Performance Improving Of HF Modem Using TCM

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Abstract - This paper deals with a problem of upgrading performance of an existing HF modem, by use of a trellis-coded modulation (TCM). Modification consists of replacement of existing DQPSK modulation with a trellis-coded 8PSK (TCM 8PSK) modulation. Also, some of the modern DSP algorithms are used to attain better performances. By introducing these solutions, much better performances can be achieved without major hardware upgrades. Performances of modified modem acquired by means of simulation are compared with commercial modems of similar design and data rate.

Keywords – HF modems, TCM modulation, Parallel tone modem

I. INTRODUCTION

Since the beginning of data transmission, HF band was very interesting for both civil and military use. Its main advantage is possibility of relatively long-range transmission with limited power. Another advantage is large number of 3 kHz voice channels in this band. But, harsh and time variable conditions of HF radio channel rendered it unsuitable for data transmission until development of DSP technology and modern error-controlling codes.

There are many commercial products that operate over HF radio channel. Over the years, different protocols, modulations and error-correcting techniques were used, with one goal in mind: more robust modems with higher data rates. Currently, data rates up to 2400 bps are most common. But, for special services (military, navy, etc.) higher and non-standard data rates are needed. In this paper a commercial HF3618 3000 bps HF modem will be discussed [1]. This modem has been developed by the end of 1980's and uses rather old techniques and can be upgraded by using more up-to-date knowledge of information theory.

In the next chapters concept of an N-tone parallel HF modem will be presented. Also, there will be given some methods of modification, which should greatly improve robustness of this particular modem. Finally, the results obtained by simulation are compared with other solutions.

II. THE N-TONE PARALLEL TONE MODEM

Current 2400 bps modems are 16-tone modems. Basically, the signal is composed of 17 OFDM tones. (16 data carriers and one Doppler-shift correction pilot tone). Pilot tone is set on 605Hz and is 7dB larger then the data carriers creating SNR loss of 1.7dB. Data carriers reside in spectral area from 935 to 2585 Hz with spacing of 110 Hz between each of the signaling tones. The signaling tones are modulated with Differential Quadrature PSK (DQPSK) with a symbol rate of 75 baud. Total bit rate is: $16\times75\times2=2400$ bps.

HF3618 3000 bps modem uses 20 data carriers with DQPSK modulation and signaling rate of 75 baud per carrier. The signal structure of this modem is given in figure 1.

This modem uses larger part of the voice band, thus making it more efficient for data transmission, but effectively reducing power of each signaling tone for approximately 1 dB.

Doppler shift correction is done by sending three pilot tones set in second, eleventh and twentieth channel (605 Hz, 1595 Hz and 2585 Hz respectively) in period of 0.5 seconds prior to data transmission. This method does not reduce SNR, but procedure for establishing connection is longer for 0.5 seconds. Maximum frequency offset which can be overcame by this method can be in range of ±75 Hz

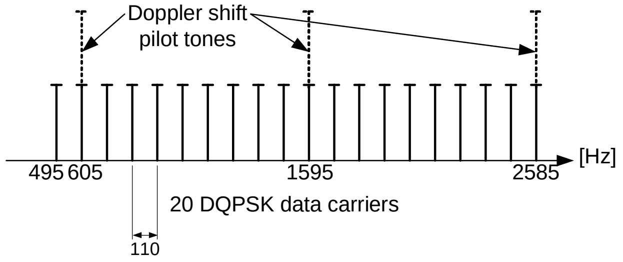

Figure 1. HF3618 signal format

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Transmitted composite OFDM signal *s(t)* in *n*-th symbol interval can be represented as in:

$$s(t)=\sum_{n=-\infty}^{\infty}\sum_{k=0}^{N_t-1}c_{n,k}\,g_k(t-n\cdot(N_tT_s)) \qquad (1)$$

where $c_{n,k}$ is symbol transmitted in *n*-th symbol period with length of T_s over *k*-th of N_t carrier tones.
OFDM complex subcarrier tones can be defined as:

$$g_k(t)=\begin{cases} e^{j2\pi f_k t} & ,\quad t\in[0,N_t\cdot T_s] \\ 0 & ,\quad other \end{cases} \qquad (2)$$

Because of the intersymbol interference (ISI) there is a "guard time" after each signaling period. Active signal period is 9 ms and the guard time is 4.5 ms as shown in Figure 2. Due to this time, effective SNR in HF modem is 1.8dB less than in ideal system.

