WHITE PAPER
Intel® WiMAX
Education

WiMAX and Northern Michigan University

A HOT TECHNOLOGY FOR A COOL UNIVERSITY

Who would have guessed that Northern Michigan University (NMU) would be the first university in the United States to provide high-speed 4G data service to every college student in the greater community?

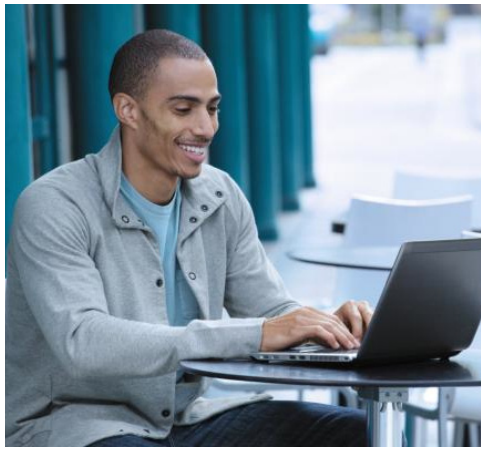
NMU is located in Marquette, nestled on the shores of Lake Superior in Michigan's Upper Peninsula. During the mid to late 1800s, Marquette grew to be a premier center of iron ore mining and shipping. In the 19th century, it became a tourist hot spot, with families pouring off passenger steamships each summer to relax in nature.

"For the past few years, WiFi hotspots allowed us to cover about 10 percent of the city of Marquette. WiMAX allows us to cover almost 100 percent of the city."

– Gavin Leach
Vice President for Finance and Administation
NMU

Today, Marquette is the largest city in the Upper Peninsula, known for its massive winter snowfalls and as the home of NMU. Visitors still venture to the secluded Upper Peninsula for the natural beauty that varies from season to season.

NMU was established in 1899 to provide teacher preparation programs, with 32 students and six faculty members. Today, NMU is the largest university in the Upper Peninsula, with five academic divisions and 10,000 undergraduate and graduate students.



Ask students at NMU why they chose to attend and the most common answer you'll receive is "the environment." The 360-acre NMU campus is safe, clean, friendly, and attractive. Over 6,000 students live off-campus in Marquette and other communities within about 15 miles of the campus.

NMU is also one of the largest notebook computer campuses in the U.S., with all full-time students receiving either a ThinkPad* or MacBook* as part of tuition. The university has received national and international awards for its innovative work in integrating technology into higher education.

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Extending Connectivity Community-Wide

Connectivity is an important part of any campus laptop program. NMU has 100 percent 802.11abgn WiFi coverage on campus and deployed WiFi 802.11abgn WiFi hotspots in the surrounding city of Marquette over the last few years to provide off-campus network access; however, due to the limitations of WiFi, a trip to campus was still the best way to directly access the NMU network.

In late 2008, NMU Chief Technology Officer David Maki began looking at 802.16e mobile WiMAX as a technology that could be used to extend the campus network off-campus. The rationale behind using the WiMAX technology was to augment the basic goal of the notebook computing initiative and also provide students, faculty, and staff affordable, equal access to broadband when away from campus.

WiMAX belongs to the 4G class of networks. Like current cellular 3G data networks, WiMAX provides a high-speed wireless data connection to any device within range of a WiMAX-enabled tower. The advantages of WiMAX and 4G networks over 3G networks are speed (up to 2X faster) and reduced latency.

Although WiMAX is broadly installed in over 100 countries with millions of subscribers, it has been slow to enter the U.S. market. In 2008, there were only a few commercial WiMAX implementations in the U.S. and no university-implemented programs.

A critical hurdle in any WiMAX implementation is RF spectrum, but unfortunately NMU did not have a spectrum license. NMU leaders and Congressman Bart Stupak built the case for a spectrum request and presented the case to the FCC in Washington. In October 2008, the FCC granted NMU an Educational Broadband Service (EBS) license.

