Frequency Coordination in the Amateur Radio Emergency Service

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Abstract. The selection of a new frequency for disaster communications use by the Stanford University community is examined in detail. Allocating frequencies in a voluntary radio service is constrained by band overcrowding, limited receiver selectivity, and small or non-existent budgets for regional coordination efforts. When presented with the challenge, individuals from the student radio club and the electrical engineering department developed a three phase plan to model, test, and deploy the use of a new narrowband VHF FM simplex channel. Computer modeling of the radio propagation environment in the San Francisco Bay Area identified several candidate frequencies for further study. Passive monitoring eliminated some of the initial choices by highlighting those exhibiting co-channel interference. An extended period of testing resulted in the final selection of a new channel. The frequency selected at the completion of the study has been in continual use since the fall of 2002 with no reports of co- or adjacent channel interference, demonstrating the effectiveness of the exercise.

I. Introduction

MANY people are familiar with the commercial radio services defined and regulated by the Federal Communications Commission. These include broadcast television and radio, and mobile telephone, data, and paging systems. Less well known radio services include land-mobile voice and data services used by construction firms, taxis, and delivery companies, and local government emergency services such as police, fire, and ambulance. The amateur radio service is often unnoticed among the above popular services, since amateur license grantees are primarily individuals, not corporations or civil agencies. The amateur service is defined by Title 47, Part 97 of the Code of Federal Regulations as having several fundamental purposes. The first principle listed in 47CFR97 is:

(a) Recognition and enhancement of the value of the amateur service to the public as a voluntary noncommercial communication service, particularly with respect to providing emergency communications [1].

Local and regional emergency communication networks are often overstressed and fail during large disastrous events. Several days after the onset of a disaster, temporary networks may be deployed by the Federal Emergency Management Agency (FEMA) or the National Guard to restore lost capacity. But local networks typically fail in the first few hours following a disaster, and the absence of communications capability for 24 to 48 hours can lead to unnecessary loss of life and/or increased damage to property. The causes of network failure include power outages exceeding equipment backup battery lifetimes, broken or downed wires, and overloading due to heavy traffic demands. A more subtle failure mechanism is the inability of emergency services from disparate locales to operate on the same frequency due to regulatory restrictions on co-channel operation which then become implemented in hardware. More succinctly, town A's fire company radios can't talk to town B's fire company radios when both towns respond to a large regional emergency.

Cellular telephone networks, while seemingly ideal for interagency communications, suffer from the fact that the network is designed to support one-to-one traffic, not one-to-many traffic necessary for deploying forces. Public safety communications generally uses a combination of point-to-point systems as well as "dispatch" radio systems, in which everyone on the network can hear the prime transmitting user. This avoids the need for relaying of messages and the corresponding possibility for misinterpretation. Civilian users tend to overload the cellular network beyond its statistical capabilities with welfare traffic. Even so-called push-to-talk cellular services do not provide true handset to handset capability. Both handsets must have access to usable base stations to make the connection.

Since the amateur service is composed of licensed individuals, they are often "first responders" in the event of a disaster, and are in the unique position provide local, regional, and national communications capabilities for the first crucial hours when communication networks fail and until backup systems can be installed and brought on-line. Once main networks are restored, amateur service operations are usually continued in support of volunteer relief agencies such as the Red Cross which do not maintain their own networks. This paper is primarily concerned with emergency communication planning in the amateur service for the Stanford campus, which is located in the San Francisco Bay Area of the state of California (Figure 1). The area is made up of nine large counties surrounding the bay and hosts a population of approximately 5.6 million people in the San Francisco–Oakland–San Jose extended metropolitan areas. The topography varies from sea level to near 1200 meters, and is a challenge for both broadcast service and land-mobile radio communications.

Two major disasters in the late 1980's and early 1990's, the 1989 Loma Prieta earthquake and the 1991 Oakland Hills fires, caused the cities and counties of the Bay Area to extensively review their emergency contingency plans. Though there are many aspects to city and county emergency planning, one overriding

