Bandwidth Efficient Coded Modulation for SDR

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***Abstract*--This paper presents a method of band width efficient coded modulation for SDR. In the proposed scheme, the input high-speed data stream is inverse multiplexed into several parallel streams. These parallel streams, now reduced in speed, are mapped into a Bi-orthogonal codes, stored in a ROM (Read Only Memory). Next, the output of the ROM, which is an orthogonal code, is demultiplexed again to further reduce the speed. The output is a set of low-speed parallel data stream, which is then modulated by means of an M-ary PSK modulator. This methodology achieves error control coding, and bandwidth efficiency for SDR. Construction of rate ¾ orthogonal coded modulation scheme, using an 8-bit orthogonal code, is presented to illustrate the concept.**

***Keywords*-- Software defined radio (SDR), error control coding, orthogonal codes, coding gain, PSK modulation.**

I. INTRODUCTION

Over the last 20 years, there has been an explosive growth in the wireless industry [1-4]. With the addition of wireless data services such as e-mail access and Internet browsing, the demand on network resources will continue to rise, leading to network congestion. It has been envisioned that a software defined radio (SDR) is the next generation cellular radio, which will coexist with cellular radios and share the same platform, while supporting variable bit rates. Consequently, the transmission bandwidth and the RF coverage footprint will vary according to the bit rate.

The transmission bandwidth will vary due to the fact that the bit duration varies according to the bit rate. As a result, the bandwidth associated with each bit rate will also vary. Figure 1 shows this for two bit rates. This is a problem since the channel bandwidth is fixed.

On the other hand, the RF coverage footprint will also vary due to the variable bit rates, according to the following equation:

$$G(dB) = 10\log\left(\frac{R1}{R2}\right) \qquad (1)$$

Where, R1 is the low-speed data rate and R2 is the high-speed data rate. This translates into several dB deficits in the link budget. The result is illustrated in Figure 2.

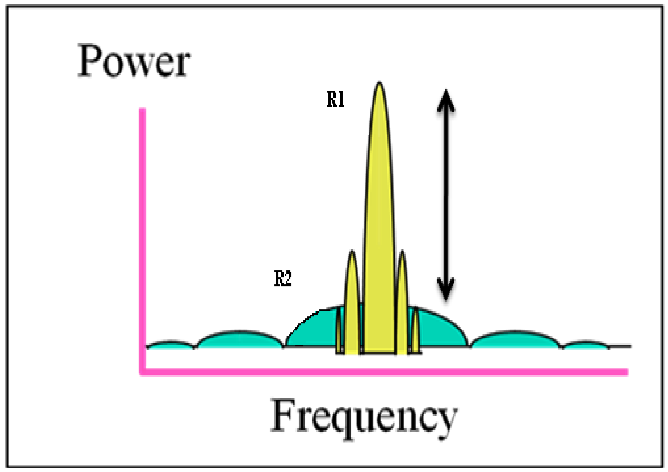

Fig. 1. Bandwidth associated with variable bit rates.
(1) Uncoded (2) Coded

For 3G standards [5], we see that there is a deficit of 11.76dB for 144kb/s, 16dB deficit for 384kb/s and 23.2dB deficit for 2MB/s. Consequently, the RF foot print will shrink for higher bit rates. This is also a problem since it will create a coverage hole for high bit rates and too much overlap of coverage due to low bit rates.

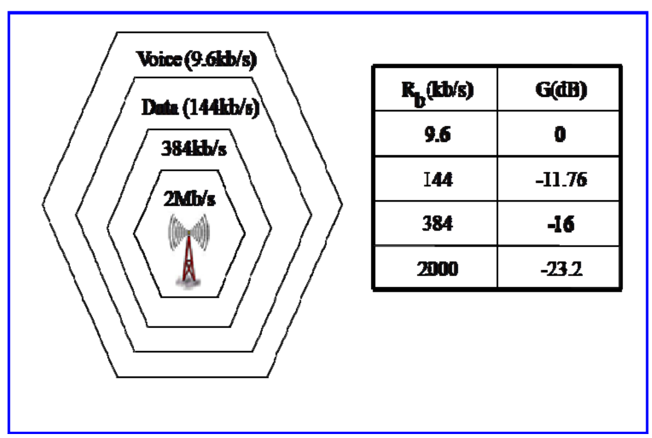

Fig. 2. RF coverage due to variable bit rates.

A possible solution to this problem would be to introduce delays and reduce the bit rate. Reduction of bit rate will simultaneously reduce the transmission bandwidth and compensate the deficit in RF footprint. Here, we assume that we can accommodate delays because we are dealing with non real time data.

This paper develops a method of radio transmission that combines delays, channel coding and modulation in a single platform to achieve bandwidth efficiency without coverage penalty. In the proposed scheme, the input high-speed data stream is inverse multiplexed into several parallel streams. These parallel streams, now reduced in speed, are mapped into a Bi-orthogonal codes [6-8], stored in a ROM (Read Only Memory). Next, the output of the ROM, which is an orthogonal code, demultiplexed again form a set of parallel stream and then modulated by means of an M-ary PSK modulator.

