North Carolina Center for Automotive Research, Inc.

Project Final Report

Department of Energy Award Number: DE-EE0001176

Project Title: Advanced Electrical, Optical and Data Communication Infrastructure Development.

Project Period: October 1, 2009 to April 30, 2011

Principal Investigator: Simon Cobb

June 20th, 2011

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North Carolina Center for Automotive Research, Inc.

EXECUTIVE SUMMARY

The implementation of electrical and IT infrastructure systems at the North Carolina Center for Automotive Research , Inc. (NCCAR) has achieved several key objectives in terms of system functionality, operational safety and potential for ongoing research and development.

Key conclusions include:

- The proven ability to operate a high speed wireless data network over a large 155 acre area
- Node to node wireless transfers from access points are possible at speeds of more than 50 mph whilst maintaining high volume bandwidth
- Triangulation of electronic devices / users is possible in areas with overlapping multiple access points. Outdoor areas with reduced overlap of access point coverage considerably reduces triangulation accuracy.
- Wireless networks can be adversely affected by tree foliage. Pine needles are a particular challenge due to the needle length relative to the transmission frequency/wavelength
- Future research will use the project video surveillance and wireless systems to further develop automated image tracking functionality for the benefit of advanced vehicle safety monitoring and autonomous vehicle control through “vehicle-to-vehicle” and “vehicle-to-infrastructure” communications.

A specific advantage realized from this IT implementation at NCCAR is that NC State University is implementing a similar wireless network across Centennial Campus, Raleigh, NC in 2011 and has benefitted from lessons learned during this project. Consequently, students, researchers and members of the public will be able to benefit from a large scale IT implementation with features and improvements derived from this NCCAR project.

PROJECT GOALS & OBJECTIVES

This project award is to facilitate an advanced electrical, communications, information technology and video surveillance infrastructure required for a modern and safe vehicle research and development center.

Key initial objectives and any variances are detailed below:

- Electrical supply into this new “green field” site, including modifications to existing transmission lines that traverse the site and building efficiency monitoring
- High speed data connectivity to facilitate client activities and research into data streaming efficiency.
- Video and audio monitoring of the vehicle areas to allow safety monitoring and future research on vehicle path prediction

- Advanced wireless encrypted telecommunications system within the buildings to allow efficient and secure communication between visiting and resident clients and their "home bases".
- Multi-channel secure site wide Wi-Fi or cellular based communications/data transmissions capability for improved development efficiency and future research into vehicle position detection, path prediction/autonomous control and inter-vehicle data sharing.
- IT and communications systems integration and optimization.
- Evaluate enhanced energy efficiency and optimization related to both building power usage efficiency and vehicle traffic flow optimization through monitoring and data sharing.

This project has achieved the majority of initial objectives as listed above. However, the following changes to program scope have been made:

1. Building efficiency monitoring is not included due to the complexity of separate electrical systems for utilities and IT systems and multiple locations on site at NCCAR.
2. Video cameras locations were changed from the original plan of three cameras each mounted on two poles. Instead, each of the six cameras is mounted on individual poles for improved coverage.
3. A multi-node Wi-Fi wireless system was implemented rather than single location WiMax system. This change allows greater system functionality and no licensing fee (WiMax uses a single long range transmission and receiver system and incurs a usage charge).

ACCOMPLISHMENTS BY TASK

Task 1.0 Electrical Power Supply – Extended to Include Additional Outdoor Supplies

The electrical supply power to the sixth test track poles was installed and commissioned in early October 2010.

The initial intention and plan was to have all electrical supply services entering into the NCCAR campus beneath ground. Timing pressures and logistical issues caused by the delays to construction of the access road and the consequential delays to a beneath ground routing along the access road shoulders, this direction was changed to an over-ground service feed running parallel to the existing high tension lines that run across the NCCAR campus. Once on site, then the supply reverts to beneath ground for distribution around the site facilities. Dominion Power pulled the electrical supply from the feed to the adjacent Lowes Regional Distribution Center.

The above ground installation included the setting of eight wooden poles supporting aluminium wire up to the frontage of the Operations Building (see Figures 1, 2 & 3).

Figure 1: Dominion Power Installation Parallel to Existing Main Power Lines

Figure 2: Above Ground Power Supply Line

Figure 3: Power Transition from Above Ground to Sub-Soil

Cables then transition to beneath ground routing to the main transformer at edge of the parking at rear of the building (see figures 4, 5 & 6).

Figure 4: Power Termination at Transformer Location

Figure 5: Transformer Base Plate Installation at Operations Building

Figure 6: Transformer Installation

Power lines enter the rear of the building and into the electrical control room (see Figure 7 below).

Figure 7: Electrical Supply into Rear of Operations Building

Connection to the Security Kiosk and Operations & Engineering Building was completed and service initiated on November 12, 2009. Supply specifications are 200Amp single phase 120/208V for the Security Kiosk and 3,000Amp 3 phase 120/208V for the Operations and Engineering Building. Both buildings are subject to 2003 IECC Envelope Compliance Certificates achieved using COMcheck version 3.4.2.

Figure 8: Electrical Supply & Telecoms into Rear of Operations Building

In addition to electrical supplies to the two buildings, NCCAR also has power feeds to the paddock for electric vehicle re-charging and RV hook-ups, and also the track area for camera and access point feeds. Figures 9 through 15 detail the installation sequence.

Figure 9: Paddock Area Awaiting Electrical Outlets (red) & Transformer Locations (yellow)

Figures 10: Paddock Area Electrical Outlets Installed (31 in total)

Figure 11: Pole Installation at Paddock

Figure 12: Power Transformer Installation at Paddock

Figures 13: Installation of Transformer at Track Location

Figure 14: Innerduct Trenches Leading to Poles

Figure 15: Transformer installation Complete (plus MDP for poles & future building)

Figure 16: Transformer Connection to Incoming Supply (sub grade)

IT System Specification Process

An initial draft IT system specification was produced and issued in May 2008 to several local IT suppliers (ATCOM/WorkSmart, Strategic Connections, Burroughs, Embarq) for feedback / refinement and then “ballpark” costing purposes. Early feedback and discussions indicated that none of the selected suppliers could provide a complete solution. Furthermore, high level IT skills and experience were clearly required to ensure an appropriate system was specified and procured.

During a meeting with the NC State University Vice Chancellor of Research in 2009, it was recommended that NCCAR contract the services of Next Services (ITng) of NC State University. This group has considerable IT system design, procurement, integration and upgrade experience, including the Wi-Fi mesh network at Centennial Campus and many high schools in rural North Carolina. NCCAR contracted with Next Services in June 2009 to provide technical design and guidance for this project.

