AN EFFICIENCY STUDY OF TELEMETRY DATA CYCLE MAPS

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ABSTRACT

Data cycle maps (DCM) describe the cyclic mapping of telemetered data. The efficiency of a DCM thus directly effects the efficiency of the use of the telemetry spectrum. The availability of this spectrum is decreasing while the demand is increasing. Certainly one of the first things to be done in trying to alleviate this bandwidth crunch is to make sure that all bits in a telemetry stream are useful and required. This paper provides results of a study on what types of bits there are in a DCM and how the bits were allocated in DCMs actually used at Edwards AFB, California.

INTRODUCTION

As part of the Air Force Flight Test Center (AFFTC) Onboard Processing (OBP) and Advanced Range Telemetry (ARTM) [1] projects, a study [3] was done to determine the efficiency of DCMs[1] in use. Specifically, this study addressed the following question:

What percentage of bits in a DCM carry information required to support a test mission?

As is becoming well known in the telemetry community, the spectrum available for use in telemetry is decreasing while at the same time the demand is increasing. Considering this, it seems reasonable to make sure that the spectrum available is used efficiently. Since DCMs define how bits are used, efficient DCMs increase the overall efficiency of spectrum usage. This study takes a first step towards efficient DCM design by analyzing what types of bits are in a DCM, what percentage of bits carry information, and what percentage of bits are traceable to test requirements.

An important point that comes out of this study is the distinction between *information* bits and *required* bits. Just because a bit is transmitted and can be translated into a useful piece of information, does not mean that it is actually information that is required. The distinction here is subtler than just sending a measurement that is of no use. For example,

[1] DCMs are often called PCM matrixes or PCM formats. The use of DCM is more generic since such an animal does not have to be pulse code modulated when sent or recorded.

sample rates tend to grow during the DCM design process. This leads to over sampling. A prime culprit of this is the power-of-2 rule, which will be discussed below.

The ARTM study referenced above analyzes more than the efficiency of DCMs. This paper summarizes the DCM efficiency portion of that study. It does so by providing a list of bit types, the main breakdown of bits in a DCM, a brief discussion of methodology, some discussion of the DCM design method at Edwards AFB and the significance of the power-of-2 rule.

BIT CATEGORIES

To answer the question regarding what percentage of bits sent are required is not as straightforward as it may seem - especially if we focus on the word *required*. The existing methods used for developing DCMs do not focus on meeting – and only meeting – a minimum requirement. Instead, as long as the minimum test mission requirements are met, there is little concern as to how much over sampling is done or how many extra parameters are sent. Until recently, this has been a more than adequate approach. It is only in the context of increasing mission requirements and decreasing spectrum availability that meeting – or even establishing – minimum requirements has become an issue.

The bits in a telemetry stream can be broken up into the following categories. Due to the time constraints and the availability of data, information for all categories was not generated. In contrast to many such lists, there is an attempt here to be exhaustive in categorizing these bits in the hope of identifying all possible ways of reducing bit usage. Any other categories the reader can supply are of interest to the author.

1. Bits Required

a) Overhead: These are words such as frame and subframe synchs, time stamps, airplane identification, etc. In the sense that synchs and other overhead information are confidence factors, some of this data may not be strictly required but is traditionally considered so. Overhead was determined to be about 0.05 percent of the formats and will not be discussed or presented further.

b) Parameter Data: These data are the true meat of the format. These bits carry the information needed by the analysis as stated in some requirements document (often a Test Point Requirement [TPR]). There is some interest in the amount of MIL-STD 1553 data transmitted in a DCM so the study makes a distinction between MIL-STD 1553 parameters and non - MIL-STD 1553 parameters.

2. Bits Not Used

a) Word Fill: When an instrumentation system sample uses less bits than the word length of the telemetry system, the extra bits in the word are filled. Thus, if a data word is 8 bits long and has to fit into a 10 bit word, then 2 bits are wasted.

b) Sent Not Defined: If you do not fill up the whole DCM with defined samples, then there are words which carry no information.

c) Bit Rate Fill: Most existing DCM formatters and decommutators only allow the use of a small number of bit rates – usually based on powers or factors of 2 of a given clock speed. Thus, if the requirements go 1 bit over one of these bit rates, the bit rate used may have to double. This would leave almost half the DCM unused.

d) Corrupted Words: This covers the cases where a sensor is not working properly, the calibration data is not correct, or the transmission corrupts the data.

