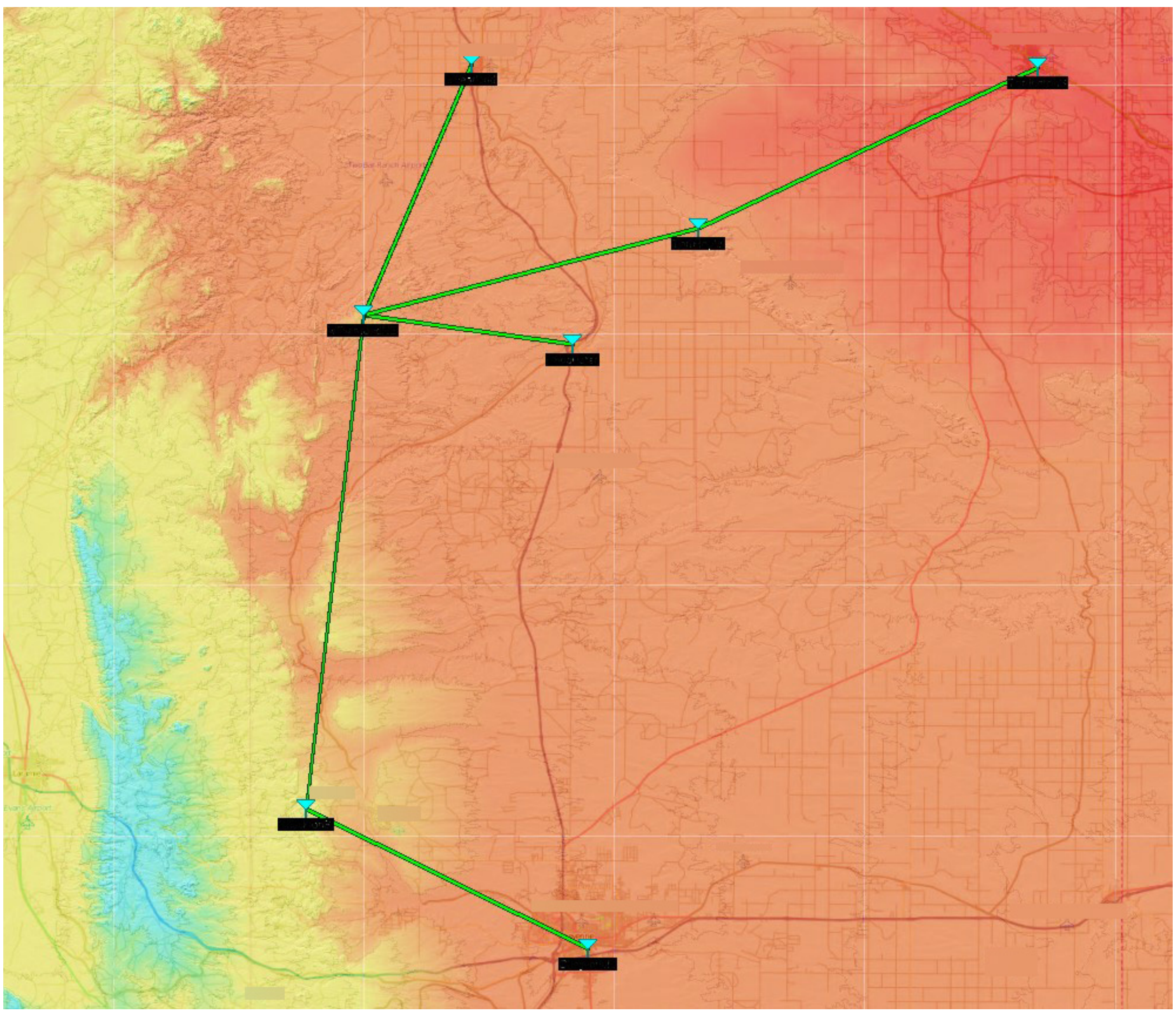

Figure 1 Conceptual Licensed Backhaul Network

Locations in towns are representative of the worst coverage case. It should be possible to link to any location in these towns with a radio above surrounding obstructions.