Cisco Systems were recommended as the best suited supplier capable of providing an integrated system to meet NCCAR requirements. Furthermore, it was recommended to approach Cisco through their senior engineering division rather than the conventional sales process.

In August 2009, Next Services and Cisco mapped out and specified an IT infrastructure that would provide the required services for NCCAR with an integrated capability of cross linking data and key events such as video archive linked to captured data etc. The basic content is detailed below and illustrated in Figure 17:

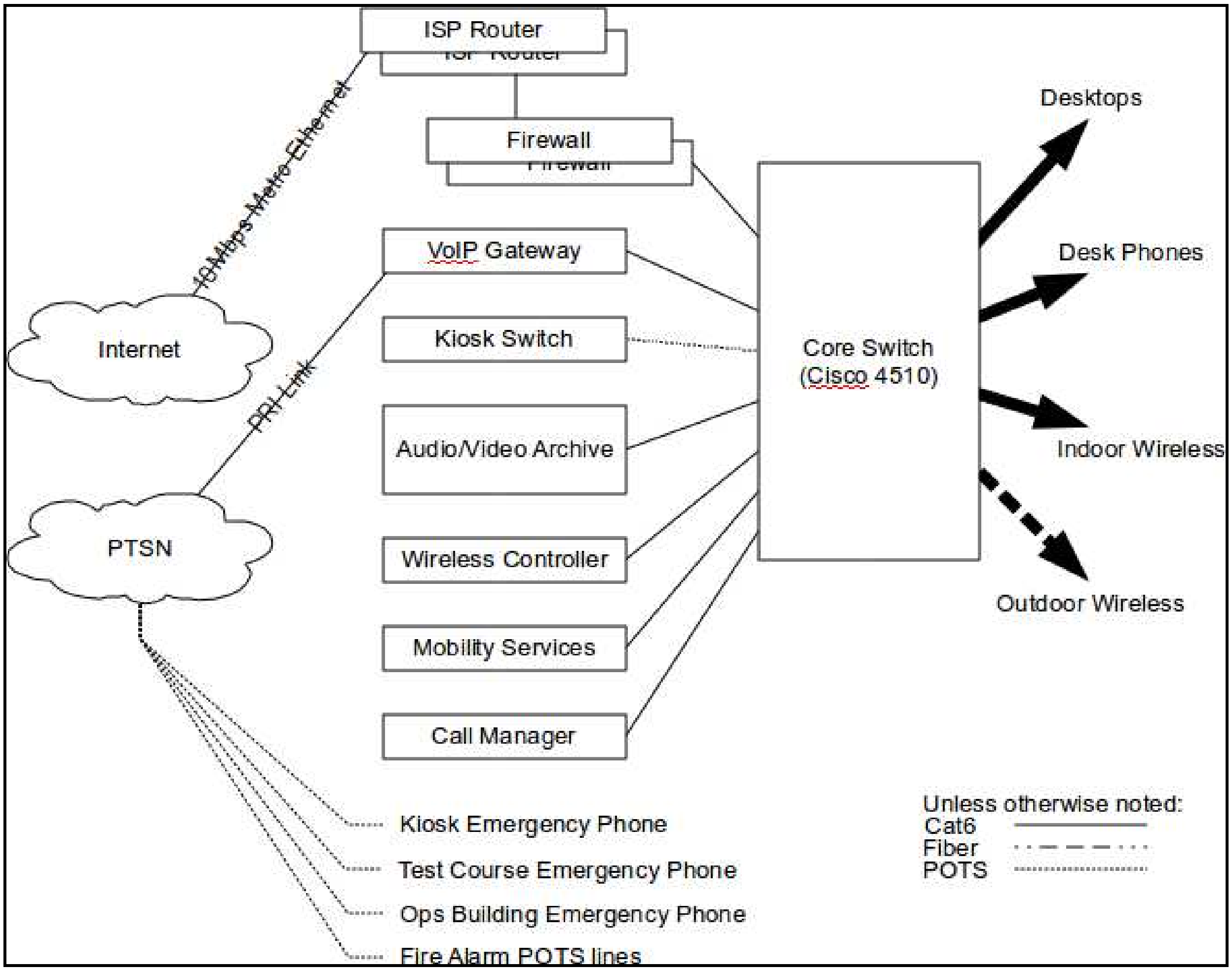

Figure 17: NCCAR IT System Schematic

Technologies

- **Controller based Wireless / Mesh Wireless** - Required site survey to properly scope and design both interior building and full track coverage. Ability to scale to high speed wireless communication and track assets, etc. via RFID.
- **Physical Security / Card Access** – Including full site exterior, interior, and security kiosk. Required site survey to scope and design coverage model
- **Core Network Infrastructure** – Capable of providing high availability while securely carrying voice, video, and data for NCCAR and their individual clients.
- **Voice** – Provide a secure unified communications platform that allows for the integration of video communications and video surveillance on an IP platform.
- **Expertise and Resources** to provide professional services for delivery, implementation, and support of all above technologies.

System Integrator Selection

NCCAR and John Bass interviewed and selected primary technology vendors / integrators capable of supplying and implementing all aspects of the NCCAR technology plan through the following steps:

- **Interview and Early Bid Process to Select a Qualified Systems Integrator**
  To determine the qualifications of prospective Cisco approved and recommended installation partner vendors, each submitted a detailed and written overview of their qualifications that met all requirements as specified by NCCAR and Next Services, outlined in the section marked "scope of project". Each vendor was given the opportunity for a formal presentation to showcase their resources, certifications, and experience. Each was required to submit a list of references that also fit the scope of project.

  Based on these presentations and references, NCCAR (with the help of Next Services) selected Internetwork Engineering (IE) as their primary technology advisor, integrator and supplier.

- **Decision Criteria:**
  Cisco is uniquely qualified to address all technologies and architectures required to meet the scope, timelines, and resources needed by NCCAR. All purchases of Cisco equipment and services would be procured through IE, a **Cisco Gold Partner** that holds advanced specializations in every technology and scope. Cisco is a key business partner to the success of NCCAR and is uniquely positioned to provide all required technologies over a single IP platform. This simplifies management and lowers total cost of ownership with a need for fewer on-site resources.

- **Technology planning and design** - initiated from the ground up by this team lead by Internetwork Engineering. The strategy was developed through a series of WebEx conference calls, planning sessions at Next Services on the NC State Campus, and a site visit to the NCCAR facility on December 1, 2009. Site routing layout for the IT infrastructure was led by Next Services and IE and subsequently outsourced to Tricom of Raleigh for fine detail design and implementation. The full sequence of team and supplier selection is detailed in Figure 18 below.

