

# COMPARING COMMERCIAL AND T&E SPECTRUM METRICS

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## ABSTRACT

There is an ongoing need to understand how spectrum is used. In the context of defending T&E use against commercial encroachment, there is a recurring question of how commercial use compares to T&E use. This comparison is complicated by the lack of consistent definitions of the terms “use” and “efficiency” as well as different requirements of these distinctly different applications.

The International Telecommunications Union (ITU) recommendations lay out a foundation of spectrum metrics as applied to different applications. The RCC 707 Spectrum Management Metrics Standard provides a T&E perspective. Some insight about commercial metrics can be obtained through an internet search. This paper combines these resources to provide a coherent approach to understanding how to compare spectrum use within these different applications and how this affects the ability to defend against telemetry spectrum encroachment.

## INTRODUCTION

There is an ongoing need to defend T&E spectrum use from commercial encroachment. Part of the approach to doing so is to better document T&E use and understand how this compares to commercial use (most notably cell phone use.) To this end, the T&E Science and Technology (S&T) Spectrum Efficient Technology (SET) focus area has funded the Spectrum Efficiency Through Metrics (SETM) project. As part of this project, a literature review of spectrum metrics was conducted on over 50 related documents.

A reasonable place to start this review is to look at existing standards for spectrum metrics. Within T&E this is mostly RCC 707 [1]. (See also [2].) This standard provides spectrum metrics for utilization, occupancy, reuse, and efficiency. In the broader telecommunications world, the

International Telecommunications Union (ITU) provides a series of recommendations some of which address spectrum metrics [3][4][5][6][7]. In particular, they define occupancy and spectrum utilization efficiency (SUE). No document explicitly defining spectrum metrics for the commercial world was found. However, there are some commercial spectrum metrics available on the internet. These are quite different from metrics in RCC 707 but give insight into commercial priorities. One of the values of the ITU recommendations is that they provide high level definitions that allow derivation of both T&E and commercial metrics. That is, they give us a foundation to analyze the relation between the two uses.

Simply from an initial look at the standards, we see that the concept of spectrum “use” is not well defined or, perhaps more accurately, it is multiply defined. This paper attempts to navigate these different definitions to provide insight into the differences in trying to measure spectrum use among the distinctly different applications of T&E and cell phones.

### **OCCUPANCY, USE, AND DENIAL TO OTHERS**

Spectrum occupancy and use occur in a combination of frequency, space, and time ( $\text{Hz} \times \text{m}^3 \times \text{s}$ ). As ITU-R SM.1046-2 [4] points out, occupancy is often thought of in terms of an active transmitter. However, a transmitter in no way prevents another transmitter from transmitting. Receivers, on the other hand, must have an interference free area of reception. So that receivers use the spectrum in the sense that transmitters that are not the target of reception can be denied the right to transmit. Thus, the ITU documents are explicit in defining spectrum use as including the denial of spectrum to others.

The RCC 707 spectrum metrics were developed by Dr. Jones primarily based on available data, which means data archived by the Integrated Frequency Deconfliction System (IFDS). This system records when frequency was *scheduled*. (Spectrum is scheduled in rectangles within a time-frequency grid based on min and max frequency and beginning and ending times.) Consistent with ITU definitions, RCC 707 defines “use” as “denial to others”. One of the difficulties in presenting T&E spectrum usage has been the question of whether “scheduled” implies “used”. *ITU-R SM.1046-2* [4] points out that “authorities deny licenses to transmitters in an attempt to guarantee interference-free reception.” This is the sense in which “scheduled” means “used”. T&E spectrum managers legally deny use to others by assigning frequencies to specific users for a scheduled time and place. This, of course, goes both ways. T&E cannot legally use commercially licensed spectrum (although there are exceptions both ways.)

There are currently efforts under way to be able to monitor spectrum use in the sense of transmitted RF power. These efforts will certainly provide useful data and the ITU provides several recommendations on how to monitor spectrum [5][7] including what data to collect [6]. But, a key point here is that “use” does not necessarily imply “occupied” in the sense of a transmission of RF power. On the other hand, the existence of RF power does not imply efficiency – transmitting static may occupy the spectrum, but it usually without value to the transmission. So, perhaps, a better way to look at spectrum use is in terms of efficiency rather than occupancy.