Distribution

Many distribution options are available. Evaluating a complete matrix of options is beyond the scope of the current work authorization. What 360°RF has done is to take several variables such as the operating band and compared them in as consistent a manner as practicable.

Coverage and Capacity

Modern radio networks use multiple coding schemes. Users closer to the access point/base station use the more efficient schemes allowed by shorter ranges. This means that overall system capacity is a function of user range.

The practical consequence of this is that distant users use a greater allocation of network capacity to obtain the same service. All wireless systems consider this, but cellular protocols like WiMAX and LTE highly optimize it, where WiFi has relatively crude compensation that assumes only a few users.

In relatively dense environments like towns it is desirable to keep links short to keep users at the highest data rates to maintain system capacity.

Operating Bands

While there are options on many bands, the chief alternatives are 900 MHz, 2.4 GHz, and 5 GHz. There are licensed options at 800, 1900, 1700, 2500, and 3650, but most of these options require implementing large coverage areas and substantial investments. Both alternatives have pros and cons. See "Licensed versus Unlicensed" on page 6.

3650-3700 MHz

3650-3700 MHz is a licensed band, but the protection offered by this license is limited. License cost is negligible and no unlicensed interferers exist. Higher power is allowed (25 W EIRP vs. 4 W EIRP in unlicensed.) Use of this band requires coordination and cooperation with other licensed users, but all of the coverage area is in a 150 km exclusion zone around "Major Town" protecting Echostar's satellite earth station. It is possible to obtain a waiver to operate in this area, and several have been granted*, including one in "Major Town"* to Extreme Highspeed, LLC[2]. Other competitors appear to use this band as well, including ABC Wireless[3] in Area "A" and 123 Communications Inc.[4] in ... which operates 64 base stations

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[2] Omitted

[3] Omitted

[4] Omitted

and CPE (looks like 5 base station and 59 customers.) Most equipment is this band is WiMAX based as it offers several advantages. See WiMAX (IEEE 802.16 standards) on page 5.

Unlicensed Bands

While unlicensed operation on 900 MHz and, to a lesser extent, 2.4 GHz are attractive for a number of reasons, they have several issues.

900 MHz

The 900 MHz band has *only one channel* for wireless LAN. There is no option to move in the event of interference and there is also very little capacity. A number of unlicensed consumer products also use this band. Licensed users exist in the band as well, but it is unlikely to suffer interference from them (or cause it), but if it happens, the installation must be moved. 360°RF recommends that 900 MHz be used only in the most rural applications.

2.4 GHz

The 2.4 GHz band is the most popular for a host of applications. It is not only used to wireless LAN, but also by cordless mice, Bluetooth®, radio controlled toys, hobby aircraft and cars, cordless phones, Zigbee® devices, smart power devices, and a host of others. While building penetration attenuates 2.4 GHz a great deal, indoor applications will interfere with nearby outdoor equipment. The interference problem is common enough that it has its own Wikipedia® page.[5] The 2.4 GHz band only has three non-overlapping channels, another challenge with its own Wikipedia® page.[6] If high speed 802.11n radios use their 40 MHz channel feature, only one 40 MHz and one 20 MHz channel is available. Based on the experience of other small town/rural ISPs this is likely to be a recurring and increasing headache.

5 GHz

The 5 GHz band is really three almost adjacent bands. There are twenty 20 MHz channels available with varying restrictions. Nine of these do not require the DFS feature designed to protect Terminal Doppler Weather Radars – none of which are in Wyoming (though the requirement is still imposed.) Most current production equipment implements this feature.

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[5] http://en.wikipedia.org/wiki/Electromagnetic_interference_at_2.4_GHz

[6] http://en.wikipedia.org/wiki/IEEE_802.11#Channels_and_international_compatibility

Effect of Frequency

The three coverage plots below show the effect of frequency of operation. All three are for identical antenna gains (13 dBi) on identical, hypothetical access points and subscriber units. The access point is arranged as four sectors on a 100 foot tower at the xyz USA Telephone Company offices. Subscriber units are modeled based on a 30 foot pole with an unobstructed view of the Access Point.

