AC 2012-5407: MOBILE DATA DESIGN AND APPLICATIONS FOR EMERGENCY RESPONSE VEHICLES

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Mobile Data Design and Applications for Emergency Response Vehicles

I. Introduction

The need for mobile data in emergency vehicles has become a concern for many organizations so that workers can be provided with timely information to assist them in producing a quicker and more effective response in critical situations. With the introduction of rugged grade mobile equipment by enterprise class manufacturers along with the advent of cellular 3G and 4G networks, many types of data can be provided to field workers to help reach this goal. In addition to providing critical information directly to the field, other data including patient diagnostic data such as electrocardiograms (EKG) or global positioning systems (GPS) / automatic vehicle location (AVL) coordinates of the ambulances can be provided. This data can be sent back to a central location to assist in patient triage as well as track workers, vehicles, and equipment in the field. Making this data path securely and readily available in a harsh environment has been tested and implemented with good results to date.

This paper documents the mobile equipment that was selected and installed in production ambulances as well as the centralized system that secures and disseminates the data on the backend. Furthermore, examples of the various data outputs are provided to demonstrate the functionality of the systems. Finally, possible improvements or augmentations such as Voice over Internet Protocol (VoIP) and telemedicine are discussed to provide even more mobile functionality to improve the emergency response. The mobile components mentioned above have been installed in 15 ambulances thus far and have successfully worked with little maintenance for several months. The GPS tracking of ambulances have become a standard application for the Rutherford County Ambulance Service's 911 Dispatch Center and is in use every day. Additionally, paramedics frequently use the Virtual Private Network connections (VPN) for patient medical record retrievals, patient transport documentation, and patient billing. Patient EKG 12 lead transmissions are also used on a regular basis (especially to the Middle Tennessee Medical Center hospital) to treat patients with thrombolytic issues.

The work represents a true system integration project that has great benefits on a daily basis. This applied research project was the work of the main author in collaboration with his faculty advisor from the Department of Engineering Technology at Middle Tennessee State University. The educational experience and benefits will be discussed here as well.

II. Mobile Equipment Specifications

The following instruments have been installed in fifteen ambulances for the purpose of mobile data communication in order to achieve VPN connections over a cellular 3G internet connection (with either a wired or wireless LAN option for the ambulance's network enabled equipment), transmitting the GPS coordinates of the ambulance, patient EKGs as IP packets, provide internet access as a mobile hotspot, etc. A network diagram is included with this inventory to demonstrate how the components connect to one another.

- **Cisco 3230 Mobile Access Router (MAR)** – this ruggedized mobile router has Cisco's Advanced IP Services Internetwork operating System, IOS, installed on it and is capable of layer 2 & 3 Virtual Local Area Network, VLAN, switching and routing, initiating / receiving VPN connections from other Cisco firewalls (in this case a Cisco ASA 5520 firewall), and various other network services such as DHCP, NTP, CDP, etc. In addition to these capabilities, the MAR also includes an internal wireless access point (WAP) for 802.11 B/G access for wireless enabled devices (laptops, PDAs, etc). The specifications for this router (hardware only) are found in [1].

- **Sierra Wireless PinPoint X Modem** – this ruggedized cellular modem is used as a Wide Area Network, WAN, (internet) connection endpoint for the ambulance as well as transmitting the GPS location of the ambulance to assist in computer aided dispatching. The specifications of this modem are listed in [2]. Specifications of the GPS collection & transmittal capabilities and configuration are listed in [3].

- **Sierra Wireless RJ11 Analog to IP Gateway** – this device is used to simulate Local Exchange Carrier, LEC, "dial-tone" to an EKG device (Medtronics LP12 Defibrillator), receive its analog signal, and then convert it to IP packets for transmission to server to render for medical personnel. The specifications for this device are listed in [4].

III. Centralized Server & Network Specifications

- **Firewall – Cisco 5520 Adaptive Security Appliance** – this firewall is used to as a central VPN termination point for all ambulance VPNs and firewalling (Global IP NAT Translation) for the EKG server located at the 911 Dispatch Center. This device is capable of initiating / receiving L2TP IPSec tunnels to / from ambulance MAR devices for secure site to site communication across the global internet. The specifications for this device are listed in [5].

- **SQL Server** – This Microsoft Windows based server is used to collect the GPS AVL UDP/IP data transmitted by the Sierra Wireless PinPoint X Modem (with a custom written application listening on a predefined IP port) and then place this data into a database for GIS map plots at the 911 Dispatch Center. Example of UDP GPS data is shown in [6].

- **Medtronics LifeNet Receiving Station** – This MS Windows based server receives the converted analog to IP packets, converts them back to an analog signal (using software designed for this purpose), then parses the data into PDF document that is readable by medical personnel. This PDF document can then be transmitted to a hospital emergency room doctor for triage as well as stored as part of the patient's medical record for archival, billing, etc. An example of this EKG PDF document is shown in Figure 8.

