Signal Capacity Modeling for Shared Radio System Planning

Gary Patrick, NTIA/OSM, 202-482-9132, gpatrick@ntia.doc.gov
Charles Hoffman, NTIA/OSM, 202-482-3456, choffman@ntia.doc.gov
Robert Matheson, NTIA/ITS, 393-497-3293, matheson@its.bldrdoc.gov

Abstract. *Almost every major Federal agency operates an independent mobile radio system in the 162-174 MHz band to provide critical radio communications with its own agents. Last year, NTIA began a joint OSM/ITS Spectrum Efficiency Initiative, which includes a study of whether a shared radio system (e.g., a trunked system) could functionally and advantageously replace most of the specialized single-agency radio systems. The first phase of this work is to understand the amount of service provided by the current single-agency radio systems. A "signal capacity model" was developed, which uses Federal Government Master File (GMF) license data to calculate the number of independent radio signals that could be received by a mobile user at 1-mile increments within a 100-mile radius of Washington, D.C. Since various radio network architectures transmit the same signal from multiple sites, different algorithms were used to calculate the signal capacity for different types of mobile networks. Peak and average signal capacity maps were produced, based on different assumptions about the probable location of users. This data will form the basis for the design of possible alternatives for future shared radio systems.*

1. NTIA's Role in System Planning

The National Telecommunications and Information Administration (NTIA) is the Executive Branch agency responsible for developing and articulating domestic and international telecommunications policy. NTIA's responsibilities include establishing polices concerning Federal spectrum assignments, allocation in use, and providing various Federal departments and agencies with guidance to ensure that their conduct of telecommunications activities is consistent with these polices. One of these policies is to ensure that Federal use of the spectrum is as efficient as possible.

There are many well-known ways to improve the efficiency of mobile radio systems used by Federal agencies [1]. These methods include decreasing bandwidth, increasing geographical frequency reuse, increasing the amount of time that a given frequency is in use (Erlang efficiency), using higher gain directive antennas, and more. The Federal government has expended considerable effort in the past on ensuring that their use of the spectrum is as technically efficient as practicable by adopting many of these spectrum efficient technologies including: narrow-banding, sharing, overlaying, relocating, and applying new spectrum distribution analytical and planning techniques. However, although these methods are well known and their adoption has been strongly encouraged, they often have not been widely applied, because they sometimes also have substantial disadvantages. Sometimes the disadvantage is merely a matter of higher cost (including the requirement to buy new equipment to replace older, less-efficient systems). Sometimes the disadvantages actually entail a decrease in performance or convenience – in addition to high cost.

Therefore, a more realistic objective regarding new mobile radio technologies has been lumped together under the title of "effectiveness." Effectiveness includes a wider range of factors than merely being spectrum efficient; effectiveness also includes usability and cost factors. Usability factors might include larger or heavier equipment with shorter battery life, poorer intelligibility, shorter operational range, more latency (delay time) between a push-to-talk command and the distant user hearing the message, less interoperability with other users, more complexity of operation, lack of needed special features like encryption and digital messages, etc. A new technology with improved spectrum efficiency – by itself – has little merit for the Federal user, if the adoption of the new technology would result in a decrease of effectiveness. A decrease in effectiveness would mean that substantial cost or usability factors outweigh the improved spectrum efficiency.

By its very definition, spectrum effectiveness means "comparing apples and oranges." How much should a 25% improvement in spectrum efficiency weigh against a 60% increase in cost or a 10% decrease in intelligibility? It is likely that the effectiveness of a proposed change would be evaluated differently by different users, for whom the relative benefits of various factors are evaluated differently. Therefore, we will not be able to derive a single formula that will serve to calculate the relative effectiveness of a proposed change as seen by all Federal users. For example, urban users competing for unused channels in a crowded urban environment will probably count spectrum efficiency as more valuable, compared to rural users, where unused spectrum is relatively more plentiful but where too many locations do not have adequate coverage from widely-spaced base stations.

Nevertheless, "effectiveness" is an important concept (even if it can't be calculated precisely), because it forces planners to evaluate proposed changes against a much broader and more complete set of criteria. Proposed changes that benefit some users – but which place other users at a disadvantage – are less likely to be pushed through on the basis of a single factor. Effectiveness-based changes are more likely to benefit a wider range of users and, therefore, such changes may actually be adopted and implemented by a larger number of users.

A study of effectiveness has led us to consider broader questions on how the Federal government is using the radio spectrum and to consider whether larger-scale structural and organizational changes – such as shared radio systems – could improve both the technical efficiency and mission effectiveness of Federal radio systems. Implementing a shared Federal radio system would be a much more challenging project than merely causing Federal users to switch to a more spectrum efficient radio technology (and it might not be worth the trouble, based only on spectrum efficiency gains). However, a large number of related factors are part of the "effectiveness" equation, including large required expenditures to independently solve problems of interoperability between public safety agencies (e.g. SAFECOM), Homeland Security (e.g., HSD and IWN), spectrum efficiency (e.g., the narrowbanding deadlines), improved radio capabilities (e.g., data, encryption, emergency capacity, greatly expanded wireless Internet systems, etc.), and very powerful economy-of-scale and complexity arguments.

