Evaluating IEEE 802.16 Broadband Wireless as a Communications Infrastructure for Public Safety Activities

J. Martin, J. Westall
Department of Computer Science
Clemson University
jim.martin/westall@cs.clemson.edu

Public safety wireless networks traditionally have been agency-owned land mobile radio (LMR) networks. However, recent advances in technology are giving agencies new and more powerful options. Current 3G public networks can provide broadband access sufficient to support voice, and, to some extent, video and data, but coverage and service is targeted toward business customers and not tailored to meet the needs of public safety. Furthermore, in emergency situations, voice and data services provided by public network providers are likely to be overloaded or damaged and thus unable to provide essential communications services to public safety agencies. In contrast, broadband wireless access systems such as 802.16 (also known as WiMAX) can provide a low-cost, wireless metropolitan area network (MAN) infrastructure with capabilities that equal or surpass those of 3G public wireless networks. WiMAX networks can be deployed for temporary or permanent use and can be much more easily isolated from large-scale failures in the electric power or telephone grids. In the proposed research, in partnership with local public safety agencies, we investigate the use of WiMAX in public safety operations.

This proposed project builds upon our current project in which we are exploring the suitability of WiMAX for public safety applications. We have become a member (observer status) of the WiMAX forum allowing us to make this important standards body better aware of the needs of public safety. We have surveyed available WiMAX equipment offerings and selected M/A-COM radios which operate in the uncongested 4.9 GHz band reserved for public safety operations. Our local campus police have applied for and been granted license to operate in this spectrum. We have recently completed a two day training session at M/A-COM and are expecting delivery of our first generation WiMAX equipment in the very near term. During the summer of 2007, working in collaboration with local police and fire departments, we will conduct field tests on the equipment. We will carefully document our field testing experiences and produce a 'best practices document' that will provide useful guidance on the deployment of WiMAX to the public safety community. We have developed simulation models of the DOCSIS MAC layer protocol and will use these models to advance the understanding and evolution of WiMAX protocols.

We now propose to extend the scope of the year 1 research objectives in the following ways:

- Extend the Clemson testbed to include true 802.16e mobile WiMAX devices
- Evaluate the performance of a core set of voice, video and data applications in mobile scenarios
- Focus on the particular problem of transporting large amounts of video data (e.g., video surveillance and in-car video)
- Extend our involvement with the WiMAX Forum lobbying for standards helpful to public safety

1. Introduction 3
2. Background 4
3. Summary of Year 1 Results 7
4. Research Goals and Objectives 8
5. Research design and methods 11
6. Review of relevant literature 14
7. Implications for policy and practice 15
8. Management plan and organization 16
9. Dissemination strategy 16
Appendix 1 References 18
Appendix 2 List of key personnel 20
Appendix 3 Project milestones and timeline 21
Appendix 4 Resumes of key personnel 22

1. Introduction

Public safety agencies are now augmenting their 900 MHz two-way voice radio networks with packet radio networks for obtaining data in the field. Several states have built dedicated wireless wide area networks to provide data and voice service that can be shared by all public service organizations in the state. For example, the South Carolina Department of Public Safety in conjunction with the Division of the South Carolina CIO operates the Palmetto 800 radio and mobile data system [PALM06]. Based on Motorola's dataTAC wireless data technology [dataTAC] and radioIP's Mobile TCP/IP Gateway products [RADIOIP], the Palmetto 800 provides voice and data connectivity over most of the state. Data rates up to 19 Kbps provide real-time access to data from the field. Nevertheless, in interviews with Clemson University police and fire department officials and with the City of Clemson police department officials, some significant limitations of the system have been identified: connectivity with the network is spotty; the mobile data terminals are expensive ($3000- $5000 each); and the low data rates are restrictive. In spite of these issues, the system has proven remarkably effective at allowing multiple organizations to interoperate during critical public safety operations.

