# E911 Caller Location of Indoor Cellular and VoIP Devices

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***Introduction:***

The percentage of households in the United States subscribing only to cellular telephone service grew from 1% in 2001 to 4% in 2003, with a projected figure of 10% by the year 2010.[1] Similarly, the number of Voice Over Internet Protocol (VoIP) subscribers will increase from 1.0 million in 2004 to 17.5 million in 2008.[2] Subsequently, the number of 911 calls initiated from a telephone other than a traditional landline phone has significantly increased since 2003 and continues to rise. According to a report prepared for New York State Department of Transportation and Public Safety,

> As the number of wireless phone subscribers increase, so does the percentage of 911 calls received from wireless phones. Current trends show that by the year 2004, the majority of 911 calls will come from wireless phones. If systematic improvements aren't made soon, the life-saving capabilities of our emergency communications system will be severely limited.[3]
>
> Twenty-five percent of 911 calls received from wireless phones are from people who are not able to describe their locations to emergency dispatchers. That equates to 2,875,000 of the total 115,000,000 wireless 911 calls made in the year 2000.”[4]

While the benefits of mobility and cost effectiveness of replacing traditional telephone land-line service with wireless or VoIP service are inherently obvious, there is a grave hidden pitfall to this choice.

According to the Wireless Communications and Public Safety Act of 1999,

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[1] Federal Communications Commission, Industry Analysis and Technology Division - Wireline Competition Bureau 12th Street S.W. Washington, D.C. 20554, “Trends in Telephone Service”, April 2005, p. 50. (document can be found at http://www.fcc.gov/wcb/trends.html)

[2] “Yankee Says VoIP to Grow 100X”, Light Reading, August 30, 2004, p. 1. (viewed on October 12, 2006), (document available at: http://www/lightreading.com/document.asp?doc_id=58449)

[3] United States Department of Transportation, “The New York State Wireless Enhanced 911 Project: Lessons Learned”, Bob Bailey, Jay M. Scott, 2002, p. 1 (source can be found at : http://www.its.dot.gov/pubsafety/docs/lessons.pdf)

[4] Bailey, p.3.

Enhanced 911 (E911) is defined as the ability to automatically locate a caller.[5] When a person in need of emergency assistance calls 911 from a traditional wire line telephone connected directly to the Public Switched Telephone Network (PSTN), accurate location information is automatically delivered to the Public Service Answering Point (PSAP). The E911 system significantly reduces the time it takes a first responder to reach the caller.

> When 911 calls are made from wireless phones, the call taker does not automatically receive the location of the caller or their callback number. While most subscribers purchase wireless phones primarily for safety reasons, few realize that enhanced 911 service is not available to them.[6]

The difficultly of obtaining the caller's location information is greatly increased when the emergency call is placed from a wireless telephone or a Voice over Internet Protocol (VoIP) telephone. In the case of the wireless caller, the current location technology is reasonably accurate if the caller is outside of a building. However, if the 911 caller is inside of a building, determining the location of the caller presents an extremely difficult technological challenge. Similarly, VoIP providers require subscribers to register an address; this information is of little use to the PSAP if the users have moved their VoIP access device to a location other than the registered address.

How to address these concerns has been the topic of numerous debates among the FCC, stakeholders, and other interested parties since the inception of E911. In a comprehensive report issued to the Commission in 2002, Dale Hatfield, former Chief of the Office of Engineering and Technology (OET) at the Commission stated "…growing dependence on wireless networks, serve to further emphasize the importance of E911 in

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[5] Federal Communications Commission, Before the Federal Communications Commission, Washington, D.C., 20554,"Implementation of 911 Act", FCC 00-327,p.1.

[6] Bailey, p. 3.

general, and wireless E911 in particular, to the safety of life and property and homeland security."[7] More recently, FCC Commissioner Copps said during a monthly meeting in September of 2006:

> The Bureau must also work quickly to further develop our standards for E911 capability for both wireless and VoIP devices. On the wireless front, we need to provide additional guidance to ensure that the location accuracy figures that carriers report accurately reflect real-world performance and are consistent across carriers. We also need to continue our efforts to make sure that consumers understand the level of protection that their mobile phones actually provide them, especially within buildings. On the VoIP front, we need to move forward with our ongoing rulemaking regarding automatic location sensing technologies.[8]

It is evident that policy makers and safety officials view this issue as one in need of immediate attention.

This Capstone project analyzes possible viable solutions that could be used to determine the location of a 911 caller when the call originates from either a wireless telephone within a building or from a VoIP telephone at a non-registered address. Furthermore, this paper explains the policy considerations of E911 and provides a method of evaluation which enables policy makers and interested stake holders to analyze and either reject or accept a particular existing or emerging technology as a feasible solution. We determined that there is no single comprehensive solution that can improve the success of locating a 911 caller from either a cellular telephone from within a building or from a VoIP at a non-registered address.

Our analysis is explained is five parts. First, Section *1, Key Definitions and*

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[7] Federal Communications Commission, Washington, D.C., 20554, "A Report on Technical and Operational Issues Impacting the Provision of Wireless Enhanced 911 Services". Dale N. Hatfield, 2002, p.ii.

[8] Federal Communications Commission, Washington, D.C., 20554, "Establishment of the Public Safety and Homeland Security Bureau", Commissioner Michael J. Copps, p.2. (source can be found at: http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-267599A3.pdf)

*Terminology,* will provide some useful definitions pertaining to location technologies and policy terminology. Next, section *2, The Federal Communications Commission (FCC) Location Requirements for E911,* describes the location requirements for a cellular or VoIP E911 caller. Section *3, Existing and Emerging E911 Location Technologies*, proceeds with a technical overview of possible solutions. Following that, Section *4, Blended Solution Analysis and Geographic Recommendations,* analyzes each technology as a possible solution and provides recommendations for disparate geographic areas and Section *5 Review of Testing Procedures,* discusses the need for a comprehensive test plan. Lastly, Section *6, Conclusions and Recommendations*, summarizes previous findings and suggestions for additional steps towards developing a feasible solution.

