Spectrum Management Metrics Development

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ABSTRACT

There is a lot of talk about there not being enough spectrum available for use by either government or industry. One would thus suppose that there are clear answers to the questions, "How much spectrum is being used?" and "How much spectrum would be used if it was available?" Unfortunately, clear answers do not exist. In fact, even if you collected data, analyzed it, and generated charts, there is likely to be (and, in fact, have been) long debates about the meaning of those charts. A fundamental problem is that there are no standard metrics for reporting spectrum usage. A well-defined and documented set of metrics would aid in any analysis and discussion of spectrum usage. The Range Commander's Council (RCC) Frequency Management Group (FMG) has initiated a formal Task, FM-37, to develop and standardize a set of spectrum management metrics. These metrics will go beyond simple usage and provide metrics for analysis of spectrum management in general, such as spectrum usage requirements, scheduling efficiencies, and prediction of impacts to spectrum availability. This paper overviews an initial draft of the document being developed under Task FM-37.

INTRODUCTION

Around 2002 there was growing concern about the availability of spectrum for telemetry. This lead to developing an agenda item for the World Radio Conference scheduled for 2007 (WRC 07). This, in turn, lead to a concern about how to defend our need for more spectrum and, more specifically, how to provide data and charts of spectrum usage. The Integrated Frequency Deconfliction System (IFDS) was being used by some of the ranges to deconflict spectrum assignments among the different ranges. Although it was incomplete in the sense that not all ranges were using IFDS (and there are always questions about accuracy of any database content) it provided a set of data that could be analyzed and charted. There is a traditional concept of Percent Occupancy (PO) that is effectively a calculation of occupied spectrum vs. total available spectrum. However, there are subtleties about spectrum utilization and PO is not necessarily the best metric to use and is certainly not the only metric that could be used.

At that time, the author was approached about this problem and, taking a mathematical approach, developed a series of metrics and associated algorithms to calculate the metrics. As further discussion continued, it became obvious that there are other questions related to spectrum *management* beyond simply asking how much spectrum is used. Some examples: How much spectrum is *required*? What is the cost associated with spectrum and spectrum management? If a test cannot be performed what is the cost and schedule impact to the test program? Is it possible to move current and estimated future telemetry usage out of one band and into another – and how much would that move cost? Thus, some preliminary metrics and algorithms for answering these questions were also developed.

In addition to developing the metrics, software was written, data was analyzed, and charts were produced. This aided in having a successful WRC-07 (in that augmented spectrum was allocated for telemetry use) and interest in spectrum metrics died.

In 2010 President Obama signed a memorandum [1], now often referred to as the Broadband Initiative, to repurpose 500 MHz of spectrum. This started a flurry of activity regarding spectrum and, in particular, the issue of how much spectrum is used and required for telemetry. This led to some data calls to range and frequency managers. This, in turn, led to a call to the author who, fortunately, still had his metrics and software in hand and was able to aid in responding to these data calls.

As part of the work prior to WRC 07, the author had also written a complete draft standard of the metrics. So, capitalizing on the current interest, he dusted that off, presented it to the Range Commander's Council (RCC) Frequency Manager's Group (FMG) and convinced them to establish a formal Task, FM-37, to review, modify, and adopt the draft as a an RCC standard. This Task will be executed via monthly telecons and formal reviews at the FMG meetings. Current expectations are for the standard to be finalized in 2014. This paper overviews this draft.

BACKGROUND AND KEY CONCEPTS

The draft starts out with the usual miscellany of introductory information of which we will highlight a few key points.

The scope of the document is spectrum *management* and is not limited to just spectrum utilization. The questions listed in the previous section illustrate this scope. The document does not describe telemetry instrumentation (transmitters and receivers), telemetry radio frequency standards, or frequency modulation standards. Most specifically, this document is not intended to cover anything covered in IRIG 106 Telemetry Standards [2].

The basic unit of spectrum usage is a *mission* in the form of a *(bandwidth, duration) pair*. A request for spectrum includes the bandwidth and duration needed. Most often the request will also include a frequency range (or a specific frequency) and a range of start times (or often a specific start time). Thus a spectrum request is met by assigning a time and frequency to a mission. Examples are given in Table 1. A mission can be thought of as a rectangle in the Time-Frequency grid as illustrated in Figure 1. At the smallest level, spectrum usage is measured as *mission occupancy* in Megahertz Hours (MH) = bandwidth x duration. More complex analyses are based on this base unit and the Time-Frequency grid.

