Implementation of Mobile VoIP using Wireless Broadband

Senior Design Project, Phase I
Computer Engineering Technology (CPET 490)

Student: Jeremy Workman
Professor: Paul Lin
Advisor: Gary Steffen

Purdue University Fort Wayne Campus
Department of Computer & Electrical Engineering Technology and Information Systems
December 16, 2008
Table of Contents:

1  Statement of Problem                   Page 3
2  Market Analysis                     Page 4
3  Proposed Requirements and Specifications  Page 5
4  Implementation Methods and Solutions    Page 7
5  Regulatory Standards and Quality Issues  Page 9
6  System Description with Block Diagram    Page 11
7  Trade-Off Study                    Page 13
8  Required Resources                Page 16
9  Project Schedule with Gantt chart     Page 17
10 Estimated Project Cost               Page 19
11 Predicted Return of Investment (ROI)/Potential Benefits  Page 20
12 Risk Analysis                      Page 21
   References                                Page 23
1 Statement of Problem

Companies and individuals are subscribing to multiple data plans for their mobile accessories and connections. An individual may subscribe to everything from a cell phone plan and data plan to a smartphone plan and wireless broadband plan. The expense related to subscribing to all these plans well eclipses their use. The problem that must be addressed is how a company or individual can combine the multiple plans into one cohesive plan. There is a need for a technology that integrates cell phones, smartphones, laptops, and other devices into one cohesive data plan. Voice plans are the linchpin for combining services and this is the area that must be addressed.

Voice over Internet Protocol (VoIP) is now a reality, especially in fixed telephony, which generates benefits for both customers and service providers by reducing costs and improving innovative services. On the mobile side, VoIP has yet to be capitalized on due to the large bandwidth consumption to provide VoIP. This proposal introduces mobile VoIP and the hurdles it must conquer to become a viable solution. One of these hurdles is bandwidth allocation for VoIP using mobile networks. The project will compare bandwidth consumption on existing networks versus new wireless broadband networks to show the feasibility of mobile VoIP on the new networks. This proposal will illustrate the need that exists for a mobile VoIP application by showing that existing voice plans are redundant, expensive, and not equipped to provide mobile VoIP solutions. The key problem becomes: how to make VoIP mobile.

- **Use of Multiple Voice/Data/Internet Plans**
  - Expensive
  - Redundant

- **Current Wireless Cellular Networks (2G and 3G)**
  - Expensive
  - Slow IP Rates

- **VoIP Alternative**
  - Not Mobile
  - Not Supported by Wireless Providers
2 Market Analysis

Voice over IP (VoIP) is becoming a popular technology in many U.S. and global organizations. A study by the IDC (International Data Corporation) found that 37% of large and medium-sized U.S. firms with PBXs (private branch exchange) have already deployed VoIP-based equipment. In addition, global revenue from VoIP carrier equipment was reached $4.3 billion in 2007, up from $1.3 billion in 2003 [1].

The key advantage to adopting VoIP is the convergence it offers. Utilizing a single network infrastructure to transmit both voice and data reduces costs and introduces improved data management and communication efficiencies within an organization [2]. There is one network that carries all electronic traffic over the same physical cabling backbone, and one device that can handle most transmissions [3].

VoIP has existed for several years, but only recently begun to take off as a viable alternative to traditional voice systems and public switched telephone networks (PSTN) [3]. The growth of VoIP in recent years has resulted from resolution of interoperability issues, refinement in standards and technologies, increasing use and affordability of broadband connectivity, and the extended access to VoIP services offered by high bandwidth wireless LAN solutions [1, 2, 3]. A study by Nemertes revealed that many telephony companies and organizations are investing in VoIP, ranging from evaluations to full adoptions [4]. Four years of collecting quantitative and qualitative data from all sizes of organizations, revealed that only one percent of the benchmark participants have no plans for VoIP. In fact, nearly one in five organizations are conducting pilots of VoIP or planning to use the technology within two years [4].

The next logical evolution of VoIP is voice over a mobile network which currently is not being implemented. However, as high-speed data capabilities of mobile networks increase, voice is expected to be the most significant mobile application. Introducing fixed VoIP to cellular telephony and mobile VoIP to fixed telephony, operators can create a unified voice and data service plan. Mobile scenarios are often unfeasible due to lack of indoor coverage, reliability and perceived high cost compared to that of fixed solutions [5]. However, a combination of the two allows companies to lower the cost of VoIP. The ability to use a single device with all the services needed is impossible to deliver over a standard telephone line. This proposal examines the feasibility of mobile VoIP adoption and takes consideration into the performance of mobile VoIP.
3 Proposed Requirements and Specifications

Packet switched networks are the key to VoIP integration. VoIP technology uses packet switching to provide several advantages over circuit switching. Third generation (3G) networks being deployed today are packet based switching networks. 3G networks use packet switching technology with Code Division Multiple Access (CDMA) technology and was created to allow for data transfer rates of 144kbps – 2Mbps [7].