### *1.0 Key Definitions and Terminology*

An expansion of the terms E911, ALI, PSAP and triangulation will reduce any ambiguity of the meaning of these expressions. The FCC defines E911 as “an emergency telephone system using the digits 9-1-1 that provides additional information to the emergency dispatcher, such as Automatic Number Identification (ANI) or Automatic Location Identification (ALI)”.[9] Additionally, the FCC states that ALI is the “delivery of the location of a wireless handset to a PSAP without the need for inquiry by the dispatcher”.[10] An ALI record, an association between a telephone number and an address, is stored in a database at the PSAP center. The ability to determine ALI information is critical in situations where a distressed caller is unable to give the emergency dispatcher his or her location. Lastly, the FCC’s definition of a PSAP is a “911 answering station

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[9] Federal Communications Commission, “Guidelines for Testing and Verifying the Accuracy of Wireless E911 Location Systems”, OET Bulletin No. 71, April 2000, p. 9.
[10] FCC, OET Bulletin No. 71, p. 9.

designated to receive 911 calls from a specific geographic area".[11]

While most technical terms used in this paper have only one possible definition, the term triangulation can be defined in many ways depending upon its application. Triangulation, broadly speaking, is a method used to calculate the location of a wireless device through the reception of two or more signals originating from different locations. Depending on the cellular protocol in use by a particular provider, triangulation may be achieved by using the signals' timing information, signal transmission origin or a combination of two or more signal parameters. Because the exact method of triangulation in use by a particular provider is irrelevant to the discussion of E911 caller location, the generic definition is inferred. Lastly, the expression, "nomadic VoIP" is defined as the ability to use a VoIP device in various locations. (A more comprehensive list of key terms and definitions can be found in *Appendix A* at the end of this paper.)

### 1.1 *The Current E911 System and Problems with Indoor Wireless and Nomadic VoIP*

In addition to key terms and definitions it is important to describe the current E911 system and how the location of a caller is determined. Every telephone number in the PSTN has an associated address defined to a particular geographic or political area. This information is hard-coded and stored in a central computer database accessible to the PSTN Central Offices (CO) throughout the United States. When a caller dials the digits 9-1-1 from a traditional land-line telephone, or routers within the CO route the incoming call to a particular PSAP based on the information stored in the database. Once the call has been routed to the correct PSAP, ALI of the caller is displayed on the call taker's computer screen. The PSAP in turn relays the address to the appropriate

[11] FCC, OET Bulletin No. 71, p. 9.

emergency responder, thus enabling the emergency responder to reach the distressed caller expeditiously.

Though VoIP subscribers are required to register an address with the provider, the VoIP device and therefore the assigned telephone number can be used in any geographic area to send and receive telephone calls. 911 calls initiated from a VoIP phone might be routed to a PSAP that is not proximal to the caller.  For example, a resident of Broomfield, Colorado who makes a 911 call from his VoIP device while vacationing in San Jose, California would be erroneously routed to the PSAP responsible for the Broomfield, Colorado area unless the user has reregistered his or her vacation address information with the provider. Currently, there is no universally accepted procedure in place to re-route a call to the correct PSAP in the event the call is erroneously routed to the incorrect PSAP.

Even if the call arrives at the correct PSAP, there may be no means to obtain the necessary location information or the location information might not be in a usable format.  Many of the location technologies used for wireless telephony and nomadic VoIP devices provide longitude and latitude coordinates. However, a longitude and latitude coordinates do not translate well to a street address.  The PSAPs must be able to provide emergency responders with a usable address format, compatible to the Mater Street Address Guide (MSAG) format. Additionally the *z*-coordinate, or vertical location above ground level, may also be necessary to determine the exact location of a 911 caller. If a first responder is provided with the street address of 20 story building and no z-coordinate, he/she would not know which floor the distressed caller is located.   PSAPs require "usable and actionable" location information so first responders know "which door to kick down."[12]

**2.0 *The Federal Communications Commission Location Requirements for E911***

The FCC defines the E911 ALI compliance standards for wireless service providers in two phases. Phase I compliance mandates that wireless carriers must provide the PSAPs with the location of the cell site or sector of the incoming call.[13] Phase II specifies that for network-based solutions ALI information must be within 100 meters for 67% of all calls and 300 meters for 95% of all calls.[14] Additionally, Phase II rules state that for handset-based solutions ALI information must be within 50 meters for 67% of all calls and 150 meters for 95% of all calls.[15] While wireless providers have been able to meet the required Phase I conditions, they face challenges fulfilling the Phase II requisites when the cellular call originates from indoors.

With respect to E911 VoIP based calls, Internet Protocol Enabled (IP-enabled) service providers are responsible for obtaining and storing address information from all VoIP subscribers. The registered address is used to provide ALI of a 911 VoIP caller to the PSAPs.[16] Additionally, the FCC states that all IP-enabled service providers must make available to customers a method to change their registered location information.[17] Many stake holders claim that this method of obtaining ALI information of a VoIP caller is unreliable as it places the responsibility on the customer to contact their service

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[12] Conversation with Steve Meer, CTO of Intrado on February 2, 2007
[13] FCC, OET Bulletin No. 71, p. 3.
[14] FCC, OET Bulletin No. 71, p. 3.
[15] FCC, OET Bulletin No. 71, p. 3.
[16] Federal Communications Commission, Before the Federal Communications Commission, Washington, D.C., 20554, "In the Matters of IP-Enabled Services, E911 Requirements for IP-Enabled Service Providers, FCC 05-116, p. 29.
[17] FCC 05-116, p. 29.

provider whenever they use the VoIP interface device at a non-registered location.[18]

As both VoIP and wireless service providers are striving to meet their respective location compliance requirements as defined by the FCC, these industries are testing new location technologies to provide the best possible ALI information. Additionally, location based services (LBS) are growing in the wireless market.[19] The following sections of this paper present some existing and new technologies that will be evaluated as potential solutions this intricate problem.