- **Various Other Centralized Network Services** – other internal centralized servers are currently available to the ambulance across the mobile VPN connection: internet browsing, patient billing software, network printing and faxing, etc.

IV. Current Network Configuration

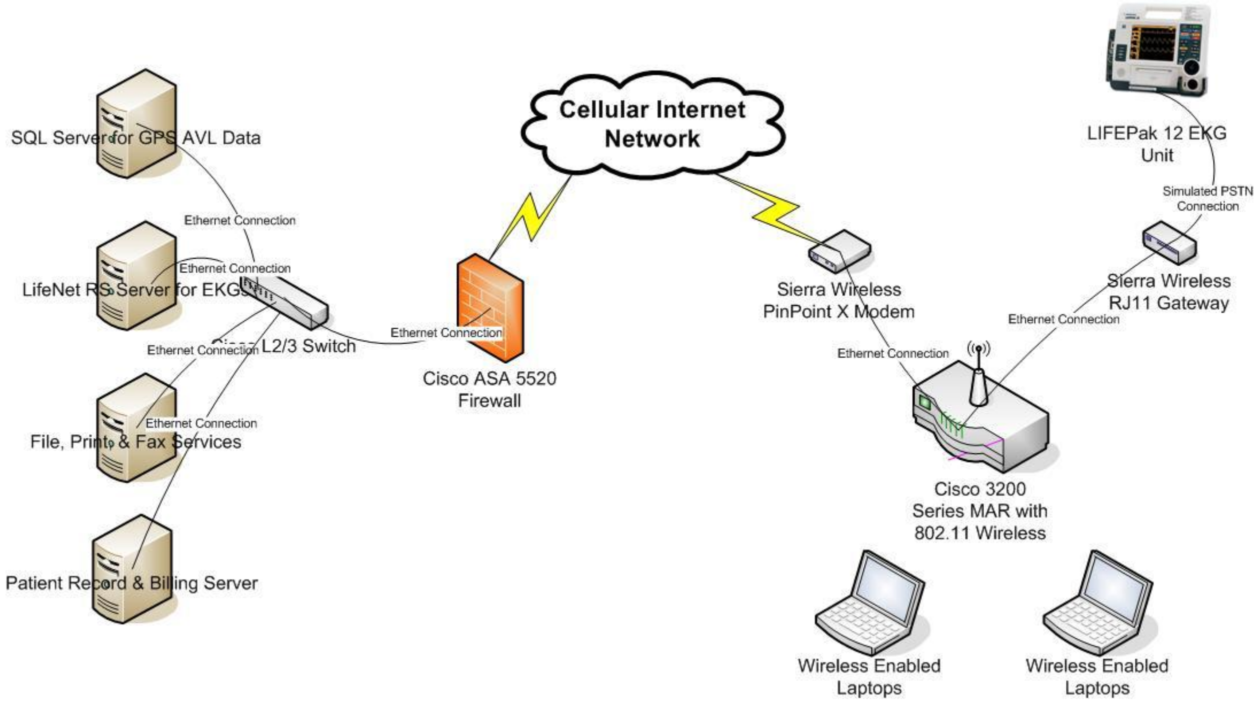


Figure 1. Current System Configuration

The diagram in Figure 1 represents how each of the components described above are connected to one another (either physically or logically). All the centralized equipment used in this system is shown on the left side of the diagram while the right side represents the mobile components. Various types of data are generated and transmitted from the ambulance to the centralized server(s) for processing. Any type of IP data can be transmitted although the 3G cellular network does have bandwidth limitations that must be considered.

Figure 2 shows how EKG transmittal is achieved both physically and logically aboard the ambulance. The patient is connected to the defibrillator and thrombolytic data is captured. This data is archived in the memory of the defibrillator and is then transmitted to the 911 center RS Server as IP packets. These packets are then rendered into a proprietary format on that server which can then be exported and transmitted via email to the emergency room. This process (transmittal and relay to the emergency room) consistently takes about 120 seconds to complete (90 seconds for raw transmission and 30 seconds to export/email to the emergency room). This is an improvement from the seven to nine minute delay incurred using the old method of transmitting EKGs.

A sample configuration of the MAR is shown in Figure 3 (some information has been omitted for security reasons). Note that the configuration shown sets up a VPN tunnel to the centralized firewall as well as creates access control lists (ACLs) to provide access to internal hosts and direct access to internet resources. All external 'WAN' connections are routed out of the MAR and through the Ethernet interface connected to the Sierra Wireless PinPoint X modem.