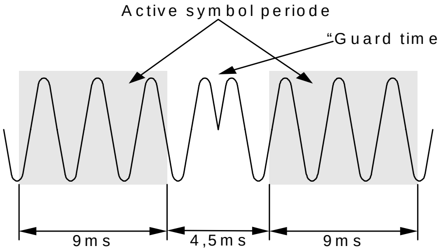

Figure 2. Signaling period and "guard time"

Modem is using one of the following two types of error-correction, depending on channel condition:

- BCH code (code length 255)
- Reed-Solomon code (symbol length 8 bits)

III. HF CHANNEL CHARACTERISTICS

HF channels are known to be very hostile environment even for an analog voice communication, let alone digital data transmission. It is known that its main characteristics are very slow Rayleigh fading, time varying impulse response and strong impulse noise, produced either by lightning or man-made machines. Reason for time variation in impulse response is the way the transmitted signal propagates.

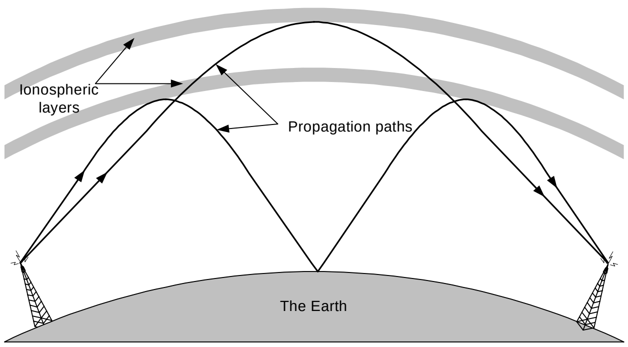

Figure 3. HF propagation paths

There are two basic propagation paths that are shown in figure 3. Due to the time variant nature of ionosphere layers there is a time dependency of channel characteristics of transmission channel.

On the receiver end, these two signals (or even more if there is a case of multiple reflections) make one composite signal with a frequency offset and slow fading. Since there is no direct wave, this is the only signal which can be received. Fading is so dominant in HF channel, that the mere effect of fading was first noticed in radio broadcast over HF on the early stage of radio communication.

There are many HF channel simulators, but the most used is Watterson simulator. Although this simulator has many flaws, it is widely used as a standard for modeling HF channels [3]. Another way is "replay simulator", which consists of a database obtained by measuring the HF channel propagation characteristics over a long time. Replay simulator is more exact, but it takes a long time to be created and is less flexible [4].

CCIR gave two definitions of HF channel for digital communication: *Good* and *Poor* [5]. Main characteristics of these two channels are given in Table 1.

Table I

Characteristics of CCIR HF channels

	Good channel	*Poor* channel
Fade rate f_d [Hz]	0.1	1
Interpath delay t_d [ms]	0.5	2

Time and space variation of signal can be diminished by using time and space diversity. This can be accomplished through time interleaving and using two or more receive points (antennae). These two methods exclude each other and can be used according to the nature of transmission. If voice transmission is used, long interleaving blocks cannot be tolerated, thus urging the use of space diversity. In data communication, time gap is not of great importance so interleaving can be used. Long interleaving blocks cannot be used if modem is part of an ARQ system.

Although interleaving can decrease error rate, it can also make periodic error bursts. These errors then must be retransmitted, thus reducing an overall data rate. Due to this reasons simulation is done using very short interleaving blocks. It is shown that space diversity can considerably decrease BER without need for long data interleaving [2]. This combination of space diversity and short interleaving blocks are ideal for both voice and data transmission.

IV. USE OF TRELLIS-CODED MODULATION

Trellis-coded modulation (TCM) is commonly used in modern digital communications. A 16-tone modem with TCM scheme is presented in [2] and is used as a reference for comparison with TCM modification of 3000 bps 20-tone parallel modem.