### *3.0 Existing and Emerging E911 Location Technologies*

While both the PSTN and VoIP telephone systems utilize a database association between telephone numbers and addresses to determine the location of a 911 caller, due to the potential nomadic nature of a VoIP caller and the reliance upon the customer initiated update this hard-coded database location system is unreliable for nomadic VoIP. Similarly, triangulation is highly effective for determining the location of a 911 cellular caller outside of a building, but due to the unpredictable propagation path and reduced signal strength of a signal inside of a building, it is ineffective for locating a cellular caller indoors. The proceeding sections describe unique location methods of new and emerging technologies that may overcome the limitations of the current E911 system. Additionally, an in-depth analysis is provided to aid the evaluation of each technology's potentiality as a viable solution. These technologies were analyzed based on the ability to meet the FCC phase II accuracy requirements, scalability, time-to-first-fix (TTFF), and the ability to effectively perform within a defined geographic environment.

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[18] Conversation with Roger Hixson of NENA, February 9, 2007
[19] Sirf Technology, Inc., "Location Based Services: Amplifying ARPU for carriers", p.2 (source can be found at: http://sirf.com/sirfamplifyingLBS.pdf)

### *3.1.0 A-GPS*

GPS was developed by the Department of Defense and is managed by the United States Air Force. The last of the 24 satellites was deployed in 1993.[20] It was released to the pubic for general use in 1996. The GPS receiver senses three or more satellites. The satellites in a low Earth orbit emit signals traveling at known speeds. Using trilateration, the location of GPS enabled devices can be determined. These receivers work well when they have LOS to the satellites, i.e. in outdoor environments. In indoor environments, the signal strength diminishes significantly rendering the GPS signal almost useless. To allow receivers to use the signal in indoor locations or in places where the signal strength is very low, certain assistance methods are used to enhance the signal.[21] The "A" in A-GPS refers to "assistance" which facilitates a better received Signal to Noise Ratio (SNR) in indoor environment at much lower received power levels.

### *3.1.1 Principles of Operation*

A-GPS provides an assistance signal to the receiver to make a better approximation of its location. A-GPS allows reduction in TTFF[22] on the location by obtaining help from the wireless base station whose location is known. It provides satellite location information to the mobile station to reduce its search space. This reduction in the time required to get a lock on the satellites reduces the long integration periods otherwise required for GPS receivers indoors. Therefore A-GPS can be used as a

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[20] United States Department of the Interior, National Parks Service, "Global Positioning Systems' History", p. 1, (source available at: www.nps.gov/gis/gps/history.html)
[21] Frank van Diggelen and Charles Abraham, "Indoor GPS Technology", Global Locate, Inc. IEEE Position, Location & Navigation Symposium, 2002 Pages 240-247
[22] G. M. Djuknic, R. E. Richton, "Geo-location and Assisted-GPS", IEEE Computer, Volume 34, Issue 2, February 2001, pages 123-125.

location technology for E-911 services as well as many other location applications. It provides better accuracy than most of the other location based systems currently in production.

### *3.1.2 Strengths*

A-GPS provides very accurate measurements in the range of 5-30 meters accuracy.[23] The accuracy varies from application to application but still meets or exceeds the FCC phase II network based requirements. The accuracy also depends on the time the receiver is allowed to integrate the GPS signal. A receiver which has been sitting at a constant position for a long time (minutes) can be located with greater accuracy than a one which has been moving around. The receiver can get an approximate location in a few seconds allowing the first responders to start moving and then provide a more accurate location as it has more time to integrate.

Scalability in GPS is the greatest benefit for the technology. As the GPS satellites are already in service, the only cost incurred is equipping a handset with a GPS capable chip set. The coverage for GPS can be considered from two perspectives. Coverage is available all over the globe at all times of the year. In that sense, GPS offers the best coverage amongst all technologies considered for the solution. As mentioned earlier, GPS suffers indoors, and A-GPS alleviates this problem somewhat.

Additionally, GPS provides the z coordinate to estimate height. According to G.M. Djuknic and R.E. Richton, “GPS receivers process the signals to compute position

[23] “Overview of Location Technologies” Openwave Presentation Nov 19th 2002

in 3D-latitude, longitude and altitude-within a radius of ten meters or better."[24] GPS chipsets can offload the location calculation from the main processor of a mobile device, allowing the main processor of the end device to do important call processing functions. GPS chipsets have already been deployed in some handsets making the technology a good choice for integration. Companies like Global Locate and Rosum have made effective use of the GPS technology and currently sell LBS in the market. Considering these strengths, GPS stands out as a good solution for suburban and rural deployments.

### *3.1.3 Weaknesses*

The GPS receivers working indoors need to have a 20dB to 30dB[25] of extra signal processing gain over the outdoor receivers due the high attenuation of GPS signals received indoors. This processing gain is achieved by having multiple correlation operations in parallel. But in the case of multi-path propagation and very low received power levels, the A-GPS technology takes more time to obtain the location.

Power consumption is one of the most important issues related to the cellular location problem. The correlation operation is a mathematically intensive operation and requires a great deal of relative power from the end device in which it resides. In some cases it might drain the cellular phone battery faster than expected. This would not be such a significant concern with nomadic VoIP users. When a PC is used as the end device, battery power is greater than a cell phone. These issues need to be addressed before this technology can become a viable solution for improved E911 location.

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[24] G.M. Djuknic and R.E. Richton, "Geolocation and Assisted GPS", IEEE Computer Magazine, vol. 34, Issue 2, February 2001, p. 123-125

[25] Frank van Diggelen and Charles Abraham, "Indoor GPS Technology", Global Locate Inc., IEEE Position, Location & Navigation Symposium, 2002 Pages 240-247

The primary weakness of GPS is that the received signal strength is very low as the satellites are far away from the receiving stations. Also, LOS is required for acquiring a lock on the satellites quickly. In urban and suburban areas, it is difficult to get the acceptable performance and reliability even when A-GPS is used. The low received signal strength is the primary reason in addition to multi-path reception which further degrades the signal. These two limitations have created problems and make it difficult for A-GPS to be a viable solution with the currently available chipsets for location in indoor locations.

