700 MHz Base Station Test Results for the FCC

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1.0 Document Goal

This document provides the test results of a Base Station which provides mobile broadband connectivity using 700 MHz spectrum using the WiFi protocol. Flow Mobile had obtained a STA from the FCC to be able to test a Base Station in the 760-776 MHZ. The purpose of this test was to prove that WiFi protocol can be used at this spectrum and a mobile Base Station can be used to help deploy a large wide-area network.

2.0 Introduction

A Base Transceiver Station (BTS) is a major component of any wireless access network to provide wireless service to users. A client terminal connects to a BTS to provide service to the user. Our demonstration is of a BTS operating in 760-776 MHz using WiFi protocol and the client used to test this BTS is based on an off-the-shelf module developed by Ubiquiti Networks.

The client can be a handheld device, a computer card that is either connected using the PCMCIA slot or USB connector. The connection between the client and the BTS uses a particular protocol. The protocol could be any of CDMA, GSM, 3G standards or Wi-Fi standards or the future LTE standards. Hence a BTS has two components for the radio connection to be established between the BTS and the Client Terminal. The two components are frequency component which is purely a radio function and a protocol component which is a required for communication.

A BTS can operate in any frequency using a particular protocol. This is the reason there are GSM BTS in 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz frequencies. In North America and certain parts of South America, the GSM networks operate in the 850 MHz and 1900 MHz whereas in the rest of the world the GSM networks operate in the 900 MHz and 1800 MHz. Handhelds that work globally on GSM protocol are referred to as quad-band phones.

Wi-Fi is ubiquitous and has reduced the price of all components associated with it. Our Wi-Fi BTS operating in the 700 MHz frequency opens the door for a dual band Wi-Fi device. In this document we will show the following:

1. A 700 MHz BTS using Wi-Fi protocols has a range that will allow for a cost effective deployment of wide-range broadband networks.
2. By performing a down conversion of frequency of Wi-Fi chips from 2.4 GHz to 700 MHz, we can take advantage of the low cost electronics, the abundantly available terminals that can easily be down-converted to 700 MHz and the system can be deployed for best performance.
3. Using Smart Antenna BTS allows us flexibility in deployment options – the weight and performance capabilities of the BTS will allow us to deploy the BTS on several locations such as light poles etc.

3.0 System Description

The system tested for this demonstration has the following components:

1. A Smart Antenna based Beam Forming BTS operating in 760-776 MHz referred to in this document as the **700 MHz Wi-Fi BTS or the BTS**
2. A client card based on a module developed by Ubiquiti referred to in this document as **700 MHz Wi-Fi Client or the Client**

3.1 700 MHz Wi-Fi BTS

Figure 1 shows the 700 MHz Wi-Fi BTS. In this section we provide a brief physical and operational description of the BTS.

Figure 1: 700 Mhz WiFi BTS Assembly

Type of BTS = Omni
Total EIRP of the BTS = 48 dBm
Transmit Power of BTS = 36 dBm
Antenna Gain = 6.5 dBi per antenna
Total weight of the System = 15.9 kg
Weight of the System including mounting brackets = 20 kg
Length and width of the BTS = 380 mm X 380 mm
The BTS is weather proofed and tested for cold and hot weather environments so the entire BTS can be an outdoor BTS between the temperatures of -40C and +60C.
Max Range Setup on the BTS = 10 km or 6.6 miles
(This means that after approximately the max distance calculated by the estimated roundtrip to the BTS, the connection will drop. By increasing the distance, the connection can be maintained at longer distances but, we did not perform that test here).

This is a setup feature where the range can be farther but the test was conducted to show coverage of 5 miles or over so the max range was set to 6.6 miles. In other tests conducted, the range was as far as 10-15 miles but those results are not presented in this document since our design requirement for our system is 5 mile range and the additional range is used to provide quality margin than for coverage.

