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FADING COUNTERMEASURE FOR HIGH FREQUENCY DATA COMMUNICATONS USING ERRORS CORRECTING CODES

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High Frequency (HF) data communication links remain relevant even in today's satellite era because they offer beyond line-of-sight without third-party equipment's and expensive satellite services. The disadvantage is that HF is a difficult medium to use, with significant channel distortion and background noise at any given frequency. This has severely limited the maximum data rate on HF data modems. In this paper the medium data rate communications on HF channels over seawater is considered using different approaches forward error correction (FEC) coding with adequate waveforms, and comparative evaluations are presented.

Keywords: high frequency, forward error correction coding, waveform, modem

Introduction

In the past, HF radio dominated beyond line-of-sight (BLOS) traffic. Data rate was limited by fading (due to multipath propagation), so that for a long time, the effective limit at long range was 75 symbols per second. Much higher rates are possible at shorter ranges, where is only one propagation path (surface wave). In recent years, data rates have risen impressively. Using a computer to sample transmissions and correct for distortions raises the data rate in a single tone to about 2400 bps.

The HF channel offers particularly intriguing challenges. The skywave channel provides support for long-haul beyond line of sight (BLOS) communications without the need for relays. However, the fading which is experienced on these circuits can be severe, and only a small percentage of skywave channels will support communications at data rates of up to 9600 bps. HF surface wave propagation provides BLOS communications as the wave propagates over the curved surface of the earth. How far beyond line of sight depends strongly on the composition of the surface. The HF surface wave propagates for distances of several hundred kilometers over highly conductive surfaces such as seawater, much farther than over fresh water or land. This phenomenon makes HF surface wave communications particularly significant for naval applications.

Signal fading and impulsive noise on HF channels significantly degrade the signal-to-noise ratio (SNR) of the received signal, leading to large burst of errors. Demodulators can reduce the number of errors by introducing error-control coding and data interleaving. The application of error control coding strategies to existing HF modems has resulted in significant performance improvements. In this paper we review the major problems encountered when waveform designing for communications over the HF band and an effective approach FEC coding for reliable naval HF data communications is investigated.

The factors affecting waveform design

The unique characteristics of the HF channel itself offer significant challenges. The ionospheric refraction which allows HF radio signals to propagate over long distances is not without its shortcomings. The received sky-wave signal may suffer distortion in the form of temporal dispersion (delay spread) as well as fluctuation in the signal's amplitude and phase (Doppler spreading). It is reported that the amplitude of the received signal is Rayleigh distributed, while the phase of the received signal is generally taken to be uniformly distributed. More typical mid-latitude sky-wave channels might show delay spreads of 1 - 4 ms with Doppler spreads of 1 Hz or less [1]. However, more typical values are 2 ms and 1 Hz respectively which are the basic parameters of standardized CCIR Poor channel. In the CCIR Good channel the two paths are separated by 0.5 ms and fade slowly at 0.1 Hz [2, 3]. In addition to the sky-wave channel, the HF surface wave channel offers interesting features and challenges. Over sea-water, the HF surface wave propagates far beyond line-of-sight, offering intriguing capabilities for Naval forces. As the surface wave begins to weaken at the periphery of the surface wave coverage region, a Rician channel is observed, with the non-fading component from the surface wave, and another, fading component, arising from a sky-wave path. The noise environment in the HF channel is also somewhat unique. CCIR Recommendation 322 provides a model for the HF noise environment. In general, it is much more impulsive than additive white Gaussian noise, with a much higher peak to mean ratio and tends to introduce burst error events.

One of biggest constraints for HF waveform design, particularly in recent years as the emphasis has shifted to higher data rates, is the channel bandwidth. Each HF communications channel bandwidth is typically limited to 3 kHz. The available bandwidth and the channel characteristics serve to limit the data rates which are achievable over HF. With the adoption of the modem serial-tone modem, naval broadcasts are moving to a 300 bps data rate and other services are being provided at rates up to 2400 bps. The demand for increased data rates imposed by modem networking protocols has led to a determined effort to push achievable data rates upward and has resulted in new and developing standards for waveforms offering rates of 9600 bps and greater. The context in which these systems are being developed is also changing. At one time, it is considered that paramount and most HF transmissions were one way, with no acknowledgment to give away information on the recipient's position. Using more bandwidth allows higher data rates. This can be achieved using adjacent sidebands, for example using the upper and lower sideband gives a total of 6 kHz of bandwidth.

