RECOVERY FROM COMMUNICATION DROPOUTS

LARRY R. D'ADDARIO

National Radio Astronomy Observatory*

2015 Ivy Road, Charlottesville, Virginia 22903, U.S.A.

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Abstract. This paper considers the effects of an unexpected loss of communication to an OVLBI satellite, and procedures for minimizing the harmful consequences to the astronomical observations. Different cases are identified, depending on whether the dropout affects the data link or the timing link, and on the duration of the dropout.

I. INTRODUCTION

As pointed out in OVLBI-ES #3, it is important to maintain continuous communication with an OVLBI satellite for as long as possible in order to keep the timing error constant. Nevertheless, unplanned losses of signal will occur. This can happen because of equipment failures or software errors (e.g., antenna mispointing); due to unusually high path loss exceeding the available margin (e.g., heavy rain); or due to spacecraft maneuvering. Upon re-acquisition of signal, it is then desirable to recover the timing as accurately as possible, even if perfect recovery is impossible. Depending on the nature and duration of the dropout, various recovery algorithms might be envisioned. Some possibilities are explored in this memo.

Of course, there are also predictable dropouts, such as when the satellite is not visible to any earth station. If these are short enough, the recovery algorithms may be useful then also. But such gaps should be less troublesome because they are known in advance. The observing program should have included a strong calibrator for each earth station pass, allowing the timing error to be re-determined astronomically.

Also of interest is the case of transfer from one earth station to another when there is no gap in coverage. Even if the two earth stations are themselves perfectly synchronized, this is a fairly complex problem. It will not be considered here.

Figure 1 shows a typical receiving arrangement at an earth station. The data link is implemented with a QPSK demodulator consisting of a Costas loop followed by two bit synchronizers and then a decoder, which detects sync words and traps header information. The data and bit-synchronized clock are sent to the tape formatter for recording. Because of tape inertia, recording must continue even during a dropout, so some "data" and "clock" must continue to be supplied to the recorder, even if they are invalid. Our task is twofold: first, we must keep a record of which segment of data is invalid so that it can later be ignored by the correlator; and, second, we must correct for any timing error that accumulates during the dropout.

Recall (OVLBI-ES #3) that the "time" written to the tape will be obtained by counting the data clock, but that our best estimate of the actual time of any sample includes an additive correction to the tape time based on the round-trip timing link. The latter enables us to measure the change in propogation time since a fixed "clock setting epoch." If a dropout has occurred between the setting epoch and now, then upon re-acquisition of signal we would like to establish what values the tape time and the propogation time measure would have had if the dropout had not occurred. Note that the tape time counter (or time-of-day, TOD, counter) may be physically part of the tape recorder's formatting logic.