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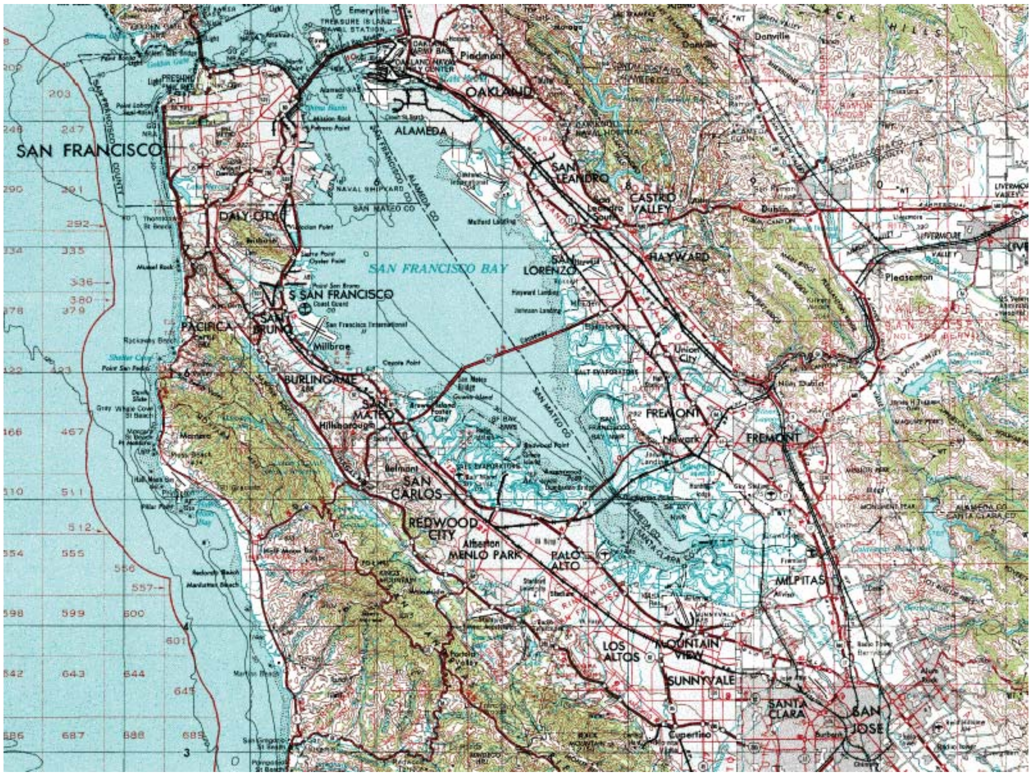

Fig. 1. San Francisco Bay Area topographic map. The Stanford University campus is located at the southwest corner of the bay near the town of Palo Alto. Significant mountain ranges (850m) lie several kilometers to the south and west of the campus, while hilly terrain (150-250m) is common in the immediate vicinity (Image credit: U.S. Geological Survey).

concern after the Oakland Hills fires was the inability of emergency services from different counties to communicate at the scene of the incident. This eventually led to the establishment of a California state-wide emergency communications plan which aspires to provide seamless inter-operation of communication networks at local, regional, and state levels.

The California Office of Emergency Services sponsors a one-day, state-wide emergency drill annually, while county and city emergency services drill more frequently on their own schedules. The amateur radio service participates in the annual state wide drill with other agencies, and drills independently at other times. Typical amateur service drills in the Bay Area are carried out weekly at the city level, monthly in support of regional hospitals, and quarterly on a county-wide basis. Most civil authorities recognize the capabilities of the amateur radio service, and amateur radio stations are installed in many city and county emergency operations centers. In some California counties, amateur radio service volunteers are categorized as "emergency responders," issued identification, and become unpaid employees of the county when activated for drills or real emergencies. In case of injury, these volunteers are covered by workman's compensation laws when deployed in hazardous situations.

Technical standards in both the civil services and the amateur radio service tend to follow a lowest common denominator approach. Though digital voice technologies provide increased capacity in commercial radio networks, disparate budget allocations between various city and county governments mean that the baseline communication capability for inter-operation is narrowband frequency modulation (FM) on the VHF and UHF radio bands. For example, Alameda County upgraded its communications facilities to a county-wide 800 MHz digital trunking system after the Oakland Hills fires, while Santa Clara County continues to use analog FM for most public safety radio services. An umbrella organization, the Association of Public-Safety Communications Officials – International, Inc. sponsors Project 25 in conjunction with the telecommunications industry as a migration path to all-digital communications in the public emergency network [2], but nationwide deployment of the technology is many years in the future. The amateur radio service mirrors the public networks in the adoption of narrowband FM modulation for its baseline local and regional networks. The selectivity of equipment produced for the amateur service tends to be lower than radios produced for government emergency services, which limits the re-use of adjacent-channel frequencies.