Synchronization is the process at the receiver of identifying that a transmission is present and determining its timing with sufficient accuracy to permit demodulation. Again, HF offers some unique challenges in this area. The extreme fading experienced over HF circuits means that it is possible that a fade could encompass the entire duration of the preamble, making detection difficult or impossible, even in channels where the average signal level is sufficient to permit fairly high rate communications. Designers have tried to mitigate this in two ways. STANAG 4285, for example, specifies an 80 symbol preamble which is reinserted every 256 symbols. This ensures that when the signal level rises to levels which will support communications, it can be detected and synchronized to. The disadvantage with this approach is that the ratio of data to known symbols is decreased. The alternative to this is to use an initial long preamble to ensure synchronization, and then only include known symbols where they are directly required to assist in demodulation. Long preambles, with durations of up to 4.8 s have been used. This is the approach which was taken in Mil-Std 188-110 A where the length of the preamble has been tied to the interleaver used; when short or no interleaving is selected, a 0.6 s preamble is sent while when long interleaving is specified, a 4.8 s preamble is used.

The degree of synchronization required depends upon the algorithm used to demodulate the data. Early techniques required synchronization which was accurate to the symbol. More modem algorithms operate effectively with synchronization which is accurate to within several symbols. This distinction can be critical at HF, where multi-path fading can result in a continually changing synchronization point. The other use for the synchronization preamble is frequency offset removal. The known symbols in the preamble are used to estimate and remove any frequency offset in the received signal.

From a waveform design perspective, the trade-offs which must be considered are the delay and reduced data rate resulting from adding symbols dedicated to synchronization versus the probability of missing a signal which could have been successfully demodulated if an insufficient number of symbols is used for synchronization.

Adaptive equalization (serial-tone, OFDM) and guard-time protection (OFDM) are common techniques used to combat the effects of ISI at HF band. Equalization is required for serial tone modulations where the symbol duration is small relative to the expected time dispersion, which is often as severe as several milliseconds. Multi-carrier and M-FSK modulations, on the other hand, do not, as a rule, require equalization since their symbol spacing is sufficiently large as to mitigate the effect of multipath delay spread for most channels. Most modern HF modems use equalization which requires estimation of the channel impulse response. As a consequence, the waveform designer must provide sufficient opportunity to make channel estimations and to maintain and update them as required.

Error Correction Coding for HF data communication system

In order to combat the effects of fading, an FEC scheme combined with an interleaver is typically used. For the best performance, the size of the interleaver is chosen to be inversely proportional to fading rate. Unfortunately, some HF channel conditions (CCIR Good channel) suffer from very slow rates which require interleavers spanning between 1 to 2 minutes. If an interleaver is not long enough, the fading process becomes correlated and the expected coding gains of FEC schemes can degrade significantly when compared to an independent Rayleigh fading channel. Since long interleaver cause large latencies at the receiver, a trade-off between latency and performance is unavoidable.

There are a number of criteria which must be considered in selecting an FEC code. Performance, complexity, compatibility and proprietary rights issues are all significant factors in the choice of a code. The relative performance of various coding schemes varies with code rate, modulation and the acceptable error thresholds.

a. Convolutional codes

Convolutional codes are soft decision, bit-error correcting codes which are usually decoded with a near maximum likelihood detection process known as Viterbi decoding. When combined with adequate interleaving, they provide good performance in the fading channels found at HF. Convolutional codes perform poorly in burst error environments, which makes it critical to achieve sufficient interleaving to break up fades.

The rate 1/2, constraint length 7 convolutional code with generator polynomials: $g_1(x) = x^6 + x^4 + x^3 + x + 1$, $g_2(x) = x^6 + x^5 + x^4 + x^3 + 1$ is commonly used for HF serial tone data transmission. Both Mil-Std 188-110 A and STANAG 4285 Annex E call for this code. When rates greater than 1/2 are required, they can be achieved by puncturing the code. Rates lower than 1/2 are achieved by repeating the bits output by the encoder. The advantage of the repetition strategy is that it is much simpler than developing alternate codecs for each data rate.

b. Reed-Solomon codes

Reed-Solomon codes (RS codes) are a class of symbol error correcting codes which provide good burst (module) error performance, particularly when erasures are used. The code itself provides an indication of error when it is not possible to correctly decode the received data. For example, a module error with 4-bit length can be corrected and a double module error can be identified at the same time using the norm criteria for RS code (72, 60) [4]. This feature can be very valuable in packet data systems. Relative to other coding schemes, RS codes work best at high rates or when the acceptable BER thresholds are particularly stringent. The major disadvantage associated with RS codes is the difficulty in incorporating soft decision information into the decoding process in a form more sophisticated than simple erasures.

