Forward error correction

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In telecommunication and information theory, **forward error correction (FEC)** is a system of error control for data transmission, whereby the sender adds redundant data to its messages, also known as an **error correction code**. This allows the receiver to detect and correct errors (within some bound) without the need to ask the sender for additional data. The advantage of forward error correction is that a back-channel is not required, or that retransmission of data can often be avoided, at the cost of higher bandwidth requirements on average. FEC is therefore applied in situations where retransmissions are relatively costly or impossible. In particular, FEC information is usually added to most mass storage devices to protect against damage to the stored data.

FEC devices are often located close to the receiver of an analog signal, in the first stage of digital processing after a signal has been received. That is, FEC circuits are often an integral part of the analog-to-digital conversion process, also involving digital modulation and demodulation, or line coding and decoding. Many FEC coders can also generate a bit-error rate (BER) signal which can be used as feedback to fine-tune the analog receiving electronics. Many FEC detection algorithms, such as the soft Viterbi algorithm, can take (quasi-) analog data in, and generate digital data on output.

The maximum fraction of errors that can be corrected is determined in advance by the design of the code, so different forward error correcting codes are suitable for different conditions.

Contents

[hide]

[edit] How it works

FEC is accomplished by adding redundancy to the transmitted information using a predetermined algorithm. Each redundant bit is invariably a complex function of many original information bits.

The original information may or may not appear in the encoded output; codes that include the unmodified input in the output are **systematic**, while those that do not are **nonsystematic**.

An extremely simple example would be an analog to digital converter that samples three bits of signal strength data for every bit of transmitted data. If the three samples are mostly zero, the transmitted bit was probably a zero, and if three samples are mostly one, the transmitted bit was probably a one. The simplest example of error correction is for the receiver to assume the correct output is given by the most frequently occurring value in each group of three.

Triplet received	Interpreted as
000	0
001	0
010	0
100	0
111	1
110	1
101	1
011	1

This allows an error in any one of the three samples to be corrected by "democratic voting". This is a highly inefficient FEC, and in practice would not work very well, but it does illustrate the principle. In practice, FEC codes typically examine the last several dozen, or even the last several hundred, previously received bits to determine how to decode the current small handful of bits (typically in groups of 2 to 8 bits).

Such triple modular redundancy, the simplest form of forward error correction, is widely used.[*citation needed*]

[edit] Averaging noise to reduce errors

FEC could be said to work by "averaging noise"; since each data bit affects many transmitted symbols, the corruption of some symbols by noise usually allows the original user data to be extracted from the other, uncorrupted received symbols that also depend on the same user data.

- Because of this "risk-pooling" effect, digital communication systems that use FEC tend to work well above a certain minimum signal-to-noise ratio and not at all below it.
- This *all-or-nothing tendency* becomes more pronounced as stronger codes are used that more closely approach the theoretical limit imposed by the Shannon limit.
- Interleaving FEC coded data can reduce the all or nothing properties of transmitted FEC codes. However, this method has limits. It is best used on narrowband data.

Most telecommunication systems used a fixed channel code designed to tolerate the expected worst-case bit error rate, and then fail to work at all if the bit error rate is ever worse. However, some systems adapt to the given channel error conditions: hybrid automatic repeat-request uses a fixed FEQ method as long as the FEQ can handle the error rate, then switches to ARQ when the error rate gets too high; adaptive modulation and coding uses a variety of FEQ rates, adding more error-correction bits per packet when there are higher error rates in the channel, or taking them out when they are not needed.

[edit] Types of FEC

The two main categories of FEC are block coding and convolutional coding.

- Block codes work on fixed-size blocks (packets) of bits or symbols of predetermined size.
- Convolutional codes work on bit or symbol streams of arbitrary length.
- A convolutional code can be turned into a block code, if desired.
- Convolutional codes are most often decoded with the Viterbi algorithm, though other algorithms are sometimes used.

There are many types of block codes, but the most notable is Reed-Solomon coding because of its widespread use on the Compact disc, the DVD, and in computer hard drives. Golay, BCH and Hamming codes are other examples of block codes.

Hamming ECC is commonly used to correct NAND flash memory errors[*citation needed*]. This provides single-bit error correction and 2-bit error detection. Hamming codes are only suitable for more reliable single level cell (SLC) NAND. Denser multi level cell (MLC) NAND requires stronger multi-bit correcting ECC such as BCH or Reed-Solomon[*dubious* – *discuss*].

Nearly all block codes apply the algebraic properties of finite fields.

[edit] Concatenate FEC codes to reduce errors

Block and convolutional codes are frequently combined in **concatenated** coding schemes in which the convolutional code does most of the work and the block code (usually Reed-Solomon) "mops up" any errors made by the convolutional decoder.

- This has been standard practice in satellite and deep space communications since Voyager 2 first used the technique in its 1986 encounter with Uranus.

[edit] Turbo codes

Main article: Turbo code

The most recent (early 1990s) development in error correction is turbo coding, a scheme that combines two or more relatively simple convolutional codes and an interleaver to produce a block code that can perform to within a fraction of a decibel of the Shannon limit.

- One of the earliest commercial applications of turbo coding was the CDMA2000 1x (TIA IS-2000) digital cellular technology developed by Qualcomm and sold by Verizon Wireless, Sprint, and other carriers.

- The evolution of CDMA2000 1x specifically for Internet access, 1xEV-DO (TIA IS-856), also uses turbo coding. Like 1x, EV-DO was developed by Qualcomm and is sold by Verizon Wireless, Sprint, and other carriers (Verizon's marketing name for 1xEV-DO is *Broadband Access*, Sprint's consumer and business marketing names for 1xEV-DO are *Power Vision* and *Mobile Broadband*, respectively.).

[edit] Commercial Products Supporting Hardware Synthesis of Forward Error Correction

- Mentor Graphics Catapult C
- Mathworks
- Forte Design

[edit] See also

- Low-density parity-check code

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[edit] External links

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