Frequency allocation is handled quite differently in the civil and amateur radio services. City, county, and state agencies are permanently allocated frequency channels for their operations by the FCC. In the amateur radio service, frequency bands are identified, but no explicit channelization or allocations are imposed by the FCC. Because of the wide range of band allocations from shortwave through microwave, operating frequency choice in the amateur service is mainly a technology choice based upon propagation considerations, modulation formats, and equipment capabilities, rather than a regulatory choice. All frequency coordination of both automated retransmission (repeater) stations and point to point (simplex) stations is on a voluntary basis by self-organized authorities. When disputes arise, the FCC usually defers to the decision of the local or national amateur frequency coordinating authority [3], [4]. The availability of inexpensive portable equipment and the good propagation characteristics over hilly terrain make the 147 MHz VHF amateur radio band quite popular as well as a site of frequent contention. The subject of the remainder of this paper is frequency coordination of a new VHF simplex channel for Stanford amateur radio emergency service use. The planning, modeling and testing which led to this new coordination took place in August of 2002, and the frequency has been used regularly for drill purposes since the fall of that year.

II. Radio Emergency Services at Stanford

The Stanford University campus is located at the north end of Santa Clara County directly on the border with San Mateo County. The populations of these two counties are 1.6 million and 700 thousand people, respectively. The core Stanford campus is 8 square kilometers in area and houses 14 thousand residents [5]. The daytime population swells to over 20 thousand due to student and staff commuters. The Stanford University Amateur Radio Emergency Service is included in the university emergency response plan. Specific facilities maintained for use by amateur service volunteers include a 450 MHz FM voice repeater at 30m elevation on campus to provide local coverage, and a 1300 MHz repeater at 850m elevation approximately 8 kilometers from campus to provide regional coverage. One 147 MHz simplex channel is identified for local tactical use.

A decade after the Oakland Hills fires, the attacks on New York and Washington, D.C. in September 2001 prompted an additional review of local Bay Area emergency planning. On the university campus, the Stanford Campus Residential Leaseholders [6], the homeowners association, undertook a major overhaul of their emergency plan in conjunction with the campus police and fire services. As part of the review, the need for a tactical radio communications facility was identified. Two candidate radio services were proposed to meet this need, the family radio service (FRS) and the amateur radio service. The family radio service was created in the mid 1990's by the FCC for recreational use and is part of the FCC's Citizens Band services. FRS uses 1/2 watt narrowband FM transmissions in the 460 MHz band. Ground testing with typical FRS hand-held units revealed that the terrain and vegetation of the campus (the Stanford sports team mascot is the Tree) prevented FRS radios from providing the needed coverage. Testing with 147 MHz amateur service hand-held radios with 5 watt capacity provided coverage that was acceptable. An additional advantage of the amateur service is the ability to use much higher transmit power levels for base station radios if necessary. Though amateur licensees may use up to 1.5 kilowatts, voice FM base stations in the 147 MHz amateur service typically use 50 to 100 watts. The disadvantage of using the amateur service for this system is that radio operators need to pass the FCC license examination, whereas FRS and citizens band systems may be operated without a license. In the end, the technical benefits of the amateur service outweighed the regulatory hurdles, and a core group of radio operators were trained and licensed.

The additional loading which the residential civil defense program would place on the existing Stanford amateur radio emergency service frequencies led to an overhaul of the existing frequency allocations. Up to that time, the 440 MHz on-campus repeater served as the prime communication channel for regular drills, with a fall back plan to operate on the repeater frequency in simplex mode if the repeater, which does have battery backup, went down for other reasons. The existing 147 MHz simplex channel had been underutilized for many years, and in the meantime, the national frequency coordination authority had reallocated the band segment containing the Stanford frequency for space satellite to Earth station links [3]. Periodic review of the voluntary amateur band plans results in reallocation of existing frequencies. Though in an emergency, amateurs may forgo any voluntary band plans and operate on any frequency as needed, the presence of weekly and quarterly drill traffic on a satellite band would not be proper. Another solution would have been to drill on a secondary channel, and switch to the prime channel in the satellite band for actual emergencies. There is a strong desire to drill on the frequencies which will be used in an actual emergency, so that operators will have radios pre-programmed and configured, and won't have to remember new procedures when under the stress of an actual deployment. It was decided that the Stanford University Amateur Radio Emergency Service should seek a new permanent 147 MHz simplex channel for regular drills and emergency use. Simplex frequencies in the amateur service are designated as first come first serve. In the amateur emergency service, channels are typically chosen by reviewing a chart of frequencies claimed for use by surrounding towns, and picking a channel in a somewhat ad hoc fashion. Use of the channel during regional drill exercises will then reveal conflicts with other users. It is up to the users of simplex channels to resolve co-channel and adjacent channel interference issues with other users. Wishing to minimize potential conflicts from the start, the Stanford amateur radio emergency service approached the university's student radio club and the electrical engineering department for technical advice on selection of a new VHF simplex channel.