As seen from the figure, the BTS is a beam-forming smart antenna system that uses digital signal processing and antenna gain combining to form a beam that can be steered to reach the terminal. The use of multiple antennas increases the total diversity on the BTS as well as adding to diversity gain. The frequency this test BTS is designed to use is a single channel and operates between 760-776 MHz.

3.2 700 MHz Wi-Fi Client

The client card also operates in the same range and has the following specifications:

Transmit Power = 28 dBm (+/- 1 dBm)
Antenna Gain = 3 dBi
Total EIRP of the client = 30 dBm to 32 dBm

Rx Rate (Mbps) 802.11g mode	Sensitivity (dBm)
6	-108
9	-106
12	-104
4.4	-103.5
17	-105.5
36	-95.5
48	93.5
54	-91.5
Rx Rate (Mbps) 802.11b mode	Sensitivity (dBm)
1	-111

	Flow Mobile
2	-108.5
5.52	-106
11	-105

4.0 System Setup

The BTS was deployed on top of a 30-foot roof attached to a 10-foot pole as show in Figure 2. The city where the test was conducted is Dickinson, ND. As shown in the picture, the BTS is at a height that is lower than some of the buildings around. This is significant since in actual deployments the height of deployment will be about 80-feet and the performance of the BTS can be expected to be better.

Figure 2: 700 Mhz BTS Installed on Rooftop

Figure 3 shows the client setup. The client we have used is similar to a CPE box for public safety purposes. Figure 4 shows the vehicle setup that is used to test the BTS.

Figure 3: Client Equipment

Figure 4: Client Equipment- Vehicle Install

5.0 Test Methodology

The main test for the system is to check the throughput in fixed and mobile environments. The test was also designed to show how a public safety vehicle would be equipped with a client. The first point of measurement was about 120 feet from the BTS and the test continued as the vehicle was driven through the town. The variable components of the test were:

1. Speed
2. Line of Sight (LOS)/Non-Line of Sight (NLOS) environments
3. City roads and freeways.

In Figures 5, 6, and 7 we show coverage and throughput.

Figure 5 shows the range test which involved driving away from the BTS in 4 different directions. In this test the speeds reached up to 65 MPH which is the speed limit in the area.