This led to a new expanded wireless network, which allowed the NMU network to be accessed throughout Marquette and changed the way students, faculty, and staff connected to the Internet off-campus. By late August 2009, David Maki and his staff, with help from Intel engineers, had completed the physical implementation of the network. In January 2010, NMU entered an agreement to expand the coverage to Negaunee, a town about 14 miles outside of Marquette where many students live.

Current WiMAX Deployment
4 Motorola* 450 Base-stations
Frequency Reuse 3 – 2.577 GHz, 2.587 GHz, 2.597 GHz
Channel width of 10 MHz
Security: supports both EAP-TTLS & EAP-TLS
Clients primarily consist of Intel WiMAX cards embedded in Lenovo* laptops; supplemental devices consist of Motorola USB* dongles and CPE devices
Fall of 2009 – 3,500+ devices active
Planned Fall of 2010 – 11,000+ devices active

Since each NMU student and staff member receives a Lenovo ThinkPad*, the university installed Intel® WiMAX cards in the new ThinkPads that were distributed in the fall of 2009 and offered owners of the older machines the option of purchasing a WiMAX USB adapter.

Student Perspectives

According to Jason Morgan, NMU senior and president of Associated Students of NMU, the increased accessibility gives students an advantage, especially during

the winter semester. "WiMAX has made it much easier to get work done when weather conditions do not allow students to get to campus. Also, I see this as a highlight to NMU. It really emphasizes the high-tech, high-touch atmosphere here."

Whitney Oppenhuizen, NMU senior and public relations major, purchased a WiMAX USB adapter for her older laptop. According to Whitney, "Now I can work on assignments whenever I have time, which allows me to be more in-depth when researching. Also, if you're living off-campus for two or three years, it saves money to pay $150 for the WiMAX adapter rather than paying for cable Internet."

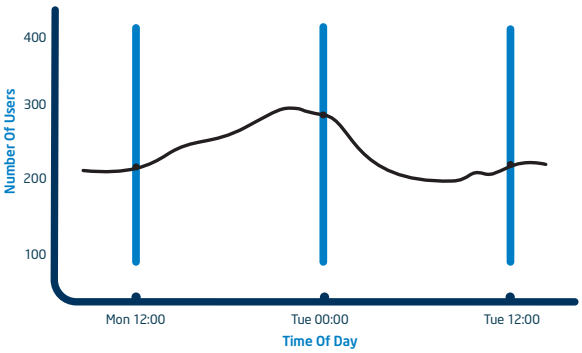

FIGURE 1. WIMAX* USERS BY HOUR

Student Craig Koski thinks WiMAX helps students work more independently and prepare for the workplace. "With the Internet at my fingertips, I am more willing to do my own research and explore things on my own. I find it much easier to do research online than to open up a textbook and search through it page-by-page."

Faculty, Staff, and Community Perspectives

Many professors use WebCT to allow students to interact with their courses, turn in assignments, and participate in online discussions.

According to Associate Professor of English Russell Prather, "I use WiMAX when I work on my classes at home, which is fairly often. I enjoy being constantly connected to students and fellow faculty members, which I think will come in especially handy during summer courses, when the only link between students and professors is the Internet. I think NMU is wise to invest in this kind of technology—reliable Internet access that connects a geographically isolated place to the rest of the country and the world."

According to NMU President Les Wong, "WiMAX helps to ensure that many of the NMU students who live off-campus enjoy wireless access comparable to their peers who live on-campus. And there is no additional university fee for this benefit. Our new EBS license takes technology to a new plateau by expanding our wireless network in a way that makes handheld and notebook devices truly portable."

Gavin Leach, NMU vice president for finance and administration, feels that WiMAX has extended students' access to educational resources. "For the past few years, WiFi hotspots allowed us to cover about 10 percent of the city of Marquette. WiMAX now allows us to cover almost 100 percent of the city. This access is important for our 6,000-plus off-campus students, as well as for students and faculty doing research and learning outside of the classroom." Congressman Bart Stupak has commented that the increased wireless penetration afforded by WiMAX is valuable on two fronts. "It not only enhances learning for NMU students, it is very helpful for emergency services and keeping citizens informed. With WiFi, the coverage is about 100 to 150 feet. With WiMAX, it's miles."