III. Planning and Propagation Modeling

Taking into account the budget (nil) and time constraints (one month) for channel selection, a three phase plan for project completion was developed. Phase one involved using public domain software and databases to model the VHF propagation environment of the Bay Area and identify the best candidate frequencies for Stanford operations. Phase two involved passive monitoring of selected frequencies during co-channel user's drills to reject poor candidates. Phase three involved use of the best candidate frequency for regular weekly drills, with the goal of identifying real conflicts with co- and adjacent channel users. At the end of the trial period, the candidate frequency would be presented to the amateur radio emergency service coordinators for Santa Clara and San Mateo counties for official adoption.

From the outset of phase one, it was recognized that a simple free-space propagation model would not accurately represent the radio environment of the Bay Area, and that the effects of terrain should be included in the modeling and selection process. As mentioned in the introduction, the topography variation is quite significant, and shadowing effects can allow frequency re-use over shorter spatial scales than free-space considerations alone would indicate (Figure 2).

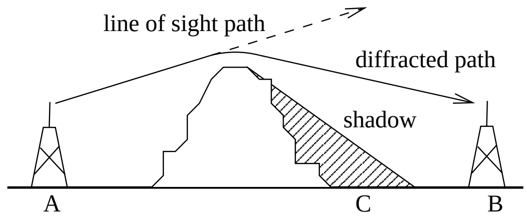

Fig. 2. Terrain effects on VHF radio propagation. The mountain prevents line of sight propagation from point A to point B. Knife-edge diffraction over the mountain allows station A to communicate with station B. Point C lies in the terrain shadow of station A. Different response teams located at points A and C may operate co-channel without experiencing interference.

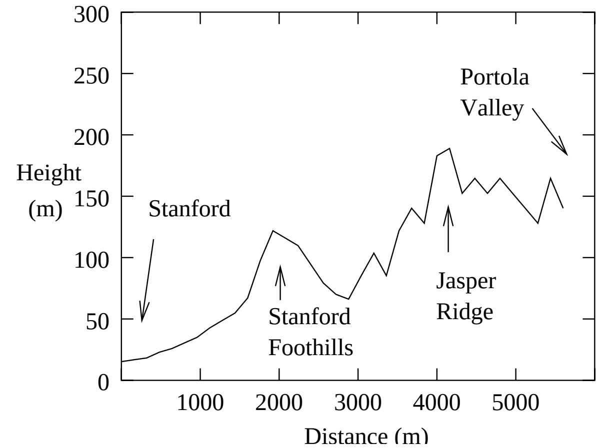

Fig. 3. Digital terrain profile. This data set, showing elevation above sea level in meters between the Stanford campus and the neighboring town of Portola Valley, demonstrates the challenging local propagation environment.

Propagation modeling that includes terrain effects is a FCC requirement for radio transmission facility licensing in the broadcast, business, and public safety radio bands. There are several commercially available software packages which help radio engineers site new towers for broadcast and other radio services, but the costs of these packages can be prohibitive for regular use in the amateur service, where funding sources are limited. Many regional amateur frequency coordinating authorities employ propagation models when reviewing applications for fixed repeater stations [4]. The most common model employed for terrain modeling in the land-mobile radio services is the irregular terrain model (ITM) developed in the late 1960's by the U.S. Department of Commerce [7]. The model combines both physical considerations such as knife edge diffraction and empirical data such as tropospheric propagation loss over typical path lengths. The computerized version of the model is also known as the Longley-Rice model after its primary developers at the National Bureau of Standards. Since the FCC requires the use of Longley-Rice for some radio service sitings, most commercial companies supplying propagation modeling software include ITM as a baseline mode, and develop a value-added product by incorporating graphical user interfaces and terrain database integration into their packages. The bare bones model is available in Fortran source code form from the Department of Commerce (C++ source is available as of November 2003) [8].