## SPECTRUM EFFICIENCY

Efficiency comes in (at least) three forms: technical, economic, and functional [8][9]. In the current context, technical efficiency means minimizing the amount of spectrum used. Economic efficiency regards costs such as equipment or return on investment. Functional efficiency relates to the value of the service. For example, a 911 call is usually of more value than calling home to say “hi”. It is perhaps useful to relate these different types of efficiency to the classic project management triangle of cost, schedule, and performance. The main difference being to replace schedule with spectrum. As with the project management triangle, it is only possible to optimize two, and not three, of the sides of the triangle.

The ITU defines Spectrum Utilization Efficiency (SUE) [4] which is generic enough to cover all three forms of efficiency.

$$SUE = M/U$$

where:

*M*: the useful effect obtained with the system in question; and  
*U*: the spectrum utilization factor for that system.

Breaking down *U* we have

$$U = B \times S \times T$$

Where:

*B*: frequency bandwidth  
*S*: geometric space, and  
*T*: denied time

Giving units of (Hz × m<sup>3</sup> × sec). That is, the five dimensional segment of time, space and frequencies under consideration.

The definition of useful effect, *M*, is a bit vaguer. It can represent anything that the user considers useful. (In fact, this vagueness makes virtually every metric looked at to be derivable from this ITU definition – including those in RCC 707.) We’ll consider economic and functional useful effects shortly, but let’s start by looking at useful effect in terms of spectrum. At its simplest, we might define technical spectrum efficiency in terms of bits sent. (And this is one of the metrics in RCC 707. However, one of the weaknesses of RCC 707 is that it does not explicitly include geographic area in any of the metrics.) But, it isn’t quite that simple when we look at different applications.

SUE for T&E Point-to-Point Telemetry

The *Spectrum Efficiency Metrics White Paper* [10] provides the following calculation for point-to-point telemetry **Error! Reference source not found.** The key difference is the introduction of transmitted distance.

$$SUE_{p-p} = \frac{\text{info rate (bps/Hz)} \times \text{Transmitted Distance}}{\text{Occupied Area}}$$

The unit of measure is thus: Bits/sec/Hz\*km/km<sup>2</sup>.

### SUE For Cell Phones

This example is to provide a contrast to the point-to-point example. The example is from ITU-R SM.1046 [4] for a pico-cellular system covering a building. A primary difference is the use of number of channels. But it also emphasizes that “area” to cell phones can be very local, such as a building, vs. the large land areas flight test uses.

In order to calculate the total bandwidth required for the whole building, the vertical re-use distance in terms of the number of floors is required. This parameter is dependent on the floor losses and is different for different types of buildings. The total number of half duplex channels required for the building can then be calculated and is equal to:

$$2 \times \text{No. of channels per cell} \times \text{No. of cells per floor} \times \text{No. of floors of separation}$$

The factor 2 is needed here to reflect the number of channels needed for two-way communications. The spectrum efficiency,  $SUE_{\text{building}}$ , of the system providing coverage in the building can then be calculated:

$$SUE_{\text{building}} = \frac{\text{Total traffic carried in the entire building}}{\text{Total No. of channels} \times \text{channel bandwidth} \times \text{total floor area}}$$

After working through the units for each of these, the unit of measure is: Bits/sec/Hz/km<sup>2</sup>.

## COMMERCIAL METRICS

Formal definitions of metrics for the commercial communications industry don’t seem to be discussed much outside of references to formal organizations such as the ITU, FCC, or IEEE. The market driven metrics they use are relatively intuitive and have a distinctly different emphasis than the ITU’s approach. In particular, there was no data found on specific frequency use. Most likely, the industry has such data but companies probably keep them proprietary.

The industry standard for both identifying metrics and finding data appears to be the *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update* [11]. Partly because it is a forecast, there is a lot of trend data and it quickly becomes clear that what they focus on is how much data is sent and how many users there are. This is broken down into types of data, devices

used, number of devices, number of connections, and the like. The following (partial) list of charts in the forecast is provided to illustrate this difference in market perspective from the more technical emphasis of the ITU and RCC metrics. The scales of the axis are of some interest: billions of devices and exabytes per month. Several other references were found during the literature search that provide more data, but the data is similar in type to the Cisco forecast.