In an effort to better understand how Federal agencies are using the spectrum and how we can improve the effectiveness of this use, NTIA has embarked on a multi-phased study of spectrum efficiency and effectiveness within the Federal government land mobile bands. The first phase of the study (described in this paper) will analyze the present Federal use of the radio spectrum in the 162-174 MHz band within a 100-mile radius of Washington, DC by developing a quantitative model of the "signal capacity" of current Federal use of the radio spectrum. The second phase will be based on the quantitative model results developed in the first phase and will explore various modern radio system alternatives to current Federal systems such as shared trunked systems. Depending on the apparent overall benefits identified by the results of this phase, one or more concepts may be selected for further studies, detailed engineering, and/or eventual large-scale or small-scale implementation.

The 162-174 MHz band in the Washington, DC area was selected for this study for the following reasons. The 162-174 MHz band is the most intensely used Federal mobile radio band, and the Washington, DC area is one of the most congested geographical areas for Federal users. Therefore, this selection of frequency band and location should provide the best of opportunities for studying Federal system operations in highly congested areas. Selection of a congested area such as Washington, D.C. provides an opportunity in terms of: 1) investigating spectrum efficiency, 2) maximum opportunity for economic savings, 3) utility for advanced technology solutions, and 4) a maximum familiarity with the territory on the part of Federal spectrum management personnel. The initial decision to include only the 162-174 MHz band in this study was intended to help obtain initial results more rapidly.

When considering the possible advantages of replacing many current smaller individual-agency radio systems with a larger shared radio system, it is necessary to have realistic information on the services provided by the current systems. This information is needed for various reasons, with the main reason being that it serves as a starting point for the design of the new system. It is the intention that any proposed new system design could include many additional factors (e.g., projected growth, etc.), but as a minimum it must match levels of service provided by current systems. Unless previous levels of service are known, there is no way to know whether any replacement system would provide equivalent service.

In addition, many advanced radio systems provide relative advantages or disadvantages that depend substantially on certain economy-of-scale factors. It is often true that the bigger the system, the more efficiently it operates. This is especially true for trunked radio systems, but such results also affect many aspects of calculating peak loading factors, etc. To compare new designed systems with current systems, it is necessary to actually have numeric values for some basic parameters, such as how many channels are required for current systems. Since these systems cannot be realistically designed or compared without this data, the first phase of this study must obtain quantitative information on current system operations.

2. Possible Sources of Current Usage Data

There are various techniques for obtaining the information needed to estimate the level of services for current systems. For example, a detailed survey could be submitted to Federal users to obtain their estimates of current and projected levels of service from their radio networks. However, a survey of this type would be quite difficult and time consuming for many of the agencies since agencies may have to survey each independent bureau and coordinate the results. Furthermore, the individual agencies probably would each have to develop suitable models to describe their own current levels of service, and NTIA would need to convert the results of these models to a common overall model.

Another method would be using the NTIA/ITS Radio Spectrum Measurement System (RSMS) to conduct measurements within the Washington, DC area, measuring the actual amount of traffic on specific radio channels for all frequencies in the band. However, the major concern with the RSMS data would be the time required to measure and analyze such data at many sites over a wide geographical area. Such a concern would be further complicated in measuring low power and intermittent applications. Furthermore, such measurements would probably not be able to collect accurate information on multi-site systems using the same frequencies, and the collected data would require much interpretation by NTIA personnel. Some limited measurements would be useful and may be considered in the future to supplement data in some aspects of this study.

The Government Master File (GMF) is another possible source of information. It contains records of the frequencies assigned to all U.S. Federal Government agencies in the U.S. Although the information contained in the GMF information is somewhat limited, it provides information on Federal radios over a wide geographic range and it is easily accessible. A cursory look at Federal licenses in the 162-174 MHz band showed 1945 specific assignments (licenses) within 100 miles of the center of Washington, DC., as shown in Figure 1.

After considering various possible methods of obtaining quantitative information on current Federal mobile radio service levels, it was decided to estimate current levels of service by analyzing the data that is already available in the GMF, using extensive computer modeling to generate maps showing a quantity called "signal capacity" (as described below). When necessary, the existing GMF data was augmented by consulting with agency representatives to provide any required additional operational data.

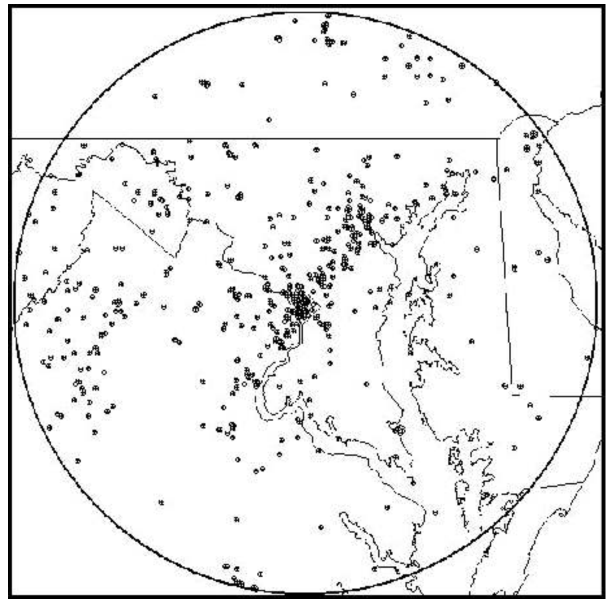

Figure 1 - Federal radios in 162-174 MHz band within 160 km of Washington, D.C.