The irregular terrain model can be operated in two modes, area prediction mode and point to point mode. As the current study is concerned with co-channel and adjacent channel interference from other cities in the Bay Area, the point to point mode was used. Using ITM in point to point mode requires several inputs, including the frequency of operation, the distance between the radio terminals, the height of the transmitting antennas, ground conductivity, atmosphere refractivity, and a digital topography profile along the line between the terminals (Figure 3). Though no explicit channelization of the amateur service radio bands is required by the FCC, due to population density and repeater stations, the 147 MHz simplex band in the Bay Area is effectively divided into twenty six 15 kHz channels. To promote coordination, frequency usage by city and county are maintained in an on-line database by the amateur radio emergency service [9]. The physical location of each city or county radio facility was taken to be the latitude and longitude coordinates reported in the master U.S. Geological Survey catalog of place names [10]. An average antenna height of 10 meters above local terrain was assumed, based on typical amateur base station installations. Average to poor ground conductivity and sea-level atmosphere were assumed. The GLOBE digital topography database from the National Geophysical Data Center at 1km postings was used for terrain profiles [11]. The interface between ITM and GLOBE was provided by the Institute for Telecommunication Sciences of the U.S. Department of Commerce [8].

Programming for the model proceeded as follows. Since ITM was available only as Fortran source with a command line interface, and the input data existed in a number of disparate databases, a driver program was written in Perl to extract needed information from the databases, run the propagation model, and sort and format the results for printing. All databases were queried to produce the needed input data in flat, comma separated variable (CSV) files in standard ASCII encoding. Since the computational requirements for ITM are quite low by modern standards, a brute force search of the parameter space was employed. The driver program looped over all 26 possible frequencies for simplex operation, and computed and stored the path loss from each town using that frequency to Stanford. These results were then sorted in oder of predicted attenuation and written to disk in fixed column, tabular format. The programming effort resulted in 100 lines of Fortran and 150 lines of Perl. Program execution time was less than two seconds on a 450 MHz Pentium II processor running version 2.4 of the Linux operating system.

Several conclusions can be drawn from viewing the output of the program (Table I). First, the major source of path loss is the $1/d^2$ component of the standard Friis free-space transmission formula where d is the distance to the remote city. Second, the ranking does not follow the $1/d^2$ law exactly, since the terrain loss can be significant even over short distances. Compare the nearby city of La Honda, located 15km away in the Santa Cruz mountains, to San Rafael, located 70km away at the north end of the bay. The La Honda frequency would be a better choice than the San Rafael frequency for co-channel operation, since the total attenuation of a signal arriving from La Honda is greater than that of a signal arriving from San Rafael. The 500m elevation change of the intervening terrain between Stanford and La Honda causes

TABLE I
PREDICTED ATTENUATION FOR VHF BAND RADIO SIGNALS

Freq. (MHz)	Location	Dist. (km)	Space Loss (dB)	Ht. Chg. (m)	Terrn. Loss (dB)	Total Loss (dB)
146.580	Los Gatos	27.8	104.7	50	43.5	148.2
146.520	La Honda	15.1	99.4	507	48.3	147.7
146.490	Millbrae	27.5	104.6	68	40.2	144.8
147.420	San Rafael	69.0	112.6	65	31.7	144.3
146.565	Oakland	43.3	108.5	22	31.8	140.3
146.550	San Francisco	45.1	108.9	46	26.6	135.4
146.460	Cupertino	16.4	100.1	24	34.3	134.3
146.505	S. San Francisco	33.3	106.3	32	20.7	127.0
147.510	Santa Clara	20.3	101.9	34	24.4	126.3
147.570	Foster City	17.5	100.7	31	24.2	124.9

17 dB greater attenuation than the terrain between Stanford and San Rafael. The choice of La Honda over San Rafael may seem counterintuitive to those who only consider free-space loss, but it demonstrates the utility of including terrain modeling.

Some additional manual interpretation of the model output was necessary, as the program does not completely capture the dynamics of amateur radio service simplex operation in the Bay Area. The top program choice, 146.58 MHz, was already allocated to a digital packet radio service. The second program choice, 146.52 MHz, is designated by the national frequency coordination authority as a nation-wide hailing frequency [3]. The fourth program choice, 147.42 MHz, had the town of Los Altos Hills, only 3 kilometers from the campus, as an adjacent channel user, and was rejected on the basis of the frequency selectivity characteristics of radios manufactured for use in the amateur service. This left two choices in the top five, 146.49 and 146.565 MHz, which were identified as candidates for phase two passive monitoring.