c. Concatenated codes

Concatenated codes attempt to use multiple encodings to overcome the shortcomings of some codes. Powerful concatenated codes have been formed by using convolutional inner codes with RS outer codes. The main disadvantage of concatenated codes is that they require two interleavers to be effective. This limits the amount of interleaving which can be applied to the inner code, with the result that for the error rates usually considered adequate at HF, i.e., in the 10^{-3} to 10^{-5} range, concatenated codes generally do not perform as well as convolutional codes by themselves. However, if a very stringent BER criterion is required, they will perform very well.

d. Trellis Coded Modulation (TCM)

This class of codes exploits the improved minimum distance properties which can be obtained by combining coding and modulation. One significant advantage of TCM is the ease with which soft decision decoding can be implemented, resulting in further coding gains. Moreover, TCM is the ease of designing a family of modems which can transmit data at traditional rates. Much of the work in TCM has focused on channels with AWGN, but this is not valid for HF channels. HF in particular represents a difficult environment for TCM because of the interaction which takes place between the coding and the equalizer. Recently, several researchers investigate the possibility of designing trellis codes suitable for fading channels where the decoder have access to perfect channel state information [3].

e. Iterative codes

Turbo codes are the best known example of iterative codes and able to be very close to the Shannon capacity bound. There are three drawbacks associated with these codes. To obtain the impressive performance that they offer, substantial interleaving is required. The computational complexity associated with these codes is substantially greater than convolutional codes, although significant strides have recently been made in reducing the computational complexity. Most of these codes are protected by patents and, as such, are subject to proprietary rights which makes their adoption for use at HF very problematic.

f. Interleaving

Depending on the kind of code employed, the interleaver may interleave symbols or bits. In the case of Reed-Solomon codes, in order to preserve the burst error capabilities of the code, symbols are interleaved. With convolutional and other bit error correcting codes, it is the bits which are interleaved. Both block and convolutional interleavers are used for HF data communications. The block interleaver has the advantage that if the data packets are sized to fit within an interleaver block, no flush is required. The drawback to the block interleaver is that it is only possible to synchronize at interleaver block boundaries. With a convolutional interleaver, on the hand, synchronization is possible once every cycle through the interleaver and, for the same end-to-end delay, better performance is achieved. The major disadvantage to the convolutional interleaver is that it requires a flush to clear out the interleaver at the end of the transmission.

Design of coded-waveform for naval reliable HF medium-data-rate communication

a) The comparison single-tone and parallel tone modems

Much of the early research into HF communications was undertaken and MIL-STD-188-110A describes three modems suitable for data rates of 2400 bps. In chronological order the modems are the 16-tone, 39-tone and single-tone modems. The three modems comprise two fundamentally different modem formats; the first two represent parallel tone modems, while the most recent addition uses only a single signalling tone.

The parallel-tone modem is able to extend the length of the channel symbol such that time-delay spread of the signal becomes a small fraction of the total symbol length. The advantages of the parallel-tone format are its simplicity and spectral efficiency. The disadvantage is the poor power efficiency. The second MIL-STD parallel-tone modem is the 39-tone. While the 16-tone modem was uncoded, the 39-tone modem uses a shortened (14, 10) Reed-Solomon code and gives a significant performance advantage.

For second format the waveform comprises a single tone, so a time-delay spread in the order of a few milliseconds causes significant amounts of ISI. To overcome this, an equalizer estimates and compensates the channel distortions, thereby removing the ISI. The MIL-STD single-tone modem uses probe sequences to measure the channel distortion. The probe sequence must be long enough to cope with the maximum amount of time-delay spread and frequent enough to allow the equalizer to track changes to the channel impulse response. The probe sequence does not carry data, so it represents lost signalling power. The advantage of the probe sequence is that it allows the demodulator to use coherent detection.

The other comparison is based on the interference tolerance of the two formats. Co-channel interference from other HF users is a problem. Even low levels of co-channel interference can seriously degrade the bit error rate (BER) performance of modems. We, therefore, consider the interference tolerance of the three MIL-STD modems. The performance of the 16-tone modem is worst of all, because of its simple demodulator and absence of error-control coding. The 39-tone modem with FEC tests reveal that it is also sensitive to the position of the interferer. When the interferer is placed on the centre of a signalling tone, it is very vulnerable, and has little to commend it over the 16-tone modem. When the interfering tone is placed between the signalling tones, the modem is the most robust, providing reliable data communications at signal-to-interferer ratios above 5 dB. In recent research OFDM modems are proposed for high data rate communications, however it is necessary to cope with several problems, for example, excessive guard-time, reduce peak to average power ratio, the tone frequency offset, symbol timing recovery, and so on [3].