The specific requirements for each sub-system include:
- Protocols
- Codec
- Bandwidth Requirement

Protocols

The main responsibilities of the VoIP protocols are to locate the users, negotiate parameters for the call, setup the call and then terminate the call [7]. Real Time Protocol (RTP) supports the transfer of media over packet switched networks and is perfect for audio transmission. The transport protocol allows the receiver to detect packet loss and timing information so the receiver can compensate for delay jitter [7]. The RTP header defines how the receiver should reconstruct the media and how the codecs packets are formed [7].

The SIP protocol was created by the IETF as a way to redesign the way telephony services were traditionally used [8]. While H.323 emulates telephony services across the IP networks, SIP creates a new way to communicate over the distributed packet network. SIP uses RTP/RTCP (Real-time Transport Protocol), RTSP (Real-time Streaming Protocol), SAP (Session Announcement Protocol) and SDP (Session Description Protocol) to directly connect two terminals without the need of a gateway [8, 9].

![Figure 2: Basic Call Setup using SIP](image)

In reality, there is no Voice over IP. It is really voice over RTP, over UDP, over IP and usually over Ethernet. The headers and trailers are required fields for the networks to carry the packets. The overhead resulting from headers and trailers can be referred to as the shipping and handling cost. An RTP packet accounts for roughly 58 bytes of overhead before there are any voice bytes in the packet which can account for 20 to 80% of the bandwidth consumed over the LAN and WAN [12].

VoIP packets are encapsulated with RTP packets which are inside UDP-IP packets. UDP is used because TCP is restricting for real-time applications. Using RTP solves the problems of unreliable, unordered packet delivery introduced by UDP [11]. Along with a digitized speech sample (20 or 30ms of a word),
the RTP header field contains the time stamp, sequence number, and content of each voice packet in order to account for QoS considerations [13].

The UDP header carries the sending and receiving port numbers for the call. The IP header carries the sending and receiving IP addresses for the call plus other control information. The Ethernet header carries the LAN MAC addresses of the sending and receiving devices. The Ethernet trailer is used for error detection purposes. The Ethernet header is replaced with a frame relay, ATM or PPP header and trailer when the packet enters a WAN [14].

**Codecs and Bandwidth Requirements**

One of the main benefits of VoIP over its analog counterpart is the ability to compress digital data. A codec converts samples of the analog audio signal several thousand times per second. Codecs use algorithms to sample, sort, compress, and packetize the audio data [15]. The codec works with the algorithm to convert and sort the data while soft switches route the compressed data [15]. The two main VoIP codecs used for audio compression are the G.711 and G.729A codec.

The G.729 has a sampling rate of 8,000 times per second and is the most common used codec in VoIP. The G.729 codec uses lossy compression which causes voice quality degradation when compared to G.711. However, the lossy compression allows for 8kbps encoding versus 64 kbps for G.711, which lowers the bandwidth needed to deliver the payload [15].

<table>
<thead>
<tr>
<th>Table 1: Link Bandwidth requirements for G.711 and G.729 [15]</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.711 with 160 byte payloads</td>
</tr>
<tr>
<td>G.711 with 240 byte payloads</td>
</tr>
<tr>
<td>G.729 with 20 byte payloads</td>
</tr>
<tr>
<td>G.729 with 40 byte payloads</td>
</tr>
</tbody>
</table>

Using RTP Header Compression (cRTP), link bandwidths requirements can be reduced further. The technique transmits via hop-to-hop which allows the 40 byte IP/UDP/RTP headers to be compressed to 2-4 bytes [15]. Another technique called Voice Activity Detection (VAD) determines when there is silence and stops sending packets. This can further reduce the link bandwidth and allow for better performance.

<table>
<thead>
<tr>
<th>Table 2: Link Bandwidth requirements using cRTP and VAD [15]</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.711 with 160 byte payloads</td>
</tr>
<tr>
<td>G.711 with 240 byte payloads</td>
</tr>
<tr>
<td>G.729 with 20 byte payloads</td>
</tr>
<tr>
<td>G.729 with 40 byte payloads</td>
</tr>
</tbody>
</table>
4 Implementation Methods and Solutions

This proposal involves the creation of a mobile VoIP system over a wireless broadband connection. First an application would be designed to run on a Wi-Fi enabled cell phone. The application will establish the connection to a VoIP operator like Skype. Using a Skype-In/Out protocol on the Wi-Fi enabled phone, one can communicate to both analog and cell phones. The design would use the Wi-Fi enabled phone to communicate to a mobile Wi-Fi router which in turn communicates with the high-speed wireless broadband service. This would create a complete mobile and wireless network and thus the need for only one data plan.

Android is the free, open source, and fully customizable mobile platform. It was created by Google to compete with mobile operating systems similar to that of the iPhone. Android is comprised of a stack of an operating system, middleware, and key mobile applications. It also contains a set of APIs that allow third-party developers to develop applications. The beta version of the Android SDK provides tools and APIs to develop applications on the Android platform using the Java programming language. It also provides tutorials to understand the current open source code. An Android market is now available to upload approved programs for download with compatible devices.