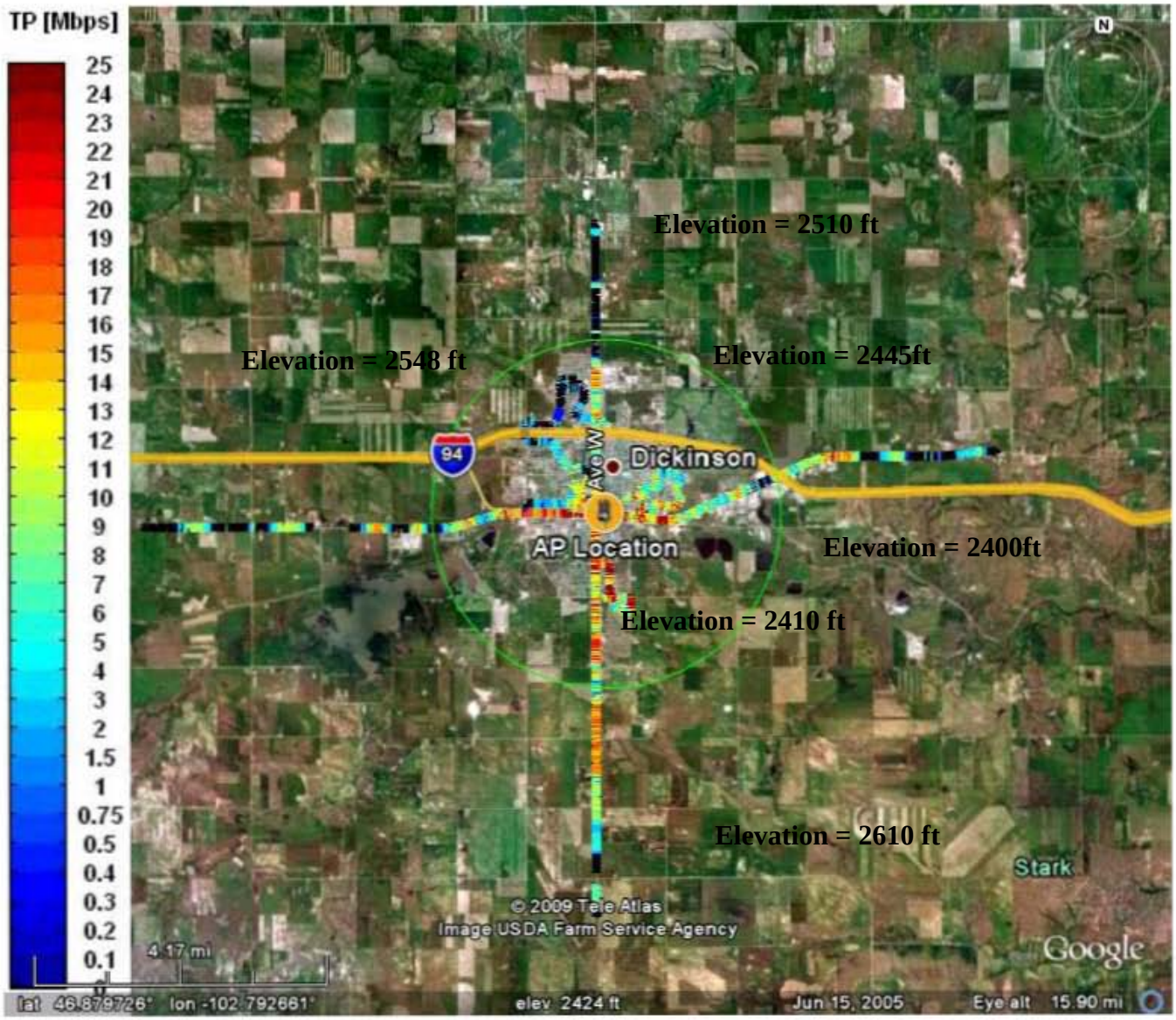

Figure 5: Spurs from the BTS in different Directions all NLOS

Please note the following:
Ground Elevation where the BTS is mounted = 2410 feet above MSL
Height of BTS from Ground = 40 feet
Total Height of the BTS = 2450 feet.

The areas where there was signal loss outside the city while driving away through all directions had either a ridge effect where the ground blocked signal or a valley effect where the signal was lost because of ground level issues. Several of these issues in city environment are usually mitigated by "Macroscopic Diversity" where multiple BTS in the city provide multiple paths of signal into the area.

Area 1 to the East: Elevation = 2445 ft. the valley Elevation = 2400 ft. 40ft drop causes loss of signal.
Area 2 to the North: Elevation= 2458 ft the valley = 2510 ft

All of these issues can be easily addressed by radio engineering in actual deployments by choosing points of high elevation and also providing enough Macroscopic Diversity of the BTS in the network.

In Figures 6 and 7 we show coverage maps in completely NLOS conditions around the town of Dickinson. Distances within the city were well over 1.3 miles in either direction.