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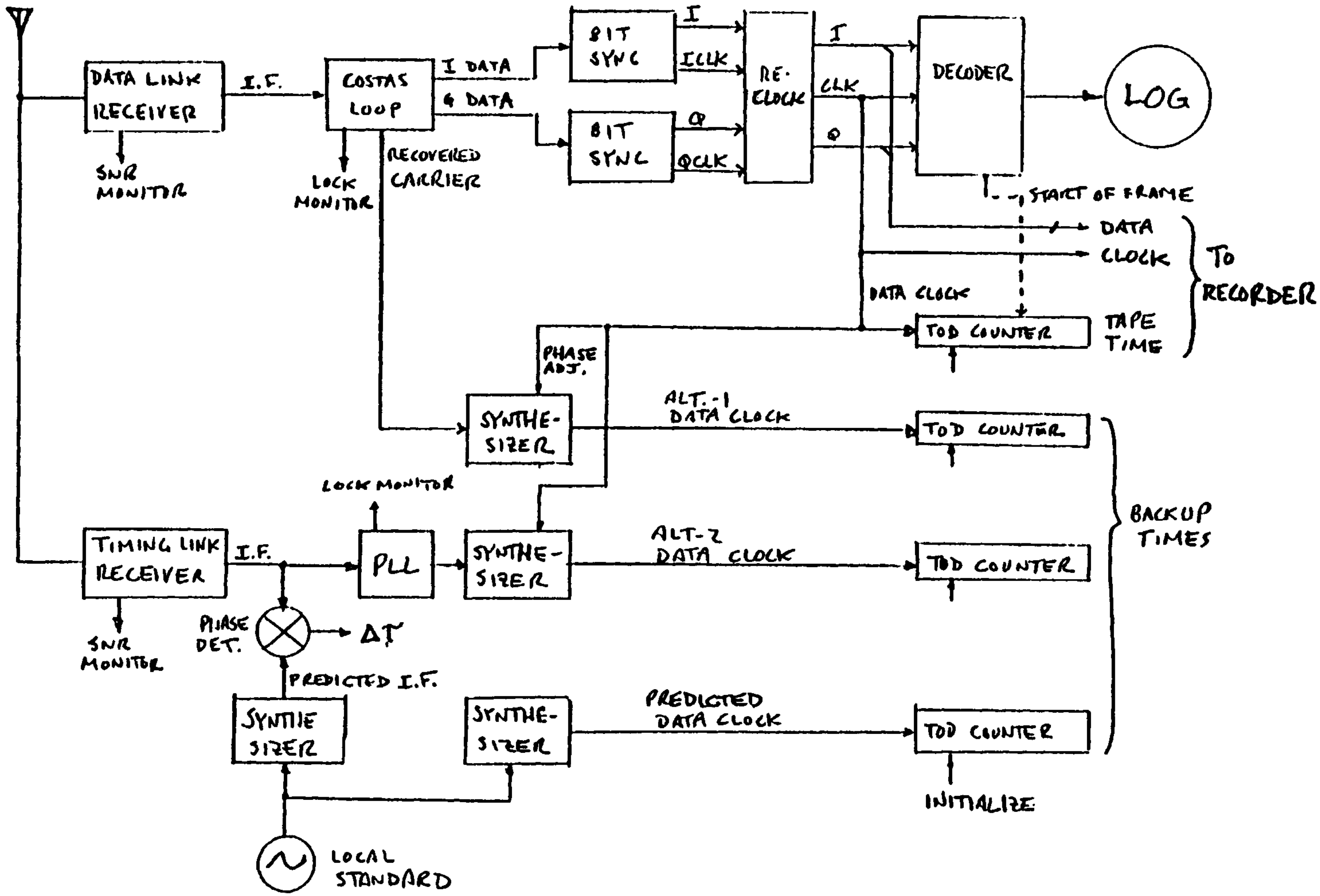
DATA LINK RECEIVER
I.F.
COSTAS LOOP
I DATA
Q DATA
BIT SYNC
BIT SYNC
I
ICLK
Q
QCLK
RE-CLOCK
I
CLK
Q
DECODER
LOG
SNR MONITOR
LOCK MONITOR
RECOVERED CARRIER
START OF FRAME
DATA
CLOCK
TO RECORDER
DATA CLOCK
TOD COUNTER
TAPE TIME
PHASE ADJ.
SYNTHE-SIZER
ALT.-1 DATA CLOCK
TOD COUNTER
LOCK MONITOR
BACKUP TIMES
TIMING LINK RECEIVER
I.F.
PLL
SYNTHE-SIZER
ALT-2 DATA CLOCK
TOD COUNTER
SNR MONITOR
PHASE DET.
ΔT
PREDICTED I.F.
SYNTHE SIZER
SYNTHE-SIZER
PREDICTED DATA CLOCK
TOD COUNTER
INITIALIZE
LOCAL STANDARD

FIGURE 1

Types of Dropout

We consider two major classes of dropout: those affecting the data link only (and not the timing link), called Type I; and those affecting the timing link, Type II. Within each type, there are various cases to consider, depending mainly on the duration of the dropout.