### Example Chart Types for Cisco Forecast

Chart Title	Axis
Global Mobile Data Traffic	Exabytes per month x year
Global Mobile Devices and Connections Growth	Billions of devices by year and device
Global Mobile Traffic Growth by Device Type	Exabytes per month x year and device
Global Growth of Smart Mobile Devices and Connections	Billions of devices by year and device
Regional Share of Smart Devices and Connections	Region and Percent of the Regional Total
Effect of Smart Mobile Devices and Connections Growth on Traffic	Exabytes per month x year and smart vs. nonsmart device
Global IPv6-Capable Smartphones and Tablets	Number of devices by year
Global Mobile Devices and Connections by 2G, 3G, and 4G	Billions of devices or connections x year and connection type
Global Mobile Traffic by Connection Type	Exabytes per month x year and connection type
Global Machine-to-Machine Growth and Migration from 2G to 3G and 4G	Billions of M2M connections x year and connection type
Global Connected Wearable Devices	Millions of connected wearables x year
Mobile Voice Minutes of Use—VoWiFi, VoLTE, and VoIP	Minutes of use (billions) x year
Growth of types of data (file sharing, video ...)	Exabytes per month x year and type of data
Busy-Hour vs. Average-Hour	Tbps x year

### SCHEDULED VS. ON-DEMAND VS. SHARING

Another way of comparing applications is via the underlying methods used by the different industries. One aspect of this is modulation method (e.g., PCM or CDMA) which can affect performance. But modulation techniques have changed for both T&E and cell phones. A more important aspect is how the service is provided. In particular, T&E spectrum is scheduled whereas cell phones are ad hoc and on-demand. This is, perhaps, the fundamental reason why the two forms of spectrum usage are difficult to compare. Scheduling is very specific about when spectrum is used and when it is not. In some sense, spectrum is always being used for cell phones. However, the fact that you can make a phone call at any moment means there was some portion of the spectrum not being used when you decided to make the call. Trying to analyze this form of non-usage is extremely difficult and can be dependent on the modulation method.

A current focus is the idea of sharing spectrum. Arguably the different methods of scheduling and on-demand usage are inherently incompatible from a sharing perspective. Fundamentally, when T&E schedules spectrum, any on-demand capability would have to be stopped for the duration. This would effectively force commercial companies to implement a form of scheduling.

So how can spectrum be shared? Potential solutions include networks, spread spectrum techniques, and cognitive radio techniques. Spread spectrum techniques (such as CDMA) require every user to coordinate keys. This is being phased out of use by cell phones because LTE is more efficient in terms of throughput. Cognitive radio (which monitors the spectrum and jumps in when a frequency is not being used) can use spectrum that might otherwise not be used but it does not guarantee a user gets as much spectrum as they need. So, networking it is.

Ethernet is a widely-used networking protocol which, effectively, allows on-demand usage. The iNET standards implement a form of Ethernet. This has the potential to move T&E from a scheduled approach to an on-demand approach. (This also potentially addresses some of the objections to metrics based on scheduling. In particular, it reduces spectrum fragmentation as described in RCC 707.) But this doesn't allow sharing with other users not part of the network. From the point of view of someone outside the network, this still looks like scheduled spectrum, albeit in larger chunks.

Cell phone methods (such as LTE and some earlier methods) are essentially complex network schemes. Every user gets (many small) dedicated slices of spectrum (in contrast to spread spectrum) but via complex monitoring and coordination protocols. There are currently some S&T funded efforts looking at using cell phone technologies for use in T&E. It is at least theoretically possible, but there are questions of cost and, if T&E and cell phones truly share the same infrastructure, security issues.

A final note is that a couple of documents found in the literature search address metrics for spectrum sharing. In particular, "Spectrum Sharing Metrics" [12] attempts to address this stating: "Useful metrics – e.g. true spectrum utilization efficiency – combine throughput and geographical area under the assumption that other systems are present in the area and use the same RF channel." The mathematics provided by this document are not simple.

## COMPARISON

It is difficult to compare T&E and commercial spectrum usage. Indeed, in the case of SUE, it is logical impossible to do so because SUE derives different units for different applications as shown in the table. In particular, notice that (T&E) point-to-point and (cell phone) personal communications have different units. It is also noteworthy that SUE allows for introduction of users as part of the unit of measure.

## SUE Units by Application

Service Classification	Unit
Satellite Broadcast System	Bits/sec/Hz
Satellite Point-to-Point	Bits/sec/hz*km <sup>2</sup>
Terrestrial Broadcast	Bits/sec/Hz*users
<b>Terrestrial Personal Communications</b>	<b>Bits/sec/Hz/km<sup>2</sup></b>
<b>Terrestrial Point-to-Point</b>	<b>Bits/sec/Hz*km/km<sup>2</sup></b>
Terrestrial Hybrid	Bits/sec/Hz*km/km <sup>2</sup> *users

Besides SUE, there are some metrics that can be compared. However, these tend to show that T&E usage, from a technical efficiency point of view, are orders of magnitudes different from commercial use. For example, let's consider number of users and bits sent. For both metrics, let's calculate some estimated maximums for T&E.