WiMAX Private Network Tutorial

The remainder of this document will highlight the steps required to implement a private WiMAX network, illustrated by the NMU experience. Although every situation is unique, this discussion will of necessity be somewhat generic. The objective is to help schools and universities determine the appropriateness of a WiMAX network.

Project Objectives

The first step in any WiMAX project is to develop concise project objectives.

Fixed WiMAX Implementations

Fixed WiMAX implementations provide Internet access to buildings, the CPE is more powerful, and an external antenna can provide additional range. Bandwidth is a consideration, since fixed implementations tend to use more bandwidth than mobile implementations.

Mobile WiMAX Implementations

Mobile WiMAX implementations can communicate with mobile devices such as laptops. Because mobile devices have lower power output and gain antennas, their range is limited compared with fixed implementations. Also, since mobile devices move around and can travel out of range of one base station, a handoff to a second base station may be needed.

Network Capacity

The next step is estimating the required bandwidth, which can be a challenging task. As far as possible, it is important to estimate bandwidth requirements over the next five to ten years, as well as the short-term requirements. Retrofitting can be an expensive proposition.

Key Variables

- Number of devices—each device generates a bandwidth demand
- Expected concurrency ratio
- Types of applications—email, Web browsing, eLearning applications, and streaming video
- Types of implementations—fixed or mobile
- Density of users—how many per square mile

- Peak load requirements—sporting events, concerts, and other large gatherings

Sample Scenario

- 1,000 users within a radius of 1.5 miles from a tower, which equates to seven square miles
- 100 of the 1,000 are active at any one point in time
- A typical user requires an average of 100 kilobits/second. The burst rate may be two or three megabits/second, but the network traffic goes to zero when users are processing data just sent. Streaming video represents a substantial and continuous traffic demand.
- In this case, the total demand would be (100 users)*(100kbps) = 10 megabits/second.

At NMU, the number of users and bandwidth demands follow a fairly predictable pattern throughout the day. See Figure 3, which shows that at 5 a.m. the number of users reached a low point of 138 and at 10 p.m. the number reached a peak of 305. Students are clearly using the service around the clock for anytime/anywhere learning.

Geography

The boundaries of RF coverage need to be determined, and a critical step in any wireless implementation is the creation of an RF coverage map. Uninhabited areas may be excluded if desired. It is helpful to create a map identifying the physical street address of all expected network users and a map of population density. As might be expected, user density directly affects bandwidth requirements. As with any outdoor wireless implementation, geography plays a big part in the design of the network. In a relatively flat area, WiMAX signals on a 100-foot tower could extend to a radius of 30 miles. In a city or mountainous area, the coverage could be as small as a one-mile radius or less.

With sufficient spectrum, the best geography for WiMAX is flat and with few trees, which can absorb the RF signal. The worst geography might be mountains or big cities. Both require more towers than a flat area, leading to higher costs. If spectrum is limited, hills or mountains provide natural barriers, blocking the signal from an adjacent tower and allowing spectrum reuse, which would be impractical on flat terrain.

The city of Marquette is approximately four-by-five miles in area with a population of roughly 20,000. It has a few hills, but fortunately, the geography proved to be a good fit overall for a WiMAX implementation. Figure 2 shows the population densities for the greater Marquette area and the downtown/university area.