Table 1 Example Frequency Assignments (Missions)

Start Time	Center Frequency (MHz)	Duration (Hours)	Bandwidth (MHz)	Mission Occupancy (MH)
2:00	2240	2	50	100
6:00	2230	7	10	70
7:00	2267.5	3	35	105
9:00	2242.5	5	5	25

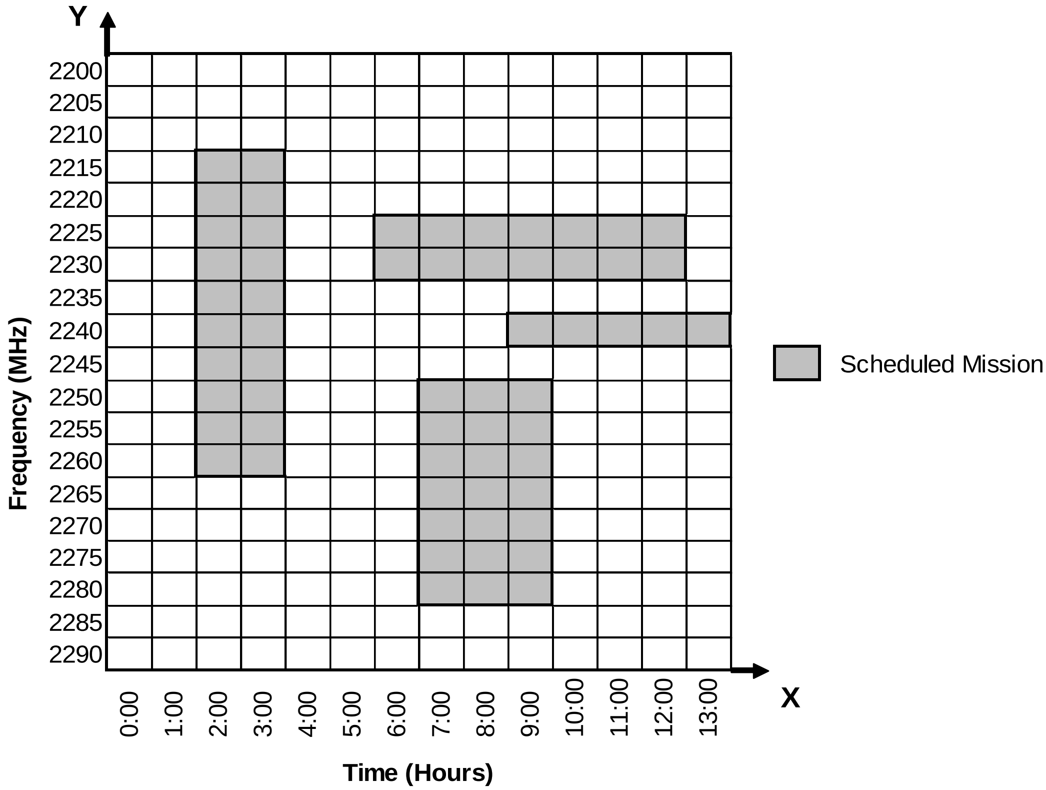

Figure 1 Example Time-Frequency Grid With Scheduled Missions

There is a key concept of *"Use" as "Denial to Others"*. Even if there is not electromagnetic energy propagating through a particular point in time and space, if it is not possible for someone to use it then it is effectively used. An important example in this document is that "scheduled" is "used". Because of logistical difficulties of testing, it is not always possible to turn transmitters on and off at exactly the time they are scheduled. Another example of this is fragmentation. Because of the difficulties of scheduling spectrum (technically it is an $\mathcal{NP}$-Hard problem [3]) it is virtually impossible to pack the time-frequency space without leaving small fragments between scheduled spectrum assignments. These fragments are not usable and are thus effectively used.

Another key concept is that of *concurrent* use. Mostly because of geographic separation (mountains or distance) it is possible to use the same frequency more than once at the same time. Thus, if you simply add up all the scheduled mission occupancies, it is possible to have more than 100% utilization. This can cause confusion when presenting utilization data.