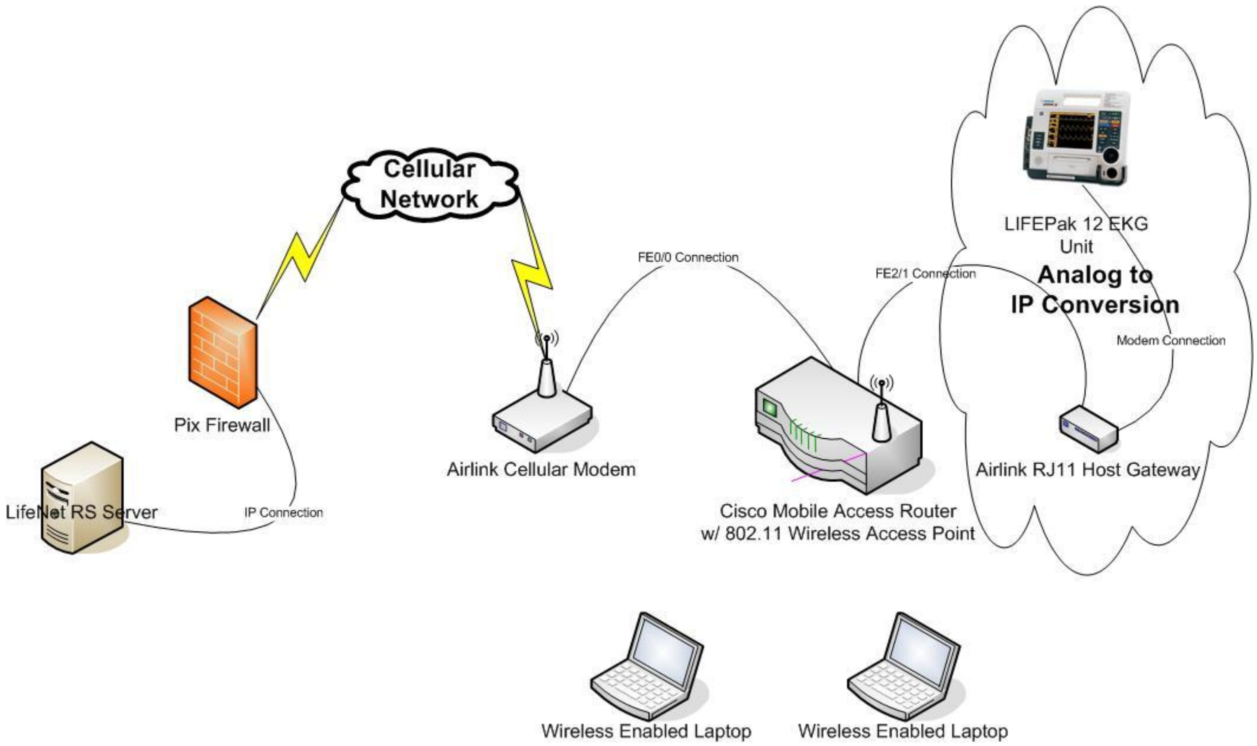


Figure 2. EKG Transmittal Diagram

```
****VPN Config****

crypto isakmp policy 10
 encr 3des
 hash md5
 authentication pre-share
 group 2
crypto isakmp key ************* address x.x.x.x
!
crypto ipsec transform-set TS1 esp-3des esp-md5-hmac
!
crypto map AMBULANCE 10 ipsec-isakmp
 set peer x.x.x.x
 set transform-set TS1
 match address ************
!
ip access-list extended NO_NAT
 permit ip 10.10.4.0 0.0.0.255 172.30.1.0 0.0.0.255
 permit ip 10.10.4.0 0.0.0.255 192.168.99.0 0.0.0.31
 permit ip 10.10.4.0 0.0.0.255 192.168.99.32 0.0.0.31
 permit ip 10.10.4.0 0.0.0.255 192.168.107.0 0.0.0.255
ip access-list extended RCG_COURTHOUSE
 permit ip 10.10.4.0 0.0.0.255 172.30.1.0 0.0.0.255
 permit ip 10.10.4.0 0.0.0.255 192.168.99.0 0.0.0.31
 permit ip 10.10.4.0 0.0.0.255 192.168.99.32 0.0.0.31
 permit ip 10.10.4.0 0.0.0.255 192.168.107.0 0.0.0.255
!
access-list 10 permit 10.10.4.0 0.0.0.255
!
route-map NAT deny 5
 match ip address NO_NAT
!
route-map NAT permit 10

****WAN - Cellular Network Config****

interface FastEthernet0/0
 ip address dhcp
 ip nat outside
 ip virtual-reassembly
 duplex auto
 speed auto
 crypto map AMBULANCE
```

Figure 3. Mobile Access Router, MAR, Configuration Example

Some local traffic (non-routed and local to the ambulance only) is envisioned and can be achieved with the layer 2 capabilities built into the MAR router.

Figures 4.a and 4.b show the configuration of the PinPoint X modem cellular provisioning and its programming to transmit GPS coordinates. Note in Fig. 4.a that a particular TCP port (in this case port 22335) can be specified for in transmitting the GPS data to increase the security of the communication. The latitude and longitude (+ 3583522, -08640451) (Fig. 4.a) of this modem is shown and its location at the time that is configuration was captured (Fig. 4.b).