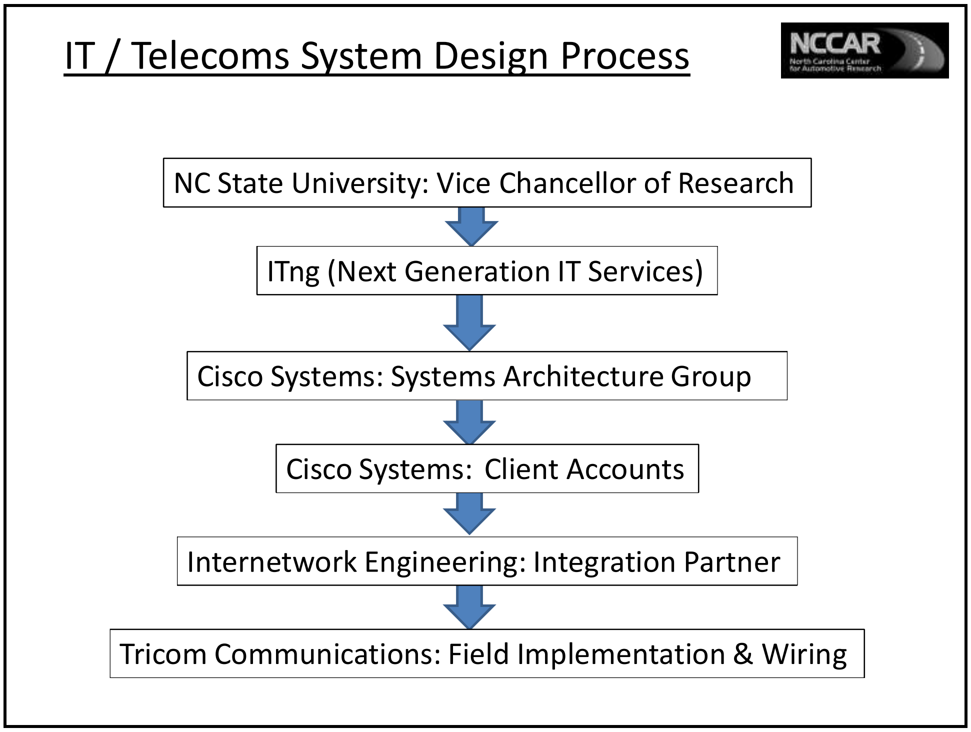

Figure 18: IT Design Specification Process

Precise cable / fiber routing and count have yet to be defined, but will be trenched adjacent to access roads and under the road course through pre-installed conduit sections.

Task 2.0 ISP High Speed Data Connectivity

Next Services advised that the best approach to implementing ISP connectivity (Ethernet transport service) for the NCCAR non-profit would be through MCNC, rather than contracting directly with Century Link (previously known as Embarq). MCNC is a non-profit organization committed to delivering technology services through the North Carolina Research and Education Network (NCREN).

MCNC owns and operates the North Carolina Research and Education Network (NCREN), a state-wide broadband network. The fiber-optic infrastructure provides internet, video, data and computing network services to North Carolina's K20 community and to many of the state's medical and research institutions.

The NCREN services and network configurations are designed to provide the community with the following attributes:

- All traffic destined for community members stays within the community,
- Very High Speed gateway internet access from multiple tier 1 backbone ISP's,
- 24 x 7 network support via experienced NCREN NOC staff,
- Continuous performance monitoring and fine tuning for optimum efficiency.

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Additional advantages are that MCNC can obtain improved commercial rates for ISP services from Century Link by virtue of its scale of purchasing. Expected uptime will be a monthly average of 99.5% (relative to a 24/7 reference).

ISP fiber runs approximately 1.5 miles from the western side of I95 (through existing conduits) and then along the shoulders of Lowes Boulevard and Technology Drive (see yellow path marked on the attached aerial view in Figure 19 below). Actual on-site data rate will be 10 Mbps, but system capability is scalable up to 50Mbps.

Figure 19: ISP Fiber Routing into NCCAR Campus (from I95 exit 176)

ISP service implementation started in December 2009. Fiber trenching / laying into the NCCAR site was completed on March 12th, 2010 – see Figures 20, 21 & 22 below:

Figure 20: Century Link Trenching Along Lowes Boulevard Towards NCCAR Site

Figure 21: ISP Fiber Markers at Head of NCCAR Access Road

Figure 22: ISP Service Installed on NCCAR Site, March 12, 2010

Figure 23: Site Fiber Awaiting On-Site Trenching

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Internal building preparation for wired ISP provision continued as shown in Figures 24 through 31 below in late March 2010.

Figure 24: ISP Wall Rack in IT Room (Operations Building)