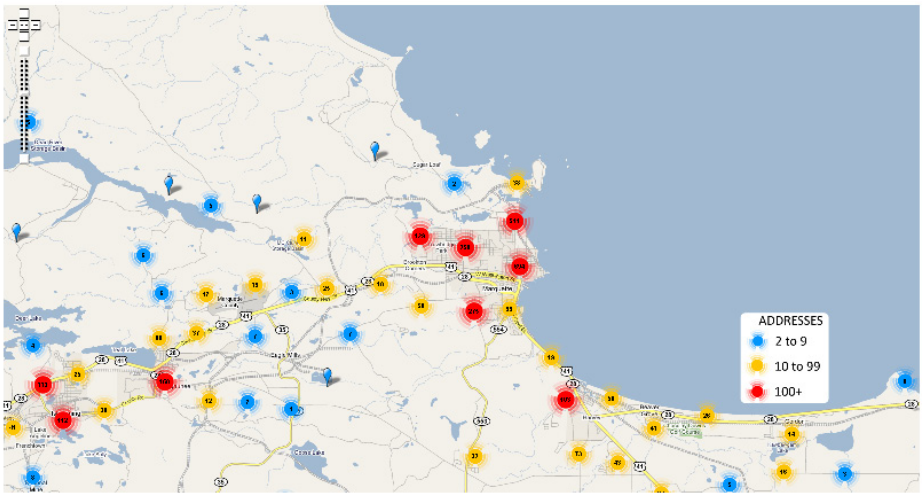

FIGURE 2. POPULATION DENSITY IN GREATER MARQUETTE AREA

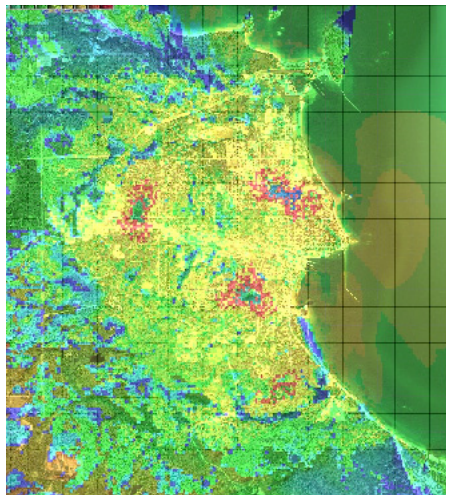

FIGURE 3. NMU COMPUTER SIMULATED COVERAGE

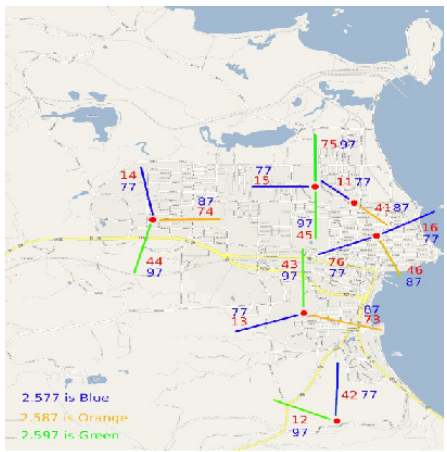

FIGURE 4. ANTENNA PLACEMENT SHOWING SECTORS AND FREQUENCIES

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FIGURE 5. FIRE DEPARTMENT HOSE DRYING TOWER FOR BASE STATION

FIGURE 6. WATER TOWER FOR BASE STATION

Spectrum

Access to licensed or unlicensed spectrum is critical to any wireless implementation. Licensed spectrum is preferred because there is less risk of interference. Although unlicensed solutions can mitigate the effects of interference, their effectiveness may be limited.

The licensed WiMAX spectrum is the 2.50-2.65 gigahertz band, referred to as the EBS band, previously used for educational television. As TV moves from analog to digital, this spectrum is freed up for new uses such as WiMAX.

The spectrum requirements depend on the geography and the required bandwidth. A single WiMAX channel can be 6, 10 or 15 megahertz, and the more megahertz per channel, the higher the network capacity. In most cases, towers have multiple antennas – one for each pie-shaped segment covered; to minimize interference it is important that an antenna on one tower has a different frequency from an antenna on an opposite tower. Typically this means four channels for optimal coverage.