GROUPS | MODEM DATA | PRINTABLE VIEW

INFO
STATUS
COMMON
Misc
USB
Serial
Telnet
TCP
UDP
DNS
Dynamic IP
PPP/Ethernet
PassThru
SMTP
Other
Low Power
Firewall - IP
LOGGING
GPS
Server 1
Misc
Local/Streaming
1X/EV-DO
I/O
Digital
Analog

AT	Name	Value	
*NETIP	Network IP	166.155.73.47	
*NETSTATE	Network State	Network Ready	
*NETOP	Carrier	Verizon	
*NETSERV	Network Service Type	1X, EV-DO Rev.A	
*NETCHAN	Channel	1019	
*NETRSSI	RSSI (dBm)	-41	
+ECIO	EC/IO (dB)	4	
	Host Mode	AT	
	Host Signl Level	DCD: LOW DTR: LOW DSR: HIGH CTS: HIGH RTS: LOW	
*NETERR	Network Error Rate	255	
	Network Bytes Sent	149187	
	Network Bytes Rcvd	8989	
	Host Serial Bytes Sent	12	
	Host Serial Bytes Rcvd	0	
	Network IP Packets Sent	357140	
	Network IP Packets Rcvd	49622	
	Host IP Packets Sent	50771	
	Host IP Packets Rcvd	230862	
+PRL	PRL Version	52008	
*PRLSTATUS	PRL Update Status	2	
*AUTOPRL	Next Schedule PRL Update	11/15/2010 08:08:36	
	Radio Module Internal Temperature	40	
*POWERMODE	PinPoint Low Power Mode State	ON	
	GPS Fix	0	
	Satellite Count	0	
	Latitude	+3583522	Map
	Longitude	-08640451	
	Number of System Resets	180	
	IP Reject Count	0	
*POWERIN	Power IN Voltage	13.17	
*BOARDTEMP	Board Temperature	41	

Figure 4.a. PinPoint X Modem Configuration Example

The RJ11 Gateway device is used for converting analog signals into IP packets for transmission over an IP network. Once this serial connection is established, a translation process occurs based on the phone number the LP12 is "calling".