Wi-Fi phones are the next generation communications devices for VoIP. They add SIP/H.323 based VoIP applications to handsets and work together with Wi-Fi installations and can be used in any Wi-Fi network. Two protocols are currently being used, namely the H.323 and Session Initiation Protocol (SIP). At present, vendors are offering hard phones based on both H.323 and SIP [18]. The key to making a successful handset will be in a hybrid offering of a Wi-Fi phone combined with traditional cell phone. The use of both Wi-Fi access and traditional services would enable overlay of the services and a door for mobile VoIP marketability.
The T-Mobile G1 has an array of features and makes a great candidate for the project. It has a touch screen, QWERTY Keyboard, 3.2 Megapixel Camera, and Music Player. The feature that is of importance is that it has the capability to communicate to the 3G Network and Wi-Fi Access. Since it runs the Android stack, it has all the applications that come with the operating system. Some of the Google apps available are Google Maps with GPS, Google Calendar, Gmail, and Google Talk. It includes a web browser and access to the Android market. The phone suits three of the needs for the project. It is Wi-Fi enabled, it runs on the open source Android Stack, and new applications can be installed.

With the increasing popularity of IP technology, real-time applications such as interactive two-way voice and multimedia over IP have become a necessity for mobile networks to support. A natural evolution of voice over IP is voice over WLAN (VoWLAN). Another issue is the integration of 3GPP systems and WLANs. The data transmission capacity of a WLAN is greater than that of a 3GPP and the bottleneck for VoWLAN becomes the 3GPP connection [17]. Wi-Fi is an IP-based, non-cellular technology that can handle data transmission as well as voice calls via the internet. However, it was intended for local area network (LAN) use and never meant to be a large-scale voice-calling network. Mobile VoIP on a Wi-Fi network (Voice over Wi-Fi/VoWi-Fi) uses SIP over 802.11x IP LAN with real-world data rates of 100 Mbps when using 802.11n router [16].

The PHS300 creates a fully portable Wi-Fi Hotspot from broadband-enabled cellular phones and modems. It’s a Wi-Fi extension to Cellular Broadband and compliant with IEEE 802.11 b/g standards. It tethers to cellular phones or cellular EV-DO USB modems for Wi-Fi access anywhere in coverage. It is compact, portable and can charge a handset via USB or power a USB modem. It has a built-in Li Ion battery that provides 2.5 hours of Wi-Fi with a 3G network and an added firewall prevents unauthorized use of the connection. The Li Ion battery can be upgraded to allow for longer Wi-Fi access with a 3G network.

A wireless broadband solution that allows for the bandwidth needs of VoIP is available. XOHM, the wireless technology from Sprint Nextel and Clearwire, is faster than 3G, ultra-reliable, and a promising alternative for fixed broadband. XOHM claims average download rates of 2 to 4 megabits per second. Commercial speed tests consistently show downloads at about 3 Mb and uploads at 500 kb to 1 Mb. The amazing thing about this new broadband service called WiMAX is the ability to sustain these speeds while being mobile.

A VoIP operator such as Skype allows for connections to SIP based networks, GSM networks, and PSTN networks. Skype uses the VoIP Skype-Out application to connect to the PSTN networks via Skype’s routing to create a seamless connection. An online number (Skype-In) allows for connections from friends, family, or business colleagues who don’t use Skype. Anyone can dial the online number from any phone or cell phone and the Skype application rings allowing for a seamless connection.
5 Regulatory Standards and Quality Issues

Speech Quality

Methods for assessing the quality of speech are fundamental to modern VoIP communications to develop meaningful measures of performance. Most published regulations for quality evaluation can be found among ITU (International Telecommunication Union) Recommendations. From these recommendations, two main assessment methods have emerged: subjective tests and objective tests [21, 22].

Subjective tests are defined in ITU-T P.800.1 and require a group of listeners to evaluate the general quality of a speech signal based on various discrete scales [21, 22]. Intrusive objective speech quality automatically accesses the performance of a VoIP system without the need for human listeners. This is typically not the case in QoS monitoring, so it is necessary to use nonintrusive methods to access VoIP speech quality. These methods often include both mimicry of human perception and a mapping to the quality measure that is trained using databases [22]. The standardized method for nonintrusive speech quality assessment is the ITU-T P.562 algorithm [21]. These standardized tests will help determine which codecs will allow for the best rates without drastically minimizing speech quality.

Performance Issues

End-to-end latency is the sum of encoding/decoding latency and transmission latency [23]. The end-to-end latency sum should be 150\text{ms or less}, and when the latency sum increases to 250ms it becomes too great to carry on a conversation [15]. The compression ratio of the codec is directly proportional to the encoding/decoding latency. Since G.711 is not compressed there is no latency, while G.729 compresses voice to 8 kbps causing about a 25ms delay [15]. However, more significant delays occur with the transmission latency. This is especially true for low bandwidth networks such as wireless LANs [23].