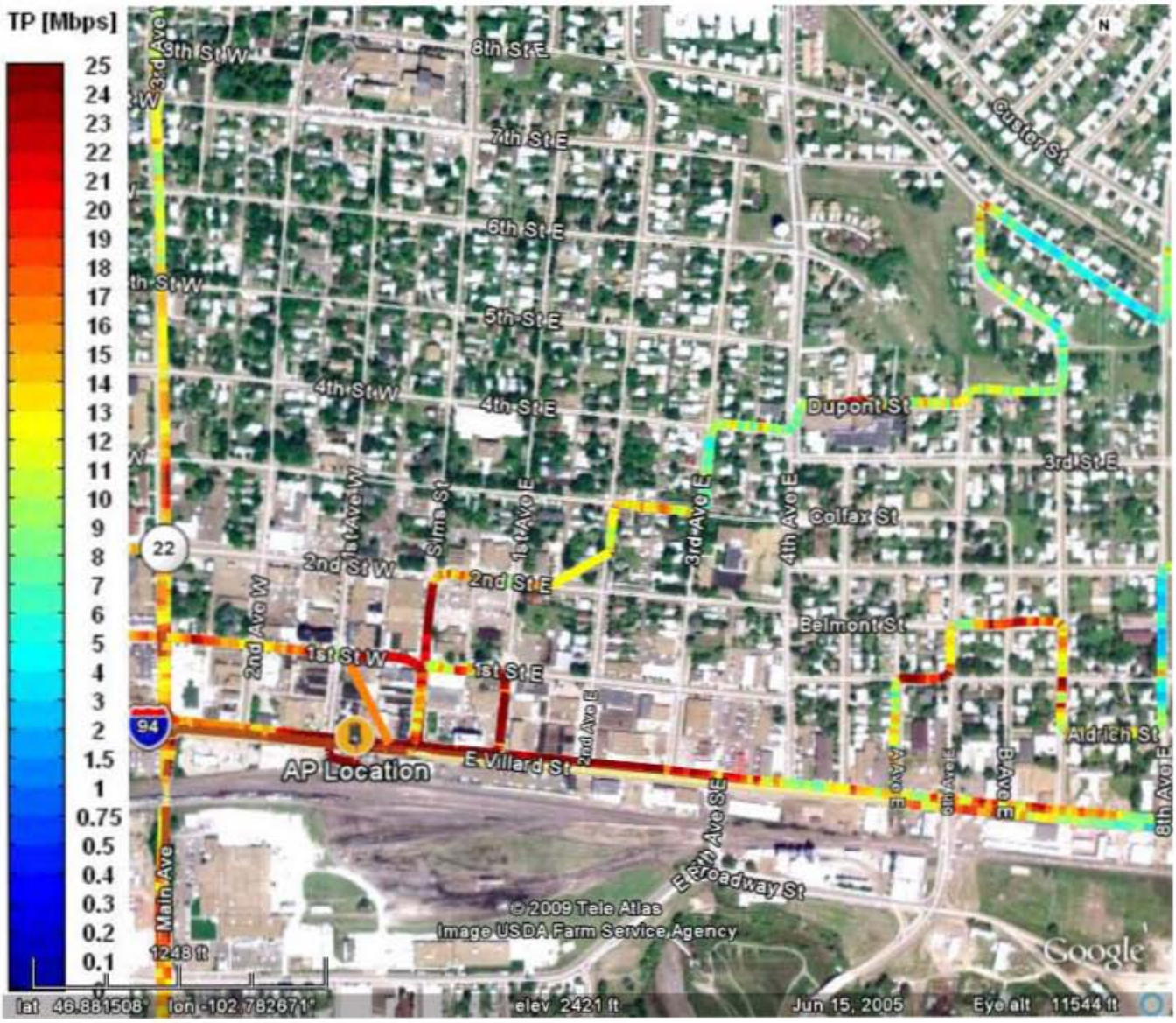

Figure 6: NLOS Conditions within the City

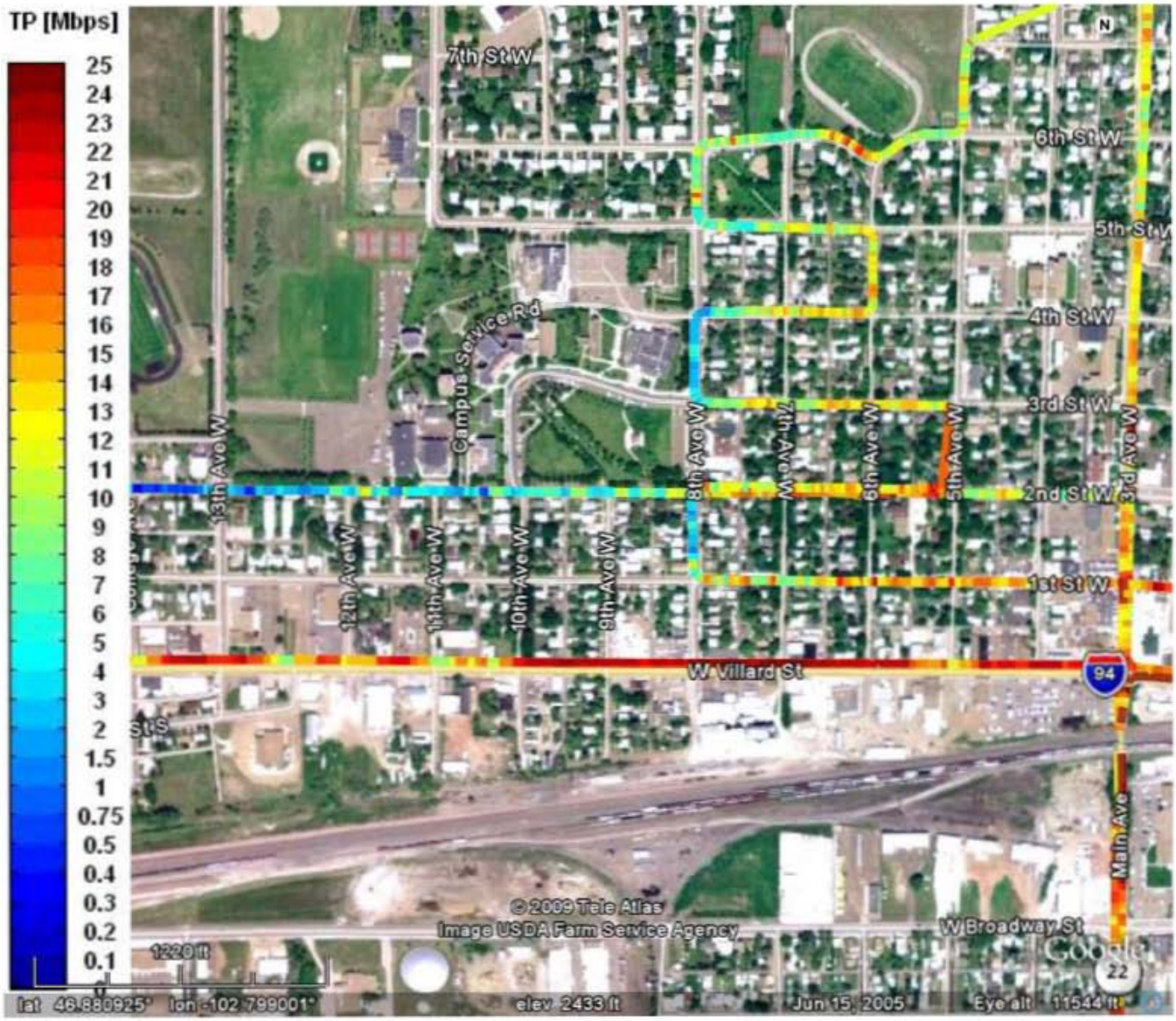

Figure 7: NLOS Conditions within the City

Table 1 shows the RSSI and throughput in one direction. The max distance is 10,000 meters as shown below. Also, please note that because the location was completely NLOS, there will be fluctuations in the throughput. Sometimes, locations far away can have better throughput than locations closer to the BTS.