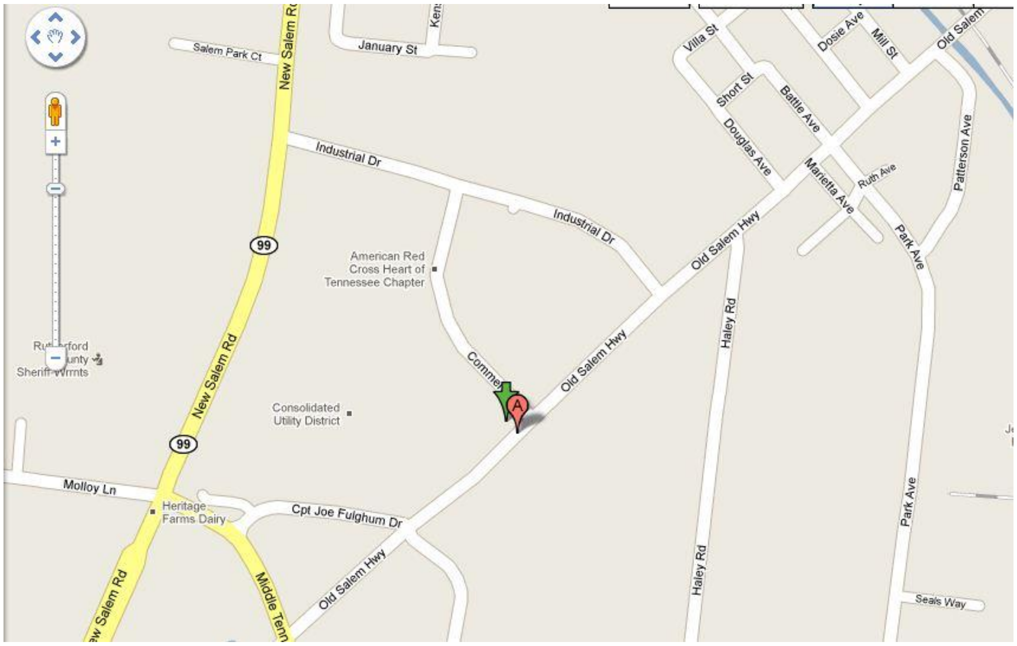


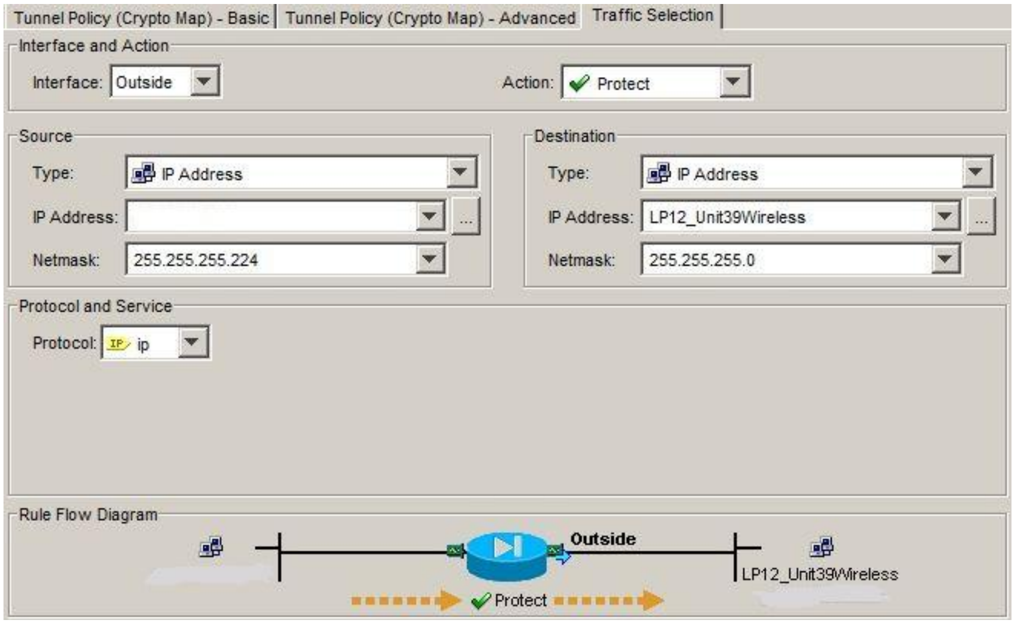
Figure 4.b. Google Map Representation of Ambulance Location Using GPS Coordinates.

V. Centralized Components

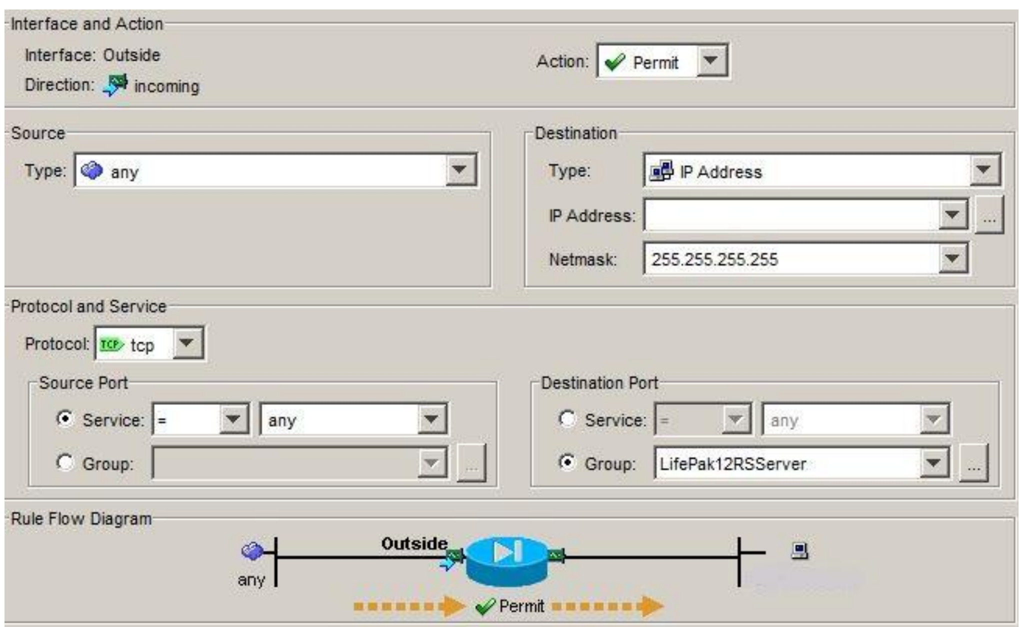
The centralized components receive these data transmissions from the ambulances and then process and forward them onto the various servers and applications used in this system. Figure 5.a below shows a typical NAT firewall rule that allows secure L2TP communication to flow to and from the ambulance. This secure communication allows the paramedics to have access to internal resources such as GPS mapping, patient records, 911 dispatch data, IP faxing, email, etc. over an open internet connection from the cellular carrier. (Note that some information has been omitted from these examples for security purposes).

Figure 5.b shows a specific firewall rule that allows IP traffic to flow to and from the LP12 Defibrillator. Note that the rule only allows TCP traffic to pass to a firewall service group (used to open multiple ports for a single firewall rule – Ports 9910 -9915 in this case) and only to a particular server for security reasons. (Note that some information has been redacted from these examples for security purposes).

The NetSerial software is used to convert the IP EKG packets back into serial communication for the RS Server to parse. This software is used to receive IP packets and then present them as analog signals on simulated virtual serial ports to the operating system and its applications. Note that particular ports can be chosen with this application so that customized firewall rules can be created to increase security.