### *3.2 Skyhook Wireless Inc.*

Skyhook Wireless uses the ubiquitous 802.11x (Wi-Fi) footprint present throughout metropolitan areas of the United States to develop and sell LBS. Skyhook Wireless' Wi-Fi Positioning System (WPS), which is designed to be used with 802.11x enabled laptops, Personal Digital Assistants (PDA), and Smart Phones, is the first wide-area location determination system to utilize a wireless access point (WAP) infrastructure.[26] Because WAPs are becoming more prevalent in the market, WPS may be a feasible solution for obtaining location information for both indoor cellular and nomadic VoIP 911 callers.[27]

#### *3.2.1 Principles of Operation*

Skyhook utilizes Received Signal Strength (RSS) Fingerprinting technology to locate mobile end users, taking advantage of the unique characteristics of discrete

[26] Skyhook Wireless White Paper, “Wi-Fi Positioning System- Accuracy, Availability and Time to Fix”. p.2.

[27] Emma Wollacott, Techworld, “Wi-Fi growth set to rise rapidly”, March 03, 2006, p.1.

802.11x signals from a nearby WAP to locate a mobile user. The 802.11x enabled device with embedded Skyhook software and chip set calculates distance and obtains unique 802.11x characteristics (RSS fingerprint) of several WAPs. The distance data and the RSS fingerprint are sent to the Skyhook database which stores correlations between each WAP's RSS fingerprint and physical address. Skyhook uses a thorough and systematic data collection method that 'scans' for active WAPs throughout the US. Skyhook claims they are able to establish a '360 degree' profile of every access point within a coverage area.[28]

Based on the known WAP addresses, the end user device location can be derived. Skyhook sends the device its own location information is nearly instantaneous. Once the end device receives its address, the location information is sent to the PSAP using the same communications channel as the voice call.[29] Additionally, Skyhook claims to posses the ability to determine the z-coordinate. However, they are still working on a format the PSAPs can use.[30]

### *3.2.2 Strengths*

Skyhook wireless performs best in urban and suburban environments because it leverages the existing infrastructure of widespread penetration of 802.11 access points and therefore offers high availability. According to Skyhook, in any given test area, there are at least six to eight known WAPs, providing a reliable set of RSS fingerprints.[31]

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[28] Skyhook Wireless White Paper, "Wi-Fi Positioning System- Accuracy, Availability and Time to Fix". p.3.

[29] Skyhook Wireless White Paper, "Wi-Fi Positioning System- Accuracy, Availability and Time to Fix". p.3.

[30] Skyhook Wireless, Conversation with Jed Rice, February 6, 2007.

[31] Skyhook Wireless White Paper, "Wi-Fi Positioning System- Accuracy, Availability and Time to Fix". p.4.

Because the range of coverage grows linearly as WAP deployments increase, Skyhook's solution seems inherently scalable. As of January, 2007 the Skyhook reference database contained 15 million WAP location records encompassing 70% of the US population and over 2,500 cities and towns.[32]

Additionally, Skyhook's solution utilizes little processing power, has no line of sight (LOS) requirements, and the radio propagation of high bandwidth/short range 802.11 access points makes TTFF less than 50 milliseconds.[33] Finally, Skyhook Wireless is already selling its technology to AOL and Skype for LBS and they claim a location accuracy of less than 50 meters.[34]

### *3.2.3 Weaknesses*

While Skyhook wireless performs well in urban and suburban environments, they fall short in rural environments where there are few WAPs. Additionally, Skyhook claims to reach over 70% of the US population; however there are coverage gaps even in urban and suburban areas where WAPs in closed corporate campuses and gated communities may be inaccessible.

Another weakness of Skyhook's solution is its use of unlicensed spectrum. Technologists believe that the regulatory system cannot risk the lives of E911 callers by operating a safety service in the unlicensed spectrum.[35] As the 802.11 band becomes more utilized, interference becomes a growing concern which could produce unreliable

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[32] Skyhook Wireless White Paper, "Wi-Fi Positioning System- Accuracy, Availability and Time to Fix". p.3.
[33] Skyhook Wireless White Paper, "Wi-Fi Positioning System- Accuracy, Availability and Time to Fix". p.3.
[34] Skyhook Wireless, Conversation with Jed Rice, February 6, 2007.
[35] University of Colorado at Boulder, Conversation with Jose Santos, Instructor, Interdisciplinary Telecommunications Department, February 6, 2007.

WAP address transmission. Jed Rice from Skyhook does not view this as a problem.

### *3.3 Cricket*

Cricket is an indoor location system that was developed by PhD student Nissanka Bodhi Priyantha as a part of his thesis defense at the Department of Electrical Engineering and Computer Science at Massachusetts Institute of Technology. Cricket is developed on the active-beacon passive-listener architecture.[36] The technology has not been tested commercially to date. However, the high degree of location accuracy warrants inclusion for consideration in the context of our research.