Type I Dropouts: Loss of Data Link Only

When the signal to noise ratio on the data link becomes too low, the bit error rate increases and eventually the sync word cannot be reliably detected. Failure to detect sync words at the anticipated time interval is our primary indicator of failure. But if the timing link remains operational (uplink receiver in lock and downlink phase detector usable) then the signal sampling times on the satellite are unaffected.

The marking of invalid data can be based primarily on the detection of sync words. Detection of a sync word at the expected interval (in bits) from the preceding sync word means that the preceding downlink frame was valid; sync detection at any other time, or failure to detect it at all, means that the preceding frame was invalid. The time resolution of this validity check is thus one downlink frame. Recording of this information can be done by writing a log file record giving the tape times[1] of the beginning and end of each invalid interval. (Supplementary information about data validity can also be obtained from an RF SNR monitor in the receiver, a lock detector in the Costas loop, and internal data error checks like parity, if any.)

The correction of timing errors is more complicated. Depending on the logic available for initializing and maintaining the time-of-day counter, various procedures for dropout recovery are possible.

Case I-A: Brief dropout, much less than one downlink frame.

During the dropout, the bit sync PLLs may be able to flywheel so that when the signal is restored they have covered the same number of cycles (bits) as if the signal had been maintained. This will be verified by detection of the sync word at the expected time. If the flywheel is not sufficiently accurate, then the next sync word will be detected "early" or "late" with respect to the flywheeling clock, and logic can be provided within the decoder to record the number of bits of error in a log file. The TOD counter, which continues to use the flywheeling clock, will be wrong by this number of bits and a correction can be applied off-line, based on the log record.

The logic can also provide a start-of-frame (SOF) pulse following each sync detection, regardless of whether the sync was on time. If the tape formatter hardware can make use of this pulse to correct the TOD counter in real time, then the off-line correction via the log file can be avoided. (This will not be possible with the VLBA formatter; see OVLBI-ES #3.)

Case I-B: Longer dropout, one or more downlink frames.

This case will be observed by the failure to detect one or more sync words. When a valid sync word is once again finally detected, the correct timing can be recovered if the number of frames that has elapsed since the last valid sync word can be determined. One way to do this is to include a "frame count" number in the downlink header, following the sync word; we assume that this is done. The logic must then determine the total timing error (relative to the flywheeling clock, which has now been unlocked for a relatively long time) and record this in the log. An off-line correction can then be effected in the same way

[1]The tape time may not be directly available to the log file generator, but it should be derivable from the current downlink frame number if the frame number of the setting epoch was remembered.

as Case A, although the magnitude will be larger. A real-time correction is probably not feasible.

Use Of Alternative Clock Sources.

The recovered carrier from the Costas loop and the timing link's downward carrier must each be synchronous with the data clock. Therefore, either could be used to synthesize an alternative to the data clock recovered from the bit streams, as indicated in Figure 1. If the data link is unusable then the Costas loop might be out of lock; but, by assumption, the timing link is still usable. (In some systems, in particular the present plan for VSOP, the timing downlink is identical with the data downlink carrier. In that case, the Alt-2 clock of Figure 1 cannot be implemented.)

The alternate data clock derived from one of the carriers will closely track the frequency of the actual data clock, including the Doppler effect on the downlink, even when the actual data cannot be received. It can therefore be used to drive a backup TOD counter which can be compared against the primary TOD counter in the formatter. But this may not be a perfect backup because of dispersion on the links. Also, the phase of the alternate clock will be arbitrary unless steps are taken to lock it to the bit stream clock when the latter is available.

Type II Dropouts: Loss of Timing Link

Case II-A: Loss of downlink only.

If the uplink continues to perform satisfactorily, this will be verified by appropriate lock monitoring circuitry on the spacecraft. It is assumed that the uplink status will be indicated in the data link header, at least in the form of an "uplink OK" bit. The downlink status will be checked by an SNR monitor on the earth station receiver. More sophisticated checks involving the behavior of the phase detector output might also be implemented.