Figure 25: Tricom Installing Cable Runs in Operations Building

Figure 26: Cable Pulls Enter IT Room

Figure 27: IT Room Overhead Cable Ladder Tray Installation

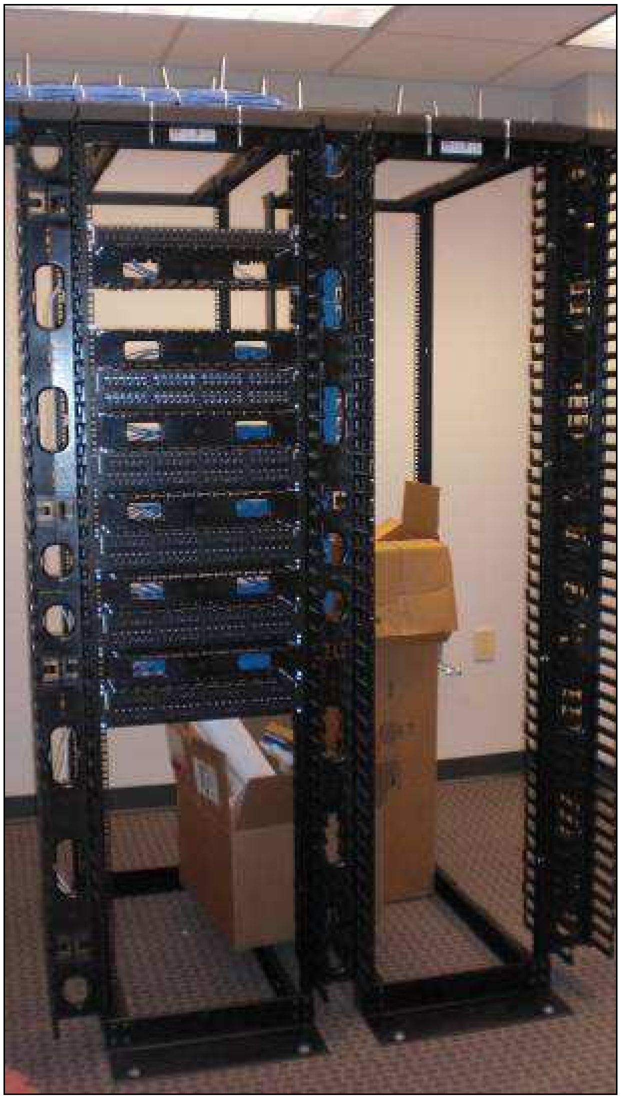

Figure 28: IT Racking System in IT Room

Figure 29: Cables Installed on Reverse Side of Racks

Figure 30: Cable Terminations in Offices

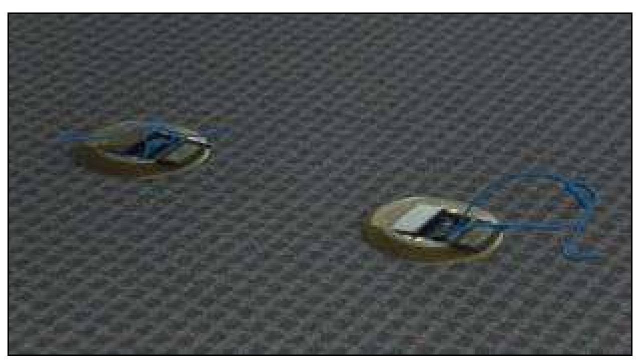

Figure 31: Floor Mounted Terminations in Conference Room 2

Task 3.0 Video and Audio Monitoring (VSOM / VSMS)

Video camera installations are completed and fully functional at the six pole locations around the NCCAR site. Five are located around the road course, whilst the sixth covers the paddock, building and entrance gate. Figure 32 below shows type of Panasonic Pan-Tilt-Zoom (PTZ) cameras specified. A further three static cameras monitor the entrance gate area and the lobby of the operations building. All six PTZ cameras can be manipulated via the VSOM software installed on the custom-built desktop PC. There is also a facility via Cisco VSOM and VPN link to view and operate the cameras from any location outside the NCCAR facility. All nine video streams are stored in a fourteen day rolling loop archive for the purpose of liability protection, safety and customer needs.

Figure 32: Panasonic WVNW964 Pan-Tilt-Zoom (x30) Video Camera

The overall site layout for the poles and the fiber / copper runs is shown in Figure 33 below. It is designed as a hub and star configuration with the operations building as the hub (it is the hub for incoming electrical power, ISP fiber and telephone). The Security Kiosk and the track are stars running from the hub, with future facilities becoming future star locations. Redundancy has been built into both fiber counts and copper capacity for future development.

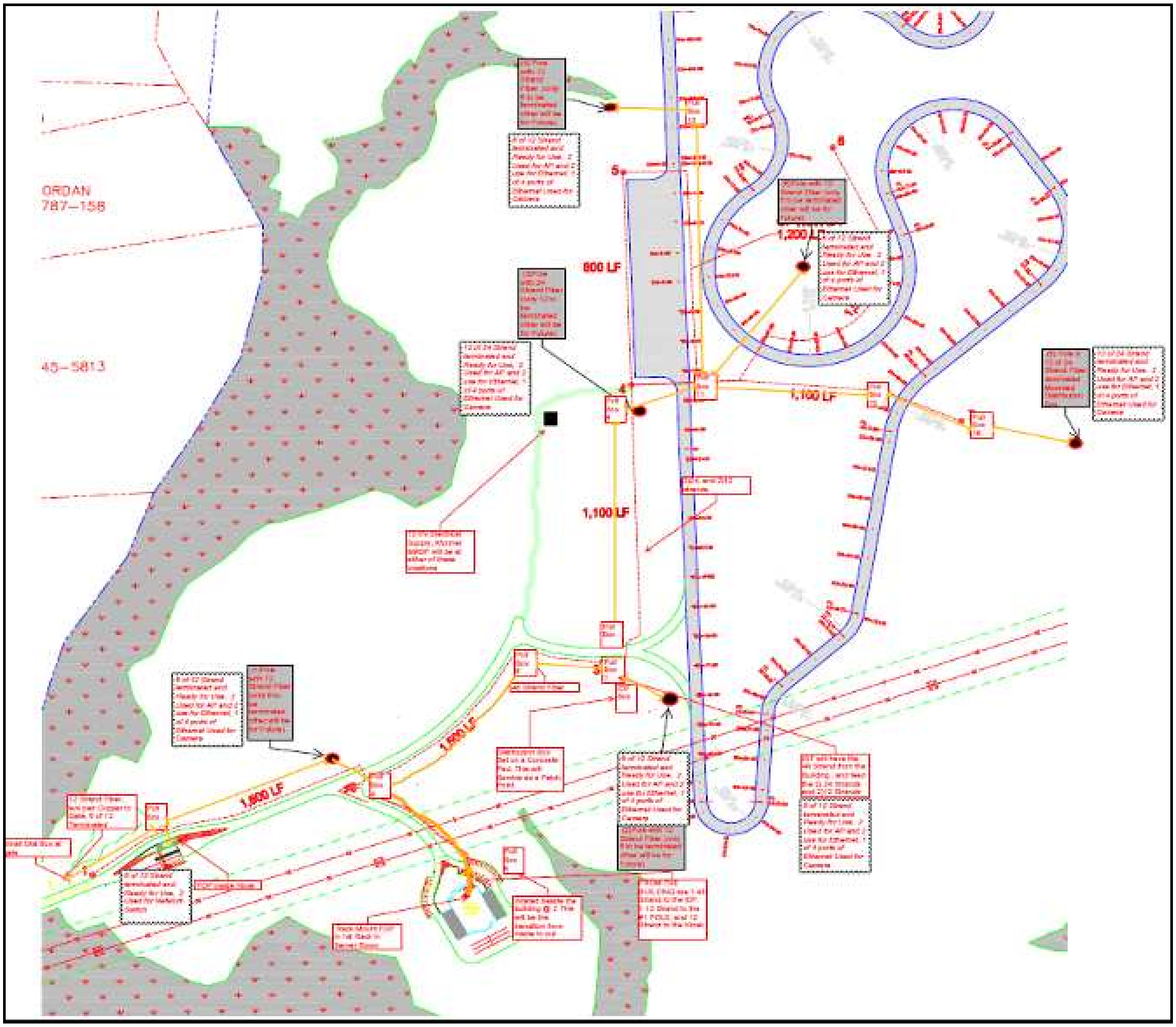

Figure 33: Site IT Infrastructure Layout Plan

PTZ cameras are mounted at about twenty five feet above ground (on thirty five feet poles). These poles have to be as rigid as possible for both good camera images and access point function in windy conditions.

Tower foundations were bored, conduit installed, wire framed and poured as shown in the figures below (Figures 34 through 37).