#### *3.3.1 Principles of Operation*

The Cricket solution consists of two types of nodes, microcontrollers, and devices that transmit ultrasonic pulses. The beacon nodes are small radio-frequency (RF) transceivers that are installed throughout buildings and periodically transmit its location information along with an ultrasonic pulse.[37] Passive receivers, embedded in the end devices listen to transmissions from the beacons. The microcontrollers in the end device measure their distances from the respective beacon and calculate their own location.[38]

#### *3.3.2 Strengths*

The strongest feature of this technology is its accuracy. The author states that Cricket has a position accuracy of ten centimeters and an orientation accuracy of three

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[36] "The Cricket Indoor Location System." Nissanka Bodhi Priyantha, Computer Science and Electrical Engineering PhD defense, Massachusetts Institute of Technology June 2005. p.3
[37] "The Cricket Indoor Location System." Nissanka Bodhi Priyantha, Computer Science and Electrical Engineering PhD defense, Massachusetts Institute of Technology June 2005. p.27
[38] "The Cricket Indoor Location System." Nissanka Bodhi Priyantha, Computer Science and Electrical Engineering PhD defense, Massachusetts Institute of Technology June 2005. p.3

degrees.[39] Along with accuracy and scalability, minimal processor use was the primary goal of this PhD project. The author is convinced that the system scales regardless of the number and density of end devices.[40] Another advantage of the Cricket technology is its neutrality to topography. It performs consistently in rural, suburban, and urban environments. Lastly, because the RF signals are transmitted only within the building, its performance is not degraded due to LOS issues that might be common in other location based technologies.

### *3.3.3 Weaknesses*

At this point, Cricket can not be considered as a potential solution because it is still in the incubator stages of development. Concomitantly, the deployment of the Cricket solution in its present state would be cumbersome and require a vast amount of equipment. Though on paper Cricket provides the most accurate location information of any solution studied to date, these obstacles are too great to overcome.

## *3.4 S5 Wireless Inc.*

S5 Wireless Inc. is a wireless location services company. They have designed and produced a solution that could improve the ability to locate a nomadic VoIP or indoor cellular 911 callers. Their technology uses a small chip or 'tag,' that can be attached or embedded into end devices to be located.

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[39] "The Cricket Indoor Location System." Nissanka Bodhi Priyantha, Computer Science and Electrical Engineering PhD defense, Massachusetts Institute of Technology June 2005. p.3
[40] "The Cricket Indoor Location System." Nissanka Bodhi Priyantha, Computer Science and Electrical Engineering PhD defense, Massachusetts Institute of Technology June 2005. p.28

### *3.4.1 Principles of Operation*

The S5 network consists of an embedded 'tag' chip, transceiver base stations operating in the 915 MHz Industrial, Scientific, and Medical (ISM) band, Location and Telemetry Servers (LATS), and a Network Operation Center (NOC). An IP backbone ties the network together. The base station uses Direct Sequence Spread Spectrum (DSSS) and, the "…S5 chip transmits a uniquely designed wireless signal that is detected by a network of receivers throughout a region."[41] The base stations forward the information transmitted by the user device to the LATS in the NOC, which contains a database of locations and the processing power to calculate the location of the end device. The LATS use the location information to triangulate the end device utilizing Time Difference of Arrival (TDOA) in x, y, and z coordinates.[42] S5 Wireless claims that this location information is accurate within ten meters of the 911 caller.[43]

### *3.4.2 Strengths*

Once the infrastructure is built out, additional end devices can be tracked without a linear increase to infrastructure, presenting a very scalable solution. The DSSS signals that the S5 device transmits are low data rate signals that have a range of 400 miles LOS and also perform well in urban environments.[44] S5 excels because the DSSS signals have favorable propagation characteristics in all three environments. Once the infrastructure is in place, increased end user devices does not require additional transceivers.

[41] "Location as Strategic Alliance.", S5 Wireless Inc, The Intrado Convergence summit 2006, Oct 26 2006.
[42] x and y are longitude and latitude respectively, while the z coordinate is the height above sea level
[43] Location as Strategic Alliance, S5 Wireless Inc, The Intrado Convergence summit 2006, Oct 26 2006.
[44] Location as Strategic Alliance, S5 Wireless Inc, The Intrado Convergence summit 2006, Oct 26 2006.

### *3.4.3 Weaknesses*

Because S5 does not leverage any existing infrastructure, it requires a critical mass of users to justify a complete build out. Therefore it does not seem well suited for rural or low density environments. Considering that a stand alone infrastructure will need to be built, with no existing technology or infrastructure to leverage, S5 compares unfavorably to some other technologies. Additionally, an IP backbone is necessary to transfer information from the base stations to the LATS. These two considerations could make this solution more costly in a low density area.

The S5 chips are designed to operate at 915MHz ISM bands.[45] Although DSSS signals are designed to be unaffected by other signals, the sheer number of devices working on 915MHz might lead to interference issues. Critics are quick to point out that interference might hinder the reliability of the network and using unlicensed spectrum for public safety always inspires concern.[46] S5 claims to have successfully tested the technology in partnership with Intrado.[47] Given the need for installation of network infrastructure, this technology might only be suited for urban and suburban areas and might be inefficient to deploy in rural areas.

### *3.5 Rosum*

Rosum is the only company currently to provide position location services using over the air Television (TV) broadcast signals combined with A-GPS. Relying on the fact that TV signals are ubiquitous, penetration is high even in rural areas. Additionally,

[45] "S5 Network Deployment Model", S5 Wireless Inc. p.1, (source can be found at: http://www.s5w.com/Products/S5_Products.html)
[46] Conversation with Roger Hixson of NENA on February 14, 2007
[47] "Location as Strategic Alliance", p.1, S5 Wireless Inc., The Intrado Convergence Summit 2006, Oct 26 2006.

GPS is already a well established technology for location determination. The chip that Rosum developed is a hybrid capable of using a combination of GPS and TV broadcast signals to provide accurate location information.