IV. Theory into Practice

Phase two passive monitoring took place during the first two weeks of August 2002. The primary base station for Stanford amateur radio emergency service operations is located at 30m elevation on campus. As part of the emergency communications plan, this facility may call upon a high frequency (3 to 30 MHz) radio facility in the hills behind campus at 150 meters elevation for state-wide relaying of traffic. Testing was carried out at the secondary facility since the facilities must be able to communicate via the tactical VHF simplex frequency in the event of an emergency. Passive monitoring of the 146.565 Oakland amateur radio emergency service weekly drill traffic led to the conclusion that co-channel operation would result in significant interference, as Oakland is essentially a straight shot across the bay from Stanford. Monitoring of the 146.49 MHz Millbrae frequency revealed that co-channel operation would be possible without significant interference.

In late August and early September 2002, phase three of the plan was put into action, and regular weekly Stanford drills commenced on 146.49 MHz. This new VHF tactical frequency was also used during quarterly regional drills. No significant co-channel or adjacent channel interference was reported over the next few months of drill operations, and in January 2003 the frequency choice was presented to regional amateur radio emergency service officials for formal adoption.

Several weaknesses in the use of the irregular terrain propagation model were identified by the testing phase. First, since a large number of Bay Area cities are located on the edge of the bay, line-of-sight over water propagation should be accounted for in the model by changing the ground conductivity when the majority of the signal path is determined to be over water. It should be noted that the model prediction worked well for the actual frequency chosen at the end of the study, since the propagation path from Stanford to Millbrae is over land. Second, the Bay Area terrain is quite variable, which can require cities to use antenna supports which exceed the 10m assumption in the model in order to “see over” neighboring hills. The databases could be augmented by polling city radio officers to obtain actual antenna heights. Third, 1km postings are almost too coarse for this type of work. An additional enhancement to the model would be the use of finer resolution topographic data. Public domain digital elevation maps at 30m postings are available from the U.S. Geological Survey, and could be incorporated into a future upgrade to the software. Many commercial packages make use of these 30m data sets.

Propagation modeling is a great aid for planning purposes, but occasionally co- or adjacent interference occurs in the real world and must be dealt with. An effective technical solution if the interference is not too strong is the use of the continuous-tone coded squelch system (CTCSS). This system mixes a low frequency (60 to 250 Hz) tone into the audio of the transmitting station. The receiver squelch is set to open only when the proper tone is present on the demodulated audio. CTCSS encoders and decoders are standard issue on both family radio service and amateur radio service equipment. The system is effective in allowing moderate channel re-use while maintaining back compatibility with unequipped radios. The Stanford amateur radio emergency service routinely drills using this tone feature, so that operators are trained and ready if interference becomes an issue during an actual deployment.

V. Conclusions

In this paper, the role that the amateur radio service plays in augmenting civil authority communication networks in times of disaster has been highlighted. The San Francisco Bay Area has heightened sensitivity to the need for disaster communications due to its large population and experiences with the 1989 Loma Prieta earthquake and 1991 Oakland Hills fires. In the wake of the 2001 terror attacks on the east coast, the Stanford homeowners association reviewed its tactical communication requirements and requested the assistance of the student radio club and the electrical engineering department in meeting its communication needs. Preliminary ground tests in the 460 MHz UHF band determined the inability of the family radio service (FRS) to provide coverage of the campus area. Further testing found that equipment designed for the amateur radio service could provide the needed coverage due to higher power transmitters and use of VHF frequencies which have better propagation characteristics across the heavily vegetated campus. The required licensing and training of community members as amateur radio service operators was not seen as an impediment to the adoption of the amateur radio service for this need.

Frequency coordination in a voluntary radio service can be simplified by defining a three phase plan which makes use of modeling, passive monitoring, and active testing to identify usable channels. Computer modeling of the radio propagation environment selects the best candidate frequencies and greatly reduces the number of channels which must be monitored during on-air testing. The availability of public domain terrain propagation models and geographic databases allows volunteers in the amateur service to use the same engineering tools as professionals to complete a frequency utilization study. Terrain shadowing effects permit co-channel operations that free-space propagation considerations alone would discount. Passive monitoring of candidate frequencies will eliminate those with significant co-channel interference. An active testing phase is necessary to identify conflicts with co- or adjacent channel users before the final adoption of the best candidate channel can take place.

Adoption of this plan for the voluntary coordination of a new VHF simplex frequency for Stanford University emergency communications needs has been a success. The plan was executed on time and within budget constraints. The frequency selected at the completion of the study has been in continual use since the fall of 2002 with no reports of co- or adjacent channel interference, demonstrating the effectiveness of the exercise. The methodologies used in this study can be readily applied by other groups in the amateur radio service, and the lessons learned can be extended to other radio services.

Acknowledgment

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