The single-tone modem is not sensitive to the frequency of the interferer and performs very well when the signal-to-interferer ratio is above 12 dB. As the level of the interferer increases the BER performance of the modem degrades rapidly. More recent versions of the single-tone modem are available with excision processing that can remove narrowband interference. To summarise, the performance of the single-tone modem is no better than the parallel-tone modems in the presence of interference. While it is possible to add interference excision processing before the demodulator, this is equally applicable to the parallel or single-tone modems. In either case, the deficiencies of the waveform require powerful error-control coding to give them credible performance.

b) Naval Application of HF Data Communications

In general, the relative strengths of groundwave and skywave signals as a function of range behave. At short range, groundwave will dominate and at long range, skywave will be the primary propagation mechanism (Rayleigh channel). At intermediate ranges, there is a transition region where the Rician channel model is appropriate. An assessment was undertaken to obtain an indication of:

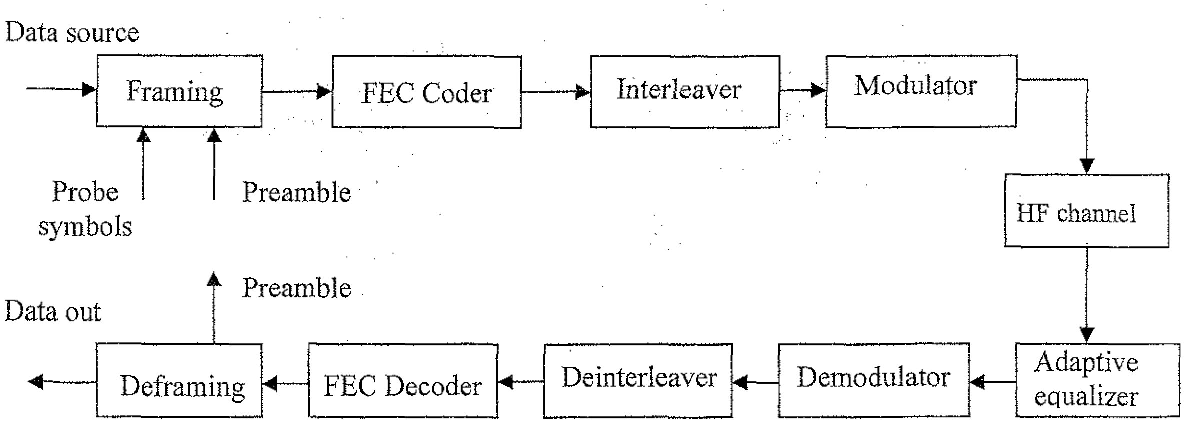
- the received signal levels and signal-to noise ratios (SNR) that could be expected by naval platforms at various ranges, and;

- the boundaries of the transition region between groundwave and skywave domination.

In Vietnam, island – to – shore and ship – to – shore communications typically are not long-haul path (the distance island – to – shore approximates 250 ÷ 370 nmi and nearer), therefore HF surface wave is able to use for these communicating situations. In this conditions a Rician channel is often observed, with the non-fading component from the surface wave, and another, fading component, arising from a sky-wave path. However, most naval broadcasts were run at 75 bps, and were often unreliable because of the lack of FEC coding.

Figure shows a structure scheme single tone modem data transfer at HF band with FEC coding and interleaving.

For medium data rate communications PSK is appreciate rather than FSK or QAM, in our scheme QPSK is chosen. In this scheme a binary Reed-Solomon is used for module errors correcting and identifying with using norm theory, which is investigated by professors B. K. Konopelko and V. A. Lipnitski [5]. In fact, with FEC scheme without ARQ and duplex transmission it is not necessary to detection uncorrected errors, but for hybrid scheme with duplex transmission it is unavoidable, therefore in our scheme the errors control strategy can be easily change. It is noted that in this scheme the symbol interleaver is used, that allows to increase to interleaving deep, thereby, the long burst errors are separated to shorter module errors. On the other hand, a module error can be corrected simpler and more effectively with the norm decoding. The smaller delay decoding compensates the interleaving delay. The other techniques (the probe symbols and adaptive equalizer) are similar to the existing.



Structure scheme single tone modem data transfer at HF band

Conclusions

A study of the current single and parallel-tone modem formats, revealed only minor advantages or disadvantages when considering the waveforms is presented. The parallel-tone modem was slightly more robust than the single-tone when considering tolerance to carrier wave interference. It is, however, necessary to cope with several problems, for example, excessive guard-time, reduce peak-to average power ratio, the tone frequency offset, symbol timing recovery, and so on. On the other hand, the complexity of the equalizers employed in the single-tone modem represents a considerable computational effort, and the probe symbols used to train the equalizer limit the maximum data rate that the modem can carry. In the proposed scheme, QPSK combinating with a Reed-Solomon coding, can be easily change errors control strategy, increase to interleaving deep and reduce decoding delay by using norm decoding.

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