Several characteristics should be reflected in any model that is used to characterize the amount of service that is being provided to Federal users by current Federal mobile radio systems in the 162-174 MHz band. The model should calculate a quantity that is closely related to the service delivered to Federal mobile radio users. Since Federal radio systems use a wide range of radio technologies, the model should be able to reduce these services to a "lowest common denominator," under which all mobile services could be added together and summarized. Ideally, the model should use only data that is easily available, as provided within the GMF. The model results should also be additive or otherwise allow easy manipulations to include different agencies or other user populations. The model should be transparent, in the sense that a given user population can identify and verify its own contribution to the total model results. The model should allow easy determination of anticipated results from prototype or imaginary alternative radio systems, to facilitate comparisons between existing and alternative systems. Finally, the model should require a minimum number of assumptions that could drastically change the model results.

3. The Signal Capacity Model

Based on the above considerations, we selected a "signal capacity" model to estimate the amount of radio service currently available to Federal users. The signal capacity model assumes that most Federal radio users operate in a mobile or portable environment and depend on a two-way voice channel created by a Federal-owned base station. Therefore, service can be quantified by merely counting the number of independent voice channels that are available at any given geographical location.

Signal capacity (SC) is defined as “the number of independent 2-way voice radio channels that can be received by a typical mobile radio user at a given geographical location.”

The SC model considers only the geographical distribution of the signal field strength from base station transmitters that could be received by mobile users. Field strength values higher than a selected threshold are considered to provide “radio coverage.” The SC model includes no information about base station receivers, or any receivers whatever. However, any future radio system designed to meet the signal capacity specifications produced by the model would obviously also need to meet suitable base station receiver functions (possibly including receive-only sites) and (probably) be capable of mobile-to-mobile operation.

This SC definition is particularly useful for our purposes for several reasons:

1. The major service provided to Federal users in the 162-MHz band is two-way voice channels to mobile users. Therefore, this definition captures most of the use in the 162-MHz band.

2. The SC is additive. This means that the SC values produced by individual transmitters can be simply added to give a cumulative SC value for the group of transmitters.

3. The SC can be calculated from data that is available in GMF license records and technical models, including transmitter data, terrain/ground cover data, and propagation models.

However, the SC definition makes many simplifications that might limit its usefulness in specific circumstances. These include:

1. There is no data on whether a given channel is lightly or heavily used. However, the actual existence of a radio channel suggests that the system was needed, and that need is presumed to exist when a future system is designed.

2. All voice channels are considered identical, whether analog or digital, narrowband or wideband, simplex or duplex, high priority or low, etc. Equally important, signal capacity considers only the radio link, with no distinction as to what capabilities are available via that link: data, encryption, database access, telephone access, wide area access, etc. For SC purposes, “a channel is a channel is a channel.”

In summary, although the SC model may not provide an exact measure of the service that a radio produces, it provides a useful measure of service that can be calculated fairly easily. The SC is a useful model because radio systems can be designed to match or exceed given SC values with a reasonable assurance that a new full-featured radio system (e.g., a trunked system) would match or exceed most performance measures of the old systems.

4. Signal Capacity Analysis Program

The signal capacity analysis program (SCAP) performs its analysis in several stages. The first stage includes reading a modified version of the GMF, which has been sorted to include assignments (licenses) in the 162-174 MHz band within a 100-mile radius of Washington, DC. Each assignment record has been augmented with a function code that tells SCAP how each assignment record is to be analyzed. The function code includes a determination of function and a network identification. SCAP uses the function code to identify base station transmitters, which are used with a terrain-based Longley-Rice propagation program to compute predicted field strengths from that transmitter. The field strength predictions are used to predict a coverage area for each transmitter; all field strengths higher than a certain threshold will be assumed to provide coverage (service) for mobile users. Each independent transmitter that provides coverage at a given location adds to the SC value.

However, the definition of SC counts only *independent* voice channels. It is necessary to determine that multiple radio signals received at a given location are actually independent, since some networks transmit identical signals from multiple sites or prevent multiple sites from transmitting simultaneously. SCAP uses the function and network identification codes to identify transmitters that might not be independent (for example, signals from the same channel of multiple simulcast sites). A network is defined as any related set of transmitters that are part of an integrated system (or network) following a uniform set of signal capacity rules. Because of the need to determine independence, the transmitters belonging to each network must be analyzed as a single unit. A minimal network includes a single transmitter, but other networks could include systems with many sites and many transmitters at each site.

SCAP uses the basic coverage information to calculate a pair of peak and average signal capacity maps for each network, following the specific algorithms for each function code. Specific algorithms have been developed for various technologies, including simulcast, trunked, various repeater networks, and more. The peak SC and average SC maps for each network can be combined to give similar paired peak and average SC maps for multiple networks by simply adding the corresponding elements representing peak or average signal capacity at respective geographical locations. The peak and average SC maps can continue to be added respectively to obtain peak and average SC maps for various larger groups of networks. Continuing the process of addition, coverage maps for groups of networks for individual agencies can become coverage maps for whole Federal departments, and finally for the Federal Government as a whole.

The SC map values are calculated at 1-mile intervals for all locations over a 200-mile square area. However, the GMF database used for these calculations included only GMF records for systems located within a 100-mile radius circle, centered on Washington, DC. Therefore, there can be some substantial "edge" effects in this modeling. A transmitter located just outside the 100-mi radius circle would not be included in the model at all, even though it could have a substantial portion of its coverage area inside the area of the map. A transmitter just inside the circle would be included in the model, but part of its coverage area could lie outside the calculated area of the square map. This reduction in the apparent size of its coverage area could affect the numbers in the average signal capacity maps.