The effect of frequency on range is clear. What is not as clear in these plots is that there are number of compensating effects that tend to equalize the results. For antennas of the type and physical same size, gain is higher as frequency increases. There are practical limits to this because as gain goes up, beamwidth goes down. If the beamwidth gets too narrow the antenna becomes difficult to point and requires a much more rigid support to maintain service in windy conditions.

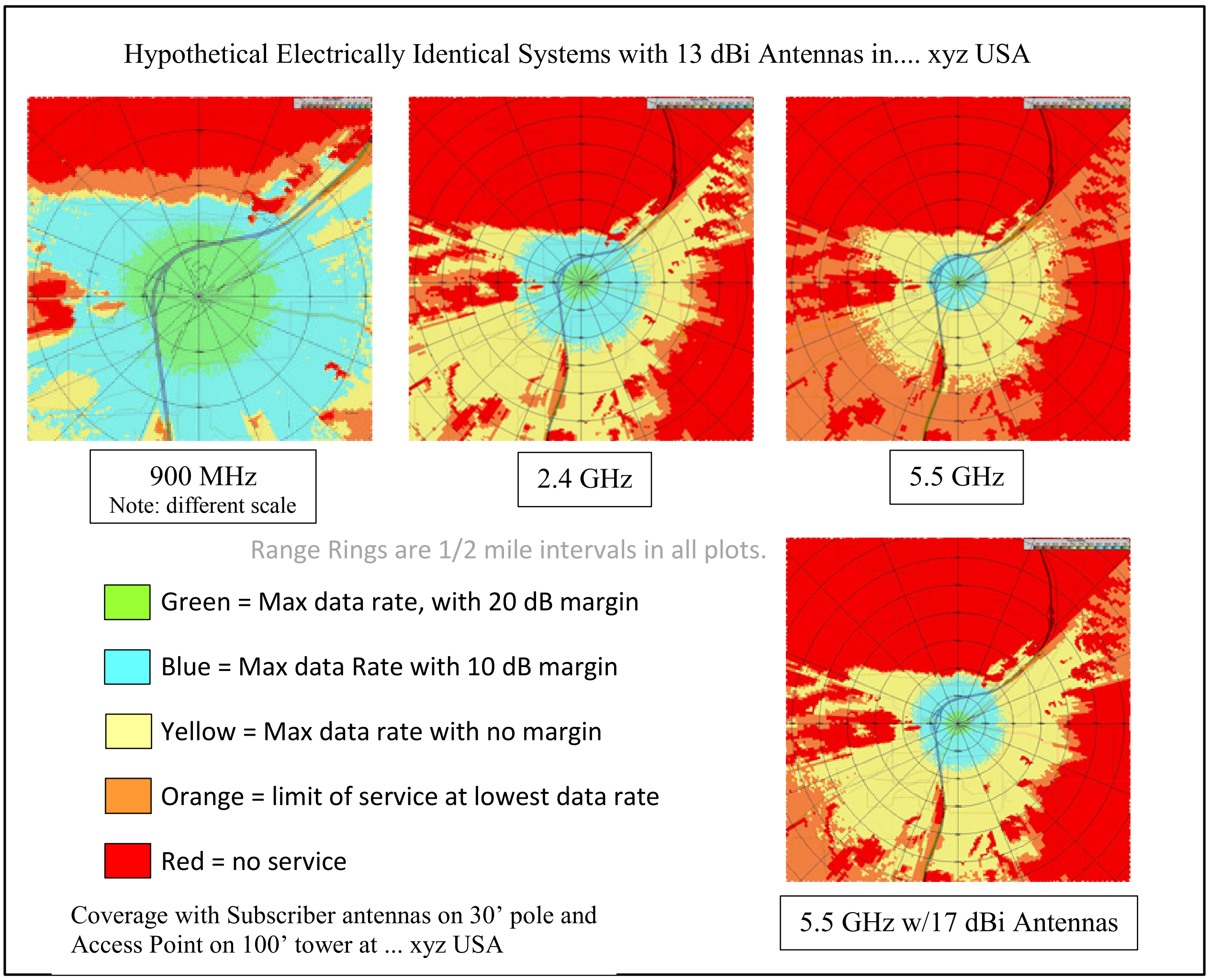

Figure 2 Effect of Frequency on Coverage

The color scheme of Figure 2 is used in all subsequent plots in this analysis. One reasonable way to interpret this is that the Blue is your primary coverage area, customers in the yellow area will see service, but will require a high proportion of system capacity at times. See Coverage and Capacity above on page 10.