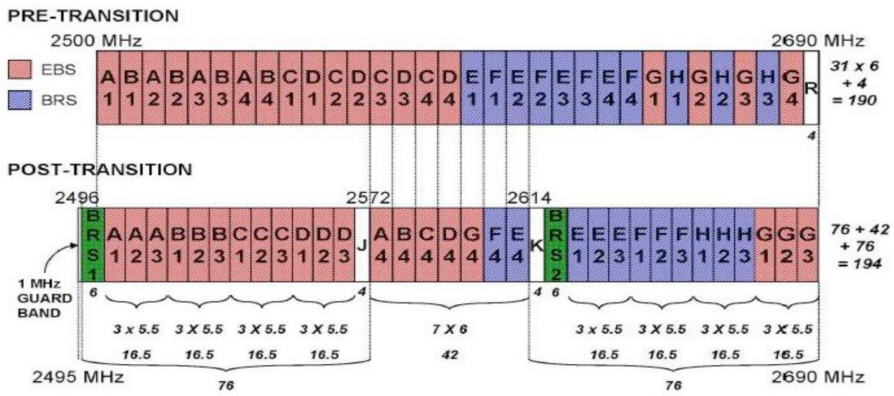

Figure 7. BRS-EBS BAND PLANS: PRE-TRANSITION AT 2500–2690 MHZ & POST-TRANSITION AT 2495–2690 MHZ

If bandwidth is insufficient, an institution can purchase or license spectrum from incumbent license holders. In rare cases, the FCC may grant a new license for spectrum. NMU did not initially have spectrum, but they were fortunate to receive permission from the FCC to implement their solution.

RF Analysis and Design

The RF design process can be demanding and should not be underestimated. It is relatively easy to design a one-tower implementation to cover a mile or two radius around one school. But designing for a 50-mile-by 50-mile, or 2,500-square-mile, area is a demanding task and could take an expert team as long as a year to implement.

Many hurdles need to be overcome. If negotiations for a particular site prove unsuccessful, a network redesign will be required. In addition to end-user coverage, backhaul needs to be considered. Backhaul is the term for Internet access from a tower back to a primary Internet connection point. If point-to-point microwave is used for backhaul, generally near-line-of-sight access is required between the tower and any intermediate hops back to the Internet.

Using specialized software, RF engineers prepare an RF coverage map that indicates the optimal locations for base stations and towers, the number of segments per tower, and the frequency reuse. Signal-level simulations assure that all areas have adequate coverage.

NMU, working with Intel engineers, used network design software to determine the number and placement of towers and accommodate all users at the lowest cost. This task is often complicated by the need for access to the antenna locations, and

FIGURE 8. MOTOROLA WAP 450P* BASE STATION

sites may need to be leased at additional cost and time. Fortunately, NMU and the city of Marquette found they had enough locations within their control.

Figure 9 is an example of the RF coverage map for Marquette.

Antenna Site Considerations

Tower sites are critical to a successful WiMAX implementation. Sites need to be considered in terms of property, towers, power, and backhaul.

Property

Without access to property, there is no site. Schools and communities often have access to property that is well suited for a tower, but leasing may be required.

Towers

A tower structure of 100 or more feet may be needed to hold the WiMAX antennas if tall buildings or other tall edifices are not available, thus increasing the costs. As with any construction project, architects, engineers, and permits are needed.

NMU was fortunate to be able to use a city-owned water tower and a tower used by the fire department to dry fire hoses as part of their tower complement. Figure 5 shows the fire department tower and Figure 6 shows the NMU antenna on a water tower.

Power

The heart of the site is the WiMAX base station, which takes the signal from the Internet connection and broadcasts it out via the antennas on the tower. Fortunately, base stations do not require a lot of power, but it is a factor that must be considered.

Base Station

For its base stations, NMU selected the Motorola WAP 450P*, which supports multiple antenna technologies that provide superior capacity and coverage in rural, suburban, and urban environments. With remote RF head design and high-power output to 10 watts per sector at the antenna ports, the WAP 450 is comparable to a 20-watt, ground-based solution. Figure 8 shows the NMU base station.

Backhaul

Where possible, a fiber connection to existing institutional routers is generally the most cost-effective backhaul. If this is not possible, point-to-point microwave running on licensed spectrum is a good alternative. Where sufficient bandwidth exists, WiMAX itself could be used for the backhaul. Fortunately, NMU was able to get fiber to each tower site.