5. Use of Peak and Average SC Maps

Although the signal capacity (SC) was defined initially at a given location, it is convenient to summarize the SC at many adjacent locations as a map, using shading to identify areas that have certain ranges of SC values. Figure 2 is an example of such a map from a single transmitter, calculated for a 200-mi square.

This map shows geographical areas of coverage from a single transmitter. Although this map follows the earlier definition of signal capacity, it is called a "peak" signal capacity (PSC) map to distinguish it from an "average" signal capacity (ASC) map described later. The light-shaded areas of the map indicate coverage from the associated transmitter. Since only one transmitter is present in this example, every point on the map will have

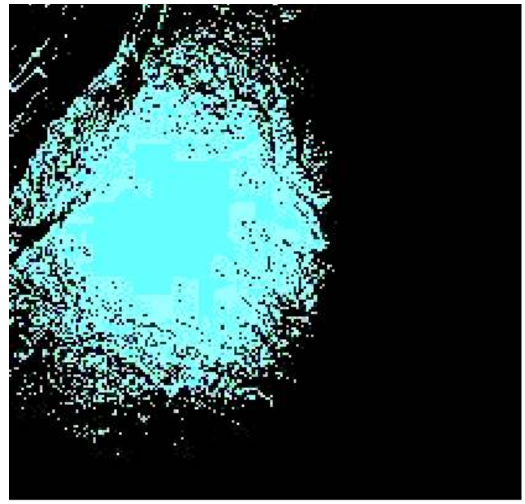

Figure 2 - PSC map for single transmitter

coverage from either 1 or 0 transmitters, giving SC values of either 0 or 1 (no coverage, or coverage by one transmitter). The peak (PSC) map can be understood as showing the maximum number of independent users that could be simultaneously served at any given location. Note that this does not imply that only one individual user can actually be served by the system at a given time. It means that users are served by only one independent signal; the "user" could be a talk group with a hundred members that are receiving a common message. Or, it could be an individual user.

An "average" signal capacity (ASC) map can also be defined, which is different from the earlier definition for signal capacity. The ASC map shows the number of independent users *per square mile* that could be served at one time if users were distributed evenly across the coverage area of a transmitter. The ASC map for an individual transmitter is determined by calculating the PSC map, totaling the number of square miles of coverage, and normalizing the PSC values by dividing by the total coverage area. The ASC values are expressed in terms of the number of independent users per square mile to which the transmitter could provide service, assuming that users are evenly spaced across all of the coverage area. Integrating the ASC values across the entire coverage area of one transmitter will always give a total of "one user." The ASC map of a single transmitter looks identical to the PSC map for that transmitter, except that the numeric value of coverage areas is different. Specifically, Figure 2 showed radio coverage of about 6,500 square miles (out of a total of 40,000 sq mi included in the map). Therefore, the ASC map shows that this transmitter would provide coverage to about .00016 independent users per square mile, if the users were evenly distributed over the whole 6,500 sq mi area of coverage. (6500 mi sq x .00016 users/mi sq = 1 user.) Note that a smaller transmitter coverage area provides larger values on an ASC map.

The PSC map and the ASC map provide two different ways of looking at the problem of providing comparable service, based on different assumptions about how mobile users are distributed geographically. The PSC map assumes that all users might be concentrated at the same geographical location. The ASC map assumes that users are evenly distributed across the coverage areas of their respective base station transmitters. In analyzing the signal capacity that is provided by an existing transmitter, one does not know whether that transmitter was intended to serve users who are statistically evenly distributed across the coverage area or users that are sometimes located in one small portion of the coverage area. Lacking this specific insight for each transmitter, the analysis covered the extreme cases by calculating both the PSC and ASC maps. In many ways, the PSC and ASC maps represent the worst and best cases of user geographical distributions, respectively. Real-world user distributions presumably must lie somewhere between these two extremes, but it is not necessarily clear exactly where. Nevertheless, the peak and average SC maps place bounds on the effects of user location.

If transmitters with one coverage area are replaced with future transmitters having a different coverage area, the assumptions about whether replacement transmitter requirements scale proportionally to coverage area or whether they do not become very important, since these two different assumptions give much different results. ASC values scale proportional to coverage area; designing a new system with microcells having 10% of the coverage area of standard cells would imply designing the microcells to handle 10% of the traffic. PSC values do not scale with coverage area. If PSC rules hold in the real world, a 10%-sized microcell would still need to handle all of the traffic of the standard cell, since it is possible that all of the users from the standard cell might sometime be crowded into that single micro-cell. Therefore, the availability of both sets of maps is important as a more complete basis for designing a range of possible alternative radio systems to match the current capabilities of Federal users in the 162-174 MHz band.

6. How Function and Network Codes Define SC Algorithms

The lowest level of a radio system that can be analyzed to produce peak or average SC maps is not a single transmitter but is instead a "network." A network is a group of transmitters (one or more) designed to cooperatively produce a specific type of service over a given area. The concept of network must be used to compute SC, because SC is defined only for independent signals. However, sometimes signals received from different transmitters are not independent. For example, signals received at the same frequency from different simulcast sites cannot contain different information. The network (as defined here) is the smallest set of transmitters that must be included in the SC calculations to obtain a correct value. Once the ASC and PSC maps for a network have been properly calculated, these values are independent quantities and SC maps from one network can be freely combined with other SC maps.