Town Coverage Plots

The following plots are based on the published performance of the Tranzeo TR-SL5-16-48 client CPE 30 feet above ground and TR6000 Access Points in a four sector configuration with 17 dBi panel antennas at 100 feet.

Range rings in all cases are ½ mile.

xyz USA

xyz USA coverage is based on a tower at the telephone company office. The surrounding terrain is fairly flat and even, so there is little irregularity in the coverage pattern.

The image on the left is a zoomed version of the right.

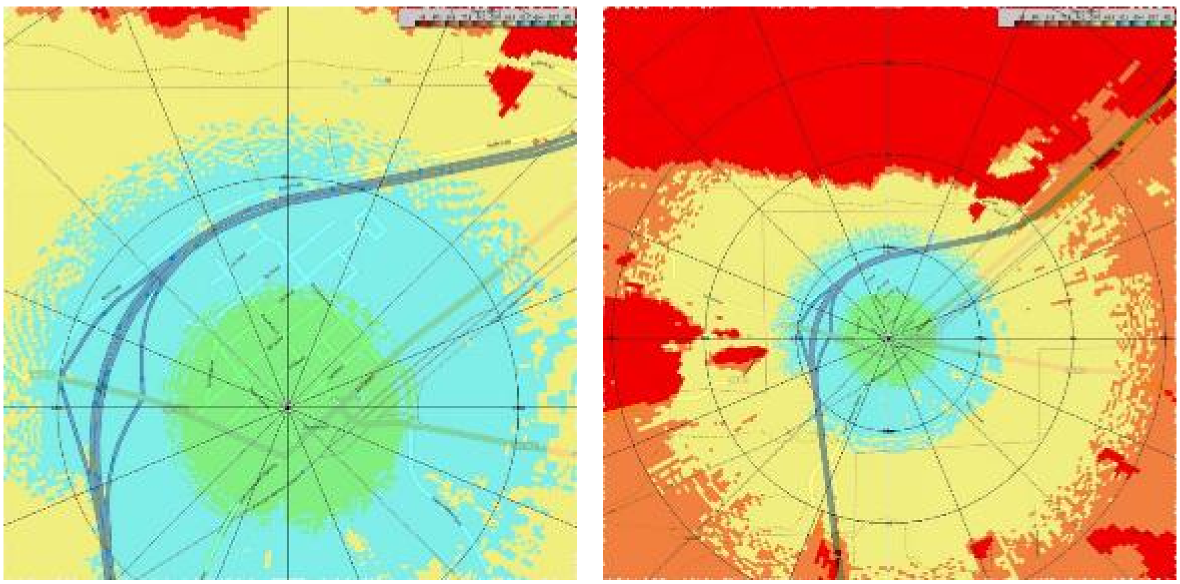

Figure 3 xyz USA Coverage

Area "A"

The terrain around Area "A" is less regular. The plots in Figure 4 and Figure 5 show the effect of a slight depression to the south of town. The rightmost plot of Figure 5 shows the effect of adding 50 feet to the tower (for a total of 150') to provide more reliable coverage.