Figure 34: Boring of Tower Base

Figure 35: Tower Base Foundation Re-Bar

Figure 36: Tower Base Ready for Concrete Pouring

Figure 37: Tower Base Completed

Site trenching, fiber and cable pulls was extensive and carried out over long distances. Pull boxes were installed to ease the installation and allow for future access. Figures 38 through 45 detail the activities.

Figure 38: Site Trenching (awaiting copper & fiber)

Figure 39: Directional Bores Under Test Track

Figure 40: Site Trenching – Innerduct in Place (awaiting copper pulls)

Figure 41: Pull Lines Ready for Copper Pulls

Figure 42: Pull Boxes Located Across Site to Facilitate Long Pulls

Figure 43: Filled & Seeded Trenches

Figure 44: Copper Cable Pull

Figure 45: Winching Copper Cable Through Innerduct

Pole mounting of cameras and access points was challenging due to the location of the poles at significant (and hence safe) distances from the track. Figures 46 through 50 detail the process.

Figure 46: Camera & AP Installation on Pole # 2

Figure 47: Mounting AP on Pole

Figure 48: Fiber & Copper Connections at Pole Base

Figure 49: Copper terminations at Base of Pole

Figure 50: Pole Installation Complete (pole #6 is only 10ft tall due to location on 25ft hill)