Jitter is the amount of variation in latency that is experienced over time [23]. IP phones have some ability to buffer incoming audio streams to compensate for jitter. Excessive jitter can disrupt conversations and this is usually caused by congestion on and by packet buffering in routers [15]. VoIP is a real-time audio service that uses the UDP transport protocol, which does not try to recover lost packets. Packet loss can create glitch sounds or dropouts in the conversation.

VoIP quality over WCDMA differs depending on the bitrates used. WCDMA 128/128 provides low quality and WCDMA 64/64 creates a low/poor quality levels, and therefore the end user experience with VoIP WCDMA is not stable and will vary [23]. Tests with WCDMA 64/64 using G.711 fail constantly and only a lower bitrates codec like G.729 is suitable for VoIP transmission over a WCDMA network [23]. The figure below shows the E-MOS (Speech Quality) levels for G.729 and G.711 using HSPDA and WCDMA. An E-MOS level of 2.5 is the threshold for poor/fair audio quality.

![ Codec Performance Evaluation (G.729 and G.711) ](image-url)
High Speed Downlink Packet Access (HSPDA) is a tremendous performance upgrade to WCDMA for packet data that delivers peak rates of 14 Mbps and that is likely to increase average throughput rates to about 1 Mbps, a factor of up to three and a half times over WCDMA [24]. HSDPA also increases spectral efficiency by a similar factor. However, even when using HSPDA, G.711 is not an appropriate codec for wireless networks due to its high bitrates [23]. End-to-end delay is the main reason for low voice quality even with the use of a G.729 codec. As the figure shows, the lower E-MOS ratings are due to the slower processing power of the embedded handsets. As more robust handsets become available, HSDPA should be sufficient for mobile VoIP applications.

![E-MOS G.729](image)

Figure 5: Overall VoIP Quality with Laptop and Embedded Handheld Clients [23]

The Fourth Generation (4G) technology that is currently being standardized will have more than enough bandwidth for mobile VoIP based upon the standards being enacted. The specification for the end-to-end media packet delay for the best and high classes of services is less than 100 ms, while for medium classes the delay is less than 150 ms [20]. The handoff delay of more than 200–250 ms makes voice conversations annoying and the handoff delay, being a component of the total end-to-end delay, should also stay within these delay limits [20]. Thus, for quality of service (QoS) streaming audio traffic belonging to either best or medium class, the handoff delay should be less than 100ms.

Wi-Fi 802.11b provides speeds of 11Mbps and since G.711 runs at a 64Kbps, this seems to be vastly more than the minimum required for VoIP codecs. However, there are many applications fighting for the Wi-Fi airwaves. One must take into account the bandwidth lost from sharing connections with multiple applications and devices.

All of the devices used in the test bed study do conform to the regulatory standards put in place for electronic devices. None of the devices will be physically altered and therefore there is no need to determine the interference from the radio signals at this time. The extent to which radio signals may interfere with the devices would be superseded by existing networks, such as emergency and FCC regulated agencies.
6 System Description with Block Diagram

The system would employ a Wi-Fi enabled smartphone or wireless IP phone. The application on the smartphone being deployed would consist of a Skype In/Out protocol that would allow VoIP communications with the VoIP operator, Skype. The application would then use a mobile Wi-Fi hotspot to connect to a 3G or WiMAX network. This mobile hotspot would connect to a wireless broadband service via a USB modem device. Once connected to the wireless broadband network, a wireless broadband hub would connect it to the internet backbone where a Skype connection will be made. Once connected to Skype using the Skype In/Out application created on the Wi-Fi enabled phone, the user can connect to PSTNs, Cell phones, and other SIP devices.

Figure 6: Wireless Mobile VoIP System Diagram

Figure 7: Application Diagram of a WiFi Phone.
Android is a set of core applications that include an email client, SMS program, calendar, maps, browser, contacts, and various other apps. All applications are written using the Java programming language. Developers have full access to the same framework APIs used by the core applications. Thus, the application architecture is designed to simplify the reuse of components; any application can publish its capabilities and any other application may then make use of those capabilities. Android also includes a set of C/C++ libraries used by various components of the Android system. Android relies on Linux version 2.6 for the core system services such as security, memory management, process management, network stack, and driver model. The kernel acts as an abstraction layer between the hardware and the rest of the software stack.

Android includes a set of core libraries which provide the same functionality available in the core libraries of the Java programming language. The Android application runs in its own process, with its own instance of a virtual machine and been written so that a device can run multiple VMs. The VM executes files in virtual machine format which is optimized for minimal memory footprint. The VM is register-based, and runs classes compiled by a Java language compiler that have been transformed into the VM format by the included proprietary tools. The VM relies on the Linux kernel for underlying functionality such as threading and low-level memory management.