(a)



(b)

Figure 5. Central Firewall NAT Rule (a) and an Example for EKG Transmittal (b)

VI. Results of Data Transmissions from Ambulance to Centralized Servers

Figure 8 shows raw table data received directly from PinPointX devices that is used for ambulance AVL (note latitude and longitude data tuples showing exact GPS location of ambulance). This data is then rendered into a web enabled mapping application for use in the 911 dispatch center for assisting in emergency calls and directing paramedics to exact locations. The example shows the Device ID (Ambulance), its latitude / longitude, its speed (Velocity), and direction.

GISSQL.avl - d....AVLDataCurrent | GISSQL.avl - dbo.AVLUnits | GISSQL.avl - dbo.EMSCodes | Object Explorer Details

DeviceID	UnitLabel	Latitude	Longitude	Velocity	Direction	TimeStampUTC	TimeStampLocal
531D430067020...	NULL	35.84419	-86.39298	8.699196688	6	10/26/2010 5:2...	10/26/2010 12:...
DA827E0067020...	NULL	35.86172	-86.42258	0	0	10/28/2010 8:5...	10/28/2010 3:5...
AA61830067020...	NULL	35.83522	-86.40451	0	100	10/27/2010 6:1...	10/27/2010 1:1...
E6BB6C0067020...	NULL	35.74097	-86.64439	0.621371192	97	10/28/2010 8:4...	10/28/2010 3:4...
5DDF920067020...	NULL	35.97452	-86.56434	0.621371192	159	10/28/2010 8:4...	10/28/2010 3:4...
EF827E0067020...	NULL	35.8541	-86.46845	0	43	10/28/2010 8:4...	10/28/2010 3:4...
E6E1940067020...	NULL	35.73238	-86.39107	0	0	10/28/2010 8:4...	10/28/2010 3:4...
B7A8690067020...	NULL	35.84428	-86.39258	6.835083112	14	10/28/2010 7:4...	10/28/2010 2:4...
DB7A860067020...	NULL	35.84487	-86.3934	0	68	9/21/2010 6:20:...	9/21/2010 1:20:...
364E210067020...	NULL	35.83553	-86.40459	1.864113576	130	10/28/2010 8:4...	10/28/2010 3:4...
E5BB6C0067020...	NULL	35.70124	-86.29822	3.10685596	20	10/28/2010 7:5...	10/28/2010 2:5...
363B940067020...	NULL	0	0	0	0	7/24/2009 6:03:...	7/24/2009 1:03:...
6AA47E0067020...	NULL	35.8442	-86.39259	4.349598344	7	10/18/2010 7:2...	10/18/2010 2:2...
123F6D0067020...	NULL	35.97356	-86.49967	0	69	10/28/2010 8:4...	10/28/2010 3:4...
FB827E0067020...	NULL	35.91126	-86.3981	1.864113576	76	10/28/2010 8:3...	10/28/2010 3:3...
95A9690067020...	NULL	35.84429	-86.39279	12.42742384	4	10/27/2010 7:3...	10/27/2010 2:3...
03837E0067020...	NULL	35.92453	-86.53721	0	53	10/28/2010 8:5...	10/28/2010 3:5...
E7BB6C0067020...	NULL	35.82663	-86.41278	65.24397516	69	10/28/2010 8:5...	10/28/2010 3:5...
0D72E0067020000	NULL	35.83668	-86.41258	0	0	12/16/2009 6:4...	12/16/2009 12:...
E4BB6C0067020...	NULL	36.02137	-86.56632	4.349598344	108	10/28/2010 8:2...	10/28/2010 3:2...
C6A9690067020...	NULL	35.65673	-86.4084	0	0	10/28/2010 7:3...	10/28/2010 2:3...
3284860067020...	NULL	35.84888	-86.39276	8.699196688	51	7/9/2010 8:50:2...	7/9/2010 3:50:2...
D41D430067020...	NULL	35.84366	-86.39342	11.184681456	4	10/28/2010 4:1...	10/28/2010 11:...
3184860067020...	NULL	35.84422	-86.39295	4.349598344	2	9/3/2010 6:42:1...	9/3/2010 1:42:1...
B2AA690067020...	NULL	35.84532	-86.39465	3.10685596	145	6/20/2010 11:3...	6/20/2010 6:32:...
F0A6690067020...	NULL	35.84415	-86.39238	12.42742384	3	10/13/2010 7:5...	10/13/2010 2:5...
D33E6D0067020...	NULL	35.84942	-86.35316	1.864113576	135	10/28/2010 8:4...	10/28/2010 3:4...
86EE540067020...	NULL	35.84413	-86.39308	3.10685596	110	10/27/2010 8:1...	10/27/2010 3:1...
88927B0067020...	NULL	35.85926	-86.39571	0	0	10/28/2010 8:4...	10/28/2010 3:4...

Figure 6. SQL Query Results Showing Ambulance GPS Data.