3. Bits Sent But Not Required

a) Power-of-2 Fill: An easy way to fit samples into a DCM is to change all required sample rates to a power of 2. For example, if you are given a sample rate of 5, it is upped to 8. However, this increase is based on a per major frame construction so that the increase is generally worse than just implementing the power-of-2 rule since the increase is also based on the number of major frames per second. A sample rate requirement is usually given in samples per second, say, 25 samples per second. A DCM has many frames per second, say, 20 frames per second. Thus, the minimum samples per second that can be sent is 20 - one per frame. But the number of samples per frame has to follow the power-of-2 rule so that the number of samples per second sent has to be of the form $F2^N$, where F is the number of frames per second. Thus, our requirement of 25 samples per second is upped to 40 samples per second.

b) Other Sample Rate Increases: Even if the power-of-2 rule is not being strictly enforced, it is possible you may change the sample rate because it needs to be periodic but does not fit into any of the slots available in the format. There may be other reasons for sample rate changes also.

c) Just-in-Case Parameters: Since changing a DCM is nontrivial, it is not unheard of for parameters to be added 'just in case' they are needed.

d) Leftover Parameters: A DCM is developed over the course of a test project. That is, an initial DCM is laid in place with the overhead parameters and an initial sampling of parameters that will almost always be used. As the project progresses, more parameters are added as they are needed. It is not necessarily the case that parameters will be removed once they are in place even if they are no longer needed.

e) Unneeded Accuracy: If a person is on the ground looking at a strip chart that has hash marks of 1,000 units, is it necessary to send data that has an accuracy of 0.001 unit? Probably not. This is a judgment call, but there are times when the data sent is over accurate.

f) Unneeded Bus Data Information: When telemetering bus data, it is not always necessary to send every bit of every message. For example, if you have multiple buses but only one bus has altitude on it, is it necessary to send the bus number as long as it is known that that word is altitude? Sometimes, this extra data is sent.

g) Improper Sample Rate Requirement: There are techniques available for determining the wavelength of most physical phenomena. Such an analysis would lead to a minimum sample rate requirement for a particular parameter. Historically, the amount of time and effort needed to perform this analysis has rarely been warranted. Thus, most stated sample rate requirements probably exceed the minimum required by the physics of the phenomena being measured.

4. Bits Required But Not Sent

This is not strictly part of the 'data in the telemetry stream', but should be mentioned in the context of this analysis.

a) Reduced Sample Rate: If you are running out of room in a telemetry stream, it may be necessary to reduce the sample rate of some parameters. It is also possible that the sample rate is reduced because the parameter can not be sampled at the required rate.

b) Not Sent At All: In the worst case, a parameter is not sent even though it is required because there is not enough room in the telemetry stream.

5. Miscellaneous Categories

a) Forward Error Correction Bits: This is an interesting category in that any bits you introduce for error correction are questionably 'required'. Similarly, the number of bits you introduce for this varies depending on the correction technique used. None of the formats in this study used error correction.

b) Compression: If the main concern is reduction of number of bits sent, then compression needs to be discussed. However, this is outside the scope of this study.

RESULT SUMMARY

The bottom line is that, over all formats studied, about 56 percent of the bits were information bits. That is, on average, for every 100 bits sent 44 of them carried no information. However, about 20 percent of the DCM is a result of using the power-of-2 rule. Thus, ***less than 36 percent of the DCM is required data***. Considering all the other types of unrequired data listed above, *the actual percent of bits in a telemetry stream representing required data is perhaps as low as 15 to 20 percent*.

Figure 1 shows the breakdown for some of the categories described above.