Table 1: RSSI and Throughput

Latitude	Longitude	RSSI	Throughput	Distance	Line of Sight
45º 52' 43.05” N	102º 47' 13.12” W	-30 dBi	25 Mbs	40 Meters	Yes
46º 52' 44.16” N	102º 47' 23.11” W	-36 dBi	25 Mbs	240 Meters	No
46º 52' 44.89” N	102º 47' 53.75” W	-43 dBi	25 Mbs	675 Meters	No
46º 52' 45.19” N	102º 48' 10.11” W	-53 dBi	15 Mbs	1200 Meters	No

46º 52' 45.19” N	102º 48' 42.51” W	-65 dBi	20 Mbs	2000 Meters	No
45º 52' 37.89” N	102º 49' 39.50” W	-73 dBi	16 Mbs	3000 Meters	No
46º 52' 33.93” N	102º 51' 22.43” W	-73 dBi	17 Mbs	5300 Meters	No
46º 52' 43.40” N	102º 47' 14.26” W	-65 dBi	20 Mbs	3000 Meters	No
46º 52' 42.31” N	102º 47' 13.19” W	-73 dBi	18 Mbs	5000 Meters	No
46º 52' 42.53” N	102º 47' 11.24” W	-83 dBi	7 Mbs	7000 Meters	No
46°52'34.61"N	102°54'48.25"W	-78 dBi	16 Mbs	9600 Meters	No

Please note that a lower RSSI does not directly mean lower throughput. When using a beam-forming smart antenna system, the RSSI does not directly correlate to the total throughput there are other factors that allow the throughput to be higher in NLOS multipath environment

6.0 Analysis of the Results

The BTS performed as expected. The main goal of showing high throughputs in mobile environment has been achieved. The BTS using 802.11 g protocol mode has provided very high raw throughput that can be used to provide broadband services in a fully mobile environment. In addition, the ability of the BTS to perform at high speeds with high throughputs demonstrates this network component can be used to build a high-speed mobile broadband network. The goal of 5 mile + range has also been demonstrated.

Our BTS uses Wi-Fi MAC protocol and down coverts the frequency of operation down to 700 MHz. Hence, we get all of the features of Wi-Fi on 700 MHz. Our system component vendors do not need to do any additional development to the MAC either on the client terminal side or the BTS side. This means that any Wi-Fi features and capabilities at 2.4GHz will be automatically available on our 700 MHz network. For instance, Wi-Fi is cable of QoS, Mobility, high data throughputs, voice, video and data. All of these will be automatically available on the 700 MHz network. The main component required to be demonstrated has been mobility and handoff. We have demonstrated these features in the 2.4 GHz network we have deployed. Hence, these will be automatically available on the 700 MHz network.

For a fully mobile broadband network to be constructed over a vast area, Wi-Fi provides all the components required. The range and performance of the individual BTS is the first step. For a fully functional network, additional components and protocols are required which are all available in Wi-Fi. 802.11r which is referred to popularly as “fast handoff” protocol in Wi-Fi was ratified by IEEE and is a part of all Wi-Fi chipsets. It provides the ability to offer fully mobile networks across multiple subnets. 802.11r is a standard implementation in Wi-Fi which when implemented in combination with Mobile IP on the backend, provides for a fully mobile network. 802.11r allows for handoff between BTS when they are in the same sub-net or different sub-nets. Hence the Wi-Fi standard has all the components required to create a fully mobile network.

7.0 Conclusion

The test was done to show that a down converted 700 MHz Wi-Fi BTS is a viable option to provide broadband coverage in rural areas. The BTS production cost is under $3,000 and its smart antenna

design makes it very easy to deploy on tough locations like pole tops instead of going for locations like towers. On the terminal side, the client card was in the $150 range for low volumes. This client was developed by down-converting Atheros AR5414 standard Wi-Fi chipset which operates in the 2.4 GHz range. The down conversion process applies to the radios only as described earlier. This means that any Wi-Fi client available in the market can be down-converted to 700 MHz range. This includes PCMCIA cards, USB adapters, Wi-Fi phones and PDAs to name a few. We have demonstrated in practice by building and testing the system in less than 12 weeks that the process is not lengthy. In addition the fact that the Wi-Fi standard itself allows for 5 MHz channels means that we are now capable of delivering a flexible solution for any frequency.