Use of TCM implies inserting redundancy bits, thus decreasing data rate. As maintaining data rate of 3000 bps is imperative, other modulation must be used. Since every tone carries two bits of information in DQPSK it is logical to use convolutional code that uses two input bits, like 2/3 rate convolutional code. If 2/3 rate convolutional codes for TCM are used, 8PSK constellation is imposed as logical choice as it uses three input bits per symbol. This way we still have two bits per symbol throughput, while introducing inherent error-correction. 8PSK TCM schemes are known for some time now, since famous Ungerböck's paper from early 80's [6].

Choice of an 8PSK trellis code was the next step. Main criteria for choosing a particular code were relatively low computation load for DSP processor (existing modem was made around TMS320C25 DSP platform), good performance over slow fading and possibility to work in presence of the impulse noise. After considering multiple trellis-coding schemes [6,7,8,9] it was decided that a 2/3-rate 8PSK trellis with 256 states have shown a good performance over low fading channels. This code is optimized for use on slow fading AWGN channels, but has no inherent protection from impulse code. As HF channel is non-AWGN channel finding adequate trellis code is another interesting area of research. Detail description of this code is given in [6] with the following parameters used:

- h_0=417
- h_1=573
- h_2=612

A 2x8DPSK modulation scheme is also considered but due to its complexity it was dropped out of consideration [9].

As a result of a very slow Rayleigh fading it is important to have interleaving of up-to 20 seconds, although to completely overcome effects of slow fading this value can be as high as 60 seconds. However, simulation was done with minimum interleaving of 2 seconds on assumption that space diversity is used. This combination of time/space diversity is good for both voice and data transmission.

Doppler shift correction tones are also omitted, enabling faster modem handshaking. Doppler shift can be overcome by the use of FFT that gives 20 equally spaced phasors, regardless of amount of Doppler shift.

By eliminating the pilot tone it is possible to use lower portion of voice band for additional data carriers, raising data rate to 3600, by the loss of only 1.8dB of SNR. This modem, using 8DPSK TCM modulation, should give much better performance than a 3600 bps modem described in [2], making this modem yet another interesting area of research.

Results obtained by this simulation were compared with following HF modems:

- Single tone 2400 bps HF modem (described in MIL-ST-188-110A)[10]
- 16-tone 2400 bps modem with 8PSK TCM (described in [2])
- 16-tone 3600 bps modem with 16PSK TCM (also presented in [2])

V. DISCUSSION OF SIMULATION RESULTS

In following figures (4 and 5) simulation results are given. HF3618 3000 bps modem is compared with similar modems described earlier. Results for these modems are taken from [2].

In Figure 4 performance of HF modems over CCIR *Good* channel are given. This figure shows that parallel tone modems are more robust than single tone.

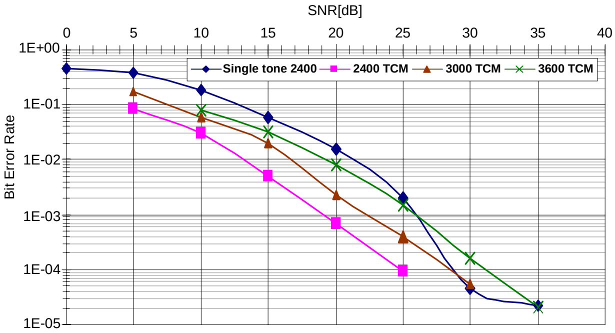

Figure 4. Performance over CCIR Good channel

It can be shown that even 50% higher data rate can be used over same channel with the same if not better results. The only area where single-tone modem has better performance than 3600 bps is that of SNR>25dB. A 3000 bps modem has lower performance than 2400 bps modem by some 3.5dB lower SNR.

Figure 5 represents performance of these modems over CCIR *Poor* HF channel. Over *Poor* channel single-tone modem has the lowest overall drop of performance and on some SNR values it almost reaches performance of 2400 TCM modem.