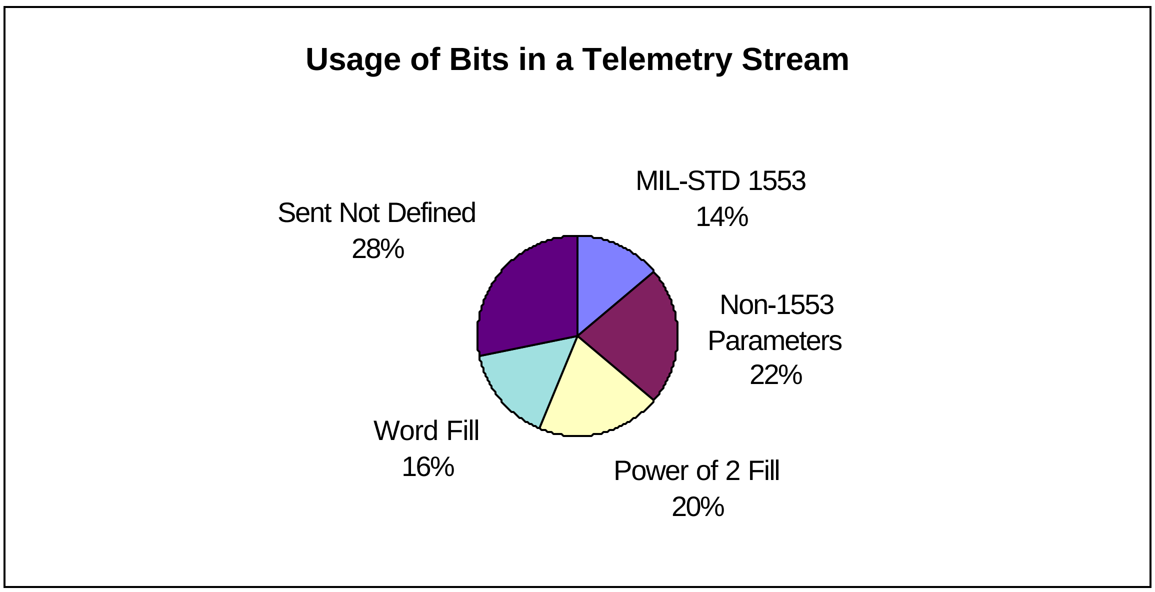

Figure 1 - Bit Usage Summary

Word fill was estimated by comparing the number of bits used by each parameter versus the word size of the format. Due to the way the estimate was made, the estimate is, if anything, higher than actual.

MIL-STD 1553 was determined by assuming any parameter using exactly 16 bits was a bus parameter. Since this is a necessary but not sufficient criterion, this estimate may be high. The percentage was also adjusted due to the power-of-2 estimate.

The Power-of-2 Fill was estimated by looking at the test point requirements for one of the aircraft. The stated requirement for each parameter was adjusted up according to the $F2^N$ requirement where $F = 25$. An average increase was then calculated. On average, the amount of data sent for a parameter due to the power-of-2 rule was estimated to be about 36.6 percent. This percentage was applied to the amount of bits used in order to get 20 percent of the total DCM wasted as shown in Figure 1.

The Sent Not Defined value was determined by reconstructing the formats bit by bit and counting the bits which were not used and subtracting the word fill estimate.

The non-MIL-STD 1553 parameters estimate is the remainder after all of the other estimates were made.

METHODOLOGY

The data was derived from the Aircraft Information Management System (AIMS) database. This database maintains historical descriptions of DCMs and, during operation, is the database that is used to setup the decommutation systems. Software was written to reconstruct the formats on a bit-by-bit basis. A total of 1,903 formats were studied. Of these, 1,747 were from a cargo transport project, 154 were from a fighter project, and 2 were from another cargo transport project. An extensive discussion of the methodology can be found in [3].

CAUTIONS REGARDING THE DCM EFFICIENCY RESULTS

The results should not be generalized to other projects or organizations. Although the results are fairly consistent over two significantly different projects – a cargo transport and a fighter – one must always be careful of generalizing statistical results. This is especially true when no extensive statistical analysis has been performed. There has been no attempt here to model the bit usage distribution or to do anything beyond simple averaging.

The power-of-2 rule estimates were taken from a single project. Even further, they were done solely based on requirements and not by directly relating the requirements to the rates actually used.

The MIL-STD-1553 estimates were made using a necessary but not sufficient condition. Thus, the estimate may be high.

There are many bit categories listed above that were not analyzed in this study.

The current method used to develop DCMs is not efficiency conscious. That is, there was no conscious attempt to make the DCMs efficient. This is discussed more in the following section.

THE DCM DEVELOPMENT PROCESS AT EDWARDS

When a project starts up at Edwards AFB, a frequency spectrum (or set of spectrums) is usually allocated based on projected requirements. Although these are not set in stone and may change, keeping to these allocations simplifies long term scheduling of frequency resources. This up front allocation of spectrum leads directly to a maximum bit rate that can be used. This, in turn, generally determines the size of the DCM. Note: this is done before any specific test is even planned. Thus, the bandwidth is seldom, if ever, determined based on a specific test's requirements.

As the project progresses, parameters are identified for inclusion in the telemetry stream. These parameters are added as needed and the DCM tends to grow over time. That is, although new parameters will be added, it is seldom that parameters are removed – even if they are no longer required. The main reason for removing parameters is if the DCM actually gets full and new required parameters will not fit, or if a major phase of testing is completed and a new phase started.

The main point here is that DCM development is not efficiency driven. But, then again, there hasn't been any reason to be so. Thus, the DCMs being developed would probably be more efficient if the people developing them had a requirement to make them so. In terms of this study, this means that the reported percentage of bits used in a DCM is, in some sense, artificially low.

CHANGING SAMPLE RATE REQUIREMENTS

Figure 2 takes a quick look at the underlying sample rate requirements that feed into a DCM design. Given a certain physical measurement, it does not seem that the number of samples per second needed to capture its frequency should change. However, Figure 2, developed from one of the projects sample rate specifications over the life of the project, shows the specified sample rate does change. Specifically, this chart maps the number of parameters against the number of different sample rates it was stated as requiring. In the extreme case, *a parameter had 12 different sample rates defined as its required rate*. The conclusion here, is that sample rate analysis could be better, or at least more consistent.