Cellular-based broadband data services such as EV-DO and WCDMA can provide wide area coverage with peak data rates exceeding 2 Mbps [WIKI07]. However, neither the coverage area nor performance are under the control of public safety agencies. Future nation-wide broadband wide area networks have been proposed, several of which are likely to include WiMAX [CYREN07, FRONT07]. However these proposals require change to current 700MHz spectrum allocation as well as a tremendous upfront cost (billions of dollars). Consequently nation-wide broadband wireless dedicated to public safety will likely not have an impact in the next decade.

It is these reasons that motivate continued interest in the use of private WiMAX networks for public safety operations. The possible scope of such networks ranges from within a city block using a single base station to an entire city using a mesh of base stations. While 802.11 (including mesh) networks are available, their very limited range and weak quality-of-service mechanisms make them difficult to deploy in emergency situations and consequently less versatile than 802.16.

We propose to leverage and extend the work conducted during the first year of the project[1]. The primary focus of year 1 has been to work with local police and fire departments in the deployment and testing of a fixed base WiMAX network on Clemson's campus. In this proposal, we outline our plan to continue with the project. The focus for the second year will be on mobile WiMAX and on the challenging task of managing large amounts of video streams in the network.

2. Background

WiMAX, defined by the IEEE 802.16 standard, is an emerging broadband Internet access wireless technology [802.16A, EMSW02]. 802.16 emerged from a market requirement to provide fixed-point, broadband line-of-sight (LoS) wireless connectivity in remote areas. However, it was not until the emergence of 802.16a, adding non-line-of-sight (nLoS) capabilities, that the technology became a serious competitor to DSL and cable [802.16B]. The 802.16-2004 standard offers data rates up to 70 Mbps over a range of 20 miles and operates in the 2-11 GHz and 10-66 GHz ranges [802.16A]. In difficult terrains the data rate will drop to 30 Mbps, and the range can drop to 1-2 miles. Although 802.16-2004 is considered *fixed* broadband wireless

[1] Throughout this proposal, we will refer to the project performed in the 2006-2007 timeframe as the year 1 project.

access, it does allow nomadic movement within the area covered by a base station. The 802.16-2004 standard has been updated by the 802.16e standard [802.16C]. This latest standard supports unrestricted mobility where an endstation can seamlessly move between areas covered by different base stations.

802.16 supports two modes: the point-to-multipoint (PMP) mode and the mesh mode. In mesh mode, there are two further operating modes: centralized or distributed scheduling. With centralized scheduling, certain stations are elected as leaders and perform bandwidth allocations for all stations in the local cluster. With distributed scheduling, stations compete with each other for channel access. Our interest is in the more popular PMP mode where nodes are organized into a cell-like structure with base stations (BS) serving many subscriber stations (SS). Frequency division duplex (FDD) can be used so that the upstream channel uses a different frequency than the downstream channel. Or more conveniently, time division duplex (TDD) can be used so that the upstream and downstream transmissions share the same channel.

Frequency (MHz)	Channel Width (MHz)	Duplexing
3400-3600 (licensed)	3.5, 7.0	TDD, FDD
5725-5850 (unlicensed)	10.0	TDD

Table 1. Fixed WiMAX Initial Profiles

Frequency (MHz)(all licensed)	Channel Width (MHz)	Duplexing
2300-2400	5.0, 8.75, 10.0	TDD
2305-2320	5.0, 8.75, 10.0	TDD
2345-2360	5.0, 10.0	TDD
2496-2690	5.0, 10.0	TDD
3300-3400	5.0, 7.0, 10.0	TDD
3400-3800	5.0, 7.0, 10.0	TDD

Table 2. Mobile WiMAX Release-1 Profiles

Tables 1 and 2 illustrate the standard profiles for fixed and mobile WiMAX. Outside North America the 3.5 GHz bands are widely used. In the United States, only the unlicensed 5.8 GHz bands are available for small deployments. Fixed wireless is used primarily for backhaul functions and also for broadband wireless Internet access in areas that do not have DSL or Cable coverage. Several companies (including M/A-COM, Proxim, AirSpan) have released fixed WiMAX products that operate at 4.9 GHz. This spectrum has been reserved in the United States and Canada, and Japan for use by public safety. In the United States, any public safety organization is allowed to obtain a local license to operate 4.9 GHz radio equipment[2]. An important conclusion from the year 1 project is that 4.9 GHz is the best spectrum choice for

[2] The license does restrict maximum transmission power and dictates procedures that local agencies must follow so they do not interfere with adjoining agencies also using 4.9 GHz equipment.

small, locally controlled WiMAX deployments[3]. Table 2 shows that the industry has not defined a profile that operates in an unlicensed region. All vendors that have fixed WiMAX equipment that operate at 4.9 GHz have expressed an interest to support mobile WiMax in the future. An objective of this year 2 proposal is to lobby the WiMAX forum to make a 4.9 GHz profile available.