Let's assume all military members and associated civilians are "users" of T&E spectrum. Using Wikipedia to provide approximate numbers, it lists about 1.5 million military members (all services) about 0.8 million reserves and about 0.7 million civilians. For completeness, throw in maybe 0.7 million contractors. So, at most, we can talk about 3 to 4 million military related users. Compare this to the number of cell phone users: roughly half the world's population of 7 billion or ¾ of the 320 million people in the US.

On the other hand, because of its relation to national security, it is possible to argue that all U.S. citizens are users of T&E Spectrum. Or, even further, that all people in countries that are U.S. allies are users.

For bits sent let's calculate a rough upper bound based on maximum throughput in all frequency bands at every test and training range 24/7.

1. MHz available: 90+10+90+50+35+540+60+775 = 1650 MHz for 8 bands listed in IRIG 106. About  $1.7 \times 10^3$
2. Transmission rate (upper end): 3/8 Bytes/Hz or 375,000 bytes per MHz. About  $3.8 \times 10^5$
3. Seconds per month  $60*60*24*30 = 2,592,000$  secs. About  $2.6 \times 10^6$
4. Say 100 test and training ranges (about 60 in IFDS). About  $1 \times 10^2$

This calculates out to about 0.17 exabytes maximum transmission per month. (Realistically, T&E uses a tiny fraction of this.) Consider that some of the Cisco forecast charts have axes of exabytes per month. In other words, even based on outlandish assumptions, T&E maximum usage wouldn't be noticeable on Cisco's charts.

Let us return now to the three types of efficiency. SUE is, essentially, a measure of technical efficiency and, as has been shown, SUE does not allow for direct comparison. In terms of economic efficiency, it would be possible to calculate and compare total costs of spectrum equipment for the two industries and somehow normalize to users or bits sent. But this would take some effort to collect data and it's not clear it would provide a useful result. A simpler

thought experiment is simply to note that the commercial world revolves around return on investment. In contrast, the T&E world spends tax money with no direct monetary return.

This leaves functional efficiency as the main useful point of comparison. So, we have national security vs. cell phone use for emergency response, business communications, and calling friends and family. Trying to compare functional value between these is extremely difficult and well beyond the scope of this paper.

### Summary Comparison

Metric	T&E	Commercial
Spectrum Occupancy	Scheduled Time Slots	On-Demand 24/7
Spectrum Efficiency	Not Comparable – Different Units	
	Point to Point	Personal Comm
Economic Efficiency	No monetary payback	Return on Investment
Functional Efficiency	National Security	Billions of Users

### SPECTRUM DEFENSE VS. SPECTRUM MANAGEMENT

Just as there are different applications for spectrum, there are different applications for spectrum metrics. And, different applications mean different approaches. Spectrum defense requires providing data to a different set of people than for spectrum management. When defending spectrum, the data is being presented to high level management (e.g., Congress) who are not always technically oriented. Data used for spectrum management is presented to people “in the trenches” and who, generally, have a technical understanding of spectrum issues.

Spectrum defense requires reduced data that might be thought of as a “one number” or a “one chart” approach to presentation. This is as much due to a lack of time of managers to research details as for any other reason. Spectrum managers need to look at details such as are provided by some of the 3-D charts produced by RCC 707 metrics. In fact, by RCC 707 emphasizing these 3-D charts, the data presented emphasizes how some portions of the spectrum are used more than others. This, in some sense, dilutes the usage message or, at the very least, distracts from the overall usage when presented to higher management. Part of the focus of the SETM project is to provide better presentation of data based on these two distinct uses.

### CONCLUSIONS

It is very difficult to compare T&E and commercial spectrum usage. This is partly due to the fundamental difference of scheduled vs. on-demand services. But it is also due to significantly different applications.

Reporting spectrum occupancy, in the sense of transmitted RF energy, does not provide a complete picture of usage. And, in fact, understanding spectrum occupancy requires some technical background which makes it difficult to present to nontechnical people.

A better approach is to consider efficiency. But even then, as exemplified by SUE, efficiency is not necessarily comparable across applications and, again, requires some technical understanding. Economic efficiency is problematic in that T&E uses tax dollars and industry focuses on return on investment. Functional efficiency again raises difficulties. First, at its simplest level (number of users or bits sent) T&E is orders of magnitude less than cell phone use. This leaves national security as the primary argument for T&E spectrum use. But putting a value on this is extremely difficult.

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