This methodology achieves bandwidth efficiency for high speed data communications over wireless networks. The outcome is a coded modulation scheme that detects and corrects bit errors with bandwidth efficiency. Construction of rate ¾ orthogonal coded modulation schemes, using an 8-bit orthogonal code, is presented to illustrate the concept.

II. BANDWIDTH EFFICIENT ENCODING

The encoder is based on orthogonal codes, where a k-bit data set is represented by a unique n-bit orthogonal code ($k < n$). We illustrate this by means of an 8-bit orthogonal code as shown in Figure 3. Here, the incoming high-speed data, R_b (b/s), is serial-to-parallel (s/p) converted into 6-parallel streams ($k = 6$). These bit streams, now reduced in speed to $R_b/6$ (b/s), are partitioned into two sub-sets, 3-bits per sub set. Each 3-bit sub-set is mapped into an 8-bit orthogonal (antipodal) code and then modulated by means of a QPSK modulator.

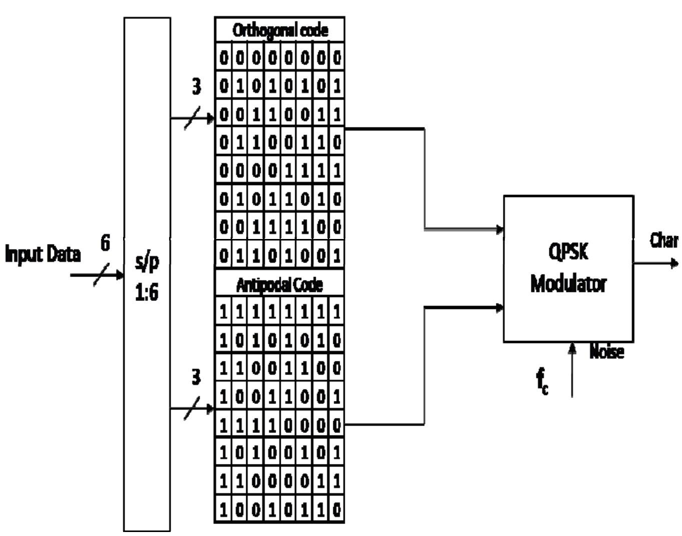

Fig. 3. Rate 3/4 bi-orthogonal coded modulation with n = 8.

The code rate is obtained as $r = 6/8 = 3/4$. It follows that, a rate 1 coded modulation scheme is also available if 16-PSK is used.

III. DECODING SCHEME

At the receiver, the incoming impaired orthogonal code is first examined by generating a parity bit. If the parity bit is one, the received code is said to be in error. The impaired received code is then compared to a lookup table for a possible match. Once the closest approximation is achieved, the corresponding data is outputted from the lookup table. A brief description of the decoding principle is given below:

An n-bit orthogonal code has n/2 1s and n/2 0s; i.e., there are n/2 positions where 1s and 0s differ. Therefore, the distance between two orthogonal codes is $d = n/2$ (Fig. 2). This distance property can be used to detect an impaired received code by setting a threshold midway between two orthogonal codes as shown in Figure 4, where the received coded is shown as a dotted line. This is given by:

$$d_{th} = \frac{n}{4} \tag{2}$$

Where n is the code length and d_{th} is the threshold, which is midway between two valid orthogonal codes. Therefore, for the given 8-bit orthogonal code, we have $d_{th} = 8/4 = 2$. This mechanism offers a decision process, where the incoming impaired orthogonal code is examined for correlation with the neighboring codes for a possible match.

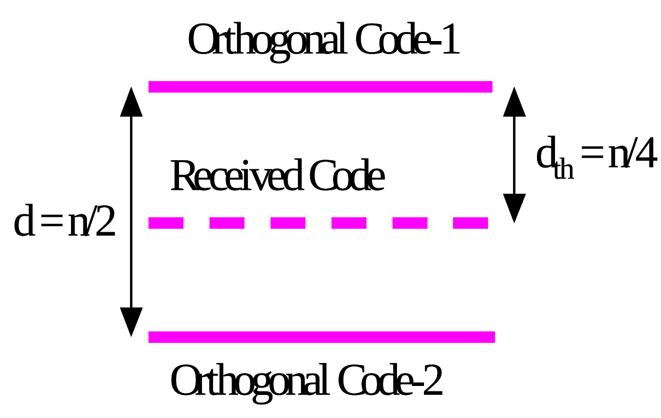

Fig. 4. Decoding principle.

The acceptance criterion for a valid code is that an n-bit comparison must yield a good cross-correlation value; otherwise, a false detection will occur. The following correlation process governs this where an impaired orthogonal code is compared with a pair of n-bit orthogonal codes to yield,

$$R(x,y)=\sum_{i=1}^{n} x_i y_i \ge (n-d_{th})+1 \qquad (3)$$

Where R(x,y) is the cross-correlation function, n is the code length, d_{th} is the threshold as defined earlier. Since the threshold (d_{th}) is in the midway between two valid codes. An additional 1-bit offset is added to equation-4 to avoid ambiguity.