3. Summary of Year 1 Results

At the completion of year 1 of the project we will have accomplished the following:

- Established a collaboration with local police and fire departments as well as our University network infrastructure organization
- Deployed fixed WiMAX equipment from M/A-COM [MACOM07]
- Demonstrated voice and video to local agencies.
- Developed initial deployment guidelines
- Established a presence in the WiMAX forum

Based upon our year 1 efforts to date, we have learned the following :

- Fixed WiMAX has the potential to be a useful technology for an agency, particularly for transporting high-volume real-time data such as video from a disaster site.
- 4.9 GHz is currently the best choice in terms of frequency. However, price points are not particularly attractive because of the limited market. The hesitancy of the WiMAX

[3] 4.9 GHz is actually a difficult frequency for radio networks to operate at. Foliage is particularly troublesome for RF waves at this frequency. However the advantage is that it is licensed (and easy to obtain a license) and the spectrum is relatively unused.

Forum to define a standard WiMAX profile for 4.9 GHz is one barrier to expanding the market.

- While video is a potentially the 'killer application', a small number of video flows can consume all bandwidth available on a channel. Intelligent systems are required in deployments involving video that uses analytics to control transmission parameters of the video. These systems are generally over-provisioned and risk massive network congestion when a large-scale event occurs causing many video cameras to transmit.
- The M/A-COM equipment, like other first generation WiMAX gear, has somewhat primitive network configuration and management support. This could be a particular problem to public safety where the majority of agencies do not have extensive experience in managing data networks. Nevertheless, our `best practices' document should be a valuable tool in addressing this issue.

4. Research Goals and Objectives

The fundamental research question

The fundamental research questions that we propose to address arise directly from the issues identified in the year 1 project. First, the year 1 project used first generation 4.9 GHz non-mobile WiMAX equipment because this is all that was available. In the first quarter of the year 2008 we expect mobile WiMAX 4.9 GHz equipment to become available. We propose to explore mobile WiMAX using a similar set of applications that we used from year 1 (data, telephony and video). Second, we plan to address the open issue how to manage a public safety network that has many video devices attached when a large-scale event occurs that overloads the

WiMAX network. Finally, while not a research question but rather a supportive component to this project, we plan to increase our involvement with the WiMAX forum.

Research objectives

We will expand the year 1 study to address mobile WiMAX. The specific research objectives to be addressed include the following:

- *Mobile application performance*: Using a combination of analytic, simulation, and live measurement techniques, we will explore the performance of a set of core applications in a mobile scenario. Figure 1 illustrates the problem description. As a vehicle that is equipped with an 802.16e subscriber station moves from one base station to a second, there will be a period of time during which performance drops to the point where there is a 'dead time' and then performance improves. While the detailed characteristics of this behavior will be highly dependent on the terrain, vehicle speeds, and specific equipment, we will obtain data that can provide a baseline for others to compare with. Of particular concern is the impact of handovers on performance sensitive applications such as VoIP and streaming video.