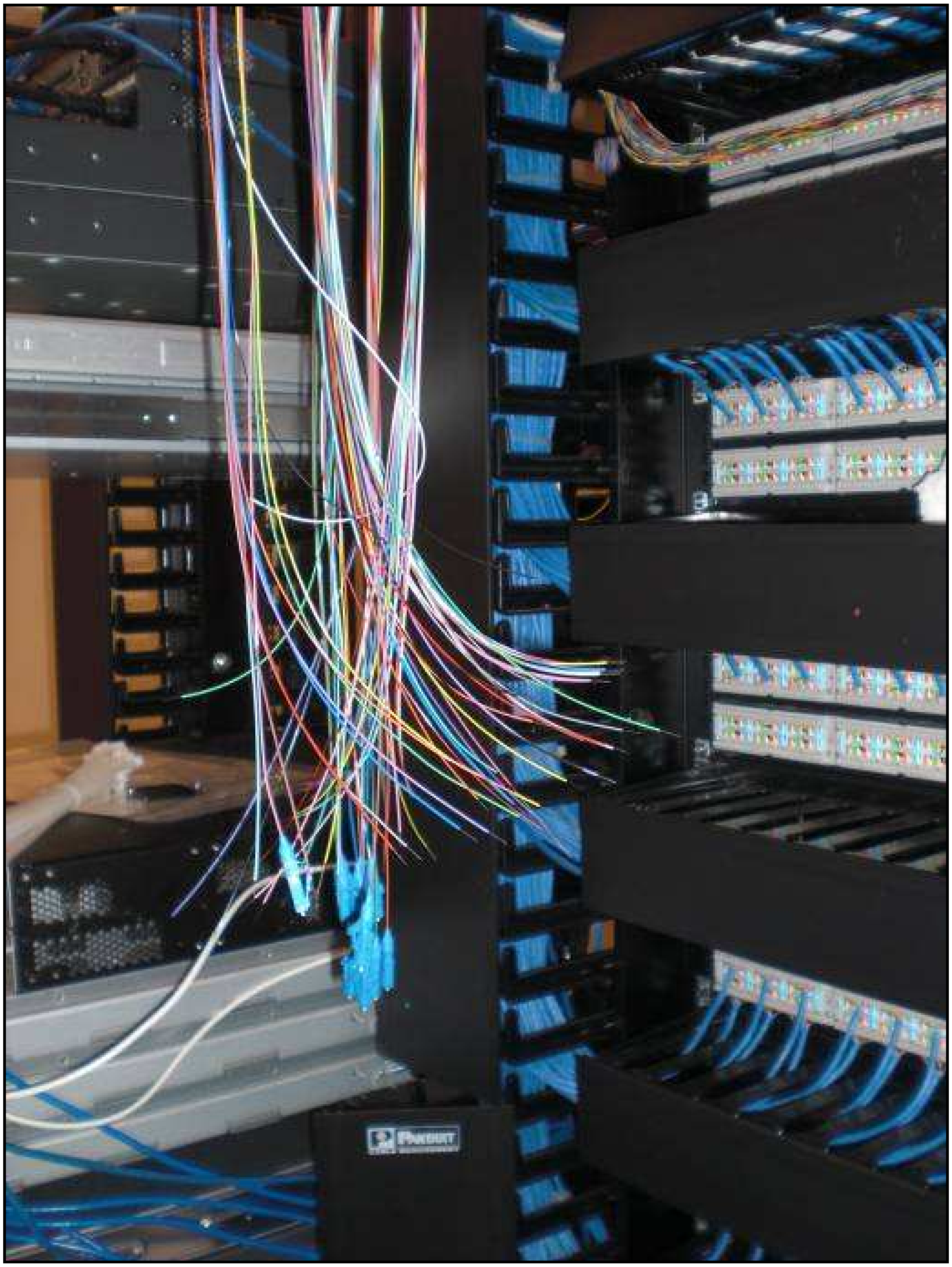

Figure 51: Site Fibers Terminating in IT Room

Figure 52: Fibers Terminated at Rear of Switch

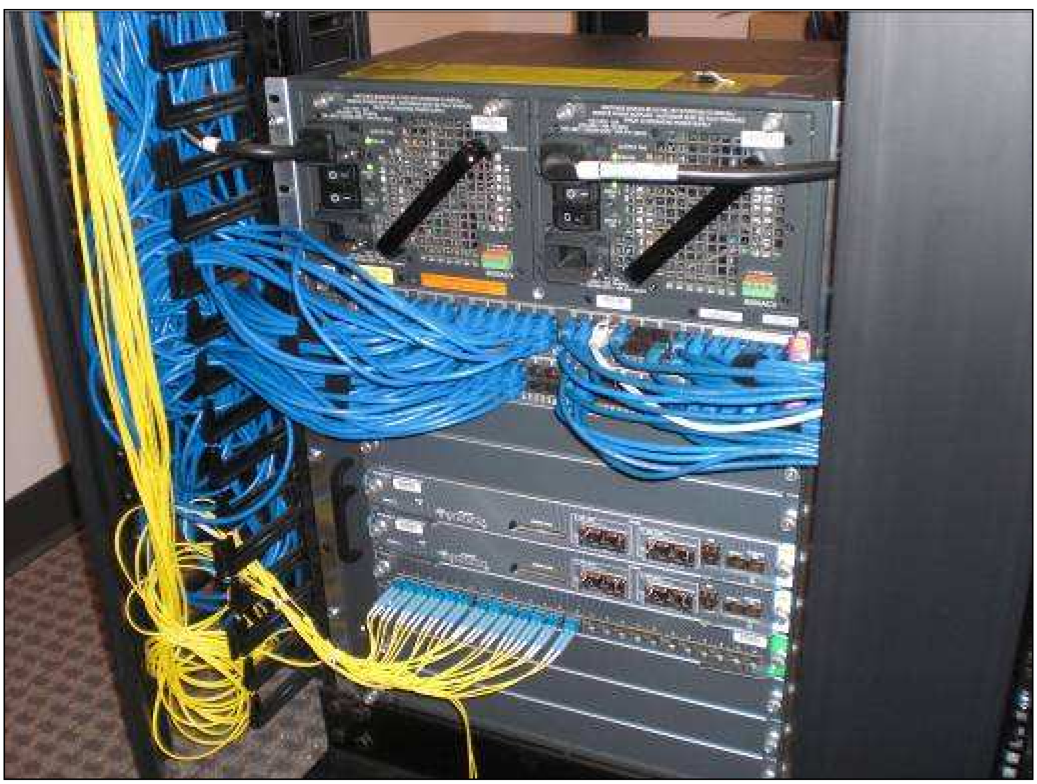

Figure 53: Fibers Terminated in Switch Ports

Video cameras were installed in all locations by December 31st, 2010. Camera commissioning was achieved in the final quarter following resolution of issues related to sourcing specific power supplies and port initiation.

A dedicated desktop PC with high capacity graphics and display features has been procured for camera control and image processing. The dedicated video monitoring PC was assembled from base components by two post-graduates from NC State University Computer Science department (Rachana Gupta & Shep Pitts, pictured below in Figure 54).

Figure 54: NCCAR Video Management PC Assembly

The video PC specifications are detailed below in table 1 and the full display of all nine on-site cameras using the VSOM monitoring is shown in Figure55:

Item	Description	Notes	Weblink
Case	Antec DF-85 Black Computer Case		http://www.newegg.com/Product/Product.aspx?Item=N82E16811129087
Motherboard	ASUS Rampage III Formula LGA 1366 Intel X58 SATA 6Gb/s USB 3.0 ATX Intel Motherboard	Only has 2 PCIe x16 slots (1 per video card)	http://www.newegg.com/Product/Product.aspx?Item=N82E16813131666&cm_re=lga_1366_x58_6gb%2fs_USB_3.0_i7-_-13-131-666-_-Product
CPU	i7 980X 3.3GHz 6 cores	6 Cores	http://www.newegg.com/Product/Product.aspx?Item=N82E16819115223&cm_re=i7_980x-_-19-115-223-_-Product
GPU	ATI Radeon™ HD 5870 Eyefinity 6 Edition Graphics 2GB GDDR5		http://www.newegg.com/Product/Product.aspx?Item=N82E16814125322&cm_re=EYEFINITY_6-_-14-125-322-_-Product
GPU Adapter	ATI Radeon™ Eyefinity Adapter	Graphics card only has 2 mini DVI port to actual DVI adapters. Add for each monitor you want to have more than 2 per card	http://www.newegg.com/Product/Product.aspx?Item=N82E16814999031&cm_re=eyefinity-_-14-999-031-_-Product
Memory	CORSAIR CMG6GX3M3A2000C8 XMS3 Dominator GT 6GB kit (2GB x 3) triple channel 240-pin pc3-16000 DDR3 2000mhz 8-8-8-24 DIMM desktop memory module	Room to expand to 12GB if needed	http://www.newegg.com/Product/Product.aspx?Item=N82E16820145318&Tpk=CMT6GX3M3A2000C8
Monitor	Asus VE248H Black 24" 1920X1080 2ms Full HD HDMI LED Backlight LCD Monitor w/Speakers 250 cd/m2 10,000,000:1		http://www.newegg.com/Product/Product.aspx?Item=N82E16824236049
Power Supply	1220 W SLI ATX Power Supply		http://www.newegg.com/Product/Product.aspx?Item=N82E16817121040&cm_re=Kingwin_Power-_-17-121-040-_-Product
Hard Drive	1TB WD Caviar Black SATA 2 (6.0G/s)	Good hard drive Raid 1 Mirror configuration will help if 1 hard drive fails	http://www.newegg.com/Product/Product.aspx?Item=N82E16822136533&cm_re=caviar_black_6.0gb%2fs-_-22-136-533-_-Product
BlueRay/DVD b	LITE-ON Black 12X BD-R 2X BD-RE 16X DVD+R 12X DVD-RAM 8X BD-ROM 8MB Cache SATA Internal Blu-ray Burner 12X Blu-ray Burner with Blu-ray 3D feature Model iHBS112 - OEM		http://www.newegg.com/Product/Product.aspx?Item=N82E16827106346&cm_re=blue_ray_burner-_-27-106-346-_-Product
OS	Windows XP SP3 32bit OEM version Professional		http://www.discountmountainsoftware.com/miwixpprofuv.html?cmp=gp

Table1: Video PC Specification

Figure 55: NCCAR Video surveillance display

Task 4.0 Wireless Encrypted Telecommunications System

NCCAR has a 50 count twisted pair service into the campus and truncated at the Operations building. A 25 count twisted pair will be installed into the Security Kiosk. The on-site communications will be controlled and manages by the Cisco Unified Communication Manager (MCS7825I4-K9-CMC2, Unified CM 7.1 7825-I4 Appliance) to allow both "hard" line and VOIP calling. Wireless / encrypted communications will be via Cisco Unified Wireless IP phones (7925G) – see Figure 56 below and the subsequent product features:

Figure 56: Cisco Wireless 7925G IP Phone

The Cisco Unified Wireless IP Phone 7925G is designed for users in rigorous workspaces as well as general office environments. It supports a wide range of features for enhanced voice communications, quality of service (QoS), and security. Some of the main benefits and highlights are listed here:

- IEEE 802.11 a/b/g radio
- Two-inch color display
- Bluetooth 2.0 support with Enhanced Data Rate (EDR)
- IP54 rated for protection against dust and splashing water
- MIL-STD-810F standard for shock resistance
- Long battery life (up to 240 hours of standby time or 13 hours of talk time)
- Built-in speakerphone for hands-free operation
- Exceptional voice quality with support for wideband audio
- Support for a wide range of applications through XML

Task 5.0 Site-Wide Wireless Data Access

The multi-pole Wi-Fi system offers the best solution in terms of coverage, data rate, research potential and running costs (i.e. avoiding system service/license fees).

Figure 57 below indicates the locations for Wi-Fi access points.

