Enhancing the Galileo Data Return Using Advanced Source and Channel Coding

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Abstract

In this paper we describe the advanced source and channel coding schemes that we plan to use to enhance the data return from the crippled Galileo spacecraft. The Gali leo spacecraft, which was launched in October 1989, is now on its way to Jupiter. Its mission includes releasing a probe into the Jovian atmosphere, Io flyby, probe data capture and rela y, Jupiter orbit al insertion, and 1(1 sate] lite encounters (Gan ymede, Call isto, Europa). The Galileo Project involves man y years of effort. in April 1991, when the spacecaft first flew by Earth, the Galileo team commanded the spacecraft to open the 4.8m high-gain antenna (HGA). "l'he HGA failed to completely deploy. All indications are that 3 of the 18 ribs are stuck to the antenna's central t ower. Several unsuccessful attempts have been made to free the stuck ribs. If the } IGA fails to deploy, the onl y way to communicate between Earth and the spacecraft is through the use of one of the two lo w-gai n antennas (LGA). If the current configurate ion (ground and spacecraft) remained unchanged, the telemetry data rate would be 10 bits per second at Jupiter arrival (1996), compared to the expected data rate of 134 kbits per second in the planned HGA configuration. A study was conducted from December 1991 through March 1992 to evaluate various options for improving Galileo's telemetry downlink performance. Among all viable options the most promising and powerful one was to perform data compression and emu-correction coding in software onboard the spacecraft. This involves in-flight re-programming of the existing flight soft ware of Galileo's processors, which has severe] y Ii mited com putat ion and memory resources. In this paper we describe t he use of the integer cosine transform (ICT) scheme for image compression, and the feedback concatenated encoding/decoding scheme for error correction coding. We also discuss the issue of interaction between data com pression and error control (cent ai nment/detecti on/correcti on) processes in the Galileo communication system design.

The Galileo image compression scheme is an 8x8 multiplicat ion-free integer cosine transform, which was first proposed by Chain. The ICT can be viewed as an integer approxi mat ion of the popular discrete cosine transform (DCT) scheme, which is regarded as one of the best transform techniques i n image coding. Its independence from the source. data and the availabilit y of fast transform algorithm make the 1X1' an at tract ive candidate for many practical image processing applications. in fact the ISO/CCITT standards for image processing in both still-image. and video image transmission include the IX']' as a standard processing component in many applications. Although the ICT has much lower complexity, the rate-distortion perform ante is not sacrificed.

The 8x8 multiplcation-free ICI' is implemented in software, which requires only 8 adds and 3 shifts per sample. This lowers the software implementation complexity. The implementation novelty of this scheme is the incorporation of the scale-factors of the t ransform process as part of the scalar quantizat ion process, thus guarantee ng orthogonalit y among the ICT transform basis functions and integer values in the ICI' matrix.

The Galileo error-correction coding scheme uses a (255,k) variable redundancy Reed-Solomon code as the outer code, and a (14,1/4) convolutional code as the inner code. The Reed-Solonlon codewords are interleaved to depth 8 in a frame. The redundancy profile of the Reed-Solomon codes is (94, 10, 30, 10, 60, 10, 30, 10). The staggered redundancy profile was designed to facilitate, the novel feedback concatenated decoding strategy [2,31. This strategy allows multiple passes of channel symbols through the decoder. During each pass the decoder uses the decoding information from the Reed-Solomon outer code to facilitate the Viterbi decoding of the inner code in a progressivel y refined manner. The feedback concatenated decoder (FCD) is implemented in software on a multiprocessor workstation. The code is expected to operate at bit signal-to-noise ratio of 0.65 dB at bit error rate of 10-7.

Finall y we discuss the issue of interaction between data compression and error control (containment/detection/correction) processes in the Galileo communication system design. The ICT and most other data compression schemes have the undesirable effect of error propagation. That is, a small loss in compressed data can cause a big loss in reconstructed data. 'The nature of error propagation depends on the compression schemes being used.

In the Galileo LGA mission operation scenerio, the volume of data returned wi 11 be drastically reduced. **in** order to maximize the scientific objectives with the limited transmission bandwidth of the LGA, most of the data are expected to be heavil y edited and compressed. These valuable data must be safeguarded against catastrophic error propagation caused by channel errors and other unforeseeable errors.

The ICT scheme is equipped with a simple but effective error containment strategy, The basic idea is to insert synchronization markers and counters at regular intervals (every 8 lines of data) to delimit uncompressed data into independent blocks. If an anomaly occurs during the transmission of data the decompressor can search for the sync hronizat ion marker and continue, to decompress the rest of the. data. The error containment strategy guarantees that error propagation wil l not go beyond 8 lines of data.

The data compression and error correcti on schemes described above have been implemented and tested. Other than deep space applications as described in the Galileo scenario, these algorithms are also ideal for commercial applications. The ICT scheme can be used in low-cost high-speed image/video commercial applications. The FCD scheme can be used for power-constrained and bandwidth critical satellite communications.

References:

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