The Signal Capacity Analysis Program (SCAP) uses the GMF license database as a source of technical information. A function code (F, N) is added to each GMF assignment record. The parameter F shows SCAP what type of technology the network uses. Different algorithms are employed for independent base stations, repeaters and multi-site repeater systems, simulcast systems, trunked base stations and multi-site systems. N shows which other transmitters to include in this analysis (all transmitters with the same N belong to the same network).

At present, the function codes are determined by NTIA staff, following a study of the GMF records and (usually) consultation with frequency management staff at the respective Federal agencies. These consultations provided very useful insights into how specific systems were used. In some cases, systems were identified that provided services that could not reasonably be supplied by a shared Federal system.

As an example of the SCAP analysis of a basic network, showing how different types of networks give different peak and average SC map results, consider a network that consists of a group of four base stations, each station having one channel. The individual coverage areas of these four base stations are shown as Figure 3. These four transmitters will be analyzed as a simulcast network (Figure 4) and as a network of single-channel trunked radio stations (Figures 5 and 6).

The PSC map for the simulcast system is shown in Figure 4. This map is calculated by first calculating the coverage areas of each base station and placing a "1" at each location where coverage is available. In locations where coverage is available from multiple base stations, the peak signal capacity for the simulcast system is still "1," since all base stations transmit an identical message, so only 1 independent message can be received at any location.

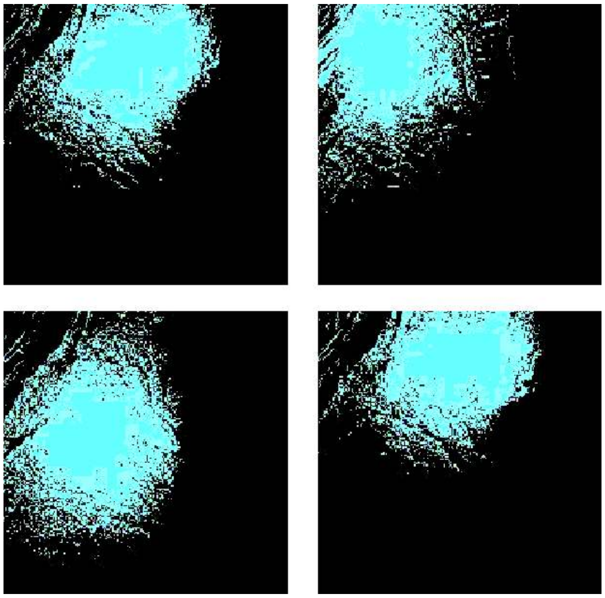

Figure 3 - Coverage areas of four transmitters

The average signal capacity is determined by dividing the peak signal capacity at a specific location by the area over which each transmitter provides coverage. In this case, the entire 4-site coverage area acts like the coverage area of a single transmitter that covers a very large area. Therefore, the simulcast ASC map looks identical to the simulcast PSC map, except for a scaling factor that shows a single relatively low average number of independent users per square mile that can be served by the simulcast system.

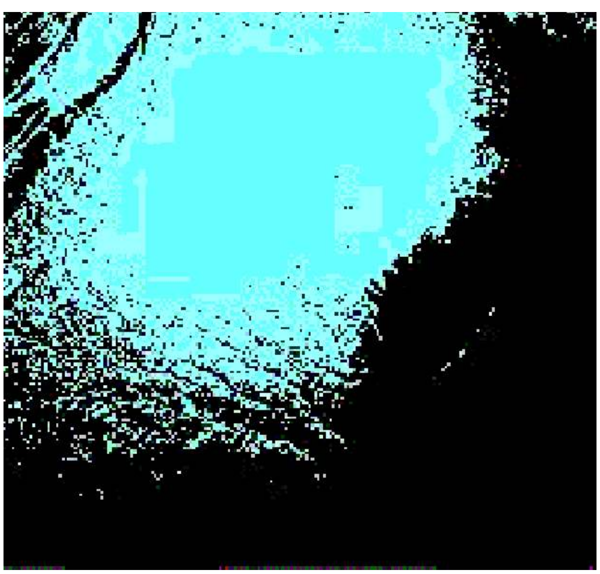

Figure 4 - PSC (and ASC) map for 4 simulcast sites

The PSC map for a 4-site trunked radio system using independent frequencies to provide coverage around each site (Figure 5) shows that each site could provide independent service to a user (serving as many as 4 independent users at some locations). PSC values add together in areas where coverage is available from multiple sites.