Figure 57: Site Locations of Camera / AP Poles

Each AP is pole mounted at 30 feet above the nominal zero ground level (main straight). Two poles were of different heights to allow the same network "plane" to be maintained consistently across the site.

Locations were determined by detailed analysis following a site visit by integration partner Internetwork Engineering, discussion on system requirements and subsequent coverage analysis.

The access points used are Cisco component number: AIR-LAP1522AG-A-K9; 802.11a,b/g Outdoor Mesh AP, FCC Cfg.

Each AP has four antennae (see Figure 58 on the next page):

Three:	2400-2483.5 MHz	(8.0 dBi Omni Ant. with N Connect)
One:	4900-5850 MHz	(8.0 dBi Omni with N Connect)

Figure 58: Access Point Detail (and PTZ Video Camera)

Internetwork Engineering completed planning, design and site surveys for Wi-Fi and security in December 2009. Wi-Fi coverage "heat maps" have defined the coverage characteristics of the NCCAR site and buildings as detailed in Figures 59 & 60 below:

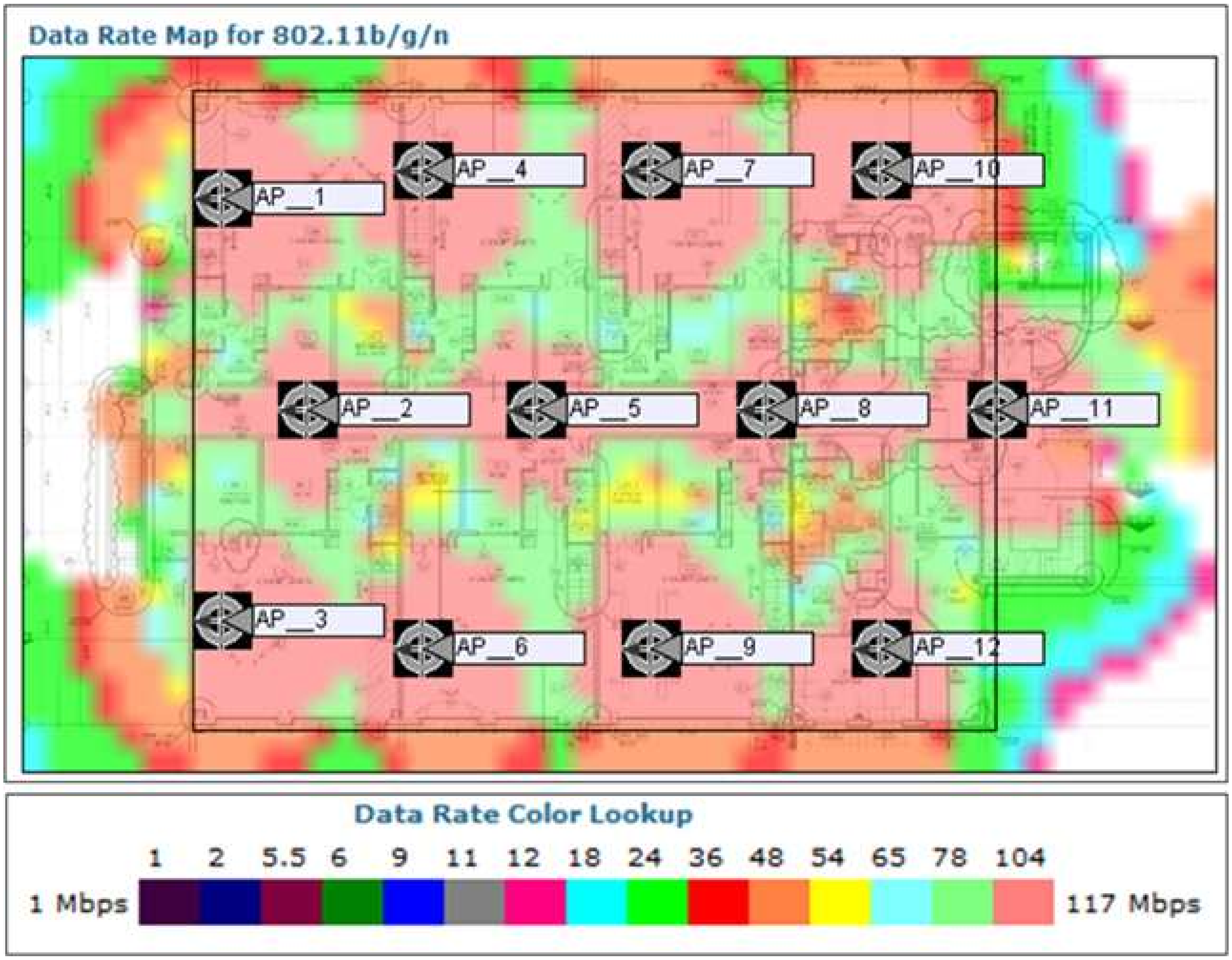

Figure 59: Operations Building Predicted Wireless “Heat Map”

Figure 60: Outdoor Predicted Wireless "Heat Map"

Once the WiFi system was installed and functional, it was vital to evaluate actual performance against the predictions and design. Performance testing was conducted by John Bass of NC State University ITng Services on March 23rd, 2011. The NCCAR WiFi network was capacity loaded using “iperf” test software and then transmission bandwidth was captured using a laptop in a car travelling around the two mile road course in both directions (within the network of five AP’s) and transmitting to another PC located in the operations building.

Figure 61: Outdoor “iperf” Test

The results are shown in Figures 62 and 63 below.

These plots show relative tcp bandwidths at different locations around the NCCAR test course while traveling at approximately 50 mph in both directions.

1. Numbers in the markers represent relative bandwidth at that point.
2. The test flow is from the laptop in the car to a desktop in the operations building.
3. The numbers in the marker are on a linear scale from 1-9 (9 is the best, about 20Mbps).

Caveats:

a) Location information was gathered from a geo-tracking app on a Droid cell phone
b) Bandwidth was gathered with iperf
c) The two data streams were correlated with Python code - the time correlation error is no more than 1 sec.
d) The merged data was mapped with Google's Javascript mapping api v3

Figure 62: WiFi Coverage / Bandwidth Test using iperf (50mph counter clockwise)

Figure 63: WiFi Coverage / Bandwidth Test using iperf (50mph clockwise)

Task 6.0 Project Management and Reporting

The completed project timing schedule is shown in Figure 64 below. The actual project duration increased from the initial plan of twelve months to eighteen months due to several factors. Primary causes were longer lead time that planned for the procurement of the six poles, poor weather at the time of site trenching and boring, plus a delay in additional project funding from the Golden Leaf Foundation.