The application to be written on the Android stack would make use of the Java language to communicate to the Skype operator. The proprietary Skype-In/Out protocol would be used to make a VoIP connection. Access to the smartphones Wi-Fi Drivers would be accessed via the Linux Kernel. The smartphone may need to be “broken” to get around the VoIP security block that is currently installed on the Linux kernel for the T-Mobile G1. Once the Wi-Fi portion of the phone is accessed and the Linux kernel is VoIP compatible, the application would need to setup a direct link to the Skype operator. This must be done with a SIP-based proprietary protocol. If a conflict with the protocol exists, a less robust SIP protocol may be needed to communicate with a VoIP provider.
7 Trade-Off Study

The trade-offs of this project deal with the determination of which hardware would make the best test bed and which ISP would make the best provider. To determine the best hardware for the project, research was done comparing different smartphones and Wi-Fi phones. The top three choices were:

- 3 Skypephone s2 Wi-Fi phone by Amoi
- T-Mobile G1 smartphone by HTC
- iPhone 3G smartphone by Apple

Table 3: Comparison of Handset Devices

<table>
<thead>
<tr>
<th></th>
<th>3 Skypephone s2 Wi-Fi phone by Amoi</th>
<th>T-Mobile G1 smartphone by HTC</th>
<th>iPhone 3G smartphone by Apple</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROs:</strong></td>
<td>Skype compatible out of box</td>
<td>Open Source</td>
<td>Multiple VoIP apps available</td>
</tr>
<tr>
<td></td>
<td>Wi-Fi Enabled</td>
<td>3G compatible</td>
<td>3G compatible</td>
</tr>
<tr>
<td></td>
<td>HSPDA broadband compatible</td>
<td>Wi-Fi Enabled</td>
<td>Wi-Fi Enabled</td>
</tr>
<tr>
<td></td>
<td>Less expensive solution</td>
<td>GPS</td>
<td>GPS</td>
</tr>
<tr>
<td><strong>CONs:</strong></td>
<td>No GSM compatibility</td>
<td>No VoIP app available for research</td>
<td>Must “break” phone for VoIP apps</td>
</tr>
<tr>
<td></td>
<td>Proprietary OS</td>
<td>VoIP block using Tmobile provider</td>
<td>More expensive hardware and plans</td>
</tr>
<tr>
<td></td>
<td>Limited Applications available</td>
<td>First version of Android OS</td>
<td>Proprietary OS</td>
</tr>
<tr>
<td></td>
<td>Shorter battery life</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Next, I looked at the various mobile hotspots available. Surprisingly, there are numerous mobile Wi-Fi routers available on the market. The top three choices were:

- PHS300 Mobile Hotpot by Cradlepoint
- KR2 Mobile Router by Kyocera
- 3G Mobile Router for UMTS/HSDPA Networks by D-Link

<table>
<thead>
<tr>
<th><strong>Table 4: Comparison of Mobile Routers</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHS300 Mobile Hotpot by Cradlepoint</strong></td>
</tr>
<tr>
<td><strong>PROs:</strong> EVDO compatible</td>
</tr>
<tr>
<td>Firewall</td>
</tr>
<tr>
<td>USB modem</td>
</tr>
<tr>
<td>Large compatibility list</td>
</tr>
<tr>
<td>Battery powered (mobile)</td>
</tr>
<tr>
<td><strong>KR2 Mobile Router by Kyocera</strong></td>
</tr>
<tr>
<td><strong>PROs:</strong> 802.11b, g, and n compatible</td>
</tr>
<tr>
<td>EV-DO compatible</td>
</tr>
<tr>
<td>Firewall</td>
</tr>
<tr>
<td>3G USB modem or PC Card</td>
</tr>
<tr>
<td>Flash Updater</td>
</tr>
<tr>
<td><strong>3G Mobile Router by D-Link</strong></td>
</tr>
<tr>
<td><strong>PROs:</strong> HSPDA or EVDO networks</td>
</tr>
<tr>
<td>VPN and firewall options</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Good Support</td>
</tr>
</tbody>
</table>
Next, I looked at the various wireless broadband ISP providers. Unfortunately, there are only a couple of providers available in the Fort Wayne area. The options that would be compatible with the mobile routers are:

- EVDO by Sprint
- EVDO by Verizon Wireless
- XOHM by Sprint and Clearwire

<table>
<thead>
<tr>
<th>EVDO by Sprint</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROs:</strong></td>
</tr>
<tr>
<td>EVDO compatible</td>
</tr>
<tr>
<td>Largest Footprint in nation</td>
</tr>
<tr>
<td><strong>CONs:</strong></td>
</tr>
<tr>
<td>Download limit</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>500kbps down / 150kbps up</td>
</tr>
<tr>
<td>Contract</td>
</tr>
<tr>
<td>Small modem selection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EVDO by Verizon Wireless</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROs:</strong></td>
</tr>
<tr>
<td>Large modem selection</td>
</tr>
<tr>
<td>Good Footprint</td>
</tr>
<tr>
<td><strong>CONs:</strong></td>
</tr>
<tr>
<td>450kbps down / 150kbps up</td>
</tr>
<tr>
<td>Contract</td>
</tr>
<tr>
<td>Download Limit</td>
</tr>
<tr>
<td>Cost</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>XOHM by Sprint and Clearwire (WiMAX)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CONs:</strong></td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>New Technology</td>
</tr>
<tr>
<td>New Technology</td>
</tr>
<tr>
<td>Compatibility issues (opportunity)</td>
</tr>
<tr>
<td>Not available in Fort Wayne</td>
</tr>
</tbody>
</table>