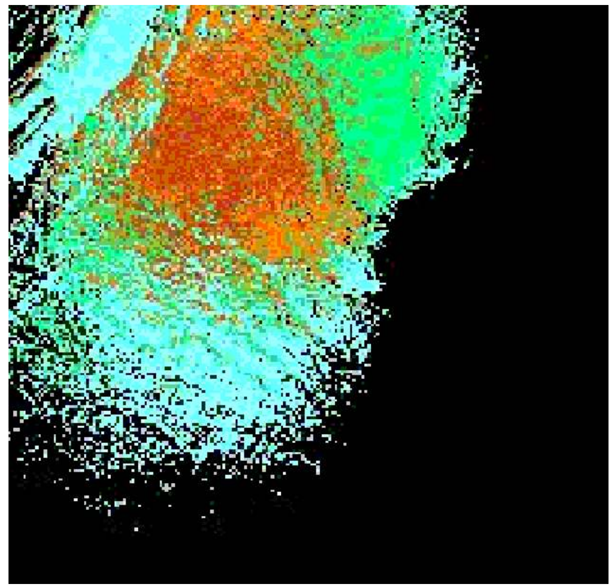

Figure 5 - PSC map for 4 trunked radio sites

The ASC values for the 4-site trunked network are calculated by finding the ASC values for each base station on an individual basis, and adding the ASC values at points where coverage is available from multiple stations (Figure 6). In this case, the transmitters operate independently, so the coverage area is the respective area for each separate transmitter. Since each transmitter can serve a different population of independent users, the ASC values add together where coverage is available from multiple transmitters.

Although not visible in these maps, the trunked ASC and PSC maps differ by more than a simple scaling factor, since the coverage areas of the 4 sites are different and the corresponding ASC numeric values for each site are therefore somewhat different.

The maps are quite different for the 4-site simulcast network and the 4-site trunked network. The peak SC per simulcast channel would be one independent user per channel over the entire 4-site coverage area. The peak SC per trunked channel would be one independent user per channel, but there would be many locations that might

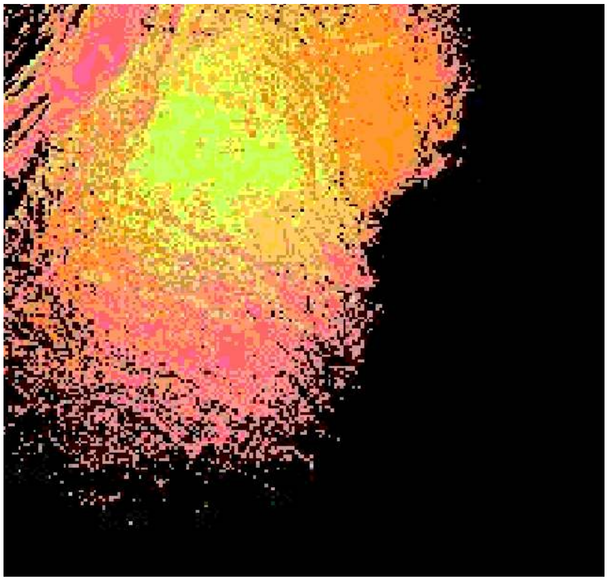

Figure 6 - ASC map for 4 trunked radio sites

provide service to 1-4 independent users, due to overlapping coverage areas from adjacent sites. The average independent usage per square mile that the 4-station simulcast system can support would be smaller than the average independent usage per square mile for the 4-site trunked system for two reasons. The coverage area per channel is larger for the simulcast system, giving a smaller numerical value for the one simulcast channel. In addition, the (individually larger) trunked ASC values add together in overlap areas. Therefore, the maximum average number of independent users per square mile is considerably larger at some locations for the trunked system.

The above examples were included to illustrate some of the principles involved in calculating PSC and ASC maps for systems using various radio technologies. It should be noted that some other technologies involve more complex calculations than the examples shown here.

7. PSC & ASC Maps for Federal Agencies

Using the techniques described above, PSC and ASC maps were computed for each major Federal department in the Washington, DC area. Figure 7 shows an example of a PSC map for some Federal agencies having a small number of radios in the 162-174 MHz band. In this example, the coverage areas for these radio systems are easily distinguished, and there are many areas on the map that have no coverage at all for these agencies.