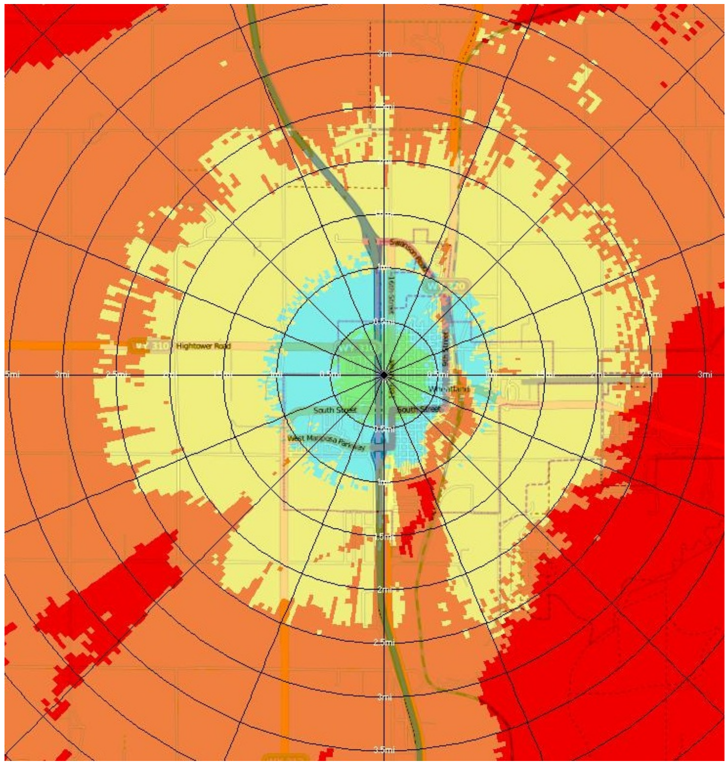

Figure 4 Area "A"; Walnut St. just east of Road "1"

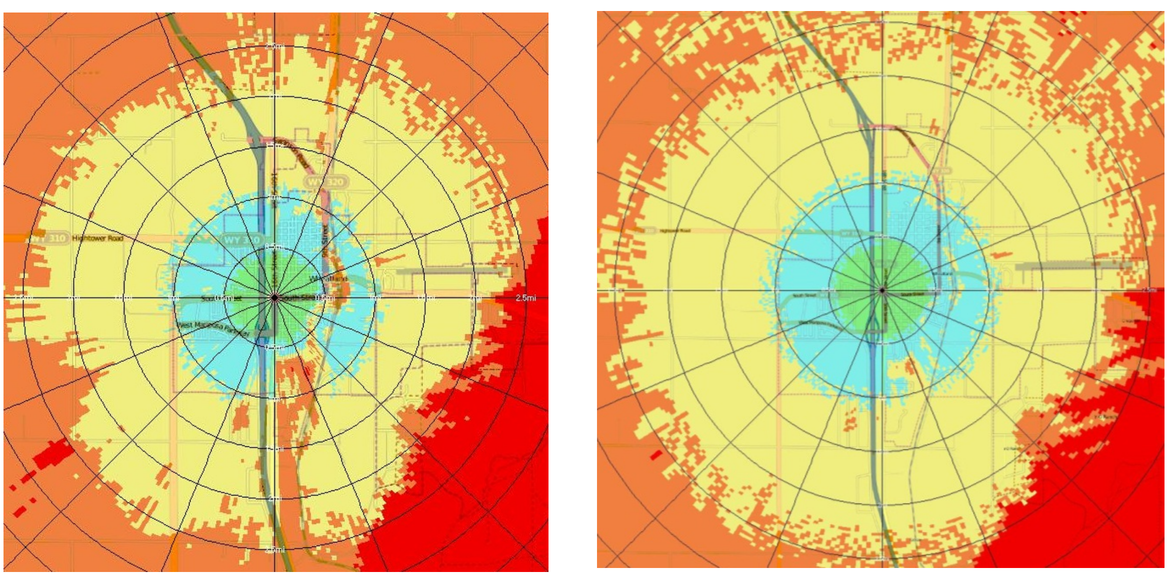

Figure 5 Area "A"; (South St.) just east of Road "1"; 100' Tower (left) and 150' (right)

Area “B”

While initial coverage of Area “B” could be provided with a single location, two will provide more reliable coverage and far better capacity. The two locations shown are on the north east side of town along Road “2” and along Road “3” near Road “4”.