Figure 7 demonstrates the AVL software application that shows the locations of each ambulance and where they are in relation to the entire county jurisdiction, the two major cities within the county, and the closest ambulance units to the two hospitals within the county. This location data is transmitted to the 911 dispatch center based on parameters defined on the PinPoint X modem.

A sample EKG, as parsed by the RS Server, is shown in Figure 8. An example of the PDF version is included in the appendices. Note that this example includes 12 lead EKG information as well as vital statistics from the patient.

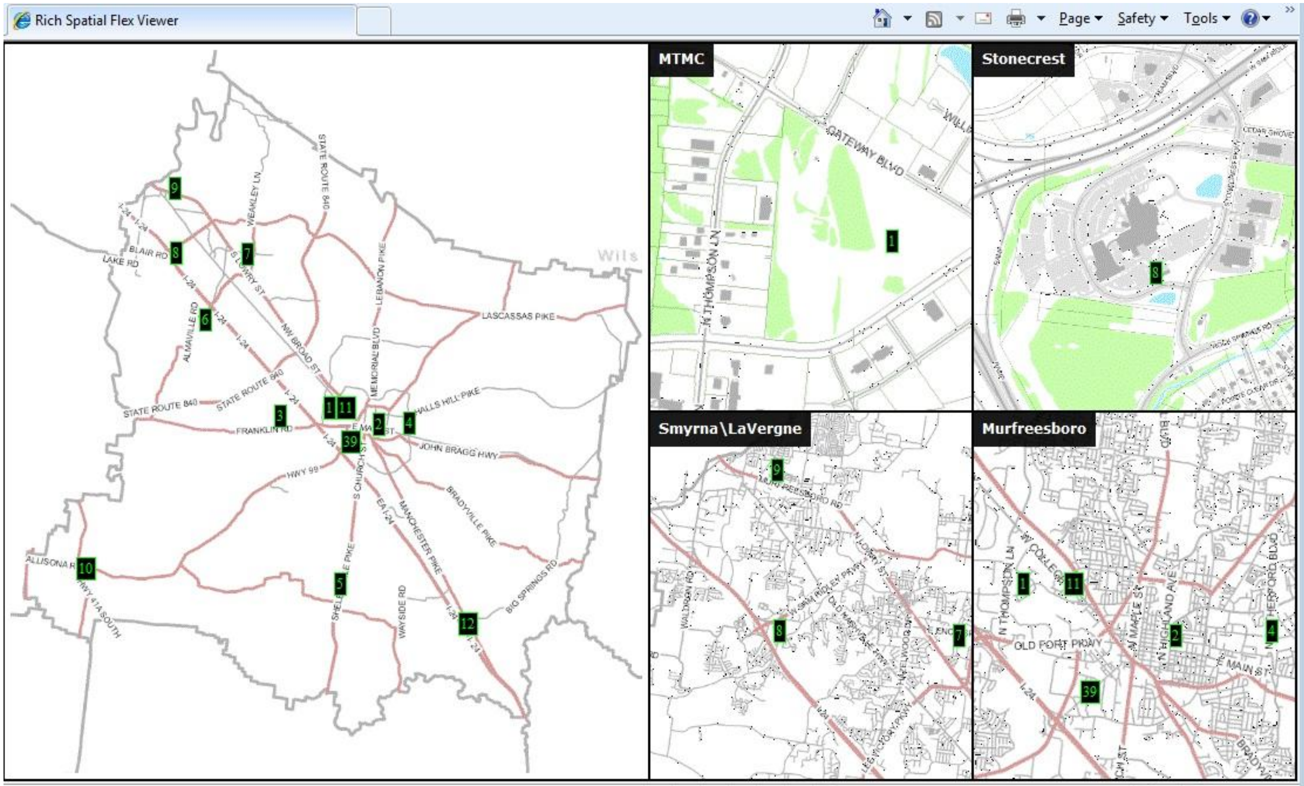


Figure 7. Software AVL Application Used at 911 Dispatch Center.