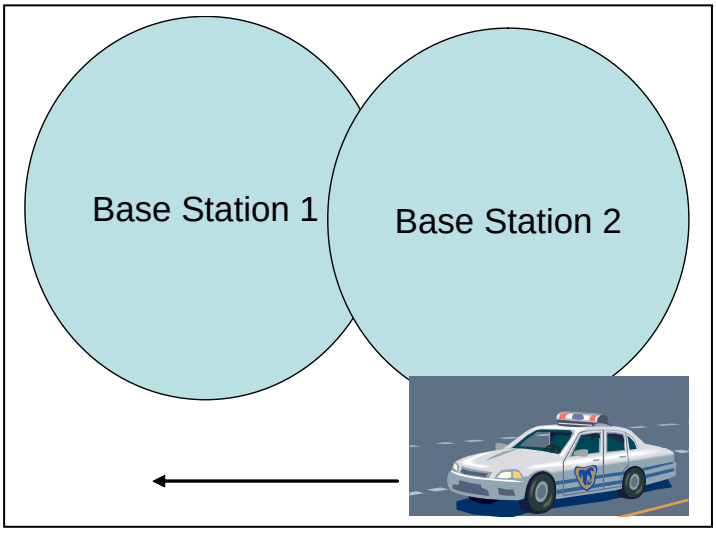


Figure 1. Mobile WiMAX Scenario

• *Video Management:* The broadband wireless Internet access community is developing Internet Mulitmedia Services/Subsystems (IMS). Targeted for large wireless networks, IMS systems manage resources and services ranging from billing, customer service, to performance. One component of an IMS system is to provision network QoS to support applications such as video streams. IMS systems are typically large and costly. In the year 2 proposal, we assume small, low cost agency operated WiMAX networks which are likely to not need an IMS. However, we envision that even small networks will be required to transport potentially a large number of video streams. Figure 2 illustrates an example scenario. There are three sets of video devices. One set consists of fixed video surveillance cameras. A second set consists of cameras mounted in police cars. And a third set is a collection of 802.11e IP surveillance cameras that require WiMAX for backhaul to the command and control center. Advanced surveillance cameras can now perform analytics at the camera (or in an edge device) and can be instructed to transmit or change frame rates when motion is detected or a specific event occurs. High end cameras, such those provided by IndigoVision, support a capped bit-rate (CBR) function where the device can be programmed to not exceed a certain data rate[4]. A large-scale disaster event is likely to cause a large number of video devices to start broadcasting. It takes only a few high bandwidth video streams and a handful of low bandwidth video streams to consume all bandwidth. Some level of distributed control is required.

[4] We have invited IndigoVision to collaborate on our project. They have expressed an interest but the details of the collaboration still need to be worked out. An example IP camera is described at http://www.indigovision.com/products_fixedcam.php

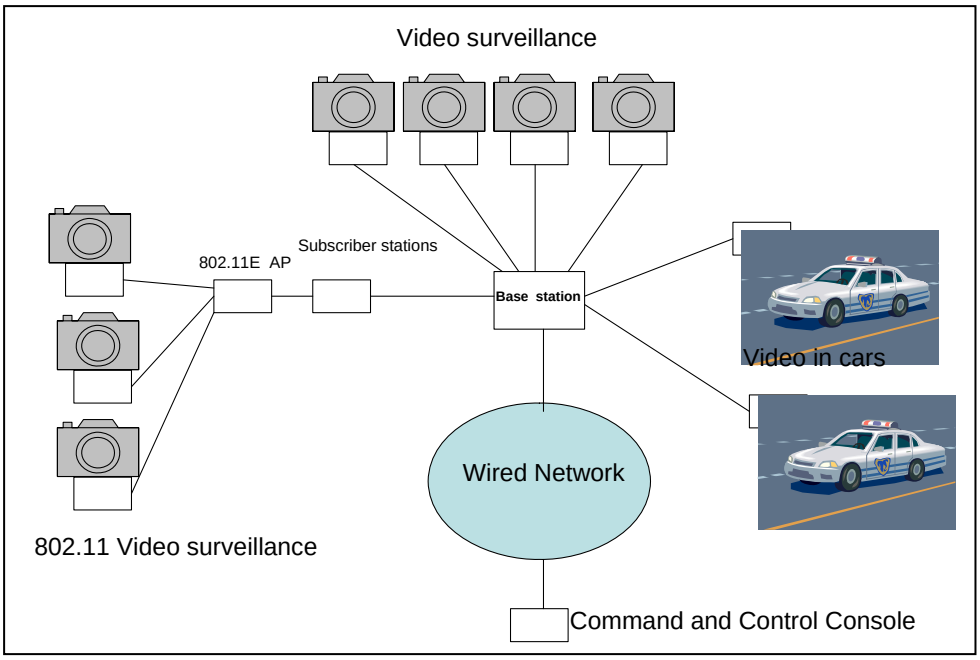


Figure 2. Video WiMAX Scenario

5. Research design and methods

We have identified five tasks that collectively achieve the research objectives. Refer to Appendix 3 for the project timeline.