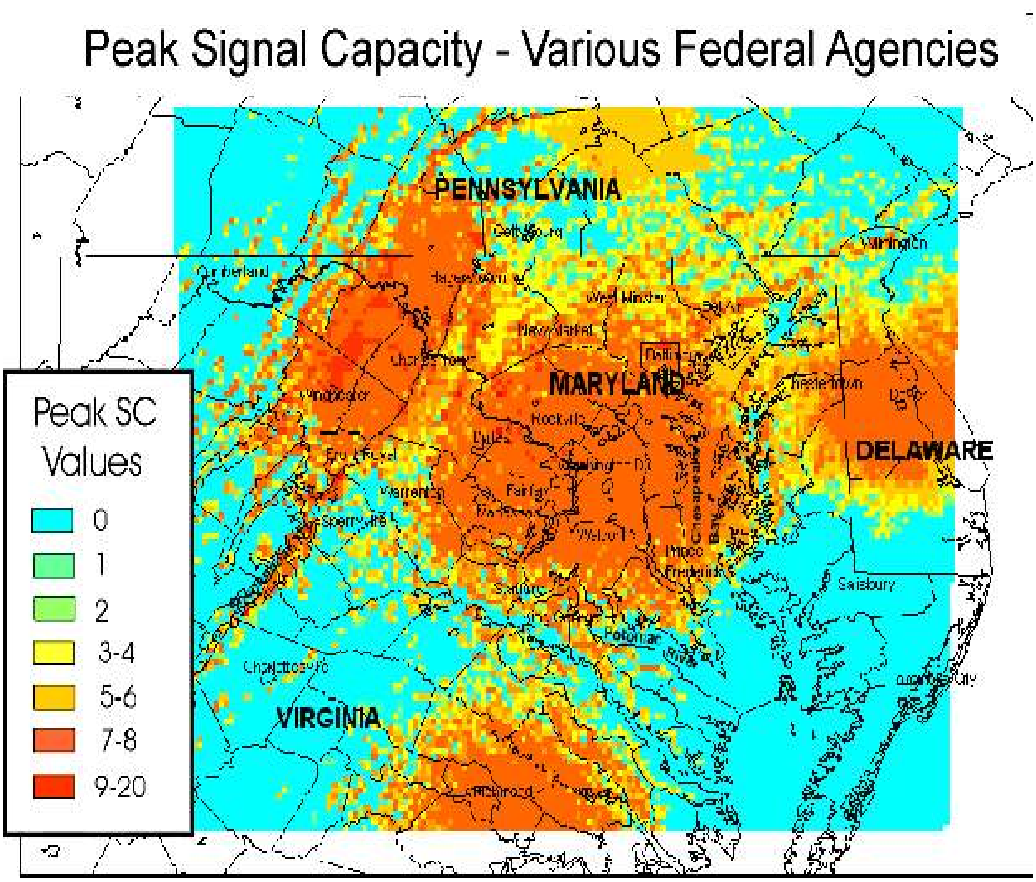

Figure 7 - PSC map for several Federal agencies

Maps produced for individual agencies can be further combined to give maps for larger groupings of agencies, or even for all agencies in the Federal government. Figure 8 shows the PSC map for all Federal agencies in the 162-174 MHz band. Some features of this map should be noted. Partly because of the large number of radio licenses used to produce the map, features associated with individual radio systems have largely disappeared. Therefore, the overall map features appear mostly as a large "bullseye," with the highest concentration of radios located near the center of Washington, D.C.

The highest PSC value on the map is "337." This means that as many as 337 independent radio channels could be received by a mobile user at some Washington locations. An additional observation is that there appear to be very few locations where radio coverage is not available from multiple radio systems.

The corresponding ASC map for all Federal agencies is shown in Figure 9. The actual ASC values in this map have been multiplied by 10,000, to give them values that are closer to the ASC values, for purposes of facilitating easier comparisons between the two maps.

Corresponding ASC and PSC values for identical locations differ by a ratio of about 5,000. This suggests a typical site coverage area is about 5000 square miles, which is equivalent to a circle about 80 mi across. Although such large areas would be more than expected for a single site, many of these radio systems involve multiple sites.