During periods when the downlink performance is worse than required for accurate timing, the timing link data should not be used for time corrections at the correlator. Upon recovery to a satisfactory level, assuming that the uplink has remained satisfactory the whole time, we can attempt to interpolate the timing error across the "dropout." If the dropout has been brief enough and the predicted orbit was accurate enough, then the phase detector output changed by less than π during the dropout. A reasonable recovery algorithm is simply to assume that this is true. If the assumption is correct, then the post-dropout times will have the same error as the pre-dropout times; else there will be a timing error discontinuity.

It can also happen that the SNR drops to the point where the phase detector output is too noisy for useful timing corrections but remains accurate to $<< \pi$. In that case, the phase can be tracked across the "dropout" without ambiguity, even if it drifts by several cycles, so that the post-dropout time will be correct without any assumptions. A more sophisticated algorithm would identify this case and act accordingly.

Case II-B: Loss of Uplink.

This is the most severe type of dropout. It must be detected on the spacecraft and reported, preferably in real time via the data link header. During the dropout, the spacecraft will continue to operate on a flywheeling oscillator, so signal samples will continue to be taken and (if the data link is satisfactory) transferred to the ground. Measurements made on the timing downlink, if any, will be meaningless.

Upon re-acquisition of the timing uplink, the phases of all on-board synthesizers will be arbitrary (with respect to the values they would have had in the absence of the dropout). There will thus be an unrecoverable discontinuity in phase of up to one-half RF cycle and an unrecoverable discontinuity in timing of up to one-half sample time. There is likely to be a much larger timing discontinuity. At best, the timing might be recovered to the nearest sample if the dropout is brief and either the on-board oscillator is sufficiently stable or the orbit knowledge is sufficiently good.

To quantify the last statement, consider a dropout of 10 s duration. If the (reconstructed) orbital velocity is known to within .02 m/s, then the downlink delay change during the dropout will be known to better than $0.2\text{m}/c = 6.7 \times 10^{-10}$ sec. Even at a sampling rate of 32 Msamp/s, this is much less than one sample, so recovery with a timing discontinuity of only $\pm 1/2$ sample is possible. One procedure to achieve this would be to re-initialize the tape TOD counter after re-acquisition, creating a new time scale with newly determined setting error and setting epoch; off-line, the offset between the old and new time scales is determined from the orbit reconstruction and applied as an additional additive correction at the correlator.

An alternative, especially for long dropouts or in cases where the orbit reconstruction is much worse than expected, is to rely on the stability of an on-board oscillator. This requires several things on the spacecraft: a stable and well-characterized oscillator[2]; a TOD counter driven by this oscillator and independent of the two-way timing link; and periodic transmission of the counter's contents along with the astronomical data. Upon re-acquisition after a dropout, the next available reading of the on-board TOD counter can be compared with the last available reading prior to the dropout, giving the elapsed time in on-board clock units. The tape TOD will have to be re-initialized after the dropout, but the offset between the old and new time scales is known to the accuracy of the on-board clock. For this to be effective, it is not sufficient for the on-board oscillator to be *stable* in the sense of having low Allen variance over the dropout time; it is necessary that the oscillator's absolute frequency be accurately known so as to determine the absolute elapsed time during the dropout. However, this should be possible if the on-board TOD counter is transmitted regularly, since this allows long-term monitoring of the on-board oscillator relative to ground oscillators that are even more stable.

Another use of an on-board stable oscillator is quite different from that considered above. A sufficiently stable oscillator can be used *during* a dropout or during complete failure of the uplink if all on-board timing is switched to this oscillator (not just the TOD counter). In practice this will result in shorter coherence times, restricting observations to strong sources at the lower frequencies. The earth station operation would be unaffected in this mode; timing link data would be meaningless and would simply be ignored.

[2]Radioastron will carry a Rubidium oscillator.