Task 1: The first task is to design and deploy a mobile WiMAX testbed. Figure 3 illustrates the proposed network. The satellite image shows Clemson University and the town of Clemson. The figure on the right presents a simplified picture. The squares are the local agency locations. The rectangles are the base stations. We obtained and deployed BS1 in year 1. We propose to acquire two 802.16e base stations (that operate at 4.9 GHz). We identify these as BS2 and BS3 in the figure. We will deploy BS2 next to the existing BS1. Using directional antennas, we will have BS1 serve the south area of campus (the athletic fields and farms). BS2 and BS3 will serve mobile stations located in the main campus and in the town of Clemson.

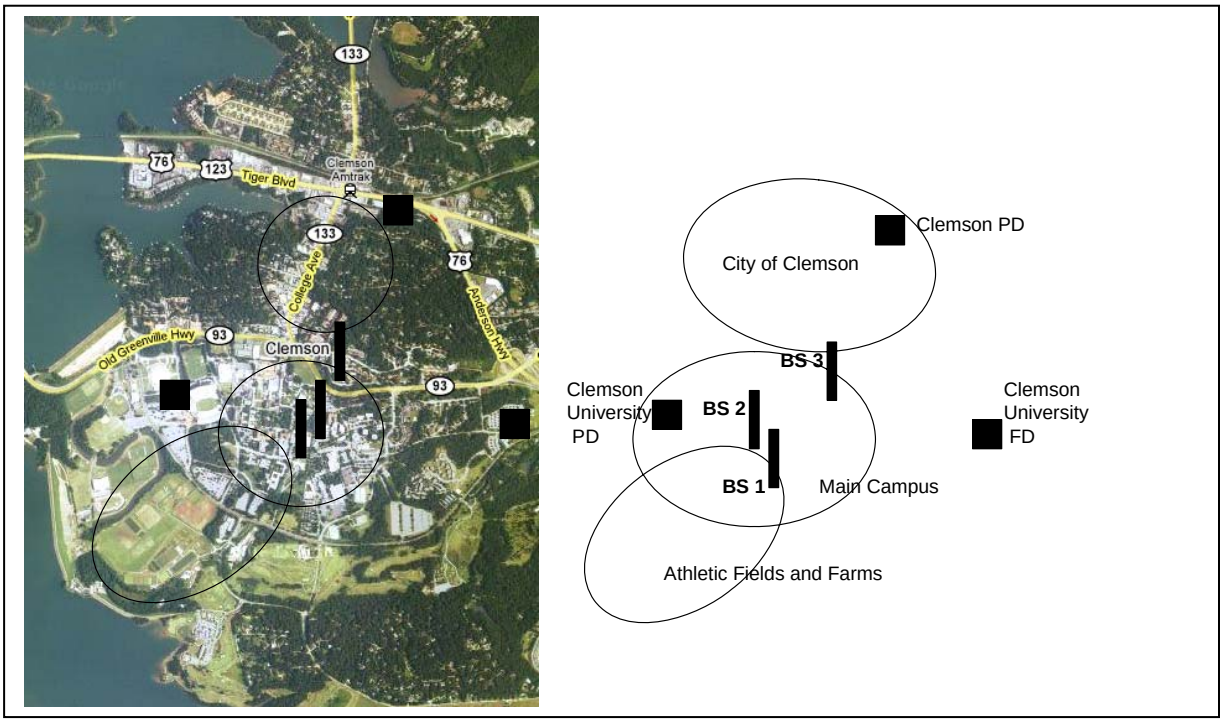


Figure 3. Mobile Testbed

Task 2: When the testbed has been verified to be operating correctly, we will deploy a set of applications identified by local public safety organizations. We anticipate the applications will include VoIP and streaming video. The main objective is to explore the impact of distance, terrain, vehicle speeds, and roaming on application level performance. The testbed provides very diverse paths allowing us to obtain a wide range of empirical results.