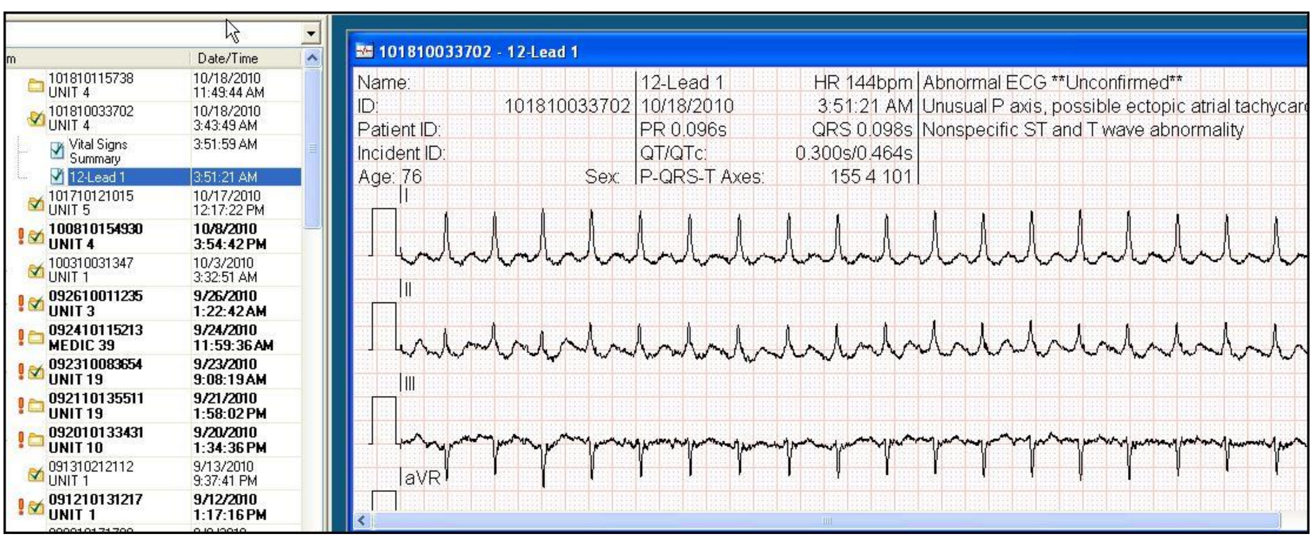


Figure 8. RS Server EKG Application Example.

VII. Proposed Upgrades for Mobile Configuration

1. **Cisco Wireless Phone** – this upgrade would allow 4 digit dial, centralized call accounting, centralized voice mail for each paramedic. These phones use the 802.11 wireless built into the MAR along with the cellular 3G VPN connection to make and receive calls. This could eliminate the need for cell phones and per minute talk time charges to cellular carriers. **Note:** This upgrade was implemented on November 24th, 2010 on an EMS Supervisor's vehicle using a MAR VPN connection, MAR 802.11 wireless capabilities, and centralized IP Telephony servers. Preliminary results show that this phone works in a mobile environment and could achieve centralized IP PBX functions over the VPN (VOIP, 4 digit dial, VM, etc.) The specifications for this device are listed in [7].

2. **OnComm Utility Associates Rocket Modem** – this replacement to the Sierra Wireless PinPoint X modem has the same functionality as the PinPoint X but also has built in routing, VPN, and 802.11 wireless capabilities. The latter feature set could possibly eliminate the Cisco MAR if the routing and VPN are robust enough. Additionally, the Rocket modem uses a USB cellular modem as its WAN connection and is not carrier specific. The manufacturer promises an upgrade (by replacing the cellular carrier's type of USB modem) to support cellular 4G networks when they become available. The specifications for this device are listed in [8]. **InMotionTechnology oMG** (Onboard Mobile Gateway) - – this replacement to the Sierra Wireless PinPoint X modem has the same functionality as the PinPoint X but also has built in routing, VPN, and 802.11 wireless capabilities. The latter feature set could possibly eliminate the Cisco MAR if the routing and VPN are robust enough. Additionally, the mobile gateway uses a USB cellular modem as its WAN connection and is not carrier specific. The manufacturer promises an upgrade (by replacing the cellular carrier's type of USB modem) to support cellular 4G networks when they become available. The specifications for this device are listed in [8].

3. **IP Video Stream for Telemedicine applications –** this upgrade is still in the evaluation phase and no equipment has been selected for use in testing yet. However, it is clear that a standards based codec (such as H.264) would be desirable for interoperability with other systems and for transmission over an IP network. Gantenbein and Robinson discuss the various codecs in use today for telemedicine applications and lay out the various pros and cons of each [9].

VIII. Summary and Conclusions

The mobile components discussed in this paper have been installed as a system in 15 ambulances thus far and have successfully worked with little maintenance for several months. The GPS tracking of ambulances have become a standard application for the Rutherford County Ambulance Service's 911 Dispatch Center and is in use every day. Additionally, the paramedics use the VPN connections for patient medical record retrievals, patient transport documentation, and patient billing. Patient EKG 12 lead transmissions are also used on a regular basis (especially to the Middle Tennessee Medical Center hospital) to treat patients with thrombolytic issues. Even though the components work well together and the system has been proven to be viable, further testing needs to be done and improvements identified. These improvements should include ensuring that all components are ruggedized and increasing the speeds of internet bandwidth from the cellular carriers as it becomes available. Cheaper alternatives for routers and modems are being studied to reduce the per ambulance cost and increase effectiveness. Also, as faster internet network speeds become available to this system, more video and telemedicine applications could become a standard method of triaging emergency patients.

This system integration applied research project has not only been a great educational experience to the author, but also directly benefited the organization where the author is employed. As it was mentioned earlier, the system has been flawlessly operating for over a year now and new components are being added as they become available. The project represents a true engineering system approach since although each component is known to work independently; putting the whole system together was a real challenge.

IX. References

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3. http://www.sierrawireless.com/Support/SupportCenter.aspx (online answer ID: A000502-032411
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