The Trade-Off Study shows that the T-Mobile G1 with the Android OS allows for the best opportunity to create a VoIP application for research. The open source code allows for great documentation and will challenge the student to create a new application. The Cradlepoint PHS300 mobile hotspot allows for the best mobility with the system. Due to its onboard Li Ion battery, the mobile hotspot becomes truly mobile and that is the key to the project. Finally, the XOHM service by Sprint allows for a contract free, high speed connection that is most compatible with future 4G systems. Although distance is a factor, most of the early testing can be done without the need of wireless broadband service.
8 Required Resources

The required resources were described in the previous implementation and solutions section. This is a summary of the hardware, software, and service providers needed to make a cohesive network. A Wi-Fi enabled phone with a Skype in/out application already installed or one that allows for a Skype in/out application to be created is needed. Also a mobile Wi-Fi router will be needed to allow for a midpoint between a Wi-Fi enabled phone and a wireless broadband provider. The last hardware required would be wireless broadband modem device that is compatible with the mobile router.

The service that is required is the Skype-Out and Skype-In subscriptions available through the Skype operator. This will allow IP connections to and from the PSTN network. Also, a wireless broadband service provider similar to Sprint’s XOHM service will allow for the fast connection for IP communications. Currently XOHM is only available in Baltimore, but networks are planned for Chicago and Dayton in the near future. Testing may be done via a trip to the closest metropolitan providing the service. Alternative slower 3G wireless broadband services may be deployed if distance is a factor. Finally, a basic data plan with the Wi-Fi enabled phone may be necessary to communicate in dead zones of the XOHM network.

<table>
<thead>
<tr>
<th>Table 6: Required hardware, software, and providers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hardware</strong></td>
</tr>
<tr>
<td>T-Mobile G1 (Android Wi-Fi enabled phone)</td>
</tr>
<tr>
<td>Cradlepoint PHS300 Mobile Hotspot</td>
</tr>
<tr>
<td>XOHM USB WiMAX Modem</td>
</tr>
<tr>
<td><strong>Software</strong></td>
</tr>
<tr>
<td>Eclipse IDE</td>
</tr>
<tr>
<td>Android SDK</td>
</tr>
<tr>
<td><strong>Providers</strong></td>
</tr>
<tr>
<td>Skype-Out Subscription</td>
</tr>
<tr>
<td>Online Number with Skype-In</td>
</tr>
<tr>
<td>XOHM WiMAX Wireless Broadband</td>
</tr>
<tr>
<td>T-Mobile Basic Plan</td>
</tr>
</tbody>
</table>
9 Project Schedule with Gantt chart

Below is the project schedule that was created using MS Project in combination with the schedule from past Senior Design projects. The schedule will be updated as the scope of the project narrows and the project becomes more defined. The current revision of the project schedule does not allow for much time to complete reports, so it is imperative that the reports are created while the Design, Development, and Testing phases are taking place.

The project allows for 11 days updating the project proposal and another 20 days working on the design aspect of the project. The project allows for 21 days developing the application and connecting a prototype to the system. Testing was given 16 days to complete with final reporting due 6 days after that. Overall, there is no downtime and multiple items will need to be worked on congruently.