Task 3: We will approximate the scenario depicted in Figure 2 by deploying on campus several IndigoVision surveillance cameras, several web cameras under our control, and several in-car video cameras. The IndigoVision cameras will be operating in a number of modes supported by video analytic software (congestion detection, motion detection, etc.). The local Clemson

agencies will provide input on realistic settings. We will setup a command and control center that can view and manage the video streams. To simulate a large-scale event we will force all video devices to transmit data. Working with local agencies, we will correlate the observed network measurables to a quantification of impact to public safety. We will then develop and evaluate methods to handle a surge of data from video devices. We anticipate developing a controller that monitors the state of the network, determines when a large-scale event occurs, and adapts the video traffic based on performance and pre-configured behaviors. The IndigoVision cameras allow us to control all aspects of the video stream in real-time, including the frame rate, compression parameters, and the peak transmission rate. The problem becomes more complex when mobility is involved. For example, when a patrol car that is sending or receiving a video stream moves from one base station to another, the quality of all active video streams being viewed will be impacted. The objective of this task is to explore distributed methods that intelligently manage public safety applications in WiMAX networks. A novel aspect of the proposed work is the coupling between the control decision with an assessment of how application performance is impacting the ability of public safety officials to manage the event.

Task 4: The WiMAX Forum controls the current deployment of WiMAX. Although the IEEE developed the protocol, the 802.16 standards group has moved on to develop the next generation WiMAX (i.e., 802.16m). Unfortunately, because of the relatively limited size of the public safety market, the WiMAX Forum largely ignores public safety requirements. We are members of the WiMAX Forum, although we are considered an 'observer' and do not have voting rights. We collaborate with the Application Working Group (AWG) on simulation technology for WiMAX. We have given three talks to the working group, one of which has been specifically on

the needs of public safety. An important objective of the year 2 project is to expand our efforts at the Forum on behalf of public safety. Two immediate areas to be addressed are the lack of a 4.9 GHz profile and a general lack of awareness of the needs of public safety. In addition to participating in Forum meetings, we plan on developing and presenting a white paper to the WiMAX Forum that conveys the application requirements of public safety in a WiMAX network.

Task 5: The final task will be to effectively disseminate the results and knowledge obtained from the project. We will rely on several methods. First, we will extend the 'best practices' book developed in the year 1 project. Second, we will present our project at several public safety technology conferences. Third, we will make our material (including software test tools) available on a University web site. This site will be designed to be a helpful source of information available to agencies on the use of WiMAX.

6. Review of relevant literature

Wireless technology is considered crucial for the public safety sector. The NIJ has published information to provide guidance to organizations on wireless technology [IMHA03]. The Department of Homeland Security has published a statement of requirements for public safety communications and interoperability [SAFECOM04]. This document provides performance guidelines for public safety applications that include operation over wireless networks. We will make use of the guidelines in our analysis.

The proposed project is unique as 802.16 is an emerging technology and there are no published measurement studies of deployed systems. There are several academic studies that are relevant. Preliminary simulation studies have focused on the physical layer [GOSH05,RAMA04]. Further studies have looked at routing issues in 802.16 mesh networks [CMZW05,WGIH05]. However these studies do not provide specific performance data points that we can use to validate our results.

The MAC layer protocol used in WiMAX is based on the MAC layer protocol used in modern Cable networks (referred to as DOCSIS). We have spent the last several years studying DOCSIS through a combination of analytic, simulation and live network analysis [MART05, MART06, MART07]. While comparing results from a cable network directly to a WiMAX network is not appropriate, the prior work has given the authors a deep understanding of the MAC layer used in WiMAX.