Table 3 Area “B” Station Locations

Site name	Latitude(°)	Longitude(°)	Elevation(m)
Area “B”1	42.06195	-104.182	1249
Area “B”2	42.08636	-104.189	1285

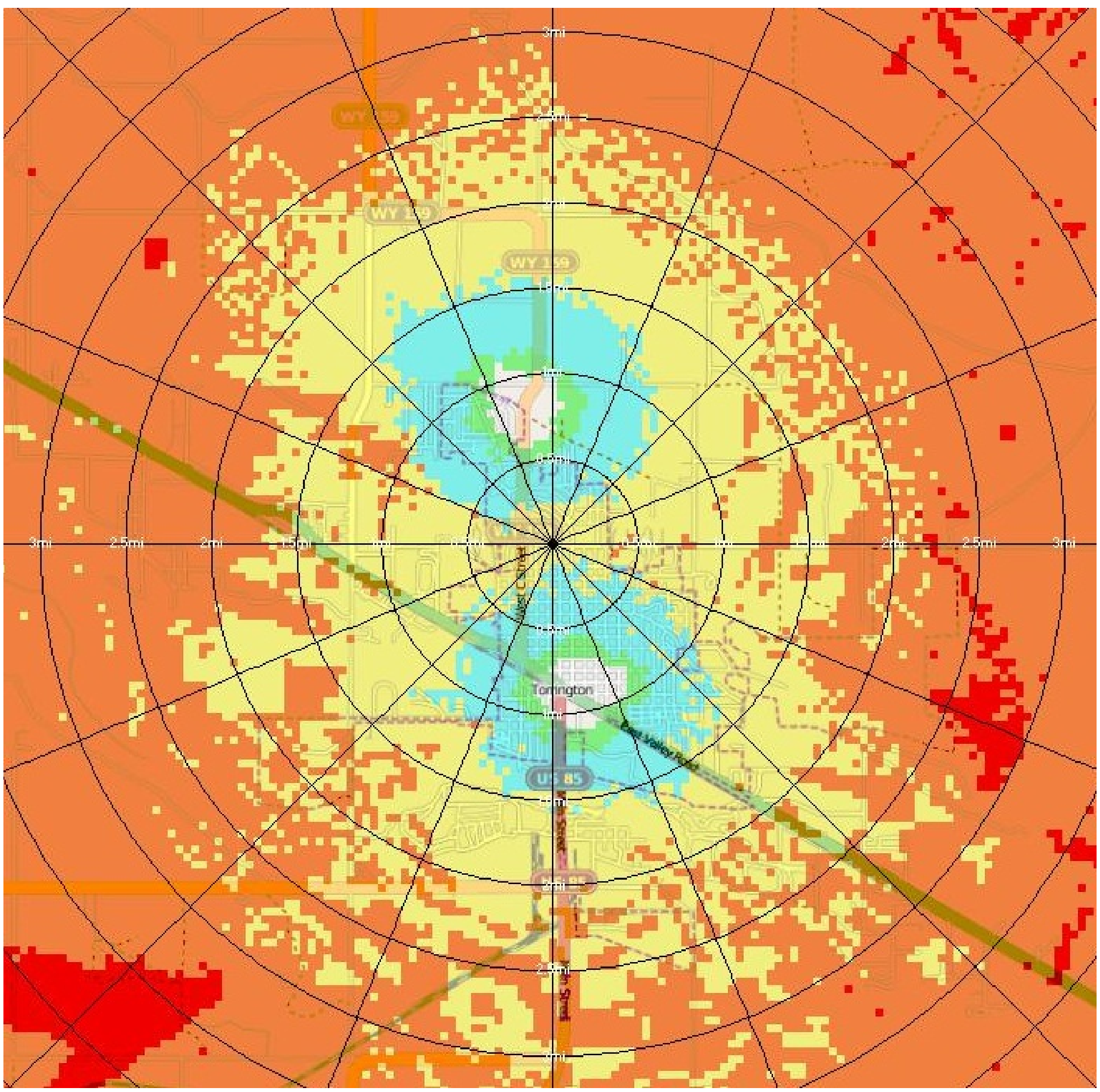

Figure 6 Area “B” Coverage