Within the draft, a standard layout is provided for each of the metrics defined in the document:

1. General Description
2. Numeric Interpretations
3. Derivation
    a. Inputs to Algorithm
    b. Algorithm
4. Specific Numerical Example
5. Example Charts as appropriate

Although some of the metrics can be defined using mathematical equations, many of them are algorithmic in nature and are presented using psuedocode (high level programming descriptions.) An important point about any metric is understanding what it means, so every metric description explicitly states what the numbers imply. One of the questions for the Task is whether or not the examples should be part of the standard. It might be more appropriate for these to be in an Appendix or User's Guide.

OCCUPANCY METRICS (AREA METHODS)

The most basic approach is to find the total MH of all the mission occupancies scheduled for a day in a contiguous band of spectrum and then divide this by the total MH available in that band for 24 hours. However, because of reuse (using the same frequency at the same time) this number can be greater than 100%. The draft defines this as *Percent Occupancy With Reuse (POWR)* (but there seems to be a consensus that a different name is needed). Many people don't understand how you can use more than 100% of a resource. Even if you understand the concept of reuse, a single number does not capture the fact that some portions of the spectrum may be used once, twice, or twenty times. The document provides an alternative method to POWR for capturing reuse, but this is a topic for discussion as part of the Task.

Another approach is to look more carefully at the missions and only count each portion of the Time-Frequency grid that is used only once no matter how much reuse is involved. This is called *Percent Occupancy* (PO). If we consider the Time-Frequency grid as a 2-dimensional area, then PO is the percent of this area that is occupied.

Once these numbers have been generated for each day (or other time period) then it is possible to do standard calculations such as averaging or taking the maximum.

It is also possible to average (or take the maximum) over cells of the Time-Frequency grid and generate a 3-dimensional average PO or POWR. An example is shown in Figure 2. These types of charts can give a more robust picture of how spectrum is being used throughout the day and throughout the band. This example shows an increase in occupancy starting in the morning, peaking at noon, and then decreasing through the afternoon and evening. Having generated the 3-D chart, it is possible to project an average or maximum occupancy onto either the time or frequency axis. Figure 3 shows a maximum projection onto the frequency axis. This particular chart shows low usage around 2330 MHz due to digital axis radio (currently being used by XM Sirius).