### *3.5.1 Principles of Operation*

Rosum requires that one of two different chip sets be embedded in the device to be located. The Rosum TV Measurement Module (RTMM) chip senses TV signals in the end device to be located. Rosum Location Servers (RLS) monitor information from Regional Monitoring Unit (RMU) and combine that with the RTMM data to compute the location of Rosum enabled end devices in its area. The RLS forwards the information to the PSAP. "The RTMM receives aiding information from the RLS and sends back to the RLS, information about the existing TV channels in the area".[48]

The Rosum Hybrid Positioning Module (HPM) chip uses a combination of TV and GPS signals to locate the user in the event one of the signals is not strong enough. The HPM chip can combine the information received from both signal sources to accurately compute the location. This "position information can either be sent back to the RTMM for display on the user device or can be forwarded to PSAPs for 911 emergency location services."[49]

In locations where the TV signals are too weak, Rosum can deploy a supplementary transceiver called the Rosum TV-GPS Plus in which "pseudo TV transmitters (PTTs) can be deployed in a limited area to enable high precision 3D

[48] "System Components", Rosum Corporation, p. 1, (source can be found at: http://www.rosum.com/components_of_rosum_tv-gps_indoor_location_systems.html )
[49] "System Components", Rosum Corporation, p. 1, (source can be found at: http://www.rosum.com/components_of_rosum_tv-gps_indoor_location_systems.html )

positioning."[50] Given that GPS signals are subject to multi-path fading in urban environments the Rosum solution may be more suited for suburban and rural settings. In rural settings, where TV broadcast signals attenuate, the Rosum solution supplements these weak signals with the PTTs and the utilization of GPS.

### *3.5.2 Strengths*

Rosum uses A-GPS and TV broadcast signals to locate the user and since an infrastructure is already in place, Rosum claims that minimal incremental build out is necessary to make this a commercially viable solution. In urban areas, GPS signals may be unusable due to multi-path fading from tall buildings and in certain rural areas there may be insufficient holes in TV broadcast penetration. In these scenarios, the HPM can provide location information by using a combination of TV and GPS signals.

The HPM chip will need to be embedded into user devices. Rosum claims that in a few years most user devices will already have TV tuner cards built in them.[51] This hardware could then be used to process the TV broadcast signals for location purposes. Rosum claims that the hybrid combination of A-GPS and TV-broadcast signals provides accurate location information irrespective of the topography. Additionally, "Rosum does not require a TV signal to be strong enough to be viewed; 50dB of processing gain allows us to use even weak TV signals for location."[52] Rosum also claims that since the frequency of TV broadcast signals is much lower than GPS signals, there is less attenuation and therefore can penetrate buildings better than GPS. Also, the HPM

[50]"Rosum TV-GPS Plus", Rosum Corporation p.1, (source can be found at: http://www.rosum.com/rosum_tv-gps_plus_indoor_location_technology.html )
[51] "Mobile TV", Rosum Corporation, The Intrado Convergence summit 2006, Oct 26 2006.
[52] "Rosum Advantages", Rosum Corporation, p.1 (source can be found at: http://www.rosum.com/rosum_TV-GPS_technical_advantages_over_GPS.html )

platform is capable of integrating GPS and TV information simultaneously to provide better location information in the situation where TV broadcast signals or GPS signals alone are not good enough.

Rosum is one of the few companies to have engineered a solution that has two underlying technologies tied into one: TV broadcast signal and GPS. This makes it an attractive solution. The fact that it relies on existing infrastructures like TV broadcast and GPS satellites reduces the additional infrastructure that will need to be installed. Rosum claims that 28 monitor units are currently serving 58 million users.[53] Rosum also claims that the price of the RTMM chips is less than one dollar (in mass production).[54] Lastly, Rosum is working on the ability to determine the z-coordinate.

### *3.5.3 Weaknesses*

Although TV-broadcast signals have good penetration, there may be places in rural America and urban canyons where the signals are too weak or not present at all. While Rosum claims that they can use pseudo transmitters to alleviate this problem, the FCC must license the PTTs. Broadcasters might be reluctant to allow Rosum to use the PTTs for fear of interference, as Rosum would be operating their PTTs in the same band. PTTs would be required in places with low TV signal coverage. Lastly, the Rosum chip will need to be integrated into user devices and doesn't have a standalone tag that can be attached to user devices.

[53] Conversation with Todd Young, Rosum Corporation, Director of Product and Business Development, February 21, 2007
[54] Conversation with Todd Young, Rosum Corporation, Director of Product and Business Development, February 21, 2007

### *4.0 Blended Solution*

Through our research efforts, we arrived at the conclusion that there is presently no single, comprehensive solution to improve location accuracy for indoor cellular and nomadic VoIP users. The evaluation of the technologies lead us to believe that there is no silver bullet to mitigate the problem of indoor cellular and nomadic VoIP 911 location. However, it is our assessment that a combination of existing or emerging technologies could be used to significantly improve location accuracy.

The technologies we chose to evaluate are in different stages of development. While Cricket is at a conceptual stage, Rosum and S5 are closer to commercial deployment. Skyhook sells its services presently. We did not expend significant resources producing a comprehensive economic feasibility analysis because many of the technologies we evaluated are not in or near production.

When evaluating these technologies, we assume a minimum threshold of 50 meters' accuracy and 95% availability. This demarcation comes from existing FCC Phase II requirements for handset solutions. Additionally, we have tried to combine the respective technologies on the basis of their ability to cover all the three topographies under consideration; urban, suburban and rural. After analyzing each of the five technologies based on their strengths and efficiencies in different topographies, ease of implementation and ease of integration, we have developed three blended solutions which might compliment each other and alleviate the limitations of a single standalone technology: A-GPS & S5, A-GPS & Skyhook, Skyhook & Rosum.

### *4.1 Topographies: Urban, Suburban, and Rural*

The three distinct topographies found in the United States are described as: urban, suburban, and rural. Each environment has distinguishing topological considerations that cause unique propagation effects of radio signals. Due to these effects, we must evaluate each technology in the context of each discrete environment.

Though Rosum seems like a potential winner in suburban and rural environments, S5 might be a better solution in the urban environment. S5 and Rosum claim they are close to commercial deployment but have yet to sell their technology to a client. One technology that seems promising in urban environments is Wi-Fi Positioning System (WPS). Skyhook Wireless has based their commercial offering on WPS technology. The company is making its presence felt in the LBS industry. They have conducted “third party” tests to verify their accuracy, availability, and time to fix. While Skyhook excels in an environment with an existing 802.11x infrastructure, the technology fails in rural areas that lack an 802.11x footprint.