7. Implications for policy and practice

While it is too early to know how successful 802.16 will be the market place, the technology holds considerable promise for providing a unified communications infrastructure for public service and public safety organizations. This infrastructure can, in theory, deliver voice, video, and data in both point-to-point or multicast modes using secure, high-speed, digital channels, free of interoperability issues and at a lesser cost than today's systems. Now that there are several WiMAX chipsets, the availability, cost, and form factors associated with WiMAX devices will make the technology even more compelling for public service activities.

Our project couples open research questions with an evaluation of communications systems that are likely to be deployed by government agencies. The results of the proposed project will help government officials make better-informed technology decisions. To facilitate this outreach in South Carolina, we will leverage our relationship the South Carolina Research Authority who operate the National Law Enforcement and Corrections Technology Center Southeast (NLECTC-SE). We will continue to work closely with industry, especially our technology vendors such as M/A-COM and IndigoVision. We will continue to work with our local agencies, and solicit involvement from additional agencies within South Carolina.

8. Management plan and organization

The project will be managed by PI Martin. CoPI Westall will assist in all phases of the project. We anticipate having one undergraduate assistant student on the project. Appendix 3 identifies the duration of work items associated with the project tasks.

9. Dissemination strategy

We plan on disseminating our work in both academic and industry oriented conferences. Academic conferences that are appropriate for this work include IEEE Broadnets and Globecom[5]. In the past we have presented our DOCSIS performance research to the cable industry's premier

[5]The IEEE Broadnets conference web site is at http://www.broadnets.org/2007/ and the Globecom web site is at http://www.ieee-globecom.org/2007/

trade show, the National Show[6]. In the same spirit, we will volunteer for speaking engagements at 802.16 industry forums such as at conferences sponsored by the WiMAX forum. To reach government technologists, we will present our work at appropriate government technology related conferences[7]. All software and planning and management tools that we developed will be made available via a project web site that we will maintain.

[6] J. Martin, "DOCSIS Performance Issues", National Cable and Telecommunications Association, The National Show, April 2005

[7] There are various government technology conferences to target as identified: http://www.govtech.net/events/

Appendix 1 References

[802.16A] IEEE 802.16-2004, IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems, 7/2004.

[802.16B] IEEE 802.16a-2003, IEEE Standard for Local and Metropolitan Area Networks Part 16a: Air Interface for Fixed Broadband Wireless Access Systems, Amendment 2: MAC Modifications and Additional PHY layer Specifications for 2-11Ghz, April 2003.

[802.16C] IEEE 802.16e-2005, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, Dec 2006.

[CMZW05] M. Cao, W. Ma, Q. Zhang, X. Wang, W. Zhu, "Modeling and Performance Analysis of the Distributed Scheduler in IEEE 802.16 Mesh Mode", MobiHoc 2005, 2005.

[CYREN07] M. O'Brien, Cyren Call, http://www.cyrencall.com/

[DataTEC] Motorola's DATATAC system. http://www.motorola.com

[EMSW02] C. Eklund, R. Marks, K. Stanwood, S. Wang, "IEEE Standard 802.16: A Technical Overview of the WirelessMAN Air Interface for Broadband Wireless Access", IEEE Communications Magazine, June 2002.

[FRONT07] S. Newman, Frontline Wireless, http://www.frontlinewireless.com/

[GOSH05] A. Ghosh, D. Wolter, J. Andrews, R. Chen, "Broadband Wireless Access with WiMax/802.16: Current Performance Benchmarks and Future Potential", IEEE Communications Magazine, Feb 2005, pp. 129-136.

[IMHA03] K. Imel, J. Hart, "Understanding Wireless Communications in Public Safety", National Law Enforcement and Corrections Technology Center, Second edition, Jan 2003. Available at http://www.nlectc.org/pdffiles/wireless2003.pdf

[MART05] J. Martin, "The Impact of the DOCSIS 1.1/2.0 MAC Protocol on TCP", Proceedings of the IEEE Consumer Communications and Networking Conference, (Las Vegas, NV, Jan 2005).

[MART06] J. Martin, M. Westall, "Validating an 'ns' Simulation Model of the DOCSIS Protocol", Proceedings of the 2006 International Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTS'06), (Calguary, CA, July 2006), pp. 297-304.