Table 7: Project Schedule of Senior Design Phase II

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progress Report</td>
<td>11 days?</td>
<td>Wed 1/14/09</td>
<td>Wed 1/28/09</td>
</tr>
<tr>
<td>Phase I Project Design review/update</td>
<td>5 days?</td>
<td>Wed 1/14/09</td>
<td>Tue 1/20/09</td>
</tr>
<tr>
<td>Meet w/ Technical Advisors</td>
<td>1 day?</td>
<td>Wed 1/21/09</td>
<td>Wed 1/21/09</td>
</tr>
<tr>
<td>Cover Page &amp; Problem Statement</td>
<td>1 day?</td>
<td>Thu 1/22/09</td>
<td>Thu 1/22/09</td>
</tr>
<tr>
<td>Solution Statement &amp; Block Diagrams</td>
<td>1 day?</td>
<td>Fri 1/23/09</td>
<td>Fri 1/23/09</td>
</tr>
<tr>
<td>System Requirements and Specifications</td>
<td>1 day?</td>
<td>Mon 1/26/09</td>
<td>Mon 1/26/09</td>
</tr>
<tr>
<td>Required Resources &amp; Estimated Cost</td>
<td>1 day?</td>
<td>Tue 1/27/09</td>
<td>Tue 1/27/09</td>
</tr>
<tr>
<td>Project Tasks and Schedule &amp; References</td>
<td>1 day?</td>
<td>Wed 1/28/09</td>
<td>Wed 1/28/09</td>
</tr>
<tr>
<td>Progress Report</td>
<td>1 day?</td>
<td>Wed 1/28/09</td>
<td>Wed 1/28/09</td>
</tr>
<tr>
<td>Interactive Design Phase</td>
<td>20 days?</td>
<td>Thu 1/29/09</td>
<td>Wed 2/25/09</td>
</tr>
<tr>
<td>Detailed System Design</td>
<td>4 days?</td>
<td>Thu 1/29/09</td>
<td>Tue 2/3/09</td>
</tr>
<tr>
<td>Detailed Requirements and Specifications</td>
<td>2 days?</td>
<td>Thu 1/29/09</td>
<td>Fri 1/30/09</td>
</tr>
<tr>
<td>Performance, Reliability, Support, Trade-Offs</td>
<td>2 days?</td>
<td>Fri 1/30/09</td>
<td>Mon 2/2/09</td>
</tr>
<tr>
<td>System Architecture</td>
<td>2 days?</td>
<td>Mon 2/2/09</td>
<td>Tue 2/3/09</td>
</tr>
<tr>
<td>System Simulation</td>
<td>6 days?</td>
<td>Wed 2/4/09</td>
<td>Wed 2/11/09</td>
</tr>
<tr>
<td>System Function Modeling</td>
<td>6 days?</td>
<td>Wed 2/11/09</td>
<td>Wed 2/18/09</td>
</tr>
<tr>
<td>Software &amp; Hardware Order</td>
<td>2 days?</td>
<td>Wed 2/18/09</td>
<td>Thu 2/19/09</td>
</tr>
<tr>
<td>Design Report</td>
<td>5 days?</td>
<td>Thu 2/19/09</td>
<td>Wed 2/25/09</td>
</tr>
<tr>
<td>Design Project Prototyping and Development</td>
<td>21 days?</td>
<td>Wed 2/25/09</td>
<td>Wed 3/25/09</td>
</tr>
<tr>
<td>Define Implementation Plan w/ timeline</td>
<td>2 days?</td>
<td>Wed 2/25/09</td>
<td>Thu 2/26/09</td>
</tr>
<tr>
<td>Prioritized hardware/software construction</td>
<td>2 days?</td>
<td>Fri 2/27/09</td>
<td>Mon 3/2/09</td>
</tr>
<tr>
<td>Incrementally build/test prototype system</td>
<td>15 days?</td>
<td>Mon 3/2/09</td>
<td>Fri 3/20/09</td>
</tr>
<tr>
<td>Document activity, Testing Results</td>
<td>15 days?</td>
<td>Mon 3/2/09</td>
<td>Fri 3/20/09</td>
</tr>
<tr>
<td>Complete System Construction</td>
<td>6 days?</td>
<td>Wed 3/25/09</td>
<td>Wed 4/1/09</td>
</tr>
<tr>
<td>Final Testing and Results</td>
<td>11 days?</td>
<td>Wed 4/1/09</td>
<td>Wed 4/15/09</td>
</tr>
<tr>
<td>Final Report</td>
<td>6 days?</td>
<td>Wed 4/15/09</td>
<td>Wed 4/22/09</td>
</tr>
<tr>
<td>Project Presentation</td>
<td>6 days?</td>
<td>Wed 4/22/09</td>
<td>Wed 4/29/09</td>
</tr>
</tbody>
</table>
The Gantt chart below shows that there is no down time available. It also shows that the project is based upon milestones. These milestones are the reports required during the Senior Design Phase II portion of the project. Once a milestone has been completed, the next task starts. The objective of the schedule is to give enough time so the project develops seamlessly over time. Based on the nature of the project, most of the time will be in development of the application. It is important to allow extra time for development and testing.

Figure 9: Gantt chart of Senior Design Phase II
10 Estimated Project Cost

The total cost involved in development of the project is pretty straightforward. The cost of the Wi-Fi enabled phone, the mobile Wi-Fi router, and the wireless broadband modem will account for the hardware cost. The software involved is free of charge due to Student Labs and the fact that the Android SDK is open source. The cost for the providers will vary, but one should account for a minimum of 4 months of expenses for the project. If we take into account hardware, software, and four months of operating costs, the total expense for the project comes to: $971.00.