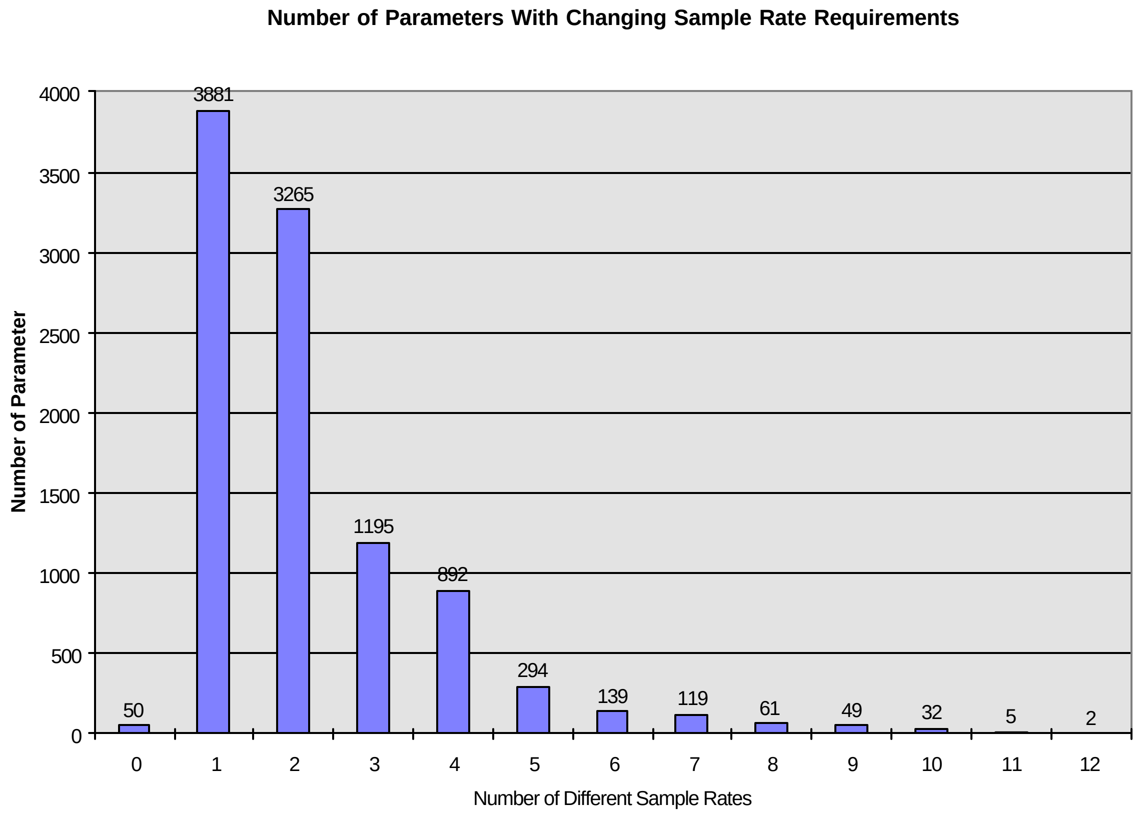

Figure 2 - Sample Rate Requirements

SIGNIFICANCE OF THE POWER-OF-2 RULE

The power-of-2 rule is pervasive in the DCM design community. The author has yet to have a DCM designer say they do not use a variant of this rule. In contrast, some people, when seeing the results of this study, have expressed surprise since their DCMs carry nearly 100 percent information bits. This may very well be true since other applications (for example missiles) have different requirements and environments from an aircraft project at Edwards AFB. However, consider the power-of-2 rule – which these people have said they use. This study showed about 36 percent waste per measurand as a consequence of the power-of-2 rule. This is roughly consistent with the 37.5 percent wasted when changing a rate of 5 to 8 or a rate of 10 to 16 – common scenarios. Assuming these numbers are correct, *even if a DCM carries 100 percent information bits, if the design used the power-of-2 rule*, *the DCM is probably less than 65 percent efficient*.

CONCLUSIONS

This study shows that in practice DCM designs are less than optimal. A major reason for this is simply that optimal DCMs have not been a requirement. This is rapidly changing although a cultural change is needed before DCM designers are truly driven by efficiency. Another reason for DCMs being less than optimal is that DCM design is difficult [4]. This is a prime reason for the use of the power-of-2 rule. That is, this rule simplifies DCM design significantly. Overcoming the difficulty of design requires further research into the structure of DCMs and the development of automated DCM design tools. Both of these are being pursued through projects at Edwards AFB. This study indicates that, if these obstacles are overcome, better DCM design and better sample rate requirements analysis could lead to a 2 to 5 fold increase in telemetry spectrum efficiency.

REFERENCES

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