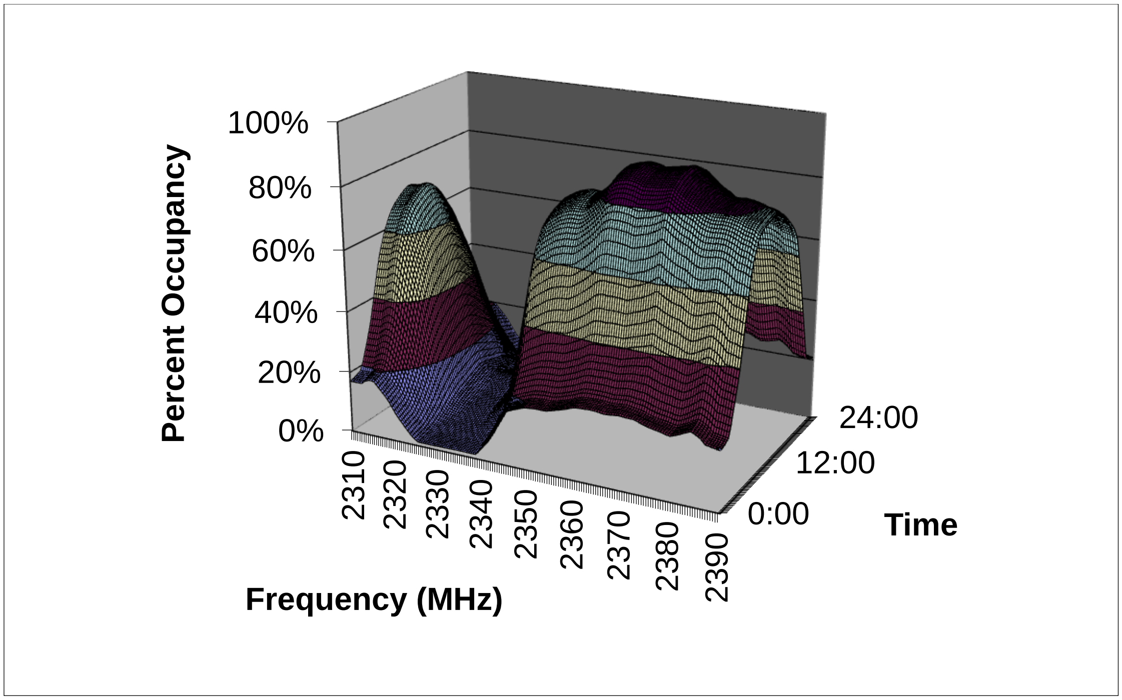

Figure 2 Example 3-D Percent Occupancy

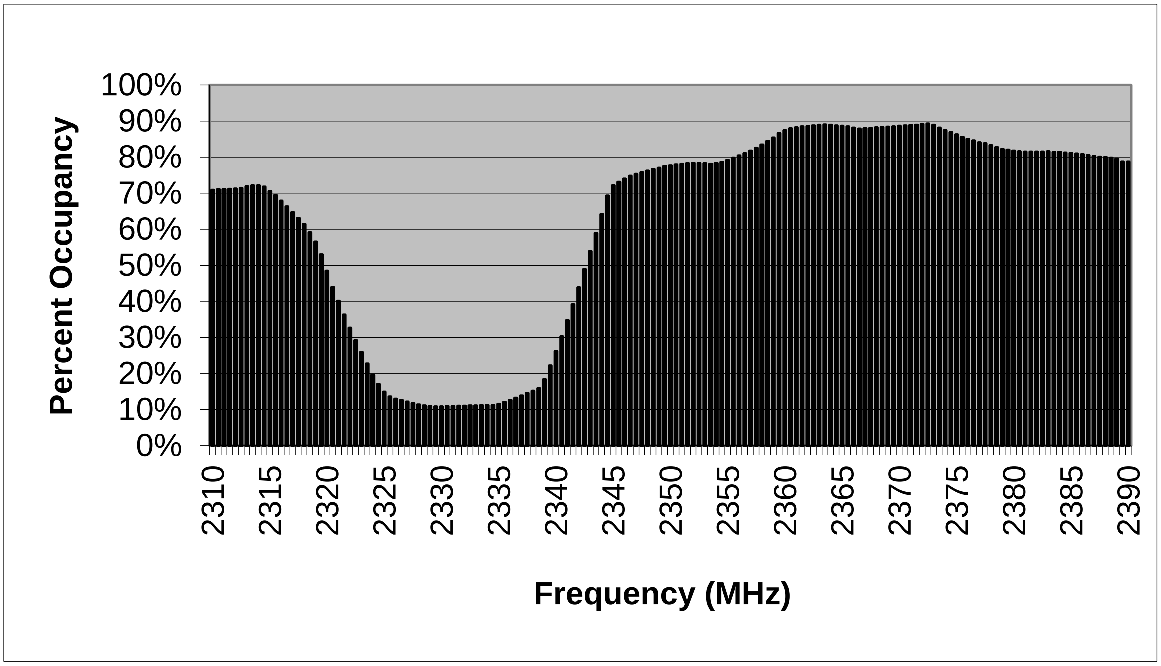

Figure 3 Example 2-D Max Frequency Projection

AVAILABILITY AND UTILIZATION METRICS

The draft introduces the concept of spectrum availability and defines utilization = 1 – availability. This is fundamentally an approach to try and capture fragmentation. Thus we also have utilization = scheduled + fragmentation.

The calculation of availability is made using the concept of a *typical mission*. (Recall that a mission is a (bandwidth, duration) pair.) Such missions can be specified by an expert or estimated by looking at the missions under analysis and mathematically selecting representative missions. Once a typical mission is identified, spectrum availability for that mission is determined by systematically placing the mission (rectangle) in every possible position of a Time-Frequency grid that already has a set of scheduled missions. Every place that the typical mission could be scheduled – does not intersect an already scheduled mission – is noted. That is, that portion of the spectrum is available for use by that mission. The algorithm uses this basic process to calculate an overall availability based on a set of typical missions. This captures fragmentation in the sense that any place that a mission cannot be scheduled is an unavailable fragment of the spectrum. Having calculated availability, utilization is easily derived. A more detailed description of this algorithm can be found in [4].

As we've gone through data calls for spectrum utilization analysis, fragmentation has been a contentious issue. There are many who support the idea that since fragments are not useable they are, in fact, used. Other people respond by asking why you can't just rearrange the schedule to reduce or eliminate the fragments. These people usually do not understand either the mathematical or logistical difficulties of scheduling spectrum. This is definitely an area of discussion for the Task.