Table 8: Estimated Project Cost for Senior Design Phase II

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-Mobile G1 (Android Wi-Fi enabled phone)</td>
<td>$193.00</td>
</tr>
<tr>
<td>Cradlepoint PHS300 Mobile Hotspot</td>
<td>$180.00</td>
</tr>
<tr>
<td>XOHM USB WiMAX Modem</td>
<td>$65.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Software</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipse IDE Student License</td>
<td>$0.00</td>
</tr>
<tr>
<td>Android SDK</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Providers</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skype-Out w/ voicemail Subscription (1 year)</td>
<td>$30.00</td>
</tr>
<tr>
<td>Online Number Skype-In (1 year)</td>
<td>$30.00</td>
</tr>
<tr>
<td>XOHM WiMAX Wireless Broadband (month)</td>
<td>$45.00</td>
</tr>
<tr>
<td>T-Mobile Basic Plan (month)</td>
<td>$35.00</td>
</tr>
</tbody>
</table>

| Total Hardware Cost | $438.00 |
| Total Monthly Operating Cost | $85.00 |
| Total Phase II Cost | $971.00 |
| Total Annual Cost | $1,020.00 |
11 Predicted Return of Investment (ROI)/Potential Benefits

The predicted return on investment (ROI) is only noticeable when we take into account the cost associated with a similar service. A comparable service would provide unlimited mobile high speed internet access with unlimited mobile voice and text. The monthly operational cost associated with competitive services would be in upwards of $160 per month. Therefore, we can assume the monthly operational cost for the test bed system would be $85 per month. This would net a savings of $75 per month versus the traditional services. The initial cost of the hardware equipment for the test bed is more expensive than that of the comparable hardware provided by the traditional service. The monthly savings per month, however, would pay for the initial hardware of the project in six months of operation.

When we consider the marketability of such a system, we must consider the main cost of time spent writing the VoIP application and the support of the application. If we take into account 68 days of design, development, and testing at 3 hours a day; we come up with 204 hours. If we assign a value to the time spent bringing the project to market, at $20 an hour, the cost would be $4,080. If we were able to sale the VoIP application created at $20 per user, we would need to get 204 users to buy the application to recoup the time spent creating it.

Next, we need consider the support of the application. The cost to support such an application would take 8 hours a day at $25 an hour plus webpage costs. The cost to operate a webpage for support and marketing purposes would cost a minimum of $400 a month. The final cost associated with supporting the application on a weekly basis would be $1700 per week. Thus, 85 new users per week would need to purchase the VoIP application to break even.

The true benefits from the project would be attained if used with multiple users over long periods of time. A corporation, organization, city, or municipality could easily recoup their costs with such a system in place. The costs associated with creating such a system should pay for itself after six months of operation.

- **Potential Benefits**
  - No need for Multiple Plans
  - $160+ Monthly Provider Cost vs. $85 Monthly Provider Cost
  - Pays for hardware in six months

- **Marketability**
  - 204 hours for Research and Development at $20/hour = $4,080
    - $20 per Application License
    - 204 users to recoup Research and Development
  - Support = 40 hours a week at $25/hour
    - Web Support = $400/month
    - Total Cost = $1700/ week
  - 85 new users/week to break even
12 Risk Analysis

Risk Assessment Matrix

<table>
<thead>
<tr>
<th>Severity of consequences</th>
<th>F</th>
<th>E</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Impossible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Critical</td>
<td>[G]</td>
<td>[A]</td>
<td>[E]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Marginal</td>
<td></td>
<td>[C]</td>
<td>[B]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Negligible</td>
<td>[F]</td>
<td></td>
<td></td>
<td></td>
<td>[D]</td>
</tr>
</tbody>
</table>

Hardware Issues

[A] The Android OS for T-Mobile G1 does not give root control over linux kernel. I will have to force control of the linux kernel, known as “jailbreaking” the device. There is a remote possibility that the loader could permanently not boot, known as bricking. This would be critical as a new device would need to be bought.

[C] The lack of compatibility between the USB wireless broadband modem and the mobile wireless broadband router is an issue. Currently the desired mobile wireless router, PHS300, is not compatible with the desired USB broadband modem. I will need to contact Cradlepoint in attempt to update their driver set for the PHS300. There are over 30 other USB wireless broadband modems to choose from so this would not be a critical issue.

[G] There is the possibility that the software will work on the emulator but not on the actual hardware. Although the project would not be a total loss, it is important that once the application is working on the emulator, testing will need to begin on the hardware. If the actual hardware device does not work, the project can be presented over the emulator.

Software Issues

[D] The application being written relies on the open source platform. This means that any borrowed code used may not be compatible with the code being worked. There is a high probability that the borrowed code will need to be altered. This project is somewhat dependent on exchanging ideas and code with other developers.

[E] The device will need to be ported. Once ported, the application created will attempt to connect with the Skype Operator to download available contacts, and inform the server that the VoIP device is connected. However, Skype uses a proprietary protocol that may have compatibility issues when attempting to add personal code. This will add to the development time if the compatibility issues cannot be resolved.

[F] The application layer uses the application framework using Java. However, in order to make use of VoIP, the lower linux and C++ libraries will need to be accessed. There is a slight probability that the
Java layers will not be able to communicate to the lower ported levels. However, Hughes Systique Corporation has already ported the phone for the SIP protocol.

**Legal Issues**

[B] The terms of the T-Mobile G1 state that altering the system would nullify any warranty of the device. Furthermore, altering the lower level code of the Android OS would break the Terms of Agreement. Therefore there is a high probability that the application would not be marketable unless the application could be installed without breaking the agreements.
References: