Processed Data Combination for Telemetry Improvement—DSS 62

J. M. Urech
DSIF Operations Section

This article documents the continuation of the study described in JPL Space Programs Summary 37-63, Vol. II, pp. 116–120, "Telemetry Improvement Proposal for the 85-Foot Antenna Network." Four methods of improving telemetry bit error rate performance by combining data with common time tags from two stations are described in the referenced article. This article discusses the method of a posteriori combination of processed telemetry data. The theory is presented and the results of a scheduled test with a Pioneer spacecraft are shown to be in good agreement. The computer program description is included as an appendix.

I. Introduction

This article is a follow-up to the original report (Ref. 1) which presented method 4, "processed data combination," as a potential telemetry improvement procedure.

The method suggested the sending of the two data streams via teletype or high-speed data line (already processed by the telemetry and command processor) from the different stations to a central computer located at either of the stations or at the SFOF. This computer will compare both information streams and select the best data. It is obvious that the process is only applicable to projects using some kind of error detection technique (such as parity error for *Pioneer*) which will allow the computer to detect erroneous words in either channel and select the corresponding good word from the other channel. Thus, the probability of having an error after combination is the joint probability of having the same word in error in both channels. This, due to the independent noise contributions, is equal to the product of error probabilities for each channel.

The processed data combination method is not affected by the time delay between the two stations, since the computer may employ a high-capacity telemetry buffer. This method may also be used by any pair of stations sharing a common view period (DSS 11/12, DSS 41/42, DSS 51/61/62).

Although the method is ideally applicable to two stations with the same configuration (two ground operational equipment [GOE] or two multiple-mission telemetry [MMT] stations), the computer program has been

developed at DSS 62 for its peculiar configuration—DSS 61 using GOE and DSS 62 the MMT. This configuration further complicates the computer program as it intends to make the formats used by GOE (DOI-5021-OP) and by MMT (DOI-5020-OP) compatible. The program description is given in the appendix.[1]

II. Basic Theory

In the case of uncoded telemetry for the *Pioneer* Project, we may use the following definitions and approximations:

P_{EL} = probability for a bit level in error (NRZ-L)

$P_{EM} = 2P_{EL}(1 - P_{EL}) \simeq 2P_{EL}$ if P_{EL} is very small, P_{EM} being the probability for a bit error (NRZ-*M*)

P_W = probability of a word in parity error, where $P_W \simeq 8P_{EL}(1 - P_{EL})^2$ and if $P_{EL} < 10^{-2}$ then $P_W \simeq 8P_{EL}$

P_U = probability of having an undetected word in error, where

$$P_U \simeq \frac{8!}{6!2!} P_{EL}^2 (1 - P_{EL})^6$$

$$\simeq 28P_{EL}^2 \simeq 0.437P_{EL}^2, \text{ if } P_{EL} < 10^{-2}$$

This is computed for the case of having two bit levels in error per word, although any even number of bit levels in error per word will be undetected by the parity bit; however, the probability of having more than two errors is much smaller.

For the general development of a combining program, two different criteria may be selected:

A. First Criterion

A word tagged in error is outputted only when that word contains a detected error in both channels. In the case of two corresponding words being different (due to a word with an undetected error), select as the output word the one coming from the channel with the most favorable signal-to-noise ratio (SNR), which also has the highest probability of being correct.

Then, the theoretical improvement may be easily computed by making a few valid approximations of the normal operating values of SNR (the exact calculations would be much longer, but for our purpose would not add any useful information).

If the subscripts 1 and 2 are used for each channel, under the assumption that channel 1 has a greater SNR, we will have:

1. Probability of an output word with a detected error

$P'_W = P_{W1} \cdot P_{W2}$ (due to independent noise contribution from both channels)

as $P_W < 1$ this always means an improvement.

2. Probability of an undetected word in error at the output

$$P'_U = P_{W1} \cdot P_{U2} + P_{W2} \cdot P_{U1} + P_{U1}(1 - P_{W2})$$
$$= P_{U1} + P_{U2} \cdot P_{W1}$$

which means a small increment in the undetected word error rate.

These results are shown in Figs. 1 and 2 for the particular case of two channels having the same SNR and therefore,

$$P'_W = P_W^2 \quad \text{and} \quad P_U = P_U(1 + P_W)$$

B. Second Criterion

A word tagged in error is outputted when both channels contain a detected error, and also if two corresponding words are different.

Then, using the same notation as before, we will have:

1. Probability of having an output word with a detected error

$$P''_W = P_{W1} \cdot P_{W2} + (1 - P_{W1})P_{U2} + (1 - P_{W2})P_{U1} - P_{U1} \cdot P_{U2}$$

2. Probability of having an undetected word error at the output

$$P''_U = P_{W1} \cdot P_{U2} + P_{W2} \cdot P_{U1}$$

These results are also shown in Figs. 1 and 2 for comparison with previous ones and for two channels having the same SNR, in which case:

$$P''_W = P_W^2 + 2P_U(1 - P_W) - P_U^2$$

and

$$P''_U = 2P_W \cdot P_U$$

[1]The assembly language listing is available by request to author.

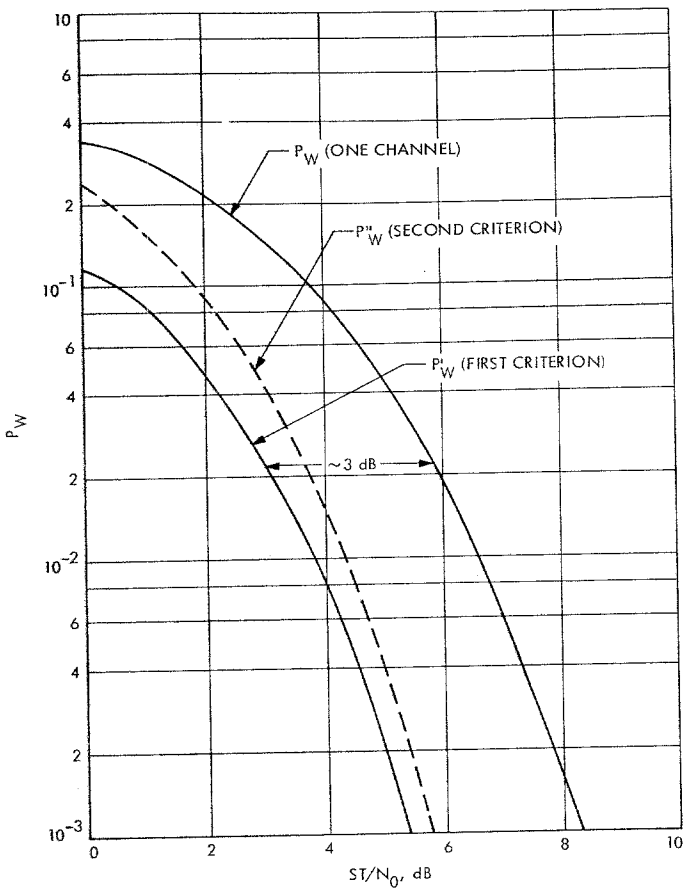

Fig. 1. Probability of a detected word error for a single channel and for the two criteria of combination

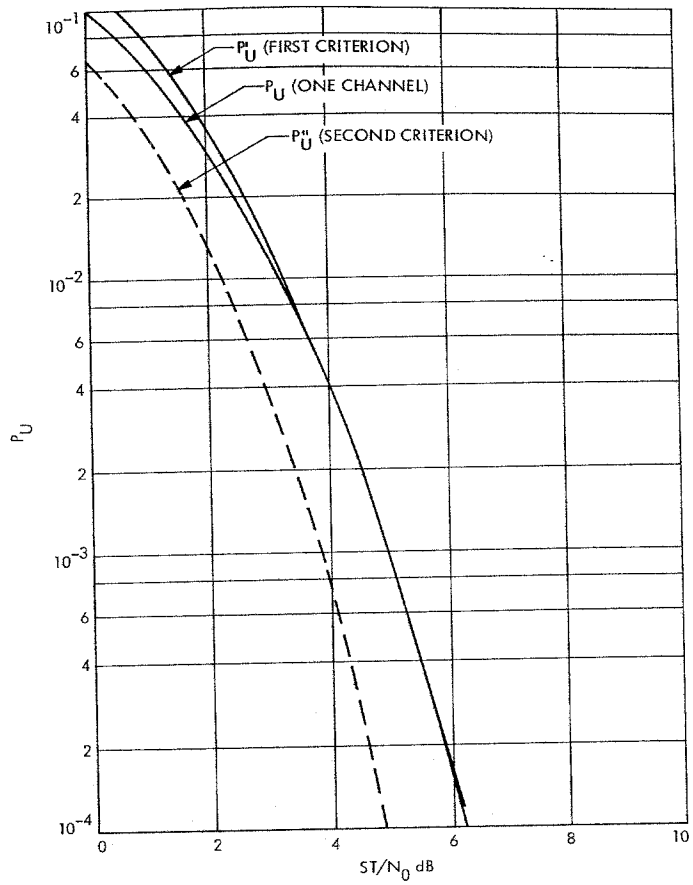

Fig. 2. Probability of an undetected word in error for a single channel and both criteria of combination

By examining both sets of curves (Figs. 1 and 2), one can see that the first procedure yields an almost *constant improvement of 3 dB* (for the operating SNR range) if the detected word error rate is considered. However, the undetected word error rate is not improved with respect to only one channel; furthermore, this rate slightly increases for very low signal-to-noise ratios. For the second criterion, the results are different. The detected word error rate shows an improvement smaller than 3 dB, but still greater than 2 dB in the normal operating range; also, the undetected word error rate is smaller having an equivalent improvement of 1 to 1.5 dB.

C. Criterion Selected for Demonstration Program

Based on the above theory, the selection of the criteria to be employed should be made by the *Pioneer* Project, which should specify the relative importance of decreasing the detected word error rate and the undetected word error rate. Nevertheless, the first criterion has been selected at DSS 62, since this computer program is not intended to be an exhaustive and definite one, but rather has been developed mainly for feasibility demonstration and testing.

III. Conclusion

The "merging" program was checked out internally at the station, and a DSN scheduled test was conducted on day 260 from 16:00 Z to 18:00 Z at DSS 61/62. The results were satisfactory and in close agreement with the basic theory, although the statistics obtained for such a short period (1.5 h) cannot be very accurate. The estimation obtained was:

Station	Percentage of error (avg)	ST/N_0 (avg), dB
DSS 61 (GOE)	0.0215	5.8
DSS 62 (MMT)	0.0114	6.4
DSS 61/62 (Merging)	0.00014	9.3

This shows a telemetry improvement close to the theoretical 3 dB.

Further tests will be conducted when both stations are available at the same time; but if this method of telemetry combination is considered useful to the DSN, the demonstration program will be modified in order to have more capabilities, such as: GOE/GOE combination and/or MMT/MMT combination, or to use the second criterion if required.

Reference

1. Urech, J. M., "Telemetry Improvement Proposal for the 85-ft Antenna Network," in *The Deep Space Network*, Space Programs Summary 37-63, Vol. II, pp. 116–120. Jet Propulsion Laboratory, Pasadena, Calif., May 31, 1970.

Appendix

Processed Data Program Description

Identification

Demonstration program for *Pioneer* science data merging

Author

Miguel A. Urech, DSS 62.

Configuration

Any TCP Phase II-C.

Purpose

Program has been written to demonstrate Method Number 4, *Processed Data Combination* of "Telemetry Improvement Proposal for the 85-ft Net" by Jose M. Urech, DSS 62, dated 11 March, 1970.

Programmed Operators

None.

Storage

Program requires locations 00200 to 00202 and 00300 to 22037.

Timing

N/A.

Source Language

SDS Meta-Symbol.

I. Program Description

The purpose of the program is to improve telemetry by means of combining two data streams already processed by TCP.

The two data streams used for this combination are:

(1) Science TTY output of program DOI-5021-OP at a GOE station, and

(2) Science TTY output of program DOI-5020-OP at a MMT station.

These two streams are first fed into the "merging computer," through R1 and R0 of the communications buffer, where they are compared word by word and the combined data outputted through T3 of the buffer with the same format as used by DOI-5021-OP.

The program has two modes of operation:

A. Merging Mode

In this mode the two data streams are compared word by word employing the following criteria:

(1) If both words are the same and different from dollar signs ($$), anyone of the two is outputted and no error is counted.

(2) If each word is dollar signs ($$), these signs are outputted and the error counter is incremented by one.

(3) If the two words are different, and one of them is dollar signs, the word not being the dollar signs is outputted and no error is counted.

(4) If the two words are different and neither is dollar signs, the word coming from the stream with the most favorable SNR is outputted, and no error is counted.

The program does not calculate the SNR of the two data streams, but this can be introduced by an input through typewriter.

The above-mentioned criteria apply only to words 4 to 16 and 19 to 32 of the data frame. Words 3, 20, and 21 (except in the case of extended frame count for word no. 3) are parity checked in both streams, and the following criteria are then used for comparison:

(1) If the two words are the same and have correct parity, anyone of them is outputted and no error is counted.

(2) If the two words are the same and both have incorrect parity, any one of them is outputted and the error counter is incremented.

(3) If the two words are different and only one has correct parity, the one with the correct parity is outputted and no error is counted.

(4) If the two words are different and both have correct parity, the word from the prime stream (that of most favorable SNR) is outputted and no error is counted.

(5) If the two words are different and both have incorrect parity, the word from prime stream is outputted and the error counter is incremented.

B. Count Error Only Mode

This mode of operation is used upon operator request or when one of the two data streams is not available for comparing in the merging mode (i.e., out-of-lock conditions, which mean that no science TTY data is available from the GOE station, nor is there frame synchronization data from MMT).

In this mode of operation the program's only function is to count errors in the available data stream as it *copies* each word.

The program determines that the DOI-5021-OP data stream is out-of-lock by means of the time tags on each frame. When the time difference between one frame and the next is not the expected one (± 2 s), the program assumes that there is missing data caused by an out-of-lock condition in the GOE computer. This means that the program will not go into a "count error only mode" until this data stream is back in lock, and time gap is determined.

The out-of-lock condition in the DOI-5020-OP data stream is easily detected by means of non-frame synchronization data.

The other most important features of the program are:

(1) The program outputs percentage of error (PE) messages every 10 min through the TTY and also on the console typewriter. The PE is calculated by the simple algorithm:

$$PE = \frac{\text{number of words in error}}{\text{number of words processed}}$$

(2) The program monitors ground receiver AGC and SPE, either from the TTY data coming from the GOE station, or directly through the analog-to-digital converter at the MMT station.

(3) The program copies any command messages appearing in the TTY data from GOE station.

II. Operation Instructions

A. Preoperational Procedures

Ensure that the TCP-II-C computer is configured as follows:

(1) MMT TTY data stream is a patched to "R0."

(2) GOE TTY data stream is patched to "R1."

(3) Batteries are on "T3," which is the SCP used for output.

Ensure that the following patches are made on the interrupt patch panel:

BLUE 6 TO GREEN 5 (100 pps)

ORANGE 21 TO GREEN 6 (TTY OUT)

BLUE 11 TO GREEN 7 (1 pps)

BLUE 19 TO BLUE 20 (ADC CONVERT)

B. Operational Procedures

Load program from paper tape with "standard fill" procedure.

Once loaded, the program requests initialization parameters, (mainly header information) which are the following:

(1) STATION ID =
Type the two digit number of the station.
Example: STATION ID = 62$

(2) SPACECRAFT ID =
Type the two digit S/C number
Example: SPACECRAFT ID = 20$

(3) DAY OF MONTH =
Type the two digit day of month
Example: DAY OF MONTH = 09$

(4) BIT RATE IS =
Type one of the two legal entries, either 08 or 16.
Example: BIT RATE IS = 08$

(5) CHANNEL DESIGNATOR =
Type the three-letter designator.
Example: CHANNEL DESIGNATOR = CEB$

(6) MESSAGE COUNT =
Type a three-digit number for the first header
Example: MESSAGE COUNT = 003$

(7) CHANNEL INDICATOR =
Type a one-letter channel indicator
Example: CHANNEL INDICATOR = B$

(8) PRECEDENCE =
Type a two-letter precedence code
Example: PRECEDENCE = SS$

(9) ROUTING 1 =
Type a four-letter routing indicator or a 0 (zero) if it is not required.
Examples:
ROUTING 1 = JSFO$
ROUTING 1 = O$

(10) ROUTING 2 =
Same as item 9.

(11) ROUTING 3 =
Same as item 10
Thus, up to three routing indicators may be requested.

(12) STATION INDICATOR =
Type the four-letter station indicator.
Example: STATION INDICATOR = LCEB$

(13) TYPE 1 IF MMT IS PRIME, OR 0 IF 5021 IS PRIME
Type 0 or 1 to indicate which stream has the most favorable SNR.

(14) TYPE 1 TO MONITOR MMT AGC, or 0 FOR 5021.
Type 0 or 1, depending on which stream (GOE station or MMT station) is desired to monitor the ground receiver AGC and SPE.
As soon as the last input is entered the program types:
PROGRAM READY
DOY HHMMSS
This indicates that the program is ready and will try to go to the "merging mode" unless forced into a "count error only mode" by breakpoint setting.

C. Breakpoint Options

Breakpoint 1 Set: Requests typewriter input in the case of operator wanting to make any real-time requests.

Breakpoint 2 Set: Go to "count error only mode" with GOE data.

Breakpoint 3 Set: Go to "count error only mode" with MMT data.

Breakpoint 4 Set: Request new Nascom header.

D. Run-Time Typewriter Inputs

(1) RO1/, RO2/, and RO3/ are used to request, change, or delete a routing indicator.
Examples: RO2/JAER$
RO2/0$ (to delete)

(2) MCT/, followed by a three digit number, is used to change the Nascom header sequence number.
Example: MCT/008$

(3) EOM/$
Put an EOM on the TTY line and terminate the program.

(4) AGC/
Type either 0 or 1, depending on which AGC and SPE is desired to monitor.

(5) RSP/$
In the event of garbled characters appearing in the GOE data stream, synchronization of this stream could be lost for comparison purposes. Under these circumstances this message would serve to resynchronize the stream.

(6) RSM/$
Same as item (5) but for the MMT data stream.

(7) BRT/
Is used to change the nominal bit rate, either 08 or 16.

(8) MMT/$
Is used to indicate that the prime stream is now that of the MMT station.

(9) PNN/$
Same as item (8), but GOE station is the prime.

(10) STR/YYYYY/XXXXXXXX$
Used to alter the contents of a memory location (YYYYY).

(11) EXM/XXXXX$
Used to display the contents of a memory location (XXXXX) on the console typewriter.

A sample printout is shown in Fig. A-1.

E. Operation Notes

The program should not be initiated in merging mode until the MMT stream has achieved frame synchronization and has typed at least ten frames. This is to avoid wrong time tag on the frames.

Since storage buffers are capable of holding only 50 data frames (about 10 min of data at 16 bps), any out-of-lock condition detected on one of the two streams and lasting more than 10 min will cause some data from the other stream to be lost. Therefore, the operator should set either B.P. 2 or 3 to force a "count error only mode."

```
* * * PN SCIENCE DATA MERGING PROGRAM * * *

        STATION ID = 62$
        SPACECRAFT ID = 2Ø$
        DAY OF MONTH = 18$
        BIT RATE IS = Ø8$
        CHANNEL DESIGNATOR = CEB$
        MESSAGE COUNT = ØØ1$
        CHANNEL INDICATOR = B$
        PRECEDENCE = S$S
        ROUTING 1 = JSFO$
        ROUTING 2 = Ø$
        ROUTING 3 = JACR$
        STATION INDICATOR = LCEB$
        TYPE 1 IF MMT IS PRIME
        OR Ø IF 5021 IS
        1$
        TYPE 1 TO MONITOR MMT AGC
        OR Ø FOR 5Ø21
        1$
        PROGRAM READY
        261   114833
        261   115ØØØ   PE   ØØØØ
        261   12ØØØØ   PE   Ø658
                         .
                         .
                         .
        261   16ØØØØ   PE   ØØ16
        261   161ØØØ   PE   Ø344
        261   162ØØØ   PE   ØØ49
        RSP/$
        261   162612
        RSM/$
        261   162754
        261   163ØØØ   PE   ØØ76
        261   164ØØØ   PE   ØØ15
                         .
                         .
                         .
```

Fig. A-1. Sample printout of typewriter initialization and periodic output