Similarly, A-GPS performs very well in rural areas due to the minimal multi-path fading and a lack of interference. However, it is an unreliable solution in urban and suburban environments. Cricket is the only solution among the technologies under scrutiny that is independent of the environment in which it is deployed. It depends on the signals transmitted from beacons that need to be installed inside a building and is the most accurate of all the technologies. Unfortunately, there are scalability limitations when considering Cricket. Concomitantly, Cricket is furthest away from commercial deployment and is therefore set aside when developing blended solutions.

### *4.2 A-GPS and S5*

GPS is a well established technology for location purposes outdoors and A-GPS simply uses external network resources to supplement the weak GPS signal indoors. A-GPS and the RFID solution provided by S5 could be blended together to form a good hybrid solution. The strengths of the individual technologies could be harnessed to provide location information in different topographies. A-GPS will prove to be an accurate location technology in rural areas due to minimal interference and its existing presence in the market.

Since GPS satellites are already in place, only S5 infrastructure would need to be deployed in urban and suburban environments. Because DSSS signals transmit at a low data rate, and behave well in urban environments, the S5 solutions succeeds where GPS falls short.

### *4.3 A-GPS- Skyhook*

As explained earlier, A-GPS is the only technology we evaluated that can be used in rural environments without extensive infrastructure build out. The Skyhook Wireless is the only LBS in the market that we evaluated. They excel in urban and suburban environments because of the widespread availability of 802.11x. Additionally, Skyhook has partnered with SiRF, a GPS chip and software company. They plan to license their technology and develop chips for handsets that can use either GPS or WPS for location purposes.[55] Thus the combination of A-GPS and WPS is a candidate worthy of consideration.

[55]Winsokski Public Relations, Beth Winsokski, "SiRF Teams with Skyhook Wireless to Deliver GPS-Wi-Fi Hybrid to Accelerate Location-Based Services"p.2. (source can be found at: http://www.skyhookwireless.com/news/sirf.html)

### *4.4 Skyhook-Rosum*

Because Skyhook WPS has shown great promise in the urban environments where a number of Wi-Fi Access Points are available, this technology can be coupled with the Rosum solution.  Rosum offers accurate location in places where TV signals are available.  Rosum's TV-GPS plus solution can overcome the limitations of Skyhook's performance in rural environments.  Because Rosum provides PTTs where broadcast TV signals are weak, these two technologies also present a compelling solution.

### *5.0 Review of Testing Procedures*

Although some of the solutions discussed previously seem to look promising, it is difficult to determine their effectiveness without examining the testing procedures. Notably, there are no test procedures for nomadic VoIP callers. While OET Bulletin 71 makes some suggestions for testing for indoor cellular calls, it leaves a lot of room for creative interpretation and warrants a stringent review to better ensure that test results permit meaningful comparisons between technologies.   In particular, there are at least four problems which should be addressed regarding current testing requirements.

First, according to OET Bulletin 71, it is suggested that ALI technologies may be certified for compliance independent of the area in which they are implemented.[56]  ALI technologies cannot be deemed reliable unless the carriers perform the tests in the area they will be serving. For example, a test for location accuracy and reliability conducted in a small geographic area of large city, is not representative of the ability to locate a 911 cellular caller in other parts of the city.

Due to the varying building structures that may exist in a large city or suburban

[56] OET Bulletin 71,p. 2.

area and the vast differences between urban and rural areas, a comprehensive and uniform test plan should be developed to ensure all types of environments are considered before a particular ALI technology can be deemed certified. Furthermore, OET Bulletin 71 provides that carriers and PSAPs should get together and agree on the area to be tested.[57] According to a 2002 report by Dale Hatfield, former Chief of the Office of Engineering and Technology (OET) at the Commission, "uncertainty as to the area over which the test results can be averaged may cause delay in the deployment, acceptance and certification of wireless E911 systems."[58] Currently, there are no specifics on how to conduct testing conducive to a particular topography nor are there clear divisions of geographic areas. The area that is tested could be the whole area, a portion of the area or a combination of both. Because of the numerous carriers that may all serve the same region, testing areas may vary from carrier to carrier within the same PSAP district. As such, to state that a particular technology meets the accuracy requirements can be misleading.

A second shortcoming is that OET Bulletin 71 provides that if Phase II requirements cannot be met, the Phase I location (a cellular sector) should be reported. [59] Although in some cases, a phase I location may be sufficient to route the call to the appropriate PSAP, the area covered by a cell sector in not nearly specific enough to locate a troubled caller. It is unclear if these location points are included in the verification of Phase II location requirements. For example, a PSAP dispatcher who receives a call from a distressed indoor cellular caller might only be provided with the

[57] OET Bulletin 71 p. 4.
[58] Federal Communications Commission, Washington, D.C., 20554, "A Report on Technical and Operational Issues Impacting the Provision of Wireless Enhanced 911 Services". Dale N. Hatfield, 2002, p.43.
[59] OET Bulletin 71, p.3.

cell sector of the originating call. Even if the sector is only 1/10 of a square mile in size (a very conservative assumption), that could easily include fifty buildings. Clearly, providing the PSAP with Phase I location information does little to help locate the distressed caller.

Third, perhaps the most alarming assertion in the OET Bulletin 71 concerns selection of data test points. In particular, the FCC suggests testing in areas where past 911 calls have been placed.[60] While this may be a good starting point, there are several caveats to this method that warrant review. In certain areas where it is known that a large amount of 911 calls are placed on a consistent basis it may be possible to use these data points to determine a testing area, but this does not hold true in every case. The area of a 911 call placed in the past does not ensure a 911 call will occur in that area in the future. A 911 call is a random event.

Furthermore, there is no consideration for future topography changes and no statement regarding re-evaluation and re-testing of an area on a regular basis. For example, a large undeveloped area where no 911 calls have been placed in the past may become the site of a real estate development project. Thus, what was once deemed as a low probability area for a 911 call may now be a high risk area as it becomes more populated.