[MART07] J. Martin, M. Westall, "A Simulation Model of the DOCSIS Protocol", to appear in Simulation: Transactions of the Society for Modeling and Simulation International, July 2007.

[PALM06] The 800 MHz Palmetto radio and mobile data system. http://www.cio.sc.gov/cioContent.asp?pageID=756&menuID=411

[RADIOIP] Radio IP Software Inc., http://www.radio-ip.com
http://www.radio-ip.com/about-radio-ip.php

[RAMA04] S. Ramachandran, C. Bostian, S. Midkiff, "Performance Evaluation of IEEE 802.16 for Broadband Wireless Access", Opnetwork Conference, 2002.

[WIKI07] Wikipedia definition of EDVO and WCDMA, http://en.wikipedia.org/wiki/Evolution-Data_Optimized

[WIMAX] The WiMAX forum, http://www.wimaxforum.org/home

[WGIH05] H. Wei, S. Granguly, R. Izmailov, Z. Haas, "Interference-aware IEEE 802.16 WiMAX Mesh Networks", IEEE Vehicular Technology Conference, May 2005.

Appendix 2 List of key personnel

PI: Dr James J. Martin

Assistant Professor
Department of Computer Science
Clemson University
Clemson, SC 29634

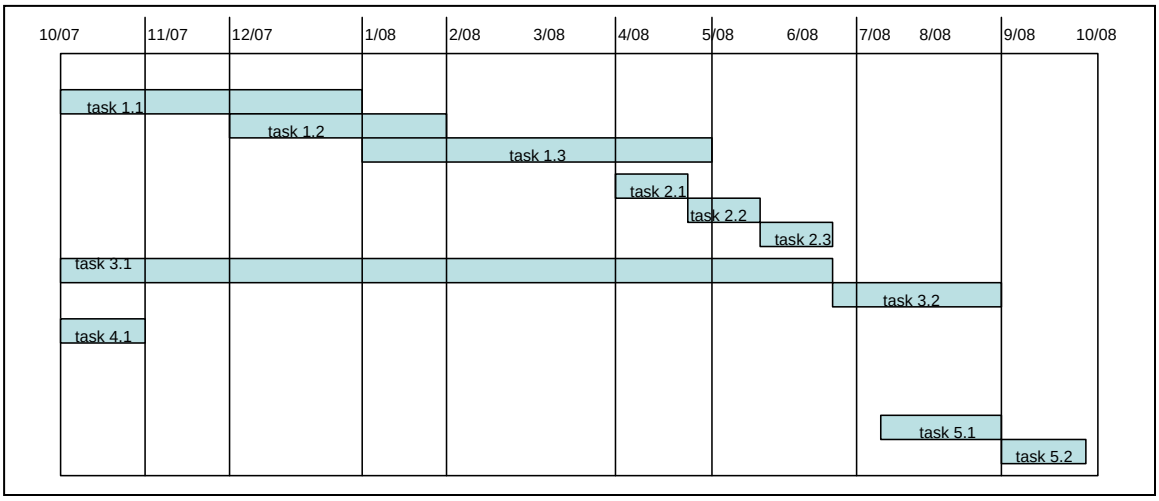
Phone: 864/656-4529
Email: jim.martin@cs.clemson.edu

CoPI: Dr. James Westall

Professor
Department of Computer Science
Clemson University
Clemson SC 29434-1906

Phone: 864/656-6868
Email : westall@cs.clemson.edu

Appendix 3 Project milestones and timeline



Task 1 - Design and deploy the testbed upgrade
1.1 select equipment
1.2 design network
1.3 deploy and test network

Task 2 – Application analysis
2.1 VoIP
2.2 video streaming
2.3 other select applications for trial use by Clemson fire and police

Task 3 –Video stream management
3.1 build high load video scenario
3.2 develop and validate distributed control capability

Task 4 - WiMAX Forum participation
4.1 – contribute a white paper on public safety application requirements
4.2 - attend meetings (throughout the year)

Task 5 - Dissemination
5.1 – update the 'best practices' guide
5.2 - update project web site
5.3 - public safety technology conferences (throughout the year)

Appendix 4 Resumes of key personnel