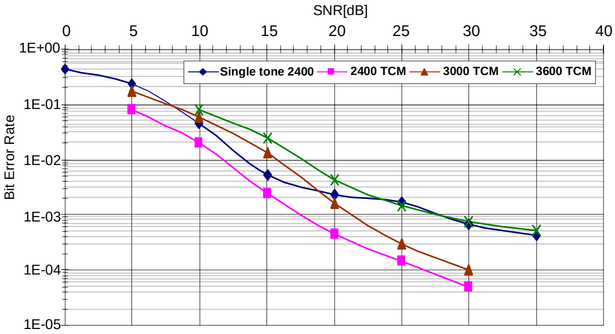

Figure 5. Performance over CCIR *Poor* channel

A 3000 bps TCM modem has performance that was expected, although on some SNR's (10-20dB) it has worse performance in comparison with single-tone modem.

Overall, results are as expected, with performance of 3000 bps modem between those of 2400 and 3600 bps modems.

VI. CONCLUSION

This simulation shows that by using TCM in some of existing HF modem techniques (such as 16 or 20-tone parallel modem) quality and robustness of data transmission can be improved significantly without decreasing data rate. Also, using modern DSP algorithms a Doppler correction pilot tone can be omitted, thus enabling a lower portion of the voice spectrum to be used for data carriers. In case of HF3618 modem, omission of the Doppler correction tones can lower channel setting time by some 0.5seconds. By adding additional tones data rate of the HF modem can be increased by losing a small amount of overall performance. Using other MPSK schemes are also in consideration. Some companies are already producing 4800 bps HF modems, which are obviously 16-tone non-TCM 16PSK modems. The biggest benefit of parallel tone modem with (or without) TCM is possibility to improve current modems with small, if any, modification of hardware, enabling simple upgrade by "flashing" new DSP code into processor. In modern systems this is a big advantage, because algorithms are changing much faster than actual design of devices. It also gives possibility to create so called "multirate" modems, with selection of modulation type during initial handshaking of modems according to channel characteristics. This is the principle which is used in wired modem communications for some time now. At present, this paper is just a study, with a goal to be used in real upgrade of the existing HF modem.

There are many possibilities that should be accounted for, whether the goal is improving performance or data rate. It is sure that, by applying newly acquired knowledge in DSP and information theory, data rate will increase, as it is sure that a HF band would remain interesting for both military and civil services.

REFERENCES

[1] http://www.telecom.imp.bg.ac.yu/services_products/pr_radio.htm

[2] *M.C. Gill, S.C. Cook, T.C. Giles and J.T. Ball* "A 300 To 3600 Bps Multi-Rate HF Parallel Tone Modem", Proc. IEEE MILCOM '95, also on http://www.s3.kth.se/~tim/pub_list.html

[3] *Watterson C.C.* "Experimental Confirmation Of An HF Channel Model", IEEE Trans of Com, Tecnol.COM-18 (DEC), 1970, pp. 792-803

[4] *Giles T.C. & Preiss M.*, "On the Design of a Voiceband HF Replay Channel Simulator", The Proceedings of the Eighth International Conference on HF Radio Systems and Techniques, University of Surrey, Guildford, UK, 10-13 July 2000

[5] *CCIR* "Use Of High Frequency Ionospheric Channel Simulators", Rec. 520-1, Recommendations and Reports of the CCIR, Vol 3, 57-58, ITU, Geneva

[6] *G.Ungerböck* "Channel Coding With Multilevel/Phase Signals", IEEE Trans. of Information Theory, IT-28, 1, 55-67

[7] *J. Du and B. Vučetić* "New MPSK Trellis Codes for Fading Channels", Electronic letters vol 26, No 16, 1992, 395-399

[8]*F. Edbauer* "Performance of Interleaved Trellis-Coded Differential 8PSK Modulation Over Fading Channels", IEEE Journal on selected areas in communications, vol. 7, No.9, December 1989, pp. 1340-1346

[9] *S. Đorđević* " Differential 8-PSK Code With Multisymbol Interleaving", Proc. TELSIKS '99 Niš pp. 596-599

[10] *MIL-STD-188-110A* "Interoperability and Performance Standards for Data Modem", US military standard, 1991.