Of note is that availability has potential use outside of reporting utilization. Certainly answering the basic question of "Can a mission be scheduled – and where?" is useful. Even further, this metric could be used as a measure of scheduling algorithm efficiency. An algorithm that provides a high availability is probably of more value than one that doesn't.

As with PO, it is possible to generate averages, maximums, 3D charts and 2D projections of 3D charts.

EFFICIENCY METRICS

Just because spectrum is being used doesn't mean the spectrum is being used *efficiently*. Currently the document has one efficiency metric – bits sent. This is intended to try and capture the difference between modulation techniques; for example, SOQPSK is more efficient that PCM/FM because you can send more bits in the same bandwidth. One of the action items for FM-37 is to consider if there are other ways of measuring efficiency.

MISSIONS AND OPERATIONS

We now start to move away from pure utilization analysis and into more general management metrics. A simple quantity to capture is how many missions have been scheduled, although there is also the concept of an *operation* which consists of one or more missions. Many tests use more than one frequency and thus more than one mission as we've defined it. This can be due to multiple vehicles, carrying pods, for redundancy or possibly other reasons. Thus we can also count operations.

Given these counts you can do standard statistical calculations such as averages, maximums, percentages, etc.

SCHEDULING OPERATIONAL METRICS

With these metrics we ask the question: "How do we analyze the process of scheduling itself?" However, part of the motivation for these metrics is to answer the question: "How much spectrum is required or would be used if it was available?" The data being captured now only captures what spectrum was ultimately scheduled. It does not include requests that were not met. Thus, the first part of these metrics identifies the data included in a standard request for spectrum as well as satisfaction categories, i.e., was the request satisfied and if not, why not. Similarly it standardizes terminology for cancellations, delays, and rescheduling. As a management tool it also captures standard reasons for cancellations, etc.

Once these types of data are recorded, it is possible to do standard statistical analysis such as number of operations cancelled for a particular reason or related percentages.

PREDICTIVE, WHAT IF, METRICS

When planning for future spectrum use, there are a couple of scenarios to consider. First, if there is a major program coming or, more generally, there is a known set of future requirements, will the existing available spectrum be able to meet those needs? Second, if spectrum is lost to telemetry use and future use will either be in reduced spectrum allocation or in new bands, can existing requirements be accommodated.

The first suggested method is a simple additive approach. Start by calculating average usage based on historic usage or estimated future requirements. Then normalize these averages for comparison across bands, and add the normalized averages. This gives an estimated spectrum requirement that can be compared to the future available spectrum. It is also possible to do this in a 3D approach using the 3D metrics described earlier.

A second suggested method is by trying to look at whether or not an estimated set of missions is schedulable in the future available spectrum. This is different from the additive method which only looks at raw capacity. This schedulable method tries to analyze whether or not the pieces (missions) will fit into the container (available spectrum). This, in essence, takes into consideration the fragmentation issue; just because you have raw capacity doesn't mean discrete pieces will fit.

SUMMARY

We have outlined a draft proposal for defining metrics for spectrum management. This draft is in the process of being reviewed and modified. Throughout the review process it is important to keep in mind the basic questions:

1. Are these metrics useful?
2. Are there other metrics or methods that are also useful or more useful?
3. Are there other things that need to be measured?

The standard itself will only establish metrics. In order for these to be used it will be necessary to collect data and develop software. Sub-objectives of the standard are to identify what data needs to be collected and to establish a foundation for software requirements. IFDS currently collects some of the required data but it is fairly clear that more data will be needed. Collecting such data will require changes in operational procedures – and not just within the frequency management community but within the user community as well.

Demand for spectrum is only going to continue to grow for quite some time. Data calls to defend our spectrum are going to keep coming. Pressure to manage spectrum better and more efficiently will not ease up. The Spectrum Management Metrics Standard is intended to be a focal point for all people concerned to respond to these demands, pressures, and data calls in a coordinated manner.

REFERENCES

[1] Presidential Memorandum: Unleashing the Wireless Broadband Revolution, http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution

[2] Telemetry Standards, IRIG STANDARD 106, Secretariat, Range Commanders Council, White Sands Missile Range, Mew Mexico.

[3] https://en.wikipedia.org/wiki/NP-hard

[4] Charles H. Jones, *Average Typical Mission Availability: A Frequency Management Metric*, Proc. International Telemetering Conf., Vol. XXXX, (2004) Paper 04-22-03