The average number of errors that can be corrected by means of this process can be estimated by combining equations (2) and (3) yielding,

$$t = n - R(x,y) = \frac{n}{4} - 1 \qquad (4)$$

In equation (4), t is the number of errors that can be corrected by means of an n-bit orthogonal code. For example, a single error-correcting orthogonal code can be constructed by means of an 8-bit orthogonal code (n = 8). Similarly, a three-error-correcting, orthogonal code can be constructed by means of a 16-bit orthogonal code (n = 16), and so on.

Table-1 below shows a few orthogonal codes and the corresponding error- correcting capabilities.

TABLE 1

ORTHOGONAL CODES AND THE CORRESPONDING ERROR CORRECTING CAPABILITIES

n	t
8	1
16	3
32	7
64	15

IV. CODING GAIN

We have established that an n-bit orthogonal code can correct t errors where t = n/4-1. A measure of coding gain is then obtained by comparing the bit error (BER) with coding, Pe(C), to the bit error without coding, Pe(U).

With coherent PSK (Phase Shift Key) modulations, the uncoded and coded bit error rates will be:

$$Pe(U)=\frac{1}{2}\,erfc\left(\sqrt{\frac{Eb}{No}}\right) \qquad (5)$$

$$\boldsymbol{Pe(C) = \sum_{i=t+1}^{n}\binom{n}{i} Pe(U)^{i}(1-Pe(U)^{n-i})} \qquad (6)$$

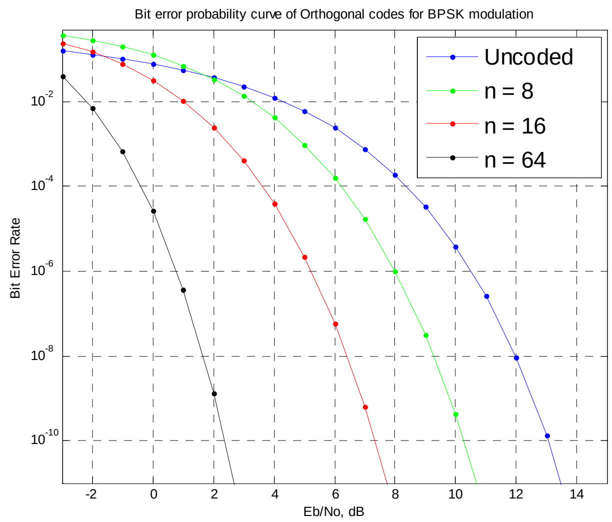

Fig. 5. BER Performance for rate ¾ Orthogonal Codes

Equations (5) and (6) are plotted in Figure 5 for several code lengths (n=8, 16 and 64). As expected, the net gain in Bit Error Rate (BER) due to coding is evident. We also note that coding gain increases for longer codes. From these results, we conclude that orthogonal codes offer coding gain with bandwidth efficiency.

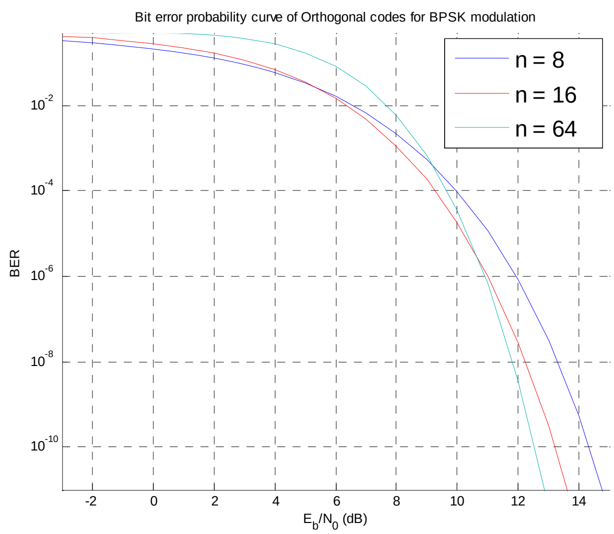

Fig. 6. BER Performance for rate ¾ regular Block Codes

The orthogonal codes perform much better than other popular coding methods. Figure 6 shows the plot for BER with PSK modulation for rate ¾ block codes at various code lengths (n= 8, 16 and 64). The comparison of the two plots clearly shows the better performance of orthogonal codes in terms of coding gain especially at lower Eb/No values. Also, there is marginal gain change in block codes for various code lengths ($d_{min} = n/2$) whereas orthogonal codes perform exceptionally well at higher value of n.

V. CONCLUSIONS

We have examined error control properties of orthogonal codes and have shown that the distance properties can be used to detect and correct errors to protect digital information from impairments. It is shown that bandwidth efficiency can be achieved by data partitioning and mapping into orthogonal space.

The proposed technique offers a simpler solution to error control coding and bandwidth efficiency for SDR. Construction of rate ¾ orthogonal coded modulation schemes along with WER performance analysis indicates that orthogonal codes offer error control coding with bandwidth efficiency.

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