Lastly, the FCC makes no mention of how many indoor cellular calls must be tested. In addressing Phase II requirements for ALI of a cellular caller, there is no specification of the percentage of indoor cellular calls that must be tested. Dale Hatfield recommends that at least ten percent of all cellular test calls originate indoors.

[60] OET Bulletin 71, p. 6.

[61]Accordingly, carriers and PSAPs can use data points exclusively comprised of outdoor cellular calls. Since the methods for locating an outdoor cellular 911 caller have been proven to fail when the call is made from within a building, a carrier who has performed their tests comprised *exclusively* of outdoor test calls will be compliant per the FCC's guidelines while, nonetheless, ignoring a large portion of 911 calls.

### *6.0 Conclusion and Recommendations*

There are several potential technologies that could enhance the ability to locate a 911 caller regardless of the communications technology. These new and emerging technologies may overcome the limitations of the current E911 system. It is the conclusion of this analysis that there exists no single panacea. There is no silver bullet. The solution should be approached from many angles instead of head on. Any solution imposed by the Commission has to work 24 hours a day, 7 days a week for 300 million Americans.

The Department of Homeland Security (DHS) and the Commission have placed a great deal of emphasis on resolving the problem of increased location accuracy. As technology advances stake holders and policy makers should focus on a layered platform to hook into, rather than a unique solution for each type of telecommunications method. This overlay system that should work in any topological environment; urban, suburban or rural. There would need to be a process to determine which technology will be used in the respective topography. It would be up to service providers, equipment manufacturers and mapping service companies to interface with the prescribed system so that every end device can route a call to the correct PSAP and deliver location information in a usable

[61] Conversation with Dale Hatfield, January 19, 2007.

format. In many environments, there might be more than one method available to locate a caller, while in others there might only be a *technology of last resort.*

As GPS chip manufacturers, network service providers and software manufacturers increasingly invest in location technologies, the list of solutions become longer and the impetus to revisit present location regulations becomes more obvious. The development of LBS technology would make it easier for the FCC to consider drafting more stringent location requirements for both cellular and VoIP service providers. Roger Hixson from NENA has suggested that the Commission put together a group of stake holders to find a comprehensive solution together.[62]

As substitution increases, more and more 911 calls are initiated from cellular and VoIP devices. According to the FCC,

The number of 911 calls placed by people using wireless phones has more than doubled since 1995, to over 50 million a year. Public safety personnel estimate that about 30% of the millions of 911 calls they receive daily are placed from wireless phones, and that percentage is growing.[63]

The conclusion of this capstone team is that there is no single technology to be implemented that would improve location technologies for E911, but a combination of such. As suggested by Dale Hatfield, we recommend that an independent body such as the FCC Technical Advisory Committee or the National Academy of Science spearhead this problem and seek to find a comprehensive solution.

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[62] Conversation with Roger Hixson of NENA on February 14, 2007

[63] Federal Communications Commission, Consumer Publications, “FCC Consumer Facts”, Washington, D.C., 20554,p.1 (available at: http://www.fcc.gov/cgb/consumerfacts/wireless911srvc.html).

*Appendix A*

1. *Attenuation* - Attenuation is the loss of signal strength over distance. It is measured in decibels (dB) per kilometer (expressed as dB/km) or per 100 feet. In the logarithmic decibel scale, a 3 dB loss means a 50 percent loss in power, as computed in the following equation. Specifically, the formula for power loss is: In this equation, a 50 percent loss would actually yield a result of -3 dB. Under certain conditions, the coefficient in the equation will be 20, in which case a result of -6 dB would indicate a 50 percent loss. When describing losses, however, the negative sign is dropped, so that a result of -6 dB is expressed as a 6 dB loss. Attenuation depends on several factors, including the wire composition and size, shielding, and frequency range of the signal. For copper cable, attenuation increases with signal frequency; for optical fiber, attenuation is relatively constant over a large frequency range. Fiber-optic cable has the least attenuation, usually fractions of a decibel per kilometer. Unshielded untwisted-pair cable (such as the silver, flat-satin cables used in short distance telephone and modem lines) has the most attenuation of any cable types used in telecommunications. This type of cable is not used directly in networks.[64]

2. *E911* – an emergency telephone system using the digits 9-1-1 that provides additional information to the emergency dispatcher, such as Automatic Number Identification or Automatic Location Identification.[65]

3. *GPS* – "The Global Positioning System (GPS) is a U.S. space-based radio-navigation system that provides reliable positioning, navigation, and timing services to civilian users on a continuous worldwide basis. For anyone with a GPS receiver, the system will provide location and time. GPS provides accurate location and time information for an unlimited number of people in all weather, day and night, anywhere in the world."[66]

4. *Multi-path fading* - In radio communications, a multipath refers to signals that are reflected back and that are out of phase with each other. Multipaths can arise in areas with a lot of communications traffic, for example. Multipath fading refers to the corruption of received RF signal due to multipath effects. [67]

5. *Nomadic VoIP Caller* -- A VoIP caller who is not at the physical location which is registered at the respective VoIP service provider.

6. *Outdoor Cellular Caller* – A cellular end user making a call while outdoors.

[64] Encyclopedia of Networking, 2nd Edition - Network Press ISBN: 0-7821-1829-1
[65] FCC, OET Bulletin 71, p. 9.
[66] "Global Positioning System – Serving the World", (available at:http://www.gps.gov)
[67] Encyclopedia of Networking, 2nd Edition - Network Press ISBN: 0-7821-1829-1

7. *Triangulation*- “is a method of estimating a position by finding the angle of arrival of radio waves transmitted from two or more sources.” [68]

[68] R. Klukas and M. Fattouche, *Line-of-Site Angle of Arrival Estimation in the Outdoor Multipath Environment*, IEEE Transactions on Vehicular Technology, Vol. 47, No. 1, February 1998, p. 342.

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