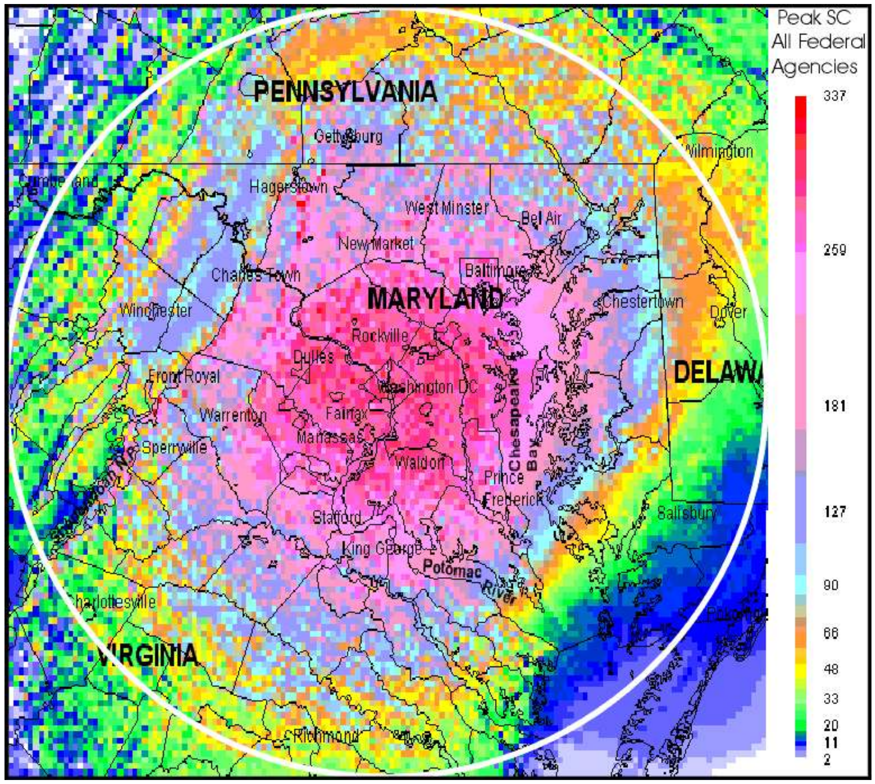

Figure 9 - PSC map for all Federal agencies in the 162-174 MHz band

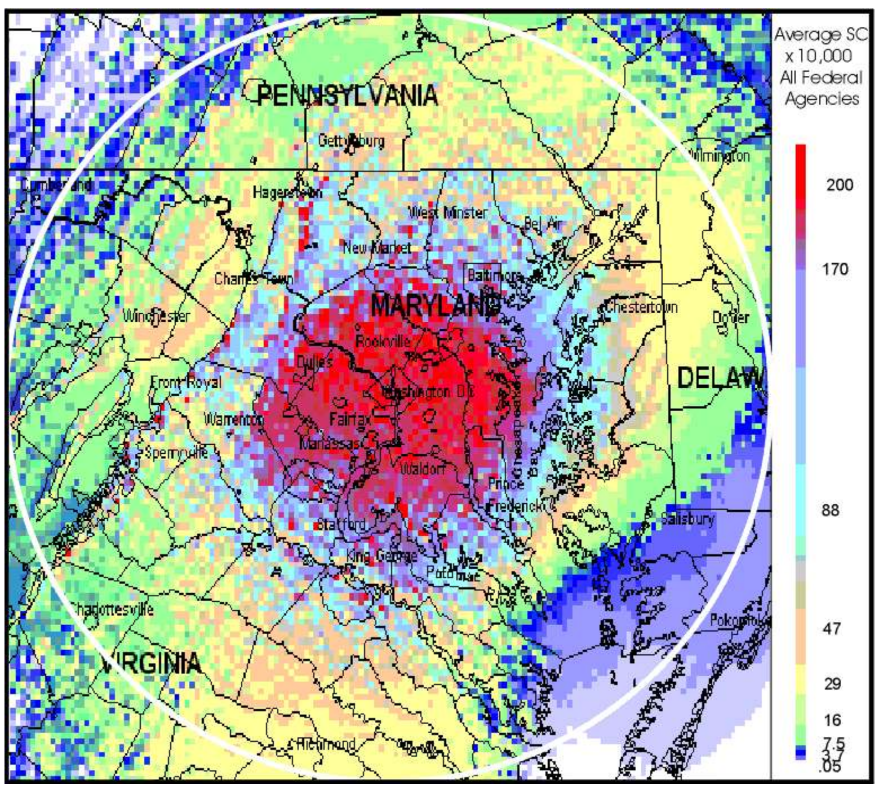

Figure 8 - ASC map for all Federal agencies in the 162-174 MHz band.

8. Conclusion

In summary, this first phase of a multi-phase effort has made a careful effort to understand the radio services provided by many different Federal agencies in the Washington, D.C. area, who are using a wide range of mobile architectures and technologies. Throughout the analysis, we had substantial interaction with many agencies to learn how each radio system was used and to confirm the correct interpretation of GMF data. We believe that we have developed a useful conceptual and quantitative model of the capabilities of current Federal agency mobile radio systems.

We believe that a proper application of modern technologies might provide opportunities for very substantial improvements to the effectiveness and efficiency of Federal mobile radio systems. This signal capacity model and the Washington, D.C. data were developed to serve as a realistic foundation for exploring these opportunities by designing alternative future shared radio systems for Federal agencies. The payoff strategy for all shared systems is essentially as follows:

1. Most current mobile radio systems provide services that could be duplicated or improved by modern shared radio systems. (The signal capacity model shows the quantitative aspects of this conversion.)

2. Trunked radio systems, for example, can carry 3-10 times more traffic (Erlangs) over each channel, compared to most single-channel radio systems and still provide very high channel availability. However, this improvement in channel capacity is present only for trunked systems with a large number of channels (ten or more). Most agencies don't use many channels, so trunked systems have fewer advantages unless multiple agencies combine their requirements within a single shared system.

3. If many agencies share a trunked system, it will require relatively fewer channels to carry the combined traffic. Moreover, multisite trunked networks could provide large coverage areas, fast priority access for selected users, very effective interoperability solutions, flexibility to reconfigure for emergencies (including additional channels and preemptive access when crowded), and many other advanced features.

4. Because of #3, shared trunked systems can require fewer frequencies, give better service and coverage, and even cost less money. However, many of these advantages disappear if there are not enough users on the trunked system. Therefore, a realistic study of trunked system advantages needs good information on the number of users, the total amount of radio traffic, and more.

Over the next couple years we intend to use this data to design multiple systems using different assumptions about how many agencies might be participating in a shared system and how fully these agencies would integrate their systems, varying the coverage area of typical sites, the use of receive-only sites versus small-cell full-feature sites, alternative ways to handle emergencies, use of advanced non-trunked technologies, and different ways to achieve interoperability.

The signal capacity model will facilitate many aspects of these studies. The SC maps show where base station coverage is needed and provide information on how many signals are needed at each location. This information can be easily modified, depending on assumptions about which agencies are to be included in a particular version of some future shared system. Some agencies will need coverage in some geographical areas, while others need coverage in different locations. Therefore, changing among different combinations of agencies will generally change both the magnitude of the highest PSC values and the shape of the coverage area on the map. Similarly, the ASC maps provide usage on a "per square mile" basis. This data allows the design of alternative future radio systems having base stations that provide different sized coverage areas. Finally, after a radio system is designed, the signal capacity model can be used to compare the current SC values with corresponding SC values derived from the new system design. Thus, the SC model will be useful at several stages in the process of designing shared radio systems.

Although none of these studies is aimed at a specific deployment of new systems, we hope that such data and studies will help provide realistic and useful insights on Federal and public safety spectrum requirements, how the benefits of shared systems and interoperability solutions scale with size or the number of users, new interoperability solutions based on shared systems, identification of the best possibilities for additional sharing of facilities and frequency bands, and more.

In current and future studies, we look forward to working closely with other agencies and organizations to help us with planning our work, performing our studies, and critiquing our results.

References

[1]. R. J. Matheson. "A survey of relative spectrum efficiency of mobile voice communication systems," NTIA Report 94-311. 1994.