Testing and Tuning

Testing and tuning is a critical stage that requires field verification of signal strength, using the theoretical coverage map as a guide for potential trouble areas. Testing involves both fixed and mobile scenarios.

In fixed scenario testing, measurements are made inside buildings as well as outside. In mobile testing scenarios, tests are conducted in a car as it drives through the city. Mobile WiMAX is more demanding than fixed WiMAX, since mobile power is less; antennas are less powerful; and there are handoff issues as the car moves from one antenna coverage zone to another.

Figure 9 illustrates the signal level measurements at various points along a vehicle test drive as well as a marine test drive.

Figure 9. GREATER MARQUETTE AREA SHOWING SIGNAL LEVELS DURING DRIVE AROUND BOAT TEST

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Major WiMAX Components

An 802.16abgn implementation includes a number of mandatory components. Some of these, such as the Radius and DHCP servers, may be already available via existing WiFi networks.

- **CAPC/ASN Gateway**
- Director of all WiMAX subscribers/clients
- Authentication and security: Interact with base stations, RADIUS server, and DHCP server to authenticate subscribers, obtain IP address, and manage security crypto key exchange and key rotations
- Mobility management: Form IPSEC tunnels between itself and base stations to manage subscriber movement, handover, reauthorization, and deauthorization
- QOS: Service low authorization for subscribers
- Network discovery and selection: Place subscriber on appropriate VLAN, based largely on RADIUS profile and ASN setup

- **EMS Control/Management System**
- Manage Global WiMAX, CAPC, and base station settings, including individual sector frequencies, available VLANs, authentication realms, and some CPE devices
- Manage and update software on CAPC, base station, and some CPE devices
- Run reports and collect statistics on individual base stations, sectors, and subscribers

- **Base Station/DAP**
- WiMAX transmission point
- Air Link scheduler for uplink and downlink resource allocation
- Manage local traffic classification
- Local service flow manager

The actual implementation period for the NMU WiMAX project covered 12 months. The chart below describes the activities on a by-month basis.

Implementation Timeline
March 2009: Ordered five (5) Motorola* base stations, CAPC, EMS, and RF heads
April 2009: Finalized agreements for antenna placements and fiber use throughout city of Marquette and Marquette Township
May/June 2009: Primary locations prepared: Cohodas Bldg, Mt. Mesnard, Marquette Township Fire Station, Mountain Water Tank Ordered 3,000+ ThinkPad* notebook computers with Intel 5350 integrated WiMAX
July 2009: Installed WiMAX equipment and test base stations using 2–10MHz channels WiMAX went into full production mode throughout City of Marquette
August 2009: ThinkPad* notebook distributed to 3,000+ active WiMAX users on the network (distributed to students, faculty, and staff)
September 2009: Ordered three (3) additional Motorola* base stations and RF Heads Reorganized WiMAX network to make use of additional channel - G4 2596.00 MHz-2602.00 MHz
October 2009: Testing of WiMAX network and Motorola* CPE equipment with 3–10MHz channels Additional locations prepared: Learning Resource Center, Marquette Fire Station 2, NMU Golf Course
November 2009: Installed two (2) additional base stations: Learning Resource Center, Marquette Fire Station 2
December 2009/Jan 2010: Upgraded WiMAX network software
February 2010: Installed WiMAX equipment in Negaunee and test base stations using 3–10MHz channels WiMAX went into full production mode throughout City of Negaunee

- Establish IPSEC tunnels between itself and other handover available base stations and CAPC for subscriber management and handovers

- **RADIUS/AAA**
- Authenticate users and devices
- Authorizes network services
- Accounting

- **DHCP**
- Dynamically provides IP addresses to clients

Subscriber Equipment

A wide range of subscriber equipment is available for use in a WiMAX network, and advances in silicon solutions promise that the future will hold a continuing parade of new devices.

Laptop and netbook users are best served with internal WiMAX solutions. Intel provides a mini-PCI card that combines the functionality of 802.16 WiMAX and 802.11 WiFi on a single internal card. At the time of publication, Acer*, Lenovo*, Dell*, Fujitsu*, Samsung*, and Toshiba* are all offering WiMAX-enabled laptops or netbooks. NMU selected the Lenovo R400 as the preferred machine for each student.