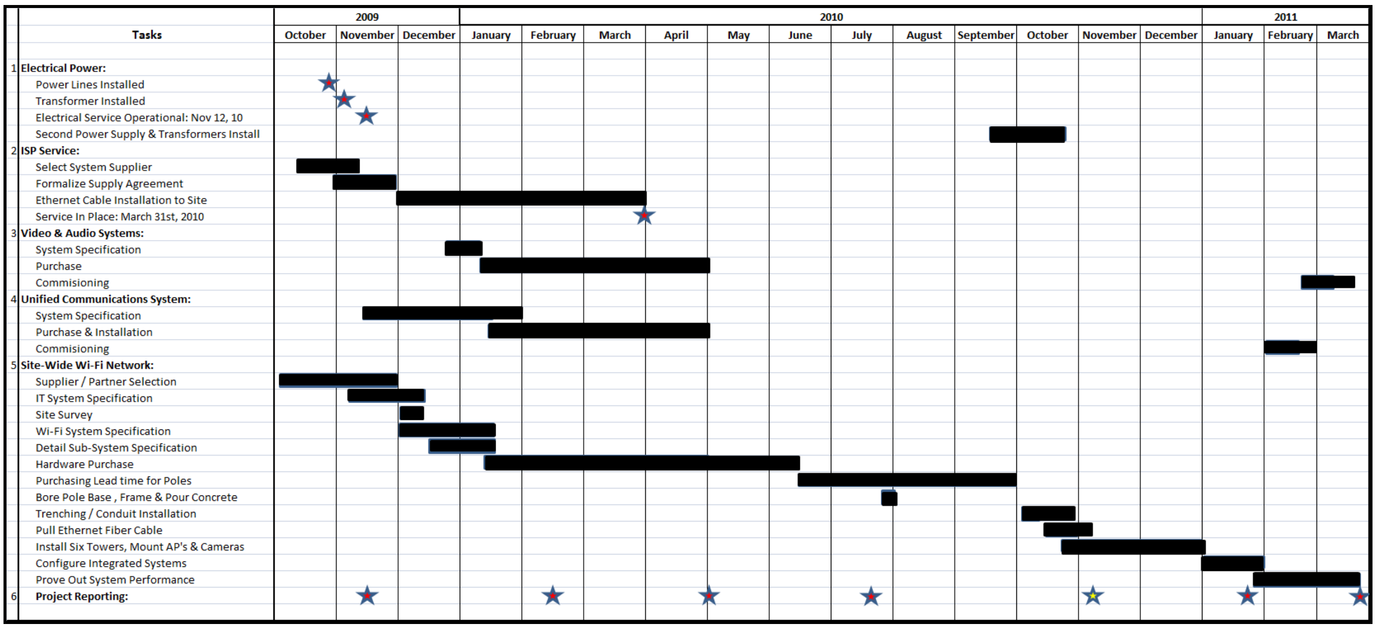

Figure 64: Final Project Timing Plan

PROJECT SUMMARY

The complete NCCAR IT system has been fully operational since the end of March 2011. Prior to that date the WiFi system was fully functional from January 2011. Key users of the NCCAR IT system have been visitors requiring internet access whilst working at or visiting NCCAR.

To date, NCCAR has served a total of 26 different clients, including a total of 636 users and 1,650 visitors. The mix of client type is detailed in the Figure 65 below:

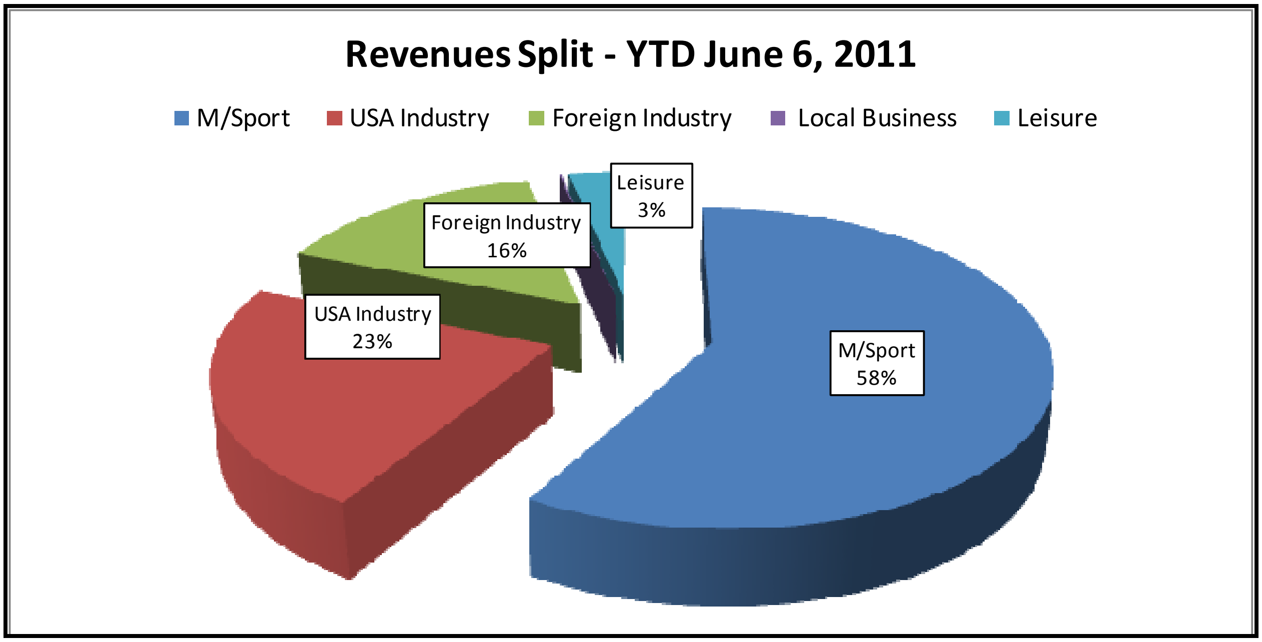

Figure 65: NCCAR Client Type (by revenues)

The overall system capabilities are very varied and range from simple data transfers whilst undertaking development activities, live data streaming from vehicles to prototype electric vehicle charging and range testing. Asset tracking and encrypted voice and data communications have been instrumental in attracting clients to use the NCCAR facility.

Video surveillance has also proven to be an invaluable tool for incident logging and post-event analysis.

The original objective to enable data streaming from a vehicle travelling at 100 mph has been achieved. The peak wireless data bandwidth of between 3 and 20 Mbps across the two mile test track is acceptable.

In conclusion, NCCAR required a scalable and adaptable electrical and IT system infrastructure to support future vehicle technology development by clients and NCCAR staff. The combination of an integrated voice, data and video system achieves these requirements and is operable by the small staff at NCCAR without constant outside technical support.

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