For users without internal WiMAX, the preferred solution is a USB dongle. Several manufacturers currently provide USB dongles for the U.S. market.

For fixed WiMAX installations, WiMAX-WiFi routers are available, some of which allow an external antenna to be attached for increased range.

Mobile hotspots are another option. Typically, a USB modem is connected to a portable battery-powered WiFi router. These routers can provide Internet access to small groups on field trips, school buses, or other situations requiring mobile Internet access from non-WiMAX machines.

FIGURE 10. MOTOROLA * USB W100 WIMAX * DON GLE

ISP Considerations

When an educational institution signs up to provide WiMAX to students, faculty, and potentially city government, it must consider ISP functionality, including authentication, accounting, administration, and support.

Authentication

As the campus network is extended beyond the campus property, security issues grow, and multiple layers of security are essential. Radius servers provide much of this functionality. User names, passwords, Mac address validation, and VPNs must all be considered.

Accounting

Accounting may be minimal, or it may be complex if the institution is providing Internet access to many parties, and billing arrangements may be required.

Support

Schools typically have an existing support structure that can be enhanced to provide off-campus WiMAX support. But additional training, diagnostic tools, and new expectations will be required. Due to the nature of wireless signal propagation, there will be times when students have

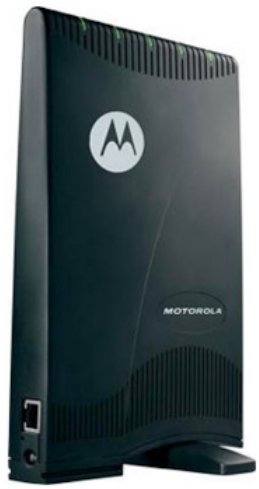

FIGURE 11. MOTOROLA * CPEI 150 CUSTOMER PREMISES EQUIPMENT

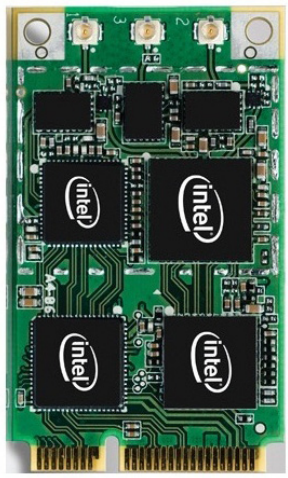

FIGURE 12. INTEL® 5350 WIMAX WIFI INTERNAL COMBO CARD

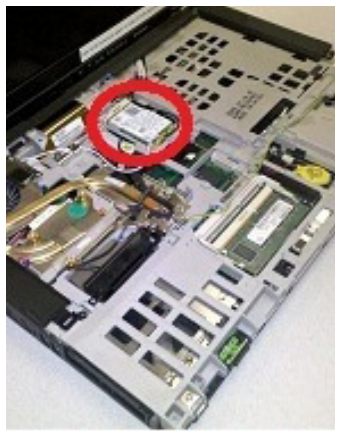

FIGURE 13. INSIDE A THINKPAD*. THE INTEL 5350 WIMAX-WIFI INTERNAL CARD IS HIGHLIGHTED

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no signal. WiMAX network support can be outsourced in whole or in part, based on the capacity of the institution.

In order to keep support costs down, a list of supported devices can be provided to end users, since it is difficult for institutions to support any and every device and operating system on the market.

The Future of Education

It is generally accepted that personalization is key to improved academic performance, and it is increasingly clear that full personalization cannot be realized until print media give way to digital media in the classroom and every other location where learning takes place, anytime/anywhere.

Wireless 4G broadband networks fill a critical need in education by enabling the full transition to digital media. Many schools will follow the path of NMU in the future.

"WiMAX has made it much easier to get work done when weather conditions do not allow students to get to campus. Also, I see this as a highlight to NMU. It really emphasizes the high-tech, high-touch atmosphere here